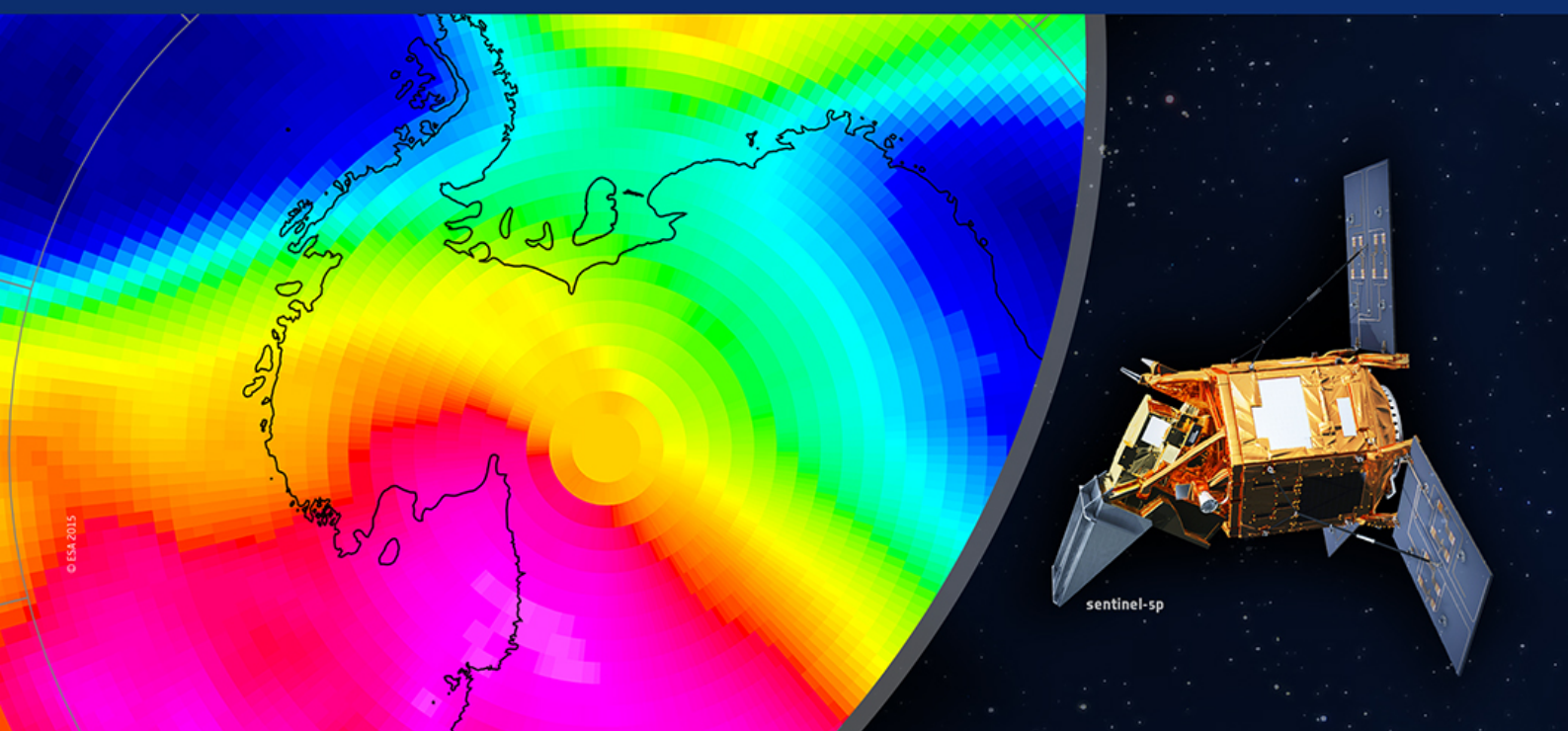


→ ATMOS 2015

Advances in Atmospheric Science and Applications



ABSTRACT BOOK

8–12 June 2015 | University of Crete | Heraklion, Greece

Programme & Abstract Book

ATMOS 2015 Workshop

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Programme

Day 1, Monday 8 June 2015			
09:00	09:45	Registration	
09:45	09:45	Welcome	E. G. Stephanou - Rector University of Crete
09:45	10:00	Opening	C. Zerefos - Academy of Athens
10:00	10:15	Conference Goals	C. Zehner - ESA
10:15	10:35	Observing the Anthropocene from Space: Past achievements and Challenges (from SCIAMACHY to GeoSCIA/Copernicus Sentinel 4, Sentinel 5, CarbonSat and SCIA-ISS)	J. Burrows - University of Bremen
GHG Session Chairs: D. Crisp, M. Buchwitz			
10:35	10:55	Carbon Dioxide and Methane Observation by GOSAT for Six Years	T. Yokota - NIES
10:55	11:15	Early Results from the NASA Orbiting Carbon Observatory-2 (OCO-2)	D. Crisp - NASA
11:15	11:45	Coffee Break	
11:45	12:00	The Greenhouse Gas Project of ESA's Climate Change Initiative (GHG-CCI): Phase 2 Achievements and Future Plans	M. Buchwitz - University of Bremen
12:00	12:15	Upper tropospheric methane observations from GOSAT from thermal infrared soundings	H. Sembhi - University of Leicester
12:15	12:30	CH ₄ Profile Retrievals from GOSAT Thermal Infrared Measurements	A. de Lange - SRON
12:30	14:00	Lunch	
14:00	14:15	Phosgene in the UTLS: Vertical Distribution from MIPAS Observations Using New Spectroscopic Data	M. Valeri - ISAC-CNR
14:15	14:30	Methane Retrievals in the Thermal and Short-Wave Infrared from IASI	D. Knappett - RAL
14:30	14:45	Multi-satellite Constraints on South America Wetland and Fire Carbon Fluxes	A. Bloom - California Institute of Technology
14:45	15:00	Tropical controls on the CO ₂ atmospheric growth rate 2010-2011 from the NASA Carbon Monitoring System Flux (CMS-Flux) Project	K. Bowman - NASA
15:00	15:15	Quantifying the impact of column integrated CO ₂ observations data on NEP and NPP by supplementary assimilation into CCDAS	R. Giering - FastOpt
15:15	15:30	Towards Disentangling Natural and Anthropogenic GHG Fluxes from Space - The CarbonSat Earth Explorer 8 Candidate Mission	H. Bovensmann - University of Bremen

15:30	16:00	Coffee Break	
16:00	16:00	Future Missions Session	Chairs: I.Aben
16:00	16:15	The Sentinel-4 Mission and its Atmospheric Composition Products	B. Veihelmann - ESA
16:15	16:30	Copernicus Sentinel-5: Long-Term Global Monitoring of Atmospheric Composition	J. Langen -ESA
16:30	16:45	Two small Limb Sounding missions to explore the forthcoming Stratosphere: ALTIUS and PICASSO	D. Fussen - BIRA/IASB
16:45	17:00	The EarthCARE mission: An Active View on Aerosols, Clouds and Radiation	P. Ingmann - ESA
17:00	17:15	ADM-Aeolus, ESA's Wind Lidar Mission and its spin-off aerosol profile products	A. Straume - ESA
17:15	18:00	DISCUSSION	
18:00	20:00	Welcome Cocktail - (in the Chemistry Department)	

Day 2, Tuesday 9 June 2015

Reactive Trace Gases Session

Chairs: J. Burrows, D. Fussen

09:00	09:15	Ozone structure and variability in the upper troposphere and lower stratosphere as seen by Envisat and ESA Third-party mission limb profiling instruments	V. Sofieva - FMI
09:15	09:30	New MIPAS V7 products	P. Raspollini - IFAC-CNR
09:30	09:45	MLS-based detection and attribution of the recovery of ozone in the Antarctic ozone hole	J. de Laat - KNMI
09:45	10:00	Continuation of GOMOS, MIPAS and SCIAMACHY-limb Ozone Record using OMPS Limb Profiler	N. Kramarova - SSAI
10:00	10:15	Uncertainties in recent satellite ozone profile trend assessments (SI2N, WMO 2014) : A network-based assessment of fourteen contributing limb and occultation data records	D. Hubert - BIRA/IASB
10:15	10:30	Twelve Years of the Atmospheric Chemistry Experiment (ACE) Satellite: Mission Status and Recent Results	K. Walker - University of Toronto
10:30	11:00	Coffee Break	
11:00	11:15	Using visible spectra to improve sensitivity to near-surface ozone of UV-retrieved profiles from MetOp GOME-2	G. Miles - RAL
11:15	11:30	Distribution and Time Evolution of the Ozone Instantaneous Longwave Radiative Effect from IASI and TES Observations	S. Doniki - Université Libre de Bruxelles
11:30	11:45	Sensitivity of Northern Hemispheric Tropospheric Ozone To Anthropogenic Emissions as Observed by Satellite Observations	J. Worden - JPL
11:45	12:00	Springtime Variability of Lower Tropospheric Ozone over Eastern Asia: Respective Role of Cyclones and Pollution as Determined from IASI	G. Dufour - LISA
12:00	12:15	Global and Regional Ozone Trends Using 20 Years of European Satellite Data	M. Coldewey-Egbers - DLR
12:15	12:30	Ozone Profile Changes and Montreal Protocol	J. Staehelin - ETHZ
12:30	14:00	Lunch	

Reactive Trace Gases Session		Chairs: M. López-Puertas, D.Loyola	
14:00	14:15	Evaluation of GOME, SCIAMACHY, GOME2, SBUV, OMI and IASI–METOP total ozone retrievals performances by comparison with SAOZ NDACC ground-based measurements	J-P. Pommerau - LATMOS
14:15	14:30	Atmospheric Sulphur from the Upper Troposphere to the Upper stratosphere: 10 Years of MIPAS Observations	M. Hoepfner - KIT
14:30	14:45	Improved Algorithms for GOMOS/ENVISAT Water Vapor Retrieval at 936 nm and O2A band	J-L. Bertaux - LATMOS
14:45	15:00	Satellite Observations of Carbonyl Fluoride (COF ₂) and Hydrogen Fluoride (HF) and their Comparisons with SLIMCAT Chemical Transport Model Calculations	J. Harrison - University of Leicester
15:00	15:15	Reanalysis of the Stratospheric Chemical Composition Based on Assimilation of EOS Aura MLS and MIPAS: methane (CH ₄) and nitrous oxide	Q. Errera - BIRA/IASB
15:15	15:45	Coffee Break	
15:45	16:00	Synergy between middle infrared and mm-wave limb sounding of atmospheric temperature and minor constituents in different cloudy scenario	U. Cortesi - Institute for Applied Physics "Nello Carrara
16:00	16:15	The Middle and Upper Atmosphere as Observed by MIPAS/Envisat	M. López-Puertas - IAA
16:15	16:30	Upper Atmospheric N ₂ O in the High Latitudes and its Descent into the Stratosphere	P. Sheese - University of Toronto
16:30	16:45	Global Atomic Oxygen and Hydrogen Abundance in the Upper Mesosphere and Lower Thermosphere as Measured by SCIAMACHY	M. Kaufmann - FZJ
16:45	17:00	Satellite measurements of NO in the mesosphere and lower thermosphere	S. Bender - KIT
17:00	17:15	The 'Limb Gap': Perspectives on Future Operational Ozone Profile Monitoring Needs	M. van Weele - KNMI
17:15	17:45	DISCUSSION	

Day 3, Wednesday 10 June 2015

Clouds/Aerosols Session

Chairs: J.Tamminen, T.Holzer-Popp

09:00	09:20	Satellite-derived Aerosol Climate Data Records in the ESA Aerosol_cci Project	T. Holzer-Popp - DLR
09:20	09:35	Polar Mesospheric Cloud Particle Size Retrieval from GOMOS / ENVISAT Observations	K. Pérot - Chalmers University of Technology
09:35	09:50	AerGom, a GOMOS retrieval algorithm optimized for stratospheric aerosols: Recent developments	C. Bingen - BIRA/IASB
09:50	10:05	Aerosol detection with infrared limb measurements in the troposphere and stratosphere	S. Griessbach - FZJ
10:05	10:20	Aerosol absorption above clouds from combined OMI and MODIS hyper spectral measurements	M. de Graaf - Delft University of Technology
10:20	10:35	Aerosol and Cloud Properties Retrieval using the ATSR Dual and Single View algorithms	G. de Leeuw - FMI
10:35	11:00	Coffee Break	
11:00	11:15	Three-dimensional distribution of a major desert dust outbreak over East Asia in March 2008 derived from IASI satellite observations	J. Cuesta - LISA
11:15	11:30	Saharan Desert Dust Sources: New Insights Based on Aerosol Vertical Profiles Retrieved from Thermal Infrared Measurements by IASI	S. Vandenbussche - BIRA/IASB
11:30	11:45	GOME-2 Cloud top height and optical depth retrieval using ROCINN V3.0	S. Gimeno García - DLR
11:45	12:00	Algorithm Development and Verification of Aerosol and Cloud Products for Sentinel-5 Precursor	L. Lelli - University Bremen
12:00	12:15	The Finokalia Ground-based Station in Crete and its potential for ESA Cal/Val Activities	V. Amiridis - National Observatory of Athens
12:15	12:45	DISCUSSION	
12:45	14:00	Lunch	

Air Quality Session		Chairs: P.Levelt , T.Wagner	
14:00	14:15	A global catalogue of SO ₂ sources and emissions derived from the Ozone Monitoring Instrument	V. Fioletov - Environment Canada
14:15	14:30	An Innovative Satellite SO ₂ and HCHO Retrieval Algorithm based on Principal Component Analysis: Contribution to the Sentinel-5P Mission	N. Krotkov - NASA
14:30	14:45	Sulfur dioxide retrievals from TROPOMI : algorithmic developments, verification on synthetic spectra and application to OMI measurements	N. Theys - BIRA/IASB
14:45	15:00	OMI/Aura, SCIAMACHY/Envisat and GOME2/MetopA Sulphur Dioxide Estimates; the case of Eastern Asia.	M. Koukouli - AUTH
15:00	15:15	Tropospheric Volcanism and Air-Traffic	C. Zerefos - Academy of Athens
15:15	18:15	Poster Session	

Day 4, Thursday 11 June 2012

Preparation for Sentinel S5P/Air Quality Session

Chairs: P.Levelt, T.Wagner

09:00	09:30	TROPOMI on the Copernicus Sentinel 5 Precursor: instrument and on-ground calibration results	P. Veeffkind and A. Ludewig - KNMI
09:30	09:45	Sentinel 5P TROPOMI Short-wave Infrared On Ground Calibration	M. Krijger -SRON
09:45	10:00	Sentinel-5 Precursor: Preparing the first Copernicus Atmospheric Mission	H. Nett - ESA
10:00	10:20	Overview of Sentinel 5 Precursor Trace Gas, UV, Cloud and Aerosol Products	D. Loyola - DLR
10:20	10:35	Sentinel-5 Precursor: Exploitation Phase of the first Copernicus Atmospheric Mission	T. Fehr - ESA
10:35	11:00	Coffee Break	

Preparation for Sentinel S5P/Air Quality Session

Chairs: M.Riese, J.Orphal

11:00	11:15	TROPOMI's CO retrieval code for the Sentinel 5 Precursor mission tested on 10 years of SCIAMACHY's 2.3 μm measurements	T. Borsdorff - SRON
11:15	11:30	Developments in the retrieval of NO ₂ from OMI and TROPOMI observations	H. Eskes - KNMI
11:30	11:45	Estimation of stratospheric NO ₂ from nadir-viewing satellites:The MPI-C TROPOMI verification algorithm	S. Beirle - MPI Chemistry Mainz
11:45	12:00	Satellite-based Trends of Tropospheric NO ₂ over Large Urban Agglomerations and an Approach Towards Their Validation	P. Schneider - NILU
12:00	12:15	Evaluation of Discrepancies in the Anthropogenic NO _x Emission Trends across Europe: Synergistic use of LOTOS-EUROS and NO ₂ Tropospheric Columns from GOME-2 and OMI.	L. Curier - TNO
12:15	12:30	The S-5P/TROPOMI formaldehyde retrieval algorithm baseline and its application to OMI and GOME-2 measurements	I. De Smedt - BIRA/IASB
12:30	14:00	Lunch	
14:00	14:15	Shortwave infrared measurements of the TROPOMI instrument on the Sentinel 5 Precursor mission	J. Landgraf - SRON
14:15	14:30	Improving the NO ₂ retrieval for S5P	A. Richter - University of Bremen
14:30	14:45	Spectroscopic database for TROPOMI/Sentinel 5 precursor	J. Loos - DLR
14:45	15:00	Improved HCOOH retrieval from IASI measurements: Comparison with ground-based measurements	M. Pommier - Sorbonne Universités

15:00	15:15	Revising the global budget of glyoxal (OCHCHO) based on OMI and GOM2 vertical columns	J-F. Müller - BIRA/IASB
15:15	15:30	Biomass burning emissions estimates from IASI CO satellite measurement	M. Krol - Wageningen University
15:30	16:00	Coffee Break	
Preparation for Sentinel S5P/Air Quality Session Chairs: W.Lahoz, Heskés			
16:00	16:15	On the consistency of top-down hydrocarbon emission fluxes inferred from GOME-2 and OMI formaldehyde observations	J. Stavrakou - BIRA/IASB
16:15	16:30	Assessing the potential of TROPOMI for global monitoring of terrestrial chlorophyll fluorescence	L. Guanter - GFZ Potsdam
16:30	16:45	GlobEmission: applications of emission estimates from satellite	R. van der A - KNMI
16:45	17:00	Monitoring air pollution at global scale using the IASI thermal infrared instrument	S. Bauduin - Université Libre de Bruxelles
17:00	17:15	Global Distribution of Tropospheric BrO Observed from Satellite	T. Kurosu - JPL
17:15	17:30	Seasonal variation of bromine monoxide over the Rann of Kutch salt marsh seen from space	C. Hörmann - MPI
17:30	18:00	DISCUSSION	
Day 5, Friday 12 June 2015			
Applications/Data Assimilation Session Chairs: W.Lahoz, H.Eskes			
09:00	09:20	Assimilating Satellite Data in the Copernicus Atmosphere Monitoring Service Global Data Assimilation System: Current Status and Prospects for the Sentinel Era	R. Engelen - ECMWF
09:20	09:35	Sodankylä satellite data centre and almost real-time monitoring of atmospheric composition in Northern Europe	J. Tamminen - FMI
09:35	09:50	Monitoring the changing environment of the 21st Century: the role of OSSEs in determining the future global observing system	W. Lahoz - NILU
09:50	10:05	Added value and optimal design of future satellite observations for air quality applications - Observing System Simulation Experiments	Lyana Curier - TNO
10:05	10:20	The atmospheric composition geostationary satellite constellation for air quality and climate science: Evaluating performance with Observation System Simulation Experiments	D. Edwards - NCAR
10:20	10:35	Fast emission estimates for rapidly changing economies constrained by satellite observations	B. Mijling - KNMI
10:35	11:10	Coffee Break	

Applications/Data Assimilation Session		Chair: M. Kanakidou	
11:10	11:25	Vertically resolved stratospheric ozone and nitrogen dioxide measurements used for surface air quality prediction	D. Degenstein - University of Saskatchewan
11:25	11:40	Benchmarking climate model top-of-atmosphere radiance in the 9.6 micron ozone band compared to TES and IASI observations	H. Worden - NCAR
11:40	12:15	DISCUSSION	
12:15	12:15	Discussion Summaries	
12:15	12:30	GHGs and Future Missions	
12:30	12:45	Reactive Gases	
12:45	13:00	Preparation for Sentinel S5P/Air Quality	
13:00	13:15	Clouds/Aerosols	
13:15	13:20	Closing	

Organising Committee

Claus Zehner - ESA

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Paul Ingmann - ESA

Herbert Nett - ESA

Thorsten Fehr - ESA

Pieterneel Levelt - Royal Netherlands Meteorological Institute

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Pepijn Veefkind - KNMI - The Netherlands

Kaley Walker - University of Toronto - Canada

Gerhard Wotawa - ZAMG - Austria

Tatsuya Yokota - NIES - Japan

Day 1, Monday 8 June 2015

Opening

Observing the Anthropocene from Space: Past achievements and Challenges (from SCIAMACHY to GeoSCIA/Copernicus Sentinel 4, Sentinel 5, CarbonSat and SCIA-ISS)

Burrows, John Philip

University of Bremen, Germany

From the beginning of the Neolithic revolution up 1800 A.D., the earth's human population is estimated to have risen from several million nomadic hunter gathers to 1 Billion rural settlement and city dwellers. This rapid development is dwarfed by the impact of the industrial revolution over the past two centuries. There are now over 7 Billion people on earth with over half living in cities, e.g. there are ~ 3 billion more citizens since I was born. This industrialisation and urbanisation has been fuelled by the use of cheap energy from fossil fuel combustion. It has resulted in large scale changes in land use, air pollution, and the destruction of stratospheric ozone, the anthropogenic modification of biogeochemical cycling, the destruction of species, ecosystems and ecosystem services. In order to test our knowledge and understanding of the Earth system, accurate long term global measurements of atmospheric constituents and surface parameters are essential. The remote sounding of the atmosphere from instrumentation on satellite platforms provides a unique opportunity to retrieve regional and global observations of key trace atmospheric constituents (gases, aerosol and clouds) and surface parameters (ocean colour, ice extent, flora etc.). This talk describes results from the SCIAMACHY (SCanning Imaging Absorption spectrometer for Atmospheric CHartography) project and its spin offs, GOME (Global Ozone Monitoring Experiment), GOME-2, and their successors ESA Sentinel 4 (GeoSCIA), Sentinel 5, CarbonSat and SCIA-ISS. The interpretation of the data from these instruments has provided a paradigm shift in our understanding of global atmospheric composition. In addition they deliver unique evidence for the development and verification of international environmental policy.

GHG Session

Carbon Dioxide and Methane Observation by GOSAT for Six Years

Yokota, Tatsuya; Kikuchi, Nobuhiro; Yoshida, Yukio; Inoue, Makoto; Morino, Isamu; Uchino, Osamu; Kim, Heon-Sook; Takagi, Hiroshi; Saito, Makoto; Maksyutov, Shamil; Kawazoe, Fumie; Ajiro, Masataka

National Institute for Environmental Studies (NIES), Japan

The Greenhouse gases Observing SATellite (GOSAT) has operated for about six years since its launch on January 23, 2009. During the past six years, all of the GOSAT standard data products were opened to general users, and many of the data products went through several updates. From the spectral data that GOSAT collected, the concentrations of major greenhouse gases (GHGs), namely carbon dioxide (CO₂) and methane (CH₄), were retrieved at NIES (released as GOSAT Level 2 data product), and their precisions (excluding biases) are now about 0.5% and 0.7%, respectively. Other groups in the research community, SRON/ KIT, University of Leicester, University of Bremen, and US OCO-2 team also retrieved the column GHGs from GOSAT TANSO-FTS Level 1B spectral data. Using GOSAT Level 2 data product, the monthly surface fluxes of CO₂ and CH₄, on sub-continental and ocean-basin scales, were estimated. The flux estimates for the first three years of GOSAT operation (2009 – 2012) are now available. The Level 2 column concentration data were also utilized to monitor GHGs' temporal and spatial changes.

In 2014, GOSAT went through some technical difficulties in the functioning of its solar paddle and sensor pointing mechanism, and the characteristics of the Fourier transform spectrometer onboard were therefore altered to some degree. The influence of this alteration on the retrieved concentrations has been detected.

In this presentation, we will summarize the six-year-long GHG observation by GOSAT and present the global distributions and variations of the GHG concentrations and the surface flux estimates. We will also explain the changes in the characteristics of the GOSAT data products after June 2014 owing to the influence of the technical difficulties.

Early Results from the NASA Orbiting Carbon Observatory-2 (OCO-2)

Crisp, David

Jet Propulsion Laboratory, California Institute of Technology, United States of America

NASA's Orbiting Carbon Observatory-2 (OCO-2) was successfully launched from Vandenberg Air Force Base in California on 2 July 2014. After completing a series of spacecraft check-out activities and orbit raising maneuvers, OCO-2 joined the 705 km Afternoon Constellation (A-Train) on August 6, 2014. Its 3-channel imaging grating spectrometer was then cooled to its operating temperatures and a series of calibration and validation activities was initiated. This instrument's rapid sampling, small (< 3 km²) sounding footprint, and high sensitivity, combined with an optimized observing strategy, are expected to provide improved coverage of the ocean, partially cloudy regions, and high latitude continents than earlier missions.

In early October, OCO-2 started routinely collecting almost one million soundings over the sunlit hemisphere each day. Around 25% of these soundings (250,000/day) are sufficiently cloud free to yield full column estimates of XCO₂. For routine science operations, the instrument's bore sight is pointed to the local nadir or at the "glint spot," where sunlight is specularly reflected from the Earth's surface. Nadir observations provide the best spatial resolution and yield more cloud-free XCO₂ soundings over land. Glint observations have much more signal over dark, ocean surfaces, yielding much more complete coverage of the globe. The initial observation sequence alternates between glint and nadir observations on consecutive 16-day ground-track repeat cycles, so that the entire sunlit hemisphere is sampled in both modes at 32-day intervals. This observation sequence is currently being optimized to yield more complete coverage of the globe. OCO₂ can also target selected surface calibration and validation sites to collect thousands of soundings as the spacecraft flies overhead. The primary surface targets include well calibrated surface sites, such as Railroad Valley, Nevada,

and Total Carbon Column Observing Network (TCCON) stations, which make precise measurements of CO² and other trace gases from the ground.

The OCO² team started delivering calibrated, geo-located, spectra to the NASA Goddard Earth Sciences Data and Information Services Center (GES-DISC) on 30 December, 2014. Deliveries of Level 2 products, including estimates of XCO², surface pressure, and solar-induced chlorophyll fluorescence (SIF) are scheduled to begin before March 30, 2015. This presentation will describe the OCO² mission status, early products, and near-term plans. It will also provide a preview of the kinds of information that will be provided by future greenhouse gas monitoring missions, such as the proposed ESA CarbonSat mission, which are expected to provide estimates of XCH₄ as well as XCO² and SIF, with far greater coverage than OCO².

Future Missions Session

The Sentinel-4 Mission and its Atmospheric Composition Products

Veihelmann, Ben; Meijer, Yasjka; Langen, Joerg; Ingmann, Paul; Koopman, Rob; Wright, Norrie; Bazalgette Courreges-Lacoste, Gregory; Bagnasco, Giorgio

ESA, Netherlands, The

The Sentinel-4 (S4) mission, together with Sentinel-5 (S5) and the Sentinel-5 Precursor (S5P) missions, is part of the Copernicus Space Component dedicated to monitoring atmospheric composition. The primary objective of the geostationary S4 mission is to provide hourly tropospheric composition data in support of the air quality applications of the Copernicus Atmosphere Monitoring Services. The Low Earth Orbit (LEO) missions S5 and S5P provide atmospheric composition data with daily global coverage for air quality, climate, and ozone/surface UV applications.

The S4 instrument is a Ultra-violet Visible Near infrared spectrometer (UVN) designed to measure Earth radiance and solar irradiance. Key features of the UVN instrument are the spectral range from 305 nm to 500 nm with a spectral resolution of 0.5 nm, and from 750 nm to 775 nm with a spectral resolution of 0.12 nm, in combination with a low polarization sensitivity and a high radiometric accuracy. The instrument observes Europe with a revisit time of one hour. The spatial sampling distance varies across the geographic coverage area and takes a value of 8 km at the reference location at 45°N. The S4 products include key air quality parameters such as tropospheric amounts of NO₂, O₃, SO₂, HCHO, CHOCHO, and aerosols. Preparatory activities for Level-2 product generation are underway. Two S4 UVN instruments will be embarked on the sequence of two geostationary Meteosat Third Generation-Sounder (MTG-S) platforms. The Flight Acceptance Review of the first MTG-S satellite is expected to take place in the first quarter of 2021. The expected S4 mission lifetime spans 15 years.

An overview of the S4 mission and the implementations status will be presented. The potential for synergetic exploitation of observations from the geostationary S4 mission and from the LEO missions S5 or S5P will be highlighted.

Copernicus Sentinel-5: Long-Term Global Monitoring of Atmospheric Composition

Langen, Jörg [1]; Ingmann, Paul [1]; Meijer, Yasjka [1]; Munro, Rosemary [2]; Retscher, Christian [2]; Veihelmann, Ben [1]

1: ESA; 2: Eumetsat

In the frame of the European Copernicus programme, two series of satellites are dedicated to the monitoring of atmospheric parameters: Sentinel-4 will focus on tropospheric constituents with relevance for European air quality with hourly temporal resolution; Sentinel-5 will observe atmospheric composition on a daily basis with full global coverage. The latter will have a precursor mission Sentinel-5p carrying a slightly simplified instrument.

The purpose of the Sentinel-5 mission is to provide long-term (2022-2040) global coverage of data on atmospheric composition. These will address the information needs of Copernicus services related to air quality, climate forcing and stratospheric ozone / surface UV irradiation.

The Sentinel-5 mission will be accomplished by flying spectrometers in the UV – visible – near infrared – short-wave infrared spectral regions (UVNS) on Eumetsat's Metop-SG series of satellites, and utilising the relevant data from three other instruments on the same platforms, namely the infrared sounder IASI-NG, the multi-spectral imager Metimage and the polarisation imager 3MI. EUMETSAT is responsible for the operational processing and dissemination of UVNS data products.

The UVNS instrument will observe spectral features suitable for retrieval of O^3 , NO^2 , SO^2 , $HCHO$, $CHOCHO$, BrO , $OClO$ and surface UV irradiation in the range 270-500nm, H^2O and cloud in the range 685-773 nm, CH_4 between 1590-1675 as well as 2305-2385 nm, and CO and H_2O in the latter band. Aerosol information will be available in all spectral bands. With a swath width of 2600 km, near-global coverage will be reached within a day at a spatial resolution of 7 km at nadir (except stratospheric ozone: ~50km). Spectral resolution will be between 0.25 and 0.6 nm.

The observation requirements have been consolidated. The instrument is currently in the detailed design phase and approaching the preliminary design review. The selection of geophysical data products is being finalised.

This paper will provide an overview of the main characteristics and status of the Sentinel-5 mission.

Sentinel-5 leaves a gap in high vertical resolution measurements of atmospheric composition in the upper troposphere and stratosphere. These are needed to monitor the climate impact of radiatively active gases and the evolution of the stratospheric ozone layer (including attribution), as well as to support NWP and improved tropospheric ozone data for air quality. Activities to detail the observation requirements for such a mission are ongoing.

Two small Limb Sounding missions to explore the forthcoming Stratosphere: ALTIUS and PICASSO

FUSSEN, Didier; CARDOEN, Pepijn; DEKEMPER, Emmanuel; DEMOULIN, Philippe; ERRERA, Quentin; FRANSSENS, Ghislain; MATESHVILI, Nina; PIEROUX, Didier; VANHAMEL, Jurgen; VANHELLEMONT, Filip; VAN OPSTAL, Bert

Belgian Institute for Space Aeronomy, Belgium

In the last decade, the number of satellite-borne atmospheric sounders with a high vertical resolution has dropped significantly with a detrimental impact on the monitoring of long term trends for essential atmospheric species like ozone.

As an answer to this critical situation, the Belgian Institute for Space Aeronomy is presently developing two LEO missions based on new concepts and/or technologies.

The ALTIUS (Atmospheric Limb Tracker for the Investigation of the Upcoming Stratosphere) mission will be designed from a micro-satellite of the PROBA class orbiting in a 700 km heliosynchronous orbit. The payload will consist of three 2D spectral imagers capable of observing the Earth's atmospheric bright limb from the ultraviolet to the NIR spectral range. Being a very agile platform, ALTIUS will also promote the concept of multi-mode observations by performing solar and stellar occultation observations, across the terminator and in the dark limb region.

The spectrometric technique will be based on Acousto-Optic Tunable Filters (AOTF) and Fabry-Pérot interferometers. The imaging capacity is an essential method to solve the major difficulty associated with the accurate determination of the tangent altitude of the sensed atmospheric region.

ALTIUS is presently at the end of a Phase B1, on its way to a full PDR review. The mission objectives are both operational (with global stratospheric ozone monitoring as a target) and scientific with expected retrievals of NO^2 , H^2O , CH_4 concentration profiles, aerosol extinction profiles and PSC detection.

As a little brother, PICASSO is aiming at a very different goal: to demonstrate that atmospheric limb remote sensing is feasible from pico-satellites. This miniature platform will restrict its observation mode to solar occultations acquired in inertial pointing mode whereas the wavelength domain is focussed on the Chapuis band with a miniaturized Fabry-Pérot spectrometer in the visible domain. Vertical profiles of refraction angles will also be derived from refractive dilution of solar intensity. Solar images will be analyzed on board due to restricted downlink capacities. PICASSO is funded by ESA and also at the PDR level with a target launch in 2016.

The EarthCARE mission: An Active View on Aerosols, Clouds and Radiation

Ingmann, Paul [1]; Wehr, Tobias [1]; Fehr, Thorsten [2]

1: ESA / ESTEC, Keplerlaan 1, 2201 AZ Noordwijk, The Netherlands; 2: ESA / ESRIN, Via Galileo Galilei, 00044 Frascati, Italy

EarthCARE (Earth Clouds, Aerosols and Radiation Explorer) is aiming at the quantification of the relationship between clouds, aerosols and radiation for the improvement of climate and weather models. In this context the mission will provide detailed information on the vertical distribution of aerosols, liquid water and ice on a global scale.

The EarthCARE mission is part of ESA's Earth Explorer programme and is implemented in cooperation with the Japan Aerospace Exploration Agency (JAXA). The satellite payload consists of two active and two passive instruments. The Atmospheric Lidar (ATLID) operates at 355 nm and is equipped with a high-spectral resolution receiver and depolarisation channel that separates molecular from particulate backscatter distinguishing cloud and aerosol types. The Japanese Cloud Profiling Radar (CPR) is a highly sensitive W-band Doppler radar (94GHz) that measures cloud profiles, precipitation and vertical motion within clouds. Due to its significantly higher sensitivity as compared to CloudSat, it will detect substantially thinner ice clouds and stratocumulus. The Doppler observation will provide novel information on convection, precipitating ice particles and raindrop fall speed.

A Multi-Spectral Imager (MSI) with a 150 km wide swath and seven channels in the visible, near-IR, short-wave IR, and thermal IR, will provide scene context information and allows the reconstruction of three-dimensional atmospheric scenes when combined with lidar and radar retrievals. A Broad-Band Radiometer (BBR) observing solar and thermal radiation reflected and emitted from the Earth in three fixed field of views (forward, nadir and backward) will make collocated measurements of the outgoing reflected solar and emitted thermal radiation.

The synergistic exploitation of the four instruments will provide 3D cloud-aerosol-precipitation scenes, with collocated broad-band radiation data, over a mission lifetime of three years. The satellite acceptance review is scheduled for October 2017.

ADM-Aeolus, ESA's Wind Lidar Mission and its spin-off aerosol profile products

Straume-Lindner, Anne Grete [1]; Elfving, Anders [1]; Wernham, Denny [1]; Culoma, Alain [1]; Mondin, Linda [1]; de Bruin, Frank [1]; Kanitz, Thomas [1]; Schuettmeyer, Dirk [1]; Dehn, Angelika [2]; Buscaglione, Fabio [2]

1: ESA-ESTEC, Netherlands, The; 2: ESA / ESRIN, Via Galileo Galilei, 00044 Frascati, Italy

Theme: Future Mission Session

The ESA Earth Explorer Atmospheric Dynamics Mission (ADM-Aeolus) shall demonstrate the potential of high spectral resolution Doppler wind lidars for operational measurements of wind profiles and their use in Numerical Weather Prediction (NWP) and climate modelling. Spin-off products are profiles of cloud and aerosol optical properties. ADM-Aeolus carries the novel Doppler wind lidar instrument ALADIN.

The ALADIN instrument will measure the zonal component of the wind field from the surface up to 30 km in clear and particle-rich air (aerosol layers and transparent clouds), and down to the top of optically dense clouds. It will also deliver backscatter and extinction profiles and lidar ratios. From these parameters, it is possible to retrieve cloud and aerosol information such as cloud-top height, multi-layer clouds and aerosol stratification, cloud and aerosol optical depth, and some limited information on cloud/aerosol type. The satellite will fly in a polar dusk/dawn orbit, providing a global coverage of ~16 orbits per day. The wind measurements (Level 1b) will be delivered near-real-time (NRT) together with a stand-alone Level 2 processor. The L2b wind profiles will be further ingested into the operational Integrated Forecasting System (IFS) at ECMWF. ECMWF will also produce an assimilated 2-D wind profile product (L2c).

Recently the two ALADIN laser transmitters were successfully qualified and delivered for further instrument integration. The instrument delivery will follow later this year and the satellite qualification and launch readiness is scheduled for 2016.

Impact studies have shown that the largest impact of ADM-Aeolus is expected in regions with few other direct wind profile observations, e.g. over the oceans, in the Tropics and in the Southern Hemisphere. Climate monitoring based on reanalysis data are expected to benefit from ADM-Aeolus observations through improvements of NWP analyses. One example is the detection of wind driven circulation changes in Arctic regions. Climate model processes involving wind dynamics, such as convectively coupled tropical waves, El Niño circulations and Monsoons, could be validated with tropical wind profiles from ADM-Aeolus.

In February 2015, the first Aeolus Science and CAL/VAL Workshop was held in ESA-ESRIN, Frascati, Italy. A summary of the workshop high-lights will be given.

In May 2015, a joint ESA-DLR-NASA airborne campaign in Iceland will provide a unique opportunity for the preparation for the ADM-Aeolus in-orbit airborne calibration and validation (CAL/VAL). The airborne Aeolus Airborne Demonstrator (A2D) will be flown together with another high spectral resolution direct detection wind lidar and two coherent wind lidar systems. Calibrations, science measurements, formation flying and satellite under flights will be performed and evaluated. First quick-look results from the campaign will be presented.

The status of the ADM-Aeolus mission and its data products will be presented together with results from impact studies, the pre-launch campaigns, and the CAL/VAL and science exploitation preparations.

Day 2, Tuesday 9 June 2015

Reactive Trace Gases

The Greenhouse Gas Project of ESA's Climate Change Initiative (GHG-CCI): Phase 2 Achievements and Future Plans

Buchwitz, Michael (1); Reuter, Maximilian (1); Schneising, Oliver (1); Boesch, Hartmut (2); Aben, Ilse (3); Bergamaschi, Peter (4); Bovensmann, Heinrich (1); Brunner, Dominik (5); Buchmann, Brigitte (5); Burrows, John P. (1); Butz, Andre (6); Chevallier,

1: University of Bremen, Germany; 2: University of Leicester, UK; 3: SRON, Netherlands; 4: European Commission Joint Research Centre (EC-JRC), IES, Ispra, Italy; 5: Empa, Dübendorf, Switzerland; 6: KIT, Karlsruhe, Germany; 7: LSCE, Gif-sur-Yvette, France;

The GHG-CCI project (<http://www.esa-ghg-cci.org/>) is one of several projects of the European Space Agency's (ESA) Climate Change Initiative (CCI). The goal of the CCI is to generate and deliver data sets of various satellite-derived Essential Climate Variables (ECVs) in line with GCOS (Global Climate Observing System) requirements. The "ECV Greenhouse Gases" (ECV GHG) is the global distribution of important climate relevant gases – specifically atmospheric CO₂ and CH₄ – with a quality sufficient to obtain information on regional CO₂ and CH₄ sources and sinks. The main goal of GHG-CCI is to generate long-term highly accurate and precise time series of global near-surface sensitive satellite observations of CO₂ and CH₄. SCIAMACHY on ENVISAT and TANSO-FTS/GOSAT are currently the two main GHG-CCI satellite instruments as their spectral radiance observations in the near-infrared range of the spectrum permit retrievals of CO₂ and CH₄ columns that are sensitive down to the Earth's surface. This is an important property of the observations to be useful for constraining the sources and sinks of CO₂ and CH₄ by inverse modelling. In addition other satellite instruments such as IASI/METOP and MIPAS/ENVISAT are also used. Phase 1 of the GHG-CCI project finished end of 2013 and entered into phase 2 in March 2014, which will continue until end of February 2017. During this ongoing phase the focus will be on improving the quality of the satellite-derived GHG data sets, on extending the time series and on performing a comprehensive validation of the products. Furthermore, a dedicated "Climate Research User Group" will assess the products with respect to their utility for model evaluation, surface flux inverse modelling, and cross ECV activities. An overview about the current status and an outlook to future activities will be presented.

Upper tropospheric methane observations from GOSAT from thermal infrared soundings

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Quantifying the global distribution and emission fluxes of anthropogenic and naturally occurring atmospheric methane is a key scientific objective for the Greenhouse gases Observing SATellite (GOSAT) mission (launched in January 2009). GOSAT's payload consists of the Thermal And Near-infrared Sensor for carbon Observation (TANSO) that comprises the Fourier Transform Spectrometer (FTS) and the Cloud Aerosol Imager (CAI) enabling coincident observations of atmospheric constituents, clouds and aerosols. The FTS observes through 3 short-wave infrared (SWIR) bands (1 to 3) and band 4 which covers the thermal Infrared (TIR) spectral range of 700 cm⁻¹ to 1800 cm⁻¹ (14.3 to 5.5 µm). GOSAT's complementary SWIR-TIR measurements can be used to better quantify the vertical distribution of methane; space-borne SWIR observations of total column dry-air mole fraction methane are well-suited to improve our knowledge of the underlying surface fluxes whereas the TIR observations characterise concentrations in the free troposphere.

We present GOSAT methane profile retrievals from the newly-developed University of Leicester GOSAT TIR retrieval scheme and assess the quality of the retrieval by comparing with HIPER Pole-to-Pole Observation (HIPPO) in situ aircraft profiles and the in situ TCCON measurement network. We demonstrate the ability of the TIR retrieval to observe regional and large-scale variability in methane through model inter-comparisons and we demonstrate the potential for synergistic SWIR/TIR retrievals to obtain better estimates of atmospheric CH₄ concentration from the surface to the upper troposphere.

CH₄ Profile Retrievals from GOSAT Thermal Infrared Measurements

de Lange, Arno [1]; Aben, Ilse [1]; Hasekamp, Otto P. [1]; Butz, Andre [2]; Landgraf, Jochen [1]

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The Fourier Transform Spectrometer (TANSO-FTS) measures Earth radiances in the Short-Wave InfraRed (SWIR) and Thermal InfraRed (TIR) wavelength ranges. In this study, we discuss the capacity to retrieve methane solely from TIR measurements in the spectral range 1210-1310 cm⁻¹. Simultaneously, we infer atmospheric abundances of H₂O and N₂O, a spectral shift, and the skin temperature. The temperature profile is taken from ECMWF data and the emissivity is calculated at high spectral resolution with the HSR code developed at the university of Wisconsin and is based on MODIS measurements. To verify the retrieval performance of CH₄ total columns, we consider clear-sky spectra co-located in space and time with ground-based measurements at seven sites of the TCCON network (Bialystok, Bremen, Darwin, Lamont, Orleans, Park Falls, and Wollongong) in the period June 2009 to December 2010. In addition, a comparison is made with the HIPPO aircraft campaigns, and the retrieved vertical profiles are also compared against TM5 model results on a global scale. The validation indicates a high bias of the TIR methane product of 46 ppbv (2.5%) with respect to co-located TCCON measurements with a small inter-stational variation (6 ppbv, or 0.3%). We investigate forward model errors and radiometric errors as a potential reason of the retrieval bias. Finally, we discuss the synergistic use of GOSAT shortwave infrared and thermal infrared measurements. The two spectral ranges differ in their sensitivity to the vertical distribution of methane. SWIR measurements are sensitive to the vertically integrated amount of methane whereas the TIR spectral range is mainly sensitive to methane in the upper troposphere. When both spectral regions are combined, height information on methane can be inferred from the measurements. This retrieval approach is applied to GOSAT measurements and first results will be presented.

Phosgene in the UTLS: Vertical Distribution from MIPAS Observations Using New Spectroscopic Data

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Carbonyl chloride (COCl₂), better known as phosgene, is a toxic gas and it was mainly used by chemical industry in the preparation of insecticides, pharmaceuticals and herbicides. Its usage has been reduced over the years due to its high toxicity. To study possible seasonal and latitudinal variations of COCl₂ in the upper troposphere / lower stratosphere (UTLS) we used the measurements from the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS). MIPAS is a Fourier Transform Spectrometer that measured atmospheric limb emission spectra from a polar orbit on board the ESA ENVISAT satellite in the time span from June 2002 to April 2012. Retrievals of phosgene were carried-out using the ν_5 band of COCl₂ in the 830-860 cm⁻¹ spectral region. In the same spectral region we find the ν_4 band of CCl₃F (CFC-11), that is much stronger than the COCl₂ signal. Therefore phosgene spectral features are hidden by the CFC-11 absorbing band. To cope with this strong interference, CFC-11 and phosgene abundances have been retrieved simultaneously. The retrieval scheme used in this work is based on the so called Optimized Retrieval Model (ORM), the scientific version of ESA level 2 processor, upgraded with the Multi-Target Retrieval (MTR) functionality and with the possibility to use Optimal Estimation (OE) to apply external constraints to the state vector. We carry-out the forward simulations using state-of-the art spectroscopic line data calculated at LISA-CNRS, not yet included in the HITRAN database. We show the global distribution of phosgene in the UTLS region and an analysis of its seasonal and latitudinal variability.

Methane Retrievals in the Thermal and Short-Wave Infrared from IASI

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RAL has developed an optimal estimation scheme to retrieve height resolved information on CH₄ from IASI measurements in the thermal infrared (7.9 micron) band. This scheme has been extensively validated in the context of UK national (NERC/NCEO) and Eumetsat funded projects and shown to perform well in comparison with column-averages from both ground-based observations and the short-wave sounder GOSAT. The scheme extracts two independent pieces of information on the profile, with sensitivity extending into the lower troposphere. Column-averaged mixing ratios with a precision of 20-40ppb can be derived, however sensitivity to the boundary layer is weak compared to short-wave sounders (and dependent on the atmospheric/surface state). IASI also measures methane lines in the 3.7 micron spectral range, where there is significant solar contribution to measurements in the daytime over land; increasing sensitivity to methane in the boundary layer. However, this spectral range has not yet been exploited due to the complexity of modelling both solar and thermal contributions to the measurements and the relatively high noise level of IASI in this spectral region. In this paper we will summarise the performance of the thermal infrared scheme and go on to present findings from an investigation into the potential of adding information on near-surface methane by exploiting the 3.7 micron band.

Multi-satellite Constraints on South America Wetland and Fire Carbon Fluxes.

Bloom, A. Anthony [1]; Worden, John [1]; Bowman, Kevin [1]; Worden, Helen [2]; Kurosu, Thomas [1]; Frankenberg, Christian [1]; Schimel, David [1]; Lee, Meemong [1]; Eldering, Annmarie [1]; Liu, Junjie [1]; Schroeder, Ronny [3]; McDonald, Kyle [3]

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The inter-annual variations of fire, wetland, and terrestrial ecosystem carbon fluxes – namely CO₂, CH₄ and CO – remain poorly understood in the tropics. For example, the roles of wetland extent, carbon availability and temperature in controlling wetland CH₄ emissions are uncertain; similarly, the temporal effects of drought on fire emissions and fire traits (such as combustion efficiency and completeness) are not well quantified. Our study is focused on tropical South America, which accounts for 30-55% of wetland CH₄ and 5-35% of fire CH₄ in the tropics. To de-convolve South America seasonal and inter-annual CH₄ emissions during 2003-2013, we characterize the temporal variability of wetland and fire CH₄ fluxes based on satellite data. We derive an ensemble of wetland CH₄ scenarios based on ERS, AVHRR, SSM/I, QuikSCAT & ASCAT wetland extent dataset, and carbon fluxes from the MsTMIP terrestrial biosphere model ensemble. We use a Bayesian fusion of land surface and atmospheric data to constrain inter-annual variations in fire carbon fluxes, and associated CH₄ fluxes: our fire emissions analysis is based on TES CO/CH₄ observations, MOPITT CO measurements, MODIS burned area OMI NO₂, GOME-2 fluorescence and GLAS-derived above-ground biomass. To evaluate the role of fire and wetland emissions in temporal variability of South America CH₄, we use SCIAMACHY CH₄, GOSAT CH₄ and TES CH₄/CO data to confront an ensemble of atmospheric chemistry and transport model (GEOS-Chem) runs. We conclude by demonstrating the future synergetic potential of OCO-2 CO₂ data to constrain fire traits, carbon fluxes and the overall tropical carbon budget.

Tropical controls on the CO² atmospheric growth rate 2010-2011 from the NASA Carbon Monitoring System Flux (CMS-Flux) Project

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Interannual variations in the atmospheric growth rate of CO² have been attributed to the tropical regions and the controls are correlated with temperature anomalies. We investigate the spatial drivers of the atmospheric growth rate and the processes controlling them over the exceptional period of 2010-2011. This period was marked by a marked shift from an El Nino to La Nina period resulting in historically high sea surface temperature anomalies in the tropical Atlantic leading to serious droughts in the Amazon. However, in 2011, unusual precipitation in Australia was linked to gross primary productivity anomalies in semi-arid regions. We use satellite observations of CO₂, CO, and solar induced fluorescence assimilated into the NASA Carbon Monitoring System Project (CMS-Flux) to attribute the atmospheric growth rate to global, spatially resolved fluxes. This system is based upon observationally-constrained "bottom-up" estimates from the Fossil Fuel Data Assimilation System (FFDAS), the ECCO2--Darwin physical and biogeochemical adjoint ocean state estimation system, and CASA-GFED3 land-surface biogeochemical model. The system is used to compute regional tropical and extra-tropical fluxes and quantify the role of biomass burning and gross primary productivity in controlling those fluxes. The potential of OCO² and Sentinel-5p to continue these critical observations used in this analysis is explored.

Quantifying the impact of column integrated CO² observations data on NEP and NPP by supplementary assimilation into CCDAS

Giering, Ralf; Blessing, Simon

FastOpt, Germany

The Carbon Cycle Data Assimilation System (CCDAS, Rayner 2005, Knorr 2008) is used to increase our knowledge about the global carbon cycle by reducing the uncertainties in regional sources/sinks in the terrestrial biosphere. This is achieved through the simultaneous assimilation of complementing satellite data streams, including column integrated CO² (XCO²), into the land biosphere model BETHY (Knorr 2000) and a subsequent propagation of posterior uncertainties to terrestrial fluxes.

BETHY simulates carbon assimilation and plant and soil respiration, embedded within a full energy and water balance. Atmospheric CO² concentrations are derived from CO² surface fluxes using the precomputed Jacobian of the Transport Model TM3. The data assimilation system uses the Bayesian approach by defining a cost function which quantifies the misfit between observations and their model equivalence, assuming Gaussian error distribution. The cost function depends on a number of process parameters of BETHY and the mean global CO² concentration. The best fit of the model to the observations is at the minimum of the cost function. It is found by a BFGS algorithm using the gradient information computed by the adjoint model. The adjoint code is generated by FastOpt's Automatic Differentiation tool Transformation of Algorithm in Fortran (TAF). By this procedure dynamically consistent Net and Gross Surface CO² fluxes are found.

Data streams integrated in CCDAS are:

- Fraction of Absorbed Photosynthetic Active Radiation (fapar) and Leaf Area Index (LAI) from 2Stream Inversion Package (TIP-GlobAlbedo)
- soil moisture from SMOS
- surface CO² concentration from FluxNet sites
- XCO² satellite product from SCIAMACHY

All model-data misfits are weighted by the inverse error estimates. The TIP GlobAlbedo fapar and LAI data misfits are weighted by their inverse error correlation matrix (preliminary results of QA4ECV). Prior estimates of the process parameters are used and deviations are weighted with assumed uncertainties. Posterior error estimates of the parameters are derived from the Hessian of the cost function at the minimum. This error is propagated by the adjoint and tangent of the prediction operator to error estimates of predicted quantities [Scholze 2007]. Again these derivative codes (Hessian,adjoint,tangent) are generated by TAF.

Preliminary result show a reduction in the posterior error estimates of net terrestrial carbon fluxes in 2010 compared to assimilation without the XCO₂ data.

Towards Disentangling Natural and Anthropogenic GHG Fluxes from Space - The CarbonSat Earth Explorer 8 Candidate Mission

Bovensmann, Heinrich University of Bremen, Germany and the CarbonSat Team

M. Buchwitz a, M. Reuter a, K. Gerilowski a, T. Krings a, O. Schneising a, J. P. Burrows a

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The greenhouse gases (GHG), carbon dioxide (CO₂) and methane (CH₄), are the main drivers of climate change, the most important environmental challenge in the 21st century. Understanding and quantifying climate feedback and forcing mechanisms involving these two dominant anthropogenic greenhouse gases requires the discrimination of natural and anthropogenic CO₂ and CH₄ fluxes globally, with regional to local spatial scale resolution. To address this need, CarbonSat was selected by ESA as one of two candidates for the Earth Explorer Opportunity mission (EE8) to be the next step in the evolution of space based GHG observations. The main goal of the proposed ESA CarbonSat Mission is to advance our knowledge on the natural and man-made sources and sinks of these greenhouse gases over this range of scales. The unique feature of the CarbonSat mission concept is its "GHG imaging capability", which is achieved by combining high spatial resolution (6 km²) and good spatial coverage (up to 240 km wide swath, with contiguous ground sampling). CarbonSat aims to deliver spatially-resolved, time varying global estimates of dry column mixing ratios of CO₂ and CH₄ with high precision (~1 to 2 ppm and ~12 ppb, respectively) and relative accuracy (<0.5 ppm and < 5 ppb, respectively on regional scales). Benefiting from its imaging capabilities along and across track, CarbonSat will provide at least an order of magnitude larger number of cloud-free CO₂ soundings than OCO₂. CarbonSat will be the first satellite mission to image small scale emission hot spots of CO₂ (e.g., cities, volcanoes, industrial areas) and CH₄ (e.g., fossil fuel production, landfills, seeps) and to quantify their emissions and discriminate them from surrounding biospheric fluxes. CarbonSat will also reveal regional details of natural fluxes, allowing discriminating among regions and across seasons the largest carbon sinks and the areas that may loose CO₂ or CH₄ to the atmosphere. This will allow a better separation of natural and anthropogenic GHG sources and sinks also on larger scales. The latter will be further supported by CarbonSat's ability to constrain the fluxes of CO₂ exchanged between the land biosphere and the atmosphere by simultaneously measuring CO₂ and solar induced chlorophyll fluorescence (SIF), a process associated with Gross Primary Production (GPP). Source/sink information will be derived from the retrieved atmospheric column-averaged mole fractions of CO₂ and CH₄ via inverse modelling.

Recent results from the CarbonSat scientific studies and supporting campaigns documenting the expected data quality and potential application areas will be presented.

Ozone structure and variability in the upper troposphere and lower stratosphere as seen by Envisat and ESA Third-party mission limb profiling instruments

Sofieva, Viktoria [1]; Tamminen, Johanna [1]; Kyrölä, Erkki [1]; Stiller, Gabriele [2]; von Clarmann, Thomas [2]; Laeng, Alexandra [2]; Weber, Mark [3]; Rozanov, Alexei [3]; Rahpoe, Nabiz [3]; Degenstein, Doug [4]; Walker, Kaley A. [5]; van Roozendaal, Mi

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Dynamical, chemical and radiative coupling between the stratosphere and troposphere are among the important processes that must be understood for prediction of global trends, including climate change. However, the upper troposphere and lower stratosphere (UTLS) region is difficult for exploration from space. For limb-viewing satellite measurements, retrievals in UTLS are challenging due to relatively low signal-noise ratio and presence of clouds.

In this work, we compare the spatio-temporal distributions and variations of the ozone field in the UTLS obtained from the limb instruments participating in the ESA Climate Change Initiative for Ozone (Ozone_cci): MIPAS, SCIAMACHY and GOMOS on Envisat, OSIRIS on Odin, ACE-FTS on SCISAT. We study seasonal variations, probability density functions, influence of Asian Summer Monsoon on UTLS ozone.

The observational distributions by Ozone_cci instruments are generally in good agreement. This similarity provides confidence of the observed patterns and allows creating Level 3 datasets and parameters, which can be useful for validation of chemistry climate models.

New MIPAS V7 products

Raspollini, Piera [1]; Aubertin, Ginette [2]; Barbara, Flavio [1]; Bernau, Marc [3]; Birk, Manfred [4]; Carli, Bruno [1]; Carlotti, Massimo [5]; Castelli, Elisa [6]; Ceccherini, Simone [1]; Dehn, Angelika [7]; De Laurentis, Marta [8]; Dinelli, Bianca M. {

1: IFAC-CNR, Firenze, Italy; 2: ABB Inc., 585 Blvd. Charest East, Québec, G1K9H4, Canada; 3: Airbus DS GmbH, Friedrichshafen, Germany; 4: DLR, Germany; 5: University of Bologna, Bologna, Italy; 6: ISAC-CNR, Bologna, Italy; 7: ESA-ESRIN, Frascati, Italy; 8

MIPAS measurements on ENVISAT represent a unique database for the study of atmospheric composition and of the time variation of atmospheric constituents.

For trend studies it is important that instrumental drifts are reduced. Some of the MIPAS spectral bands are affected by time-dependent non-linearity that have been recently corrected.

In addition to this non-linearity correction, the forthcoming new version of MIPAS products (Version 7) contains several other improvements: a new approach for handling continuum leading to a more stable retrieval, a new selection of spectral intervals for the analysis of the full resolution measurements aiming to reduce the bias between full resolution and optimized resolution measurements, the regularization of the H₂O profiles. Furthermore, the implementation of the retrieval of five new species (HCFC²², CFC¹⁴, HCN, COF², CC¹⁴) leads to a total of 15 species in ESA products.

The latest improvements implemented in the ESA processor, the results of the validation of the products and some preliminary results on the trend of some ozone depleting substances will be presented and discussed.

MLS-based detection and attribution of the recovery of ozone in the Antarctic ozone hole

de Laat, Jos; van Weele, Michiel; van der A, Ronald

Royal Netherlands Meteorological Institute, Netherlands, The

Unambiguous and persistent recovery of ozone in the Antarctic ozone hole would constitute an important landmark in stratospheric ozone research. For many decades the Antarctic ozone hole is considered one of the prime examples of both the detrimental effects of human activities on our environment and effective and successful international implementation of environmental mitigation policies.

In response to these policies the atmospheric concentrations of ozone depleting substances (ODS) are on the decline. Expectations are that signs of recovery of stratospheric ozone and ozone in the Antarctic ozone hole should become visible shortly. For the Antarctic ozone hole some success has been claimed but this has also become a matter of substantial debate. The WMO 2014 ozone assessment report does not yet claim recovery of ozone in the Antarctic ozone hole. Traditionally, recovery has been studied by the use of multi-variate regression of long-term ozone records. However, there are many uncertainties involved in the practical application of these regressions because of implicit choices on spatiotemporal averaging of ozone (monthly/seasonal means, extension of the Antarctic vortex area).

In this talk we will introduce a novel approach for unambiguous and persistent recovery of ozone in the Antarctic ozone hole. Rather than focusing on time and area averages of total ozone columns or ozone profiles, we make use of the time evolution of the probability distribution of vertically resolved ozone in the Antarctic ozone hole. Specifically we show that in the 10-year record of MLS satellite measurements of ozone in the Antarctic ozone hole there is a significant decline in the occurrence of extremely low ozone (near 100% ozone depletion) in favor of the occurrence of low ozone (80-90% ozone depletion). We argue that through changes in the observed probability distributions we can provide the required fingerprint for the detection of ozone recovery in the Antarctic ozone hole. Through combination with the MLS observations of primarily temperature and N₂O we argue that the observed fingerprint can be attributed to the ongoing decline in OD

We will discuss the advantages of our method for detection and attribution over the more traditional regression techniques and briefly discuss the potential of continuation of detection and attribution of ozone changes in the light of the currently available and planned (e.g. Sentinel 5P) satellite remote sensing capacity.

Continuation of GOMOS, MIPAS and SCIAMACHY-limb Ozone Record using OMPS Limb Profiler

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Ozone Mapping and Profiler Suite (OMPS) was launched on 28 October 2011 on board of Suomi National Polar-orbiting Partnership (SNPP) satellite. OMPS represents next generation of US ozone monitoring system. The instrument suite consists of 3 ozone sensors designed to measure total and vertical ozone distribution. The OMPS Limb Profiler (LP) sensor acquires solar radiances scattered from atmospheric limb in UV and visible spectral ranges to retrieve vertical ozone profiles from cloud top to 60 km with vertical resolution of about 2 km. In this study we will examine the suitability of using LP profiles to continue the ozone record from GOMOS, MIPAS and SCIAMACHY-limb observation on the ENVISAT satellite. The ENVISAT mission ended in April 2012, while OMPS LP observations started in March 2012. Since the overlap between them is too short, we will use Aura MLS and ACE-FTS data, which have more than 3-year overlap with OMPS LP, as transfer standards to determine biases between LP and the ENVISAT sensors. ACE-FTS and GOMOS are occultation instruments that use astronomical bodies to do accurate altitude registration and provide ozone profiles in number density units versus altitude coordinate. These data are particularly suitable to assess the altitude registration accuracy of OMPS-LP and SCIAMACHY. MIPAS and MLS measure in mixing ratio versus pressure

coordinate, thus the comparison with LP requires unit conversion, which involves temperature profiles. Uncertainties related to unit conversion will be accounted for in the analysis. We will use the combined ENVISAT/OMPS dataset to determine inter-annual variability and long-term changes and compare them with MLS, ACE-FTS, and nadir satellite sensors such as SBUV/2, OMI and GOME-2. For reliable detection of long-term ozone changes it is important to have several independent datasets that can be compared.

Uncertainties in recent satellite ozone profile trend assessments (SI2N, WMO 2014) : A network-based assessment of fourteen contributing limb and occultation data records

Hubert, Daan [1]; Lambert, Jean-Christopher [1]; Verhoelst, Tijn [1]; Granville, José [1]; Keppens, Arno [1]; Cortesi, Ugo [2]; Degenstein, Doug A. [3]; Froidevaux, Lucien [4]; Godin-Beekmann, Sophie [5]; Hoppel, Karl W. [6]; Kyrölä, Erkki [7]; Leblanc, T

1: Belgian Institute for Space Aeronomy (BIRA-IASB), Belgium; 2: IFAC-CNR, Italy; 3: U Saskatchewan, Canada; 4: JPL-Pasadena, USA; 5: LATMOS-IPSL, France; 6: NRL, USA; 7: FMI, Finland; 8: JPL-TMF, USA; 9: DLR, Germany; 10: U York, Canada; 11: Chalmers U,

Numerous vertical ozone profile data records collected over the past decades from space-based platforms have the potential to allow the ozone and climate communities to tackle a variety of research questions. A prime topic is the study and documentation of long-term changes in the vertical distribution of atmospheric ozone, as targeted by the recent SPARC/IO3C/IGACO-O3/NDACC Initiative (SI2N) and WMO's ozone assessment. Such studies typically require data records with documented mutual consistency in terms of bias and long-term stability. Ground-based networks play a pivotal role in evaluating which satellite records comply with end-user requirements and are fit for their purpose. They provide high-quality, independent measurements on a pseudo-global scale from the ground up to the stratosphere.

Here, we present an assessment of the long-term stability and mutual consistency of fourteen limb/occultation ozone profile data records, using NDACC/GAW/SHADOZ ozonesonde and NDACC lidar network data as reference standards. We show how a harmonized analysis framework and robust statistical methods allow us to derive reliable estimates of the drift, bias, and short-term variability of each satellite data record. We examine the dependence of these parameters on altitude and, whenever feasible, on latitude and season. The analysis is furthermore performed in four different ozone profile representations, as it turns out that auxiliary data used for unit and representation conversions can impact data quality. We discuss the mutual consistency and compliance of satellite data sets with respect to specific user requirements from GCOS and from climate research groups. We conclude by reflecting on the implication of our results for trend assessments on recently merged ozone profile records (Ozone_CCI, GOZCARDS, SWOOSH, ...)

Twelve Years of the Atmospheric Chemistry Experiment (ACE) Satellite: Mission Status and Recent Results

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In August 2015, the Canadian-led Atmospheric Chemistry Experiment (ACE) mission will complete its twelfth year in orbit on board the SCISAT satellite. The long lifetime of ACE has provided a valuable time series of composition measurements that contribute to our understanding of ozone recovery, climate change and pollutant emissions. These profiles of atmospheric trace gases and aerosols provide altitude-resolved data that are necessary for understanding processes that occur at specific altitudes or over limited vertical length scales.

The SCISAT/ACE mission uses infrared and UV-visible spectroscopy to make its solar occultation measurements. There are two instruments on board SCISAT. The ACE Fourier Transform Spectrometer (ACE-FTS) is an infrared FTS operating between 750 and 4400 cm⁻¹ and the ACE-MAESTRO (Measurements of Aerosol Extinction in the Stratosphere and Troposphere Retrieved by Occultation) is a dual UV-visible-NIR

spectrophotometer which was designed to extend the ACE wavelength coverage to the 280-1030 nm spectral region. From these measurements, altitude profiles of atmospheric trace gas species, temperature and pressure are retrieved. In addition to the mission and instrument status, a review of current science and validation results from the ACE mission will be presented in this paper.

Using visible spectra to improve sensitivity to near-surface ozone of UV-retrieved profiles from MetOp GOME-2

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STFC Rutherford Appleton Laboratory, United Kingdom

We present the results of a technique that uses information from the Chappuis ozone bands in the visible part of the spectrum to improve the near-surface sensitivity of UV-retrieved ozone profiles from GOME-2 aboard MetOp-A and B. The RAL UV ozone profile algorithm, which contributes to the ESA Ozone ECV, has already been optimised to use the temperature dependence of ozone absorption in the Huggins bands to extend profile information to the lower troposphere. By virtue of the higher land surface reflectivity and lower Rayleigh scattering at visible wavelengths, the Chappuis bands can, in principle, increase sensitivity to near-surface ozone. However, in practice, there are several major challenges; not least those associated with the characterisation of surface reflectance on similar spectral scales to ozone absorption, other interfering gases and instrumental features that need to be accounted for. We will show that it is possible to identify ozone enhancement in the boundary layer using the combination of UV and visible spectral information which UV measurements alone cannot detect. We compare our results to both chemical transport models and ozonesondes.

Distribution and Time Evolution of the Ozone Instantaneous Longwave Radiative Effect from IASI and TES Observations

Doniki, Stamatia [1]; Hurtmans, Daniel [1]; Clarisse, Lieven [1]; Clerbaux, Cathy [1,2]; Coheur, Pierre-François [1]; Worden, Helen M. [3]; Bowman, Kevin W. [4]

1: Université Libre de Bruxelles, Belgium; 2: Sorbonne Universités; UPMC Université Paris 06; Université Versailles St.-Quentin; CNRS/INSU; LATMOS-IPSL, Paris, France; 3: National Center of Atmospheric Research (NCAR), USA; 4: Jet Propulsion Laboratory (J

Ozone is the third most important greenhouse gas in terms of radiative forcing (0.4 W/m^2) as a result of increases in ozone precursor emissions since pre-industrial times. Consequently, tropospheric ozone is recognized as one of the key atmospheric Essential Climate Variables by GCOS and WMO. Until recently, the ozone radiative forcing calculations were entirely model based, which led to significant discrepancies due to different model characteristics, as shown in the IPCC AR5. Satellite sounders operating in the infrared now offer the possibility to infer directly the Longwave Radiative Effect (LWRE) of ozone in the 9.6 micron band, with respect to its vertical distribution, allowing to better constrain model estimates of the ozone radiative forcing and its future predictions. Measurements of the ozone LWRE from the NASA Aura TES sounder have for instance been used to reduce intermodel RF uncertainty in the IPCC AR5.

In this presentation we calculate the ozone LWRE by exploiting the measurements of IASI on MetOp, which are performed at unprecedented temporal and spatial sampling and therefore allow investigating ozone radiative impacts on various scales. The calculation method, which we show to be more precise than previous methods based on an anisotropy correction for the angular integration, is very briefly presented. We then focus the presentation on the first daily global distribution of the LWRE from IASI and show also the first seasonal variations. The global variability of the LWRE and more local processes, such as stratospheric intrusions, are analyzed, considering also the impacts of surface temperature and humidity changes. Finally we present preliminary results of the comparison between IASI and TES/Aura. We show that IASI LWRE measurements continue and extend those of TES and that together they represent a robust dataset to benchmark future chemistry-climate model assessments, such as the Chemistry-Climate Model Initiative (CCMI).

Sensitivity of Northern Hemispheric Tropospheric Ozone To Anthropogenic Emissions as Observed by Satellite Observations

Worden, John [1]; Jiang, Zhe [1]; Verstraeten, Willem [2]; Boersma, Folkert [2]; Payne, Vivienne [1]; Neu, Jessica [1]; Bowman, Kevin [1]; Fischer, Emily [3]

1: JPL / Caltech, United States of America; 2: KNMI; 3: Colorado State University

Atmospheric composition is rapidly changing in response to changes in industrialization, land-use, and climate. Tropospheric ozone is at the nexus of atmospheric chemistry, air-quality, and climate as it is not only the third most important greenhouse gas and a primary air pollutant, but also affects carbon dioxide by damaging plants and the lifetime of atmospheric methane by influencing the oxidative capacity of the atmosphere.

Observed trends in free-tropospheric ozone as observed by ozone-sondes and more recently by satellite measurements from the Aura TES and IASI instruments do not agree with models that are driven by observed changes in ozone pre-cursor emissions. As a consequence, estimates of ozone radiative forcing and the future trajectory of tropospheric ozone concentrations are highly uncertain. In this study, we explore the use of satellite observations of ozone and its pre-cursors for constraining the sensitivity of Northern hemispheric tropospheric ozone to anthropogenic emissions. New measurements of peroxyacetyl nitrate (PAN) from the Aura TES instrument suggest that one explanation for the model/data mismatch in trends is reduced, modeled ventilation of reactive nitrogen into the free-troposphere over Asia. Ultimately, continued well validated observation of ozone and its pre-cursors from IASI, AIRS, CRIS, and Trop-OMI will be needed to solve this critical scientific question.

Springtime Variability of Lower Tropospheric Ozone over Eastern Asia: Respective Role of Cyclones and Pollution as Determined from IASI

Dufour, Gaëlle [1]; Eremenko, Maxim [1]; Cuesta, Juan [1]; Doche, Clément [2]; Foret, Gilles [1]; Beekmann, Matthias [1]; Cheiney, Audrey [3,1]; Wang, Yong [4]; Cai, Zhaonan [4]; Liu, Yi [4]; Takigawa, Masayuki [5]; Kanaya, Yugo [5]; Flaud, Jean-Marie [1]

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Air quality monitoring from space gives a helpful complement to in situ measurements and regional chemical transport models (rCTM) in order to draw a more comprehensive picture of pollution processes. In the case of tropospheric ozone important progresses in the field of atmospheric sounding from space have been accomplished during the last decade. The lower troposphere is now available from IASI (Infrared Atmospheric Sounding Interferometer) with a maximum of sensitivity between 3 and 4 km. We use satellite observations from IASI on board the MetOp-A satellite to evaluate the springtime daily variability of lower tropospheric ozone over East Asia. The availability of semi-independent columns of ozone from the surface up to 12 km simultaneously with CO columns from IASI provide a powerful observational dataset to identify the processes controlling tropospheric ozone enhancement at synoptic scales. In addition, we combine IASI observations with meteorological reanalyses from ERA-Interim in order to investigate in more details the processes that control the spatial and temporal distribution of lower tropospheric ozone. The succession of low- and high-pressure systems drives the day-to-day variability of lower tropospheric ozone over North East Asia. A case study analysis in May 2008 shows that reversible subsiding and ascending ozone transfers in the UTLS region occurring in the vicinity of low-pressure systems and associated with tropopause perturbations affect the free and lower tropospheric ozone over large regions, especially north to 40°N and largely explain the ozone enhancement observed with IASI in the North Asian troposphere. Irreversible downward transport of ozone-rich air masses from the UTLS to the lower troposphere occurs more locally. Its contribution to the lower tropospheric ozone column is difficult to dissociate from the tropopause perturbations induced by the weather systems. Over Chinese highly polluted regions, the analysis of ozone observations in correlation with CO and

NO₂ observations reveals a more complex situation where the photochemical production of ozone often plays a concomitant role to explain ozone enhancements in the lower troposphere.

Global and Regional Ozone Trends Using 20 Years of European Satellite Data

Coldewey-Egbers, Melanie [1]; Loyola, Diego [1]; Braesicke, Peter [2]; Dameris, Martin [3]; van Roozendael, Michel [4]; Lerot, Christophe [4]; Balis, Dimitris [5]; Koukouli, MariLiza [5]; Zimmer, Walter [1]

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We provide a new perspective on the current state of the ozone layer using a comprehensive long-term total ozone data record, which has been recently released as an Essential Climate Variable (ECV) within the framework of the European Space Agency's Climate Change Initiative (ESA-CCI). The data record has been compiled from European satellite sensors GOME/ERS-2, SCIAMACHY/ENIVSAT, and GOME-2/MetOp, which provide global observations for the last 20 years.

A key issue is the detection of the expected onset of ozone recovery and its spatial fingerprint as a consequence of the 1987 Montreal Protocol and its subsequent amendments. The protocol controls and regulates the production and release of Ozone Depleting Substances (ODSs) and measurements indicate that their stratospheric concentrations peaked and have begun to decrease since the turn of the century.

We use the GOME-type Total Ozone ECV (GTO-ECV) data record in order to disentangle the various aspects of ozone change and variability at global and regional scales using a multivariate regression analysis taking into account several explanatory variables describing natural and/or anthropogenic forcings. It turned out that given dominant natural variability due to complex feedback mechanisms between chemical and dynamical atmospheric processes the expected midlatitude onset of ozone recovery is still not significant and would need additional years of observations. A regional increase in the tropical Pacific is a likely manifestation of a long-term change in El Niño - Southern Oscillation intensity over the last two decades induced by strong El Niño in 1997/98 and strong La Niña in 2010/11.

The results are compared with appropriate ground-based measurements at various locations and two Chemistry-Climate Model simulations. Furthermore we will provide an outlook on the second phase of the ESA ozone CCI project. The climate data record will be further extended with GOME-2/MetOp-B and OMI/Aura data and we will address the spatial and temporal sampling inhomogeneities among the different satellite instruments which may have systematic effects and may therefore lead to erroneous average estimates.

Ozone Profile Changes and Montreal Protocol

Staehelin, Johannes [1]; Harris, Neil [2]; Tummon, Fiona [1]; Hassler, Birgit [3]

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Stratospheric concentrations of ozone depleting substances (ODSs) have slowly decreased since the mid-1990s due to the successful implementation of the Montreal Protocol (1987) and its subsequent enforcements. Comprehensive analysis of profile ozone changes is vital to documenting the beneficial effect of the Montreal Protocol on the ozone layer, particularly since ozone recovery is expected to first become visible in the upper stratosphere where ODSs are photolyzed and affect ozone most strongly. The global picture needs to be based on merged satellite ozone series since no single satellite instrument covers the entire period from the 1970s, when ODSs started affecting stratospheric ozone, until the present.

Seven merged satellite data sets were analysed by applying a multiple linear regression model describing the annual cycle and including proxies for the QBO (Quasi-Biennial Oscillation), solar cycle, ENSO (El Niño Southern Oscillation), and volcanic aerosols [see Tummon et al., Atmos. Chem. Phys. Discuss., 14, 25687–25745, 2014]. Long-term ozone trends were calculated for the period 1984–2011 using a piece-wise linear regression, with a

change in trend prescribed at the end of 1997. The best agreement amongst data sets is seen in the mid-latitude lower and middle stratosphere, with larger differences in the equatorial lower stratosphere and the upper stratosphere. In most cases, differences in the choice of underlying instrument records that were merged produced larger differences between data sets than the use of different merging techniques. For the 1984–1997 period, (downward) trends tend to be most similar between data sets (with largest negative trends ranging from -4 to -8%/decade in the mid-latitude upper stratosphere). This is largely due to the fact that most data sets are predominantly (or only) based on SAGE-II for this period. Trends in the middle and lower stratosphere are much smaller, and particularly for the lower stratosphere, large uncertainties remain.

For the recovery period (1998–2011), the picture is less conclusive: trends varied from approximately -1 to +5%/decade in the mid-latitude upper stratosphere. Again, middle and lower stratospheric trends were smaller and for most data sets not statistically significant. These differences might be explicable for several reasons: (i) from 2005 onwards, when the SAGE-II instrument was switched off, observations from several different instruments are used to complete the time series; (ii) ODS concentrations are decreasing much more slowly than they increased in the first period (i.e. leading to smaller trends).

Overall, however, there is a clear shift from mostly negative to mostly positive trends between the two periods over much of the profile. The data sets and trends derived from them provide important information for model validation. Given the effects of changing climate on ozone and its recovery, it is vital that measurements of the ozone profile from space continue so that we can document ozone profile changes in future.

The work presented here results from the SI2N activity, which is an initiative supported by SPARC, the International Ozone Commission (IO3C), IGACO O3/UV of GAW (Global Atmosphere Watch), and NDACC (Network for the Detection of Atmospheric Composition Changes).

Evaluation of GOME, SCIAMACHY, GOME2, SBUV, OMI and IASI–METOP total ozone retrievals performances by comparison with SAOZ NDACC ground-based measurements

Pommereau, Jean-Pierre [1]; Goutail, Florence [1]; Clerbaux, Cathy [2,3]; Coheur, Pierre [3]; Lerot, Christophe [4]; Danckaert, Thomas [4]; Van Roozendaal, Michel [4]

1: LATMOS, CNRS, UVSQ, France; 2: LATMOS, CNRS, UPMC, France; 3: ULB, Belgium; 4: IASB, BIRA, Belgium

High accuracy global total ozone measurements from space are key data for evaluating the amplitude of ozone depletion, understanding its contribution and consequences on climate change and predicting the future evolution of both ozone and climate. Long series of total ozone data are available, but showing still systematic significant differences between them. Here most recent data available from GOME-ERS2, SCIAMACHY-Envisat, GOME2-Metop reprocessed with the GODFIT V3 (GOME-Type Direct FITing) algorithm developed in the frame of the ESA Ozone Climate Initiative (Lerot et al., 2014), from NASA SBUV v8.6 (McPeters et al., 2013), NASA-AURA-OMI (Levelt et al., 2007) and IASI Metop A and B (Clerbaux et al., 2009), are compared with SAOZ total ozone ground-based NDACC measurements available at several stations distributed in latitude in the world since the early 90's (Pommereau and Goutail, 1988).

The comparison does show some small mean biases between satellites and SAOZ, as well as between satellites, depending on the satellites observing periods. But most significant is the amplitude of the seasonal variations of the satellite-SAOZ difference varying with the satellite data used varying for example at northern mid-latitude from 2% amplitude with the GODFIT GOME, SCIA and GOME2 data, 3% with SBUV and 4% with IASI. Although the seasonal cycle of stratospheric temperature contributes partly in the case of SBUV measurements in the UV, the largest identified cause of seasonal variation of the satellite-SAOZ difference appears related to a Sun Zenith Angle dependence affecting possibly both satellites and/or ground-based measurements. The origin of this SZA dependence is further explored by looking at the satellite-SAOZ differences at various NDACC stations distributed in latitude.

Atmospheric Sulphur from the Upper Troposphere to the Upper Stratosphere: 10 Years of MIPAS Observations

Hoepfner, Michael [1]; Glatthor, Norbert [1]; Bruehl, Christoph [2]; Grabowski, Udo [1]; Guenther, Annika [1]; Kellmann, Sylvia [1]; Krysztofiak-Tong, Gisèle [3]; Leyser, Adrian [4]; Linden, Andrea [1]; Sinnhuber, Bjoern-Martin [1]; Stiller, Gabriele [1];

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Sulfur dioxide (SO₂) and carbonyl sulfide (OCS) are the most important trace gases of the atmospheric sulfur budget. These gases are the main players responsible for the existence and modulation of the stratospheric aerosol layer. For example, an increase of the stratospheric aerosol burden is discussed as contribution to the so-called global warming hiatus, a decrease in the rise of global temperatures since about 1998. Further, it is essential to correctly understand and model the stratospheric sulfur cycle with regard to the proposals of possible artificial climate cooling (so-called geo-engineering) by injection of sulfur into the stratosphere. This can only be achieved by validation of model results with observations.

Another important aspect about OCS is related to the global carbon cycle. OCS can be used as proxy for the photosynthetic uptake of CO₂ due to its similar diffusion pathways into leaves. But – in contrast to CO₂ - this uptake is irreversible. Thus, understanding of global OCS fluxes may contribute to assess gross primary productivity in the biosphere.

We will give an overview of the highlights of OCS and SO₂ observations from MIPAS/Envisat between 2002 and 2012 in combination with results from global chemistry-transport models. In case of SO₂, for the first time a global picture of the vertically resolved distribution of SO₂ between 15 and 45 km altitude has been obtained. It indicates evaporation of H₂SO₄ aerosols above the Junge-layer, conversion to SO₂ by photolysis, the poleward transport due to the Brewer-Dobson circulation and the 'CCN explosion', i.e. the rapid reformation of aerosol particles over the poles during sunrise in springtime. Further, the distribution of SO₂ in the region of the upper troposphere and lower stratosphere has been investigated gaining an altitude-resolved time-series of SO₂-injections from small and medium-size volcanic eruptions into the stratosphere. The global picture of SO₂ in the upper troposphere indicates e.g. elevated levels at the top of the Asian monsoon circulation which might be connected to an aerosol layer recently discovered at similar altitudes. In the MIPAS dataset of OCS several features related to the stratospheric aerosol layer as well as its tropospheric sources (oceanic release, biomass burning) and sinks (vegetative and soil uptake) are analysed.

Improved Algorithms for GOMOS/ENVISAT Water Vapor Retrieval at 936 nm and O₂ A band

Bertaux, Jean-Loup [1]; Hauchecorne, Alain [1]; Dalaudier, Francis [1]; Blanot, Laurent [2]

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The evolution of water vapor in the lower stratosphere is still a case for controversy, while its exact trend in response to climate change is important. The GOMOS instrument on board ENVISAT (launched 2002 in a helio-synchronous polar orbit) contains a high resolution spectrometer for the measurement of O₂ at 760 nm (A band) and H₂O at 936 nm, with a spectral resolution of 0.073 nm for O₂ and 0.093 nm for H₂O. GOMOS is the first instrument measuring H₂O by the technique of stellar occultation, which in principle is insensitive to long term drift, an essential feature for long term monitoring of a possible trend. Seven stars are sufficiently bright to provide useful measurements for stratospheric and tropospheric H₂O in the altitude range from 5-10 to 45 km, the lower limit being dictated by the presence of clouds. Over the lifetime of GOMOS, more than 800,000 vertical profiles have been obtained, about 50,000 of them suitable for H₂O.

The H₂O retrieval is severely hampered by a strong intra-pixel CCD non uniformity. Nonetheless, a comparison with other H₂O instruments is undergoing in 2015 in the frame of WAVAS-II efforts (conducted by Gabriella Stiller and Stefan Lossow), while O₂ measurements may be compared to ECMWF re-analysis of pressure-

temperature profiles. Some comparisons will be presented, showing that GOMOS H₂O results are at their best in the upper troposphere and lower stratosphere (UTLS), where spectral H₂O features are larger than artifacts due to CCD non-uniformity and vertical resolution of GOMOS higher than other instruments.

A new type of retrieval algorithm is being developed in the frame of an ESRIN contract, the preliminary results of which will be presented.

Satellite Observations of Carbonyl Fluoride (COF₂) and Hydrogen Fluoride (HF) and their Comparisons with SLIMCAT Chemical Transport Model Calculations

Harrison, Jeremy [1,2]; Chipperfield, Martyn [3]; Dudhia, Anu [4]; Boone, Chris [5]; Bernath, Peter [6]; Froidevaux, Lucien [7]; Anderson, John [8]; Russell III, James [8]

1: Department of Physics and Astronomy, University of Leicester, Leicester, United Kingdom; 2: National Centre for Earth Observation, University of Leicester, Leicester, United Kingdom; 3: School of Earth and Environment, University of Leeds, Leeds, United Kingdom

The majority of fluorine in the atmosphere has resulted from the anthropogenic emission of chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbons (HFCs). Most tropospheric fluorine is present in its emitted 'organic' form due to the molecules having long lifetimes (up to a decade or longer). Thus they are able to reach the stratosphere where they are broken down, liberating fluorine. The principal 'inorganic' degradation products found in the stratosphere are carbonyl fluoride (COF₂), carbonyl chloride fluoride (COClF), and hydrogen fluoride (HF); of these HF is the most abundant. In fact at the top of the stratosphere most of the fluorine is present as HF, which, due to its extreme stability, is an almost permanent reservoir of stratospheric fluorine. The second most abundant stratospheric 'inorganic' fluorine reservoir is carbonyl fluoride (COF₂). Whereas all fluorine-containing species are effectively sources of HF, COF₂ is formed largely from the atmospheric degradation of CFC-12 (CCl₂F₂), which is now banned under the Montreal Protocol, and HCFC-22 (CHF₂Cl), the most abundant HCFC and classed as a transitional substitute under the Montreal Protocol. All COF₂ ultimately degrades to HF.

The use of satellite remote-sensing techniques allows the measurement of COF₂ and HF atmospheric abundances with impressive global coverage, and the investigation of trends, and seasonal and latitudinal variability. This work presents global distributions and trends of COF₂ using data from two satellite limb instruments: the Atmospheric Chemistry Experiment Fourier transform spectrometer (ACE-FTS), onboard the SCISAT-1 satellite, which has been recording atmospheric spectra since 2004, and the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) instrument onboard the ENVIRONMENTAL SATellite (Envisat), which has recorded thermal emission atmospheric spectra between 2003 and 2012. Global distributions and trends of HF are derived using data from the ACE-FTS, and the HALogen Occultation Experiment (HALOE) instrument, onboard the Upper Atmosphere Research Satellite (UARS), which recorded atmospheric spectra between 1991 and 2005. All observations are compared with the output of SLIMCAT, a state-of-the-art three-dimensional chemical transport model (CTM). The model aids in the interpretation of the satellite observations, and the comparison provides a validation of emission inventories and the atmospheric degradation reaction schemes used in the model.

Reanalysis of the Stratospheric Chemical Composition Based on Assimilation of EOS Aura MLS and MIPAS: methane (CH₄) and nitrous oxide (N₂O)

Errera, Quentin [1]; Botek, Edith [1]; Chabrilat, Simon [1]; Christosphe, Yves [1]; Hegglin, Michaela [2]; Ménard, Richard [3]; Skachko, Sergey [1]; van Weele, Michiel [4]

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This contribution presents analyses of stratospheric methane (CH₄) and nitrous oxide (N₂O) based on assimilation of EOS Aura MLS (v3.3) and MIPAS (IPF v6.0) by the Belgian Assimilation System of Chemical Observations (BASCOE) during the period 2005-2012. Several assimilation aspects will be discussed that intent to improve the analyses and then add value to the observations, namely (1) the use of the Averaging Kernels of the observations, (2) the use, for MIPAS, of the observational error vertical correlation matrix in addition to the standard deviation error given at the tangent point, (3) the removal of the systematic differences between the MLS and MIPAS observations using ACEFTS as anchor and (4) the implementation of CH₄-N₂O correlations in the background error covariance matrix of BASCOE. Analyses will be validated against independent data from ACEFTS and NDACC FTIR observations. In particular, the impact of the relatively poor availability of MIPAS data during the years 2005-2007 on the time consistency of the analyses will be evaluated.

Synergy between middle infrared and mm-wave limb sounding of atmospheric temperature and minor constituents in different cloudy scenario

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The exploitation of the synergy between infrared and mm-wave limb sounding measurements is one of the key strength of the scientific payload proposed for the PREMIER mission candidate to the Core Missions of ESA Earth Explorer 7. As part of the preparatory activities of PREMIER, the PremierEx campaign was conducted in the

Arctic region (Kiruna, Sweden) with the high altitude research aircraft M-55 Geophysica in March 2010. In this work, we discuss the synergistic use of MARSCHALS and MIPAS-STR data acquired during the

Premier Ex scientific flight conducted on March 10, 2010 by using an innovative approach to the problem of atmospheric data fusion. We compare the quality of synergistic and individual retrieval products and present our conclusions on the potential of combined exploitation of the information associated to infrared and mm-wave limb observations of the UTLS. The cloud coverage (low clouds in the first part, no clouds in the central part and high tropospheric clouds at the end) observed along the flight provided representative test cases to evaluate the synergy in three different cloudy scenarios.

The Middle and Upper Atmosphere as Observed by MIPAS/Envisat

López-Puertas, Manuel [1]; Funke, Bernd [1]; García-Comas, Maya [1]; Gardini, Angela [1]; Jurado-Navarro, Aythami [1]; von Clarmann, Thomas [2]; Stiller, Gabriele [2]; Kiefer, Michael [2]; Kaufmann, Martin [3]; Smith, Anne K. [4]; García, Rolando R. [4];

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In addition to the nominal routine observations of the lower atmosphere (6-70 km), MIPAS also observed the middle and upper atmosphere using the special modes of Middle Atmosphere (MA, 18-102 Km), Upper Atmosphere (UA, 42-172 Km) and Noctilucent Clouds (NLC, 42-102 Km). Observations in these modes were taken regularly (1 out of 5 days) since mid-2007 until the failure of Envisat in April 2012. The wide spectral range, high spectral resolution and high sensitivity allowed MIPAS to measure many species in the middle atmosphere with large sensitivity including, temperature, and O₃, H₂O, CH₄, N₂O, NO₂, NO, CO, and CO₂ concentrations. The inversion of these quantities in those regions required, however, a complex retrieval algorithm that needs to incorporate non-[local thermodynamic equilibrium] effects.

In this work we present some results of recent analysis of this dataset carried out by comparing with other instruments (e.g. SABER and ACE) and 3D model simulations of WACCM. In particular we plan to cover, the solar cycle effects on mesospheric temperature; the nighttime ozone variability in the high latitude winter mesosphere, and the CO_x (CO+CO₂) solar cycle and trends in the mesosphere and lower thermosphere.

Upper Atmospheric N₂O in the High Latitudes and its Descent into the Stratosphere

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In the dark polar winter, increases in N₂O concentrations in the upper stratosphere and lower mesosphere have been observed and attributed to solar proton events and energetic particle precipitation. It has been suggested that the N₂O production occurs at higher altitudes and descends into the upper stratosphere, where it can then be converted into NO_x and play a role in the catalytic destruction of O₃. This study will present ACE-FTS [Atmospheric Chemistry Experiment – Fourier Transform Spectrometer] N₂O measurements and climatologies throughout the atmosphere, from the stratosphere to the lower thermosphere. The ACE-FTS measurements show that in the polar-regions in the lower thermosphere there is a continuous source of N₂O production that is highly correlated to the Ap index (a proxy for geomagnetic activity). From year to year, the Arctic summer ACE-FTS N₂O measurements are fairly consistent. However, the Arctic winter measurements in the middle atmosphere are highly dependent on the local dynamics. The ACE-FTS measurements and variations in the upper stratosphere will be compared to correlative N₂O data from the satellite instruments MIPAS and MLS. We will investigate the possible sources and sinks of N₂O in the upper atmosphere and quantify the effect its descent into the stratosphere has on stratospheric NO_x and O₃ concentrations.

Global Atomic Oxygen and Hydrogen Abundance in the Upper Mesosphere and Lower Thermosphere as Measured by SCIAMACHY

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Research Centre Jülich, Germany

SCIAMACHY on Envisat performed observations of mesospheric and lower thermospheric airglow. These measurements were utilized to derive global datasets of atomic oxygen and atomic hydrogen abundance. Both species are key parameters in the mesospheric chemistry and they are essential for the quantification of the energy budget of the middle and upper atmosphere. In this paper, we compare the SCIAMACHY oxygen and hydrogen data with measurements of other instruments and investigate their 11 year solar cycle dependence.

Satellite measurements of NO in the mesosphere and lower thermosphere

Bender, Stefan [1]; Sinnhuber, Miriam [1]; Funke, Bernd [2]; López-Puertas, Manuel [2]; Pérot, Kristell [3]; Urban, Joachim [3]; Walker, Kaley [4]; Burrows, John [5]

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Solar, auroral, and radiation belt electrons and soft solar X-rays produce nitric monoxide (NO) in the mesosphere and lower thermosphere (MLT, 50--150 km). Thus, the NO content in this atmospheric region reveals how solar activity and variability impacts the atmospheric composition. NO downward transport during polar winters then influences the lower atmosphere, in particular by catalytically depleting ozone. This in turn changes the heating and cooling rates and eventually the atmospheric circulation.

We present an overview and comparison of satellite measurements of NO in the MLT region. Results are shown for the data from ACE-FTS, MIPAS, SCIAMACHY, and SMR. MIPAS and SCIAMACHY are on board the now defunct ESA satellite Envisat and measured from July 2002 until April 2012. SMR is on board the Swedish-led satellite and ESA third-party mission Odin, still delivering data since October 2003. ACE-FTS is on board the Canadian satellite SCISAT-1 and is also still delivering data since February 2004. MIPAS, SCIAMACHY, and SMR are limb sounders and provide global data, however, the MLT region was only scanned at selected days. ACE-FTS is a solar occultation instrument which provides almost daily coverage of the atmosphere up to 120 km, but only at a limited number of latitudes.

We compare the daily zonal mean NO data of the four instruments in the MLT region. In addition to the MLT scans from SCIAMACHY, we present the results from its nominal scans (0--90 km). These are daily data from 08/2002 until 04/2012 and useful up to 80 km. We find that the data are consistent and valuable for further evaluating the chemistry and dynamics in the middle atmosphere.

Having established a consistent data set, we can use it to extract solar and geomagnetic forcing parameters with different statistical approaches. With the derived parameters, we aim to build a simple model of the NO content in the mesosphere driven by solar and geomagnetic activity. Eventually, this helps improving models of solar variability in climate and chemistry-climate models.

The 'Limb Gap': Perspectives on Future Operational Ozone Profile Monitoring Needs

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1: KNMI, The Netherlands; 2: Forschungszentrum Jülich, Germany; 3: ECMWF, UK; 4: Universität Bremen, Germany; 5: Rutherford Appleton Laboratory, UK

At the end of 2014 ESA launched a study called 'Operoz' with the aim to exactly define what would be needed in terms of an operational capacity for long-term ozone profile monitoring at high vertical resolution. Here we present the results of the ESA study and ask for feedback from the ESA atmosphere community.

Over the years several internationally coordinated strategic documents (e.g. GCOS, WCRP-SPARC, CEOS, ESA Convoy, as well as other frameworks) have made reference to an upcoming 'Limb Gap'. This 'Limb Gap' refers to a lack of planned limb observations of ozone as well as other atmospheric constituents after more than two decades with multiple satellite missions using limb view including UARS(1991-2005; HALOE, CLAES, MLS), ERBS (1984-2005; Sage-II), Envisat (2001-2012; MIPAS, SCIAMACHY, GOMOS), Scisat (2003 - present; ACE-FTS, Maestro) EOS-Aura (2004-present; HIRDLS, MLS) and Odin(2001-present; OSIRIS, SMR).

Since 2012 the US-based Suomi-NPP mission carries the OMPS instrument which combines ozone measurements in nadir and limb viewing modes. OMPS can be considered as the first operational limb sounder for ozone profiling. A successor for the OMPS limb component is planned on JPSS-2 (2022+). In Europe there is a need to better define the required limb capacity on top of the planned Copernicus Space Segment including Sentinel 4, 5 and 5p for nadir-based ozone monitoring.

In this presentation the three basic questions that have been addressed in Operoz are covered: (i) Why do we need operational limb monitoring of ozone profiles on top of the operational nadir sounders (mission objectives), (ii) What do we need to observe exactly (observational requirements), and (iii) how could a compliant limb capacity be envisaged (reality check)?

The answers from the Operoz project on these three questions will be presented together with concrete recommendations for a small to medium size space mission targeting global ozone profiles at high vertical resolution. The mission objectives relate to (i) operational ozone services as part of the Copernicus Atmospheric Monitoring Service and (ii) long-term ozone (trend) monitoring. Additional mission objectives for an operational mission using limb geometry have also been suggested in Operoz. The observational requirements will be presented for potential specific mission extensions on top of a minimum mission for long-term ozone profile monitoring using limb view.

Day 3, Wednesday 10 June 2015

Clouds/Aerosols

Satellite-derived Aerosol Climate Data Records in the ESA Aerosol_cci Project

Holzer-Popp, Thomas [1]; de Leeuw, Gerrit [2]; Pinnock, Simon [3]; Klueser, Lars [1]

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Within the ESA Climate Change Initiative (CCI) project Aerosol_cci (Phase 1: 2010 –2014; Phase 2: 2014-2017) intensive work has been conducted to improve algorithms for the retrieval of aerosol information from European sensors ATSR-2 (ERS-2), AATSR (3 algorithms), MERIS (3 algorithms), synergetic AATSR/SCIAMACHY, GOMOS (all on ENVISAT), PARASOL and OMI (EOS-Aura) (both part of NASA's A-Train). Whereas OMI and GOMOS were used to derive absorbing aerosol index and stratospheric extinction profiles, respectively, Aerosol Optical Depth (AOD) and Ångström coefficient were retrieved from the other sensors. The cooperation between the project partners, including both retrieval teams and independent validation teams, has resulted in a strong improvement of most algorithms. In particular the AATSR retrieved AOD is qualitatively similar to that from MODIS, usually taken as the standard, MISR and SeaWiFS. This conclusion has been reached by several different ways of validation of the L2 and L3 products. Using AERONET sun photometer data as the common ground-truth both 'traditional' statistical techniques and a 'scoring' technique based on spatial and temporal correlations were applied. Quantitatively, the limited AATSR swath width of 512km results in a smaller amount of data. Nevertheless, the assimilation of AATSR-retrieved AOD, together with MODIS data, contributes to improving ECMWF / MACC climate model results. In addition to the multi-spectral AOD, and thus the Ångström Exponent, also a per-pixel uncertainty is provided and validated. By the end of Aerosol_cci Phase 1 the ATSR algorithms have been applied to both ATSR-2 and AATSR resulting in an AOD time series of 17 years dating back to 1995.

In phase 2 this work is continued with a focus on the further improvement of the ATSR algorithms as well as those for the other instruments and algorithms, mentioned above, which in phase 1 were considered less mature. The first efforts are on the further characterization of the uncertainties and on better understanding of the cloud screening in the various algorithms. Other efforts will focus on surface treatment and possible improvement of aerosol models used in the retrieval. A yearly re-processing of the full 17-year global ATSR-2/AATSR data set is planned to evaluate the effect of different changes and to monitor further improvement.

As a new additional focus in phase 2 it is envisaged to produce a full-mission dataset of dust AOD from IASI with four different algorithms, which are based on different retrieval techniques. A major task within the project is the first inter-comparison of those IASI dust retrieval algorithms on the basis of a large set of observations. For this purpose one year of IASI observations (2013) over the major dust belt of the Northern hemisphere, including the Northern Atlantic Ocean, the Sahara desert, the Arabian Peninsula as well as the Central Asian desert regions, is consistently processed with all four algorithms and similar retrieval output (visible and infrared AOD, AOD uncertainty, retrieval quality, cloud flags) is generated in order to facilitate the comparison of results.

The retrieval inter-comparison, called Round Robin exercise, consists of an analysis of the different sensitivities of the four algorithms to dust and environmental conditions. The retrieval methods are based on different retrieval strategies such as look-up tables, optimal estimation and singular value decomposition. The sensitivity analysis will reveal the major uncertainties of infrared dust remote sensing from space as well as specific strengths and weaknesses of the different retrieval approaches under varying environmental conditions and can be used to select the best-suited approach for specific conditions.

The Round Robin exercise includes the evaluation of retrieval results from the four different algorithms with external data. AERONET sun photometers are used for evaluation as well as observations from the German SALTRACE campaign over the tropical Atlantic Ocean in summer 2013. Evaluation of subsets, for example subdivided by atmospheric moisture or surface characteristics, will thus allow for an improved understanding of

the feasibility of hyperspectral infrared dust remote sensing with different approaches under varying conditions.

The presentation will summarize the concept and status of the Aerosol_cci project in both phases and discuss in particular the achievements regarding the 17 year ATSR time series and the 1 year IASI round robin exercise.

Polar Mesospheric Cloud Particle Size Retrieval from GOMOS / ENVISAT Observations

Pérot, Kristell [1]; Hauchecorne, Alain [2]; Montmessin, Franck [2]; Bertaux, Jean-Loup [2]

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GOMOS (Global Ozone Monitoring by Occultation of Stars) is a stellar occultation instrument, combining four spectrometers and two fast photometers, that flew on board the European platform ENVISAT from 2002 to 2012. Polar mesospheric clouds (PMCs), that form during summer in the polar upper mesosphere, could be detected using the photometers' signals. Their main properties (occurrence frequency, peak altitude, radiance) have been retrieved from 2002 to 2010, leading to a 16-summer (in both hemispheres) database of more than 21000 clouds.

PMCs are very sensitive to changes in their environment. That makes them important tracers for the complex mechanisms that control the summer mesopause region. A better understanding of the microphysical processes going on in this atmospheric region is essential in order to model their growth, their transport mechanisms and their lifetime. To that purpose, the particle size distribution is an important parameter. This presentation will be focused on PMC particle sizes retrieved from GOMOS spectral observations in the northern hemisphere. The retrieval method will be explained, and results based on the obtained 8-year dataset will be described and compared to PMC particle sizes derived from the measurements of other instruments.

AerGom, a GOMOS retrieval algorithm optimized for stratospheric aerosols: Recent developments

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AerGom is a retrieval algorithm recently developed for the GOMOS instrument onboard Envisat as an alternative to the GPR official algorithm. A main objective of the AerGom project was the need to improve the stratospheric aerosol extinction product for which GPR is known to present quite poor performances, especially out of the reference wavelength of 500 nm. However, AerGom retrieves extinction profiles for particulate matter and gaseous species concentrations as well.

The AerGom algorithm has been chosen and confirmed (during the Phase II of the project) as main algorithm for the development of stratospheric aerosol data records in the framework of Aerosol_CCI (Climate Change Initiative), what reinforced the interest to further improve the algorithm.

This presentation shows the current issues identified for AerGom and the latest developments and improvements brought to this algorithm. These aspects and the current performances will be illustrated using the most recent datasets.

Aerosol detection with infrared limb measurements in the troposphere and stratosphere

Griessbach, Sabine; Hoffmann, Lars; Spang, Reinhold; von Hobe, Marc; Müller, Rolf; Riese, Martin

Forschungszentrum Jülich, Germany

Stratospheric aerosol is known for its impact on climate. Recent research found that especially the volcanic aerosol in the lower stratosphere at mid and high latitudes has been underestimated regarding its impact on radiative forcing due to a lack of measurements in this region (Ridley, 2014). The stratospheric sulfate aerosol is significantly influenced by volcanic eruptions. In the last decade the stratospheric aerosol burden has increased likely due to several smaller volcanic eruptions. However, the pathways of sulfur from these eruptions into the stratosphere are uncertain.

Polar orbiting infrared limb sounders, such as Envisat MIPAS, are particularly suited for measuring and tracing aerosol in the upper troposphere and stratosphere. They measure vertical profiles and provide global coverage at day- and nighttime during all seasons. Also, due to the limb geometry they are highly sensitive towards aerosol and clouds. For the discrimination between ice clouds and aerosol (especially in the troposphere) there are several methods available for IR nadir instruments. Here, we present a new method for IR limb measurements to detect aerosol and to discriminate it from ice clouds. The new method was tested for MIPAS measurements and we confirmed the MIPAS aerosol detections by comparing with other instruments. We also analysed the MIPAS aerosol detection sensitivity and the accuracy of the aerosol altitudes.

We applied the new aerosol detection method to the 10 years of Envisat MIPAS measurements. The time series of the MIPAS aerosol measurements is dominated by volcanic sulfate aerosol. However, also volcanic ash (Griessbach, 2014), mineral dust, bush fires and non-ice polar stratospheric clouds can be identified in the MIPAS aerosol data. The high sensitivity and the global coverage of the MIPAS measurements allows us to trace single volcanic eruptions in the horizontal as well as in the vertical on a daily basis for several months. The MIPAS aerosol data clearly shows how smaller volcanic eruptions at high latitudes (e.g. the Sarychev eruption in 2009) contribute to the stratospheric sulfate aerosol layer in the tropics.

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Aerosol absorption above clouds from combined OMI and MODIS hyperspectral measurements

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Smoke aerosols affect clouds both through aerosol-cloud interactions and aerosol-radiation interactions, the latter formerly known as the semi-direct effect. By absorption of sunlight, aerosols can heat the atmosphere locally, and reduce the amount of radiation received at the surface and the top-of-atmosphere (TOA). This changes the atmospheric lapse rate and column stability, influencing convection and cloud forming processes. Aerosol-cloud interactions are notoriously difficult to isolate in remote sensing measurements, as cloud droplets and aerosols have to be discriminated in mixed layers. Aerosol-radiation interaction measurements, on the other hand, are as challenging as aerosol-cloud interactions, even though the cloud and aerosol layers can be physically separated. From space, measurements of aerosols in cloud scenes have been very difficult, since cloud screening is often applied before aerosol parameters were retrieved. Some very promising new techniques have been developed recently to distinguish aerosols from clouds using active measurements, polarised

measurements, or hyperspectral measurements. Using shortwave hyperspectral measurements, the absorption by aerosols, which is large in the ultraviolet (UV), can be distinguished from the scattering by cloud droplets, retrieved in the shortwave infrared (SWIR).

Interestingly, this can be used directly to quantify the aerosol direct effect (DRE) of small smoke particles that drift over clouds, without retrieving aerosol parameters first. By simulating the aerosol-free cloud scene, and comparing with the measured aerosol-cloud scene, the DRE can be determined with very high accuracy. Application of this method to SCIAMACHY measurements over the southeast Atlantic Ocean during the African monsoon dry season (June-Sept.) in 2006-2009, revealed aerosol DRE over clouds up to $128 \pm 8 \text{ Wm}^{-2}$ instantly and a monthly average of about 35 Wm^{-2} [De Graaf et al, 2012]. This is much larger than previously estimated with climate models, that simulate a monthly mean aerosol DRE up to about 6 Wm^{-2} . A first attempt to reconcile simulations with observations failed to identify the processes in the models that are responsible for the underestimation of the DRE, but cloud brightness is most likely the most critical parameter [De Graaf et al, 2014]. This is now under investigation.

Here, we will present aerosol DRE over clouds from combined OMI and MODIS hyperspectral measurements. Since SCIAMACHY was lost in 2012, new measurements from OMI and MODIS can help to continue the observation of aerosol absorption over clouds from space. Each instrument by itself does not provide enough information on both aerosols and clouds, but OMI gives detailed information of UV aerosol absorption, while MODIS broadband channels provide cloud information from the SWIR range of the spectrum. OMI and MODIS are flying in formation in the A-Train constellation, providing observations about 7 minutes after one another. This creates uncertainties in the observed scene, especially in scenes where convection is strong and cloud parameters change rapidly. However, OMI and MODIS overlap at MODIS shortest wavelength band, 469 nm, which can be used to test the matching of the spectra. Furthermore, MODIS provides cloud products at $1 \times 1 \text{ km}$ resolution, and better, which can be used to test and improve the cloud retrieval algorithm that was developed for the much larger SCIAMACHY and OMI pixels.

Application of this unique hyperspectral method to OMI and MODIS is used to prepare for TROPOMI, which will provide information on both the UV and the SWIR. If successful, TROPOMI will provide aerosol DRE over clouds from one instrument with an unprecedented accuracy and unprecedented spatial resolution.

We will introduce the newly developed algorithm for the combined OMI-MODIS measurements, and present measurements of aerosol DRE over the southeast Atlantic Ocean.

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De Graaf M., N. Bellouin, L.G. Tilstra, J. Haywood, P. Stammes, Aerosol direct radiative effect of smoke over clouds over the southeast Atlantic Ocean from 2006 to 2009, *Geophys. Res. Lett.*, 2014, doi: 10.1002/2014GL061103

Aerosol and Cloud Properties Retrieval using the ATSR Dual and Single View algorithms

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1: FMI; 2: UHEL

The ATSR Dual View (ADV) and ATSR Single View (ASV) aerosol retrieval algorithms have been developed for use with the Along Track Scanning Radiometer ATSR-2 which flew on the ERS-2 satellite (1995-2003) and the Advanced ATSR (AATSR) which flew on the ENVISAT satellite (2002-2012) (both from the European Space Agency, ESA). The ATSR instruments provide two views: one near-nadir and the other at 55 degrees forward. Each view provides the radiances at the top of the atmosphere (TOA) in 7 wavebands from the visible (VIS) to the thermal infrared (TIR). The TIR wavebands are mainly used for cloud detection, in combination with a number of tests including shorter wavelengths. The VIS and NIR (near-infrared) wavebands are used for aerosol retrieval. ADV is applied over land where the ratio of both views in the $1.6 \mu\text{m}$ band are used to account for effects of the land surface reflectance on the radiation at the top of the atmosphere (TOA), assuming that the effect of aerosols on the TOA reflectance is small. The dual view algorithm provides

information on the aerosol properties over land with a quality which is similar to that of other satellites which are commonly used as the 'standard' for aerosol retrieval (in particular MODIS, MISR). However, ATSR has a smaller swath resulting in less coverage than MODIS. Over ocean only one of the views is used (forward) and also here the quality of the data is competitive with that of other instruments. The advantage of the ATSR-2/AATSR combination is that it provides a time series of 17 years, longer than any other of the currently available quality products (MODIS, MISR, SeaWiFS). This time series will be further expanded with those from the Sea and Land Surface Temperature Radiometer (SLSTR) on the ESA/EU GMES Sentinel-3 mission which is planned to be launched in the autumn of 2015. The AOD time series is one of the Aerosol ECVs.

The Dual View algorithm provides aerosol data on a global scale with a default resolution of 10x10km² (L2) and an aggregate product on 1o x1o (L3). Optional, a 1x1 km² retrieval products is available over smaller areas for specific studies. Since for the retrieval of AOD no prior knowledge is needed on surface properties, the surface reflectance can be independently retrieved using the AOD for atmospheric correction.

For the retrieval of cloud properties, the SACURA algorithm has been implemented in the ADV/ASV aerosol retrieval suite. Cloud properties retrieved from AATSR data are cloud fraction, cloud optical thickness, cloud top height, cloud droplet effective radius, liquid water path.

In the presentation an overview will be presented of the aerosol and cloud remote sensing activities and applications at FMI and UHEL. The application of ADV/ASV to produce an AOD ECV for 17 years, with applications over different locations across the world, shows the different temporal variations of the AOD between 1995 and 2012. Spatial variations will be highlighted. The simultaneous retrieval of aerosol and cloud properties provides information on aerosol-cloud interaction.

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Three-dimensional distribution of a major desert dust outbreak over East Asia in March 2008 derived from IASI satellite observations

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Desert dust storms strongly affect the environment and significantly contribute to climate forcing. The regional impact of desert dust storms depends on the vertical distribution of dust plumes resulting from long-range transport. Dust layers can impact chemical balances, atmospheric stability or cloud properties in the vicinity of the altitude at which they are transported and also at other altitudes. Near the surface, dust can directly affect air quality and settle down on the surface by dry deposition. The quantification of such impacts are highly uncertain, particularly due to the sporadic character of dust emissions as well as the large variability of dust properties and occurrence linked to the meteorological controls.

In the current presentation, we describe the daily evolution of the three-dimensional (3D) structure of a major dust outbreak initiated by an extratropical cyclone over East Asia in early March 2008, using new aerosol retrievals derived from satellite observations of IASI (Infrared Atmospheric Sounding Interferometer). For this, we have developed a novel auto-adaptive Tikhonov-Philips-type approach called AEROIASI to retrieve vertical profiles of dust extinction coefficient at $10\text{ }\mu\text{m}$ for most cloud-free IASI pixels, both over land and ocean. The dust vertical distribution derived from AEROIASI is shown to agree remarkably well with along-track transects of CALIOP space-borne lidar vertical profiles (mean biases less than 110 m, correlation of 0.95 and precision of 260 m for mean altitudes of the dust layers). AEROIASI allows the daily characterization of the 3D transport pathways across East Asia of two dust plumes originating from the Gobi and North Chinese deserts. From AEROIASI retrievals, we provide evidence that (i) both dust plumes are transported over the Beijing region and the Yellow Sea as elevated layers above a shallow boundary layer, (ii) as they progress eastwards, the dust layers are lifted up by the ascending motions near the core of the extratropical cyclone and (iii) when being transported over the warm waters of the Japan Sea, turbulent mixing in the deep marine boundary layer leads to high dust concentrations down to the surface. AEROIASI observations and model simulations also show that the progression of the dust plumes across East Asia is tightly related to the advancing cold front of the extratropical cyclone.

Saharan Desert Dust Sources: New Insights Based on Aerosol Vertical Profiles Retrieved from Thermal Infrared Measurements by IASI

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Desert dust is the most important aerosol in annual mass burden, mainly present in the Tropics but reaching Europe from time to time. Dust aerosols are a major actor in the climate: they absorb, scatter and reemit radiation, impacting the Earth energetic balance along the solar and terrestrial spectrum. Their presence in the atmosphere may lead to surface warming or cooling, and to atmospheric warming in the dusty layers, with possible impacts on the atmospheric circulation. Furthermore, dust aerosols are efficient cloud/ice condensation nuclei, therefore impacting the lifetime and physical properties of clouds, and the amount or location of rainfalls. For all these reasons, studies of dust atmospheric load and sources are of great scientific and societal interest.

In the last years, we have developed and improved a retrieval strategy to obtain vertical profiles of desert dust aerosols, from thermal infrared measurements performed by IASI (Vandenbussche et al, AMT 2013). This strategy has been used to process one year of IASI data in the major dust area. Here, we use this dataset to look at the desert dust sources in North Africa. Our dataset allows a new insight in the study of those sources since it provides vertical profiles (not only AOD) twice a day, making possible to partly distinguish local emissions from transported dust. In addition, IASI measurement times are of particular interest when desert dust sources are concerned. The mid-morning overpass (9h30 local time) allows to catch scenes right after the

nocturnal low level jet breakdown, while the evening overpass (21h30 local time) gives insight at a time at which the solar spectrum based instruments cannot measure. On the other hand, MODIS onboard Terra, providing AOD above deserts thanks to the Deep Blue algorithm, has an overpass time of 13h30 local time, at which the dust emissions are the lowest.

In this contribution, we will quickly present the recent improvements to the retrieval strategy, show and discuss the results in term of dust source studies (including comparisons with literature dust source maps), then discuss the causes of uncertainties and possible biases.

GOME-2 Cloud top height and optical depth retrieval using ROCINN V3.0

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Cloud information from UV/VIS/NIR spectrometers aboard spacecraft platforms is highly valuable for the construction of cloud property climatologies, since it is complementary to the information retrieved using IR spectrometers, imagers and active sensors (cloud radars and lidars).

Thick clouds scatter most of the incoming radiation back to space, thus preventing light from traversing the lowest layers of the atmosphere. Without cloud information, this cloud blocking effect would be interpreted as a reduced amount of atmospheric gas by the retrieval algorithm. On the other hand, other cloudy scenarios can lead to an increase of the photon path length due to scattering events, what would be interpreted as an artificial increase of the gas amount. These effects are just two of the many possible manners clouds can affect the quality of the trace gas retrievals. Therefore, precise cloud information is not only valuable by itself but it is mandatory for the accurate retrieval of atmospheric trace gases.

The ROCINN algorithm retrieves cloud top height (pressure), cloud optical depth and cloud albedo from GOME-2 measurements in and around the oxygen A-band (~760nm) taking as input the cloud fraction computed with the OCRA algorithm (a color space approach based on the PMD reflectances). This paper presents the latest version of the ROCINN algorithm. There are two variants of the ROCINN algorithm: one that treats clouds as reflecting boundaries (CRB) (i.e. Lambertian equivalent reflectors) and a second one that treats clouds as scattering layers (CAL). The ROCINN-CRB algorithm has been successfully used operationally for GOME/ERS-2 and GOME-2/MetOp-A and -B instruments since over one decade. The CAL algorithm treats clouds in a more realistic way and provides cloud properties closer to reality. ROCINN V3.0 in the CRB and CAL variants is incorporated into the latest UPAS operational processor and is meant to be the new operational algorithm for the official reprocessing of GOME-2-A and -B trace gas products generated at DLR in the framework of EUMETSAT O3M-SAF. In the same way, ROCINN V3.0 is the baseline algorithm for the generation of the official TROPOMI/S5P cloud products.

In this work, we present and analyze cloud properties from GOME-2 on both MetOp-A and Metop-B retrieved with the algorithms ROCINN-CAL and ROCINN-CRB. Additionally, we compare the GOME-2 cloud properties retrieved with ROCINN with independent cloud products, e.g. from the AVHRR sensor also flying on MetOp. Moreover, in order to assess the accuracy of ROCINN, sensitive studies to different observing and atmospheric scenarios using both, measured and synthetic spectra, will also be presented.

Algorithm Development and Verification of Aerosol and Cloud Products for Sentinel-5 Precursor

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In the framework of the Sentinel-5 Precursor project, one pillar of the L2 working group (composed by the Royal Netherlands Meteorological Institute KNMI, the Institute of Environmental Physics IUP and the German Aerospace Center DLR) activity is the assessment of potential biases between aerosol and cloud products which will be inferred by the respective algorithms from TROPOMI measurements. Specifically, Aerosol Layer Height (ALH) and Cloud Top Height (CTH) are the focus of the comparison. These quantities are derived by fitting reflectances in the oxygen A-band (755-775 nm), synthetically generated with radiative transfer models (RTM) and measured by sensors, appropriate in this context, such as SCIAMACHY and GOME-2. The verification of CTH, together with the analysis of cloud cover and optical thickness, has been accomplished upon synchronization of the respective forward RTMs for a variety of cases covering the full range of cloud properties in the troposphere. Then, seasonal biases have been assessed from real measurements of selected GOME-2 orbits. Verification of ALH is based on the evaluation of the altitude of the ash plume emitted by the Icelandic volcano Eyjafjallajökull in May 2010 as seen by GOME-2. The retrievals were colocated with measurements derived from multiple passive sensors, such as CALIPSO, MISR, MERIS, and SCIAMACHY. Additionally, the feasibility of deriving Aerosol Optical Thickness (AOT) from TROPOMI (footprint size 7x7 km²) is assessed comparing AOT retrieved with two different approaches: the optimal estimation fit of the oxygen A-band SCIAMACHY (60x40 km²) spectra and the multi-channel surface-optimized residual minimization of the MERIS (1x1 km²) radiances. In this way, spatial scale effects can also be investigated.

The Finokalia Ground-based Station in Crete and its potential for ESA Cal/Val Activities

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The ground-based station of Finokalia is situated in Greece (35° 20'N, 25° 40'E) on the north coast of Crete. No significant human activities occur at a distance shorter than 15km from the station, which makes the site ideal for monitoring and characterizing natural aerosols in the Eastern Mediterranean basin. The station is equipped with advanced in-situ instrumentation for surface measurements, being operational for more than 20 years. It is recognized as one of the most significant locations in Europe for aerosol monitoring, being part of European Networks like EUSAR, ACTRIS and ICOS. From mid-2015, the station will be equipped with advanced ground-based remote sensing instrumentation including, (i) a multi-wavelength combined backscatter/Raman/depolarization PollyXT lidar system, (ii) a sun/lunar CIMEL photometer and (iii) a PANDORA instrument. The station will be included in EARLINET and AERONET networks, constituting an advanced European core site, unique in Mediterranean.

We present here the upgraded instrumentation fleet of the Finokalia station and its potential for cal/val activities related to future ESA research- and service-oriented missions (Sentinels and Earth Explorers). Results from a recent ESA campaign (CHARADMexp) which has been implemented on June 2014, employing all the aforementioned in-situ and remote sensing instrumentation are presented to demonstrate the potential of the site.

Air Quality

A global catalogue of SO₂ sources and emissions derived from the Ozone Monitoring Instrument

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Satellite sulfur dioxide (SO₂) measurements from the Ozone Monitoring Instrument (OMI) satellite sensor processed with the new Principal Component Analysis (PCA) algorithm, averaged over a period of several years, are used to detect large point emission sources. Roughly 200 continuously emitting point sources releasing from about 100 kT to 5000 kT of SO₂ per year have been identified and grouped according to the source origin: volcanic, coal-burning power plants, smelters, and sources related to the oil and gas industry. In addition, nitrogen dioxide (NO₂) measurements by OMI are used to better differentiate between the source types. Examples of SO₂ emission sources located in various regions of the world are given.

To estimate the emission levels from these sources, a new method has been developed. It is based on fitting satellite SO₂ vertical column density to a three-dimensional parameterization as a function of the coordinates and wind speed. An effective lifetime (or, more accurately, decay time) and emission rate are then determined from the parameters of the fit. The method has been validated using OMI data in the vicinity of approximately 50 large US near-point sources. The obtained results are then compared with available emissions inventories. The correlation between the estimated and reported emissions is about 0.91 with the estimated lifetimes between 4 and 12 hours. It is demonstrated that individual sources with annual SO₂ emissions as low as 30 kt y⁻¹ can produce a statistically significant signal in OMI data.

The obtained emission information can be used to improve available emissions inventories, since some of the sources seen by OMI are not included in the inventories. SO₂ measurements by two other satellite sensors, SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY), and Global Ozone Monitoring Experiment -2 (GOME-2), are also discussed. Quantitatively, the mean amount of SO₂ in the vicinity of the sources, estimated from the three instruments is in general agreement. However the better spatial resolution of OMI makes it possible for this instrument to detect smaller sources and with more details compared to the other two instruments.

An Innovative Satellite SO₂ and HCHO Retrieval Algorithm based on Principal Component Analysis: Contribution to the Sentinel-5P Mission

Krotkov, Nickolay Anatoly (1); Li, Can (2,1); Joiner, Joanna (1); Fioletov, Vitali (3); McLinden, Chris (3); Veefkind, Pepijn (4); Theys, Nicolas (5); De Smedt, Isabelle (5)

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We present a new retrieval algorithm developed at NASA Goddard Space Flight Center for global observations of SO₂ and HCHO using spaceborne UV-Vis spectrometers. By applying the principal component analysis (PCA) technique to measured satellite reflectance spectra, we can extract spectral features (principal components or PCs) that explain the variance of the spectra. Since SO₂ and HCHO typically has very small signals outside of major source regions, the leading PCs (that explain the most variance) extracted from clean background areas can be used to represent atmospheric processes (e.g., ozone absorption, rotational Raman scattering) and measurement details (e.g., wavelength shift) other than the absorption by SO₂ or HCHO. We can then estimate the loading of SO₂ or HCHO, by fitting the PCs and pre-computed SO₂ or HCHO Jacobians to the measured radiance spectra. We will present PCA retrievals of SO₂ and HCHO using Aura/Ozone Monitoring Instrument (OMI) and NASA/NOAA S-NPP/Ozone Mapping and Profiler Suite (OMPS). We will also compare the PCA

retrievals to other algorithms. For example, comparison with the previous generation OMI standard planetary boundary layer (PBL) SO₂ product indicates that the PCA algorithm reduces the retrieval noise by a factor of two and greatly reduces retrieval artifacts. This allows the detection of weaker anthropogenic SO₂ sources from space. Finally, we will discuss the most recent progress in our algorithm development, as well as the contributions that our group can make to the Sentinel-5P (S5P) mission as a member of both the ESA S5P validation team and the NASA Earth Science U.S. Participating Investigator program.

Sulfur dioxide retrievals from TROPOMI : algorithmic developments, verification on synthetic spectra and application to OMI measurements

Theys, Nicolas [1]; De Smedt, Isabelle [1]; van Gent, Jeroen [1]; Danckaert, Thomas [1]; Hörmann, Christoph [2]; Hedelt, Pascal [3]; Wagner, Thomas [2]; Van Roozendaal, Michel [1]; Veefkind, Pepijn [4]

1: Belgian Institute for Space Aeronomy, Belgium; 2: Max Planck Institute for Chemistry (MPIC), Mainz, Germany; 3: Institut für Methodik der Fernerkundung, Deutsches Zentrum für Luft-; 4: Koninklijk Nederlands Meteorologisch Instituut (KNMI), De Bilt, the

The TROPospheric Monitoring Instrument (TROPOMI) will be launched in 2016 onboard the ESA Sentinel-5 Precursor (S-5P) platform and will provide global observations of atmospheric trace gases, with unprecedented spatial resolution. Sulfur dioxide (SO₂) is a key atmospheric constituent and measurements from TROPOMI will improve the monitoring capability of SO₂ from anthropogenic and volcanic emissions, and will extend the long-term datasets from past and existing UV sensors (TOMS, GOME, SCIAMACHY, OMI, GOME-2, OMPS).

In this presentation, we give an overview on the work done on SO₂ retrievals as part of the S-5P level-2 processor development. Within the S-5P project, BIRA-IASB is in charge of the development of the prototype algorithm for the retrieval of SO₂, while MPIC and DLR are responsible for the verification algorithms, developed in parallel to test and challenge the prototype algorithm. We will describe the different algorithms, their main features and discuss the results of the inter-comparison of the SO₂ algorithms applied to synthetic and measured (OMI) spectra. We will also show results of the prototype algorithm applied to OMI with a focus on anthropogenic SO₂, for strongly polluted regions (including validation results in China) and weak sources (only detectable in long-term averaged data).

OMI/Aura, SCIAMACHY/Envisat and GOME2/MetopA Sulphur Dioxide Estimates; the case of Eastern Asia.

Koukouli, Mariliza [1]; Balis, Dimitris [1]; Theys, Nicolas [2]; Brenot, Hugues [2]; van Gent, Jeroen [2]; Hendrick, Francois [2]; Wang, Ting [3]; Valks, Pieter [4]; Hedelt, Pascal [4]; Lichtenberg, Guenter [4]; Richter, Andreas [5]; Krotkov, Nickolay [6]

1: Laboratory of Atmospheric Physics, Aristotle University of Thessaloniki, Greece.; 2: Belgian Institute for Space Aeronomy, Brussels, Belgium.; 3: Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China.; 4: German Aerospace Center

The EU FP7 Monitoring and Assessment of Regional air quality in China using space Observations, Project Of Long-term sino-european co-Operation, MarcoPolo, project focuses on deriving emission estimates from space. Long term satellite observations of sulphur dioxide, SO₂, over the greater China area from the SCIAMACHY/Envisat, GOME2/MetopA and OMI/Aura missions are compared and their relative strong points and limitations are discussed. Rigorous spatiotemporal statistical analysis based on novel analysis techniques [Fioletov et al., 2011; 2013] is performed for each data set in order to reduce noise and biases and enhance pollution signals in satellite datasets. Furthermore, identification of point sources such as power plants, smelters and urban agglomerations, as well as definition of their relative contribution to the regional SO₂ levels, form the main findings of this investigation. Comparison of different satellite datasets and their post-processed products with ground based MaxDOAS SO₂ measurements in Xianghe, China, located at ~ 50 km southeast of downtown Beijing, helps validate the satellite datasets.

Tropospheric Volcanism and Air-Traffic

Zerefos, Christos (1,2); Kapsomenakis, Ioannis (1); Amiridis, Vassilis (3); Solomos, Stavros (3); Eleftheratos, Kostas (4); Gerasopoulos, Evangelos (5,2); MACC VAL team, MACC VAL team (1)

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Volcanic effects and their consequences have been observed in Europe originating either from European (Icelandic, Italy) or from distant large volcanic eruptions (e.g. Kasatochi in the Aleutians and Africa). The interference of the volcanic plumes with air traffic corridors have been noticed and studied thoroughly in the case of 2010 eruptions of Eyafallajökull. There have been similar eruptions that have not interfered with air traffic in the past decade such as the recent Bárðarbunga (September 2014) whose forward trajectories were below 6000m. The present study aims at looking for evidence of columnar SO_2 amounts that have followed excursions from Icelandic and volcanic eruptions of importance to Europe in general. Columnar SO_2 records from remote sensing spectrophotometers over Europe and from space as well as simulated by models will be compared. The columnar SO_2 measurements are also compared with ground based SO_2 monitors from the Airbase dataset. Finally the impact of the above mentioned volcanic eruptions in traffic will be assessed.

Day 4, Thursday 11 June

Preparation for Sentinel S5P/Air Quality

TROPOMI on the Copernicus Sentinel 5 Precursor: instrument performance, the L0-1B processor and on-ground calibration results

Veefkind, Pepijn [1,2]; Kleipool, Quintus [1]; Ludewig, Antje [1]; Aben, Ilse [3]; de Vries, Johan [4]; Levelt, Pieternel [1,2]

1: Royal Netherlands Meteorological Institute (KNMI), The Netherlands; 2: Delft University of Technology, Netherlands, The Netherlands; 3: Netherlands Institute for Space Research, The Netherlands; 4: Airbus Defence and Space, The Netherlands

The Copernicus Sentinel 5 Precursor (S5P), scheduled for launch in 2016, is the first of the Sentinels dedicated to monitoring of the atmospheric composition. The main application areas of the mission are air quality, climate and the ozone layer. The single payload of the S5P mission is TROPospheric Monitoring Instrument (TROPOMI), which is developed by The Netherlands in cooperation with ESA. TROPOMI is a nadir viewing shortwave spectrometer that will measure in the UV-visible wavelength range (270-500 nm), the near infrared (710-770 nm) and the shortwave infrared (2314-2382 nm). TROPOMI will have an unprecedented spatial resolution of about 7x7 km² at nadir. The spatial resolution is combined with a wide swath to allow for daily global coverage. The high spatial resolution serves two goals: (1) emissions sources can be detected with more accuracy and (2) the number of cloud-free ground pixels will increase substantially. The TROPOMI/S5P geophysical (Level 2) data products include nitrogen dioxide, carbon monoxide, ozone (total column, tropospheric column & profile), methane, sulphur dioxide, formaldehyde and aerosol and cloud parameters.

In this contribution we will present the TROPOMI instrument, with a focus on performance aspects, the development of the L0-1B processor and the first results from the on-ground calibration campaign.

Sentinel 5P TROPOMI Short-wave Infrared On Ground Calibration

Krijger, Matthijs; Snel, Ralph; Tol, Paul; van Hees, Richard; Cadot, Sidney; Aben, Ilse

SRON Netherlands Institute for Space Research, Netherlands, The

During 2014 and 2015 the TROPOMI instrument, currently being implemented on Sentinel-5P, was calibrated on ground. We will report on the first results of the Short Wave InfraRed (SWIR) module and lessons learned.

Sentinel-5 Precursor: Preparing the first Copernicus Atmospheric Mission

Nett, Herbert [1]; McMullan, Kevin [1]; Ingmann, Paul [1]; Fehr, Thorsten [2]

1: ESA/ESTEC, Keplerlaan 1, NL-2201 AZ Noordwijk; 2: ESA/ESRIN, Via Galileo Galilei, I-00044 Frascati RM

Sentinel-5 Precursor (S-5P) will be the first of a series of atmospheric missions to be launched within the European Commission's Copernicus (former GMES) Programme. With a planned launch in 2016 and a nominal lifetime of 7 years S-5P is expected to provide continuity in the availability of global atmospheric data products between its predecessor missions SCIAMACHY (Envisat) and OMI (AURA) and the future Sentinel-4 and -5 series. The latter will comprise payload instruments on board the operational satellites MTG-S (S-4, geostationary component) and MetOp Second Generation (S-5, polar orbiting component), the first units of which will be launched in the 2020-2021 timeframe.

Due to its enhanced spatial, temporal and spectral sampling capabilities, as compared to its predecessors, S-5P will deliver unique data on the sources and sinks of trace gases with a focus on the lower Troposphere

including the PBL. The S-5P satellite will carry a single payload, TROPOMI (TROPOspheric Monitoring Instrument) which is jointly developed by The Netherlands and ESA. Covering spectral channels in the UV, visible, near- and short-wave infrared it will measure various key species including tropospheric/stratospheric ozone, NO₂, SO₂, CO, CH₄, CH₂O as well as cloud and aerosol parameters.

In order to meet the demanding accuracy requirements, in particular for the CH₄ product, routine use of cloud mask data during Level 2 processing is envisaged. For this purpose S-5P will be operated in a loose formation with NASA's Suomi-NPP spacecraft that will carry the high-resolution cloud imaging instrument VIIRS. The S-5P spacecraft is currently undergoing an extensive validation program, with a focus on the pre-launch characterization of the TROPOMI flight model instrument. Moreover, the integration of the Ground Segment is in progress. The system level validation, following the integration of latest versions of the Level 1B and Level 2 processor components, will be completed end 2015.

The presentation will provide an overview of the S-5P mission, including the preparation status of Spacecraft and Ground Segment. Furthermore, an outline of the operational concept, with a focus on the early in-flight calibration and validation tasks will be given.

Overview of Sentinel 5 Precursor Trace Gas, UV, Cloud and Aerosol Products

Loyola, Diego G. [1]; Veefkind, Pepijn [2]; Aben, Ilse [3]; Richter, Andreas [4]; Van Roozendaal, Michel [5]; Siddans, Richard [6]; Tamminen, Johanna [7]; Wagner, Thomas [8]

1: German Aerospace Center (DLR), Remote Sensing Technology Institute, Oberpfaffenhofen, D-82234 Wessling, Germany; 2: Royal Netherlands Meteorological Institute (KNMI), De Bilt, The Netherlands; 3: Netherlands Institute for Space Research (SRON), Utrecht

The Sentinel 5 Precursor (S5P) mission is a sun-synchronous polar satellite system scheduled for launch in 2016. The payload of the S5P mission is the TROPOspheric Monitoring Instrument (TROPOMI) that will provide key information on air quality, climate and the ozone layer with high spatial resolution and daily global coverage.

We present an overview of the work being performed for the development of TROPOMI geophysical products including O₃, NO₂, SO₂, HCHO, CO, CH₄, as well as UV, cloud and aerosol properties. The European teams responsible for these activities are organized in three groups covering: (i) retrieval algorithms, (ii) scientific verification, and ultimately (iii) the data processors to be used in the ground-segment for the generation of the operational S5P products. It is planned to maintain this project organization during the complete mission in order to ensure the timely provision of state-of-science data products that are continuously improved and validated.

The work on TROPOMI/S5P geophysical products is funded by ESA and national contributions from The Netherlands, Germany, Belgium and Finland.

Sentinel-5 Precursor: Exploitation of the first Copernicus Atmospheric Mission

Fehr, Thorsten [1]; Nett, Herbert [2]; Ingmann, Paul [2]; McMullan, Kevin [2]; Bargellini, Pier [1]

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Sentinel-5 Precursor (S-5P) will be the first in a series of atmospheric composition satellites to be launched within the European Commission's Copernicus Programme with the primary objective to provide space-borne information for the Copernicus Core Services, in particular the Atmosphere Monitoring Service (AMS) and the Climate Change Service (CCS). In addition, S-5P data will support a wide range of scientific topics related to atmospheric processes focussing on Air Quality, tropospheric and stratospheric ozone and climate forcing.

The mission is expected to provide continuity in the availability of global atmospheric data products between its predecessor missions GOME (ERS-2, 1995-2011), SCIAMACHY (Envisat, 2002-2012), GOME-2 (MetOP, 2006-), OMI (AURA, 2004-) and the future Sentinel-4 and -5 series (from 2020/2021 onwards).

The single payload of S-5P is TROPOMI (TROPOspheric Monitoring Instrument), a nadir-viewing spectrometer covering spectral channels in the UV, visible, near- and short-wave infrared, which is jointly developed by The Netherlands and ESA. The mission will operationally provide key atmospheric trace gas products, including ozone columns and profiles, tropospheric and total NO₂, SO₂, CO, CH₄, HCHO as well as cloud and aerosol parameters. S-5P will be operated in a loose formation with NOAA's Suomi-NPP spacecraft taking advantage of the VIIRS instrument for high-resolution cloud masking to support in particular the CH₄ retrieval.

The presentation will provide an end-to-end overview of the S-5P mission operations concept that will be in place following the successful launch and commissioning of the satellite. A special focus will be given to the data access for the science community. The preparations for the geophysical validation will be outlined, including the S-5P Validation Team and corresponding ESA activities. Operational mission performance tasks, which are fundamental to secure the quality of the S-5P data products, will be presented. Finally, the opportunities for exploiting the S-5P/SNPP formation flight for scientific and operational products will be highlighted.

Detailed information on the S-5P mission will be available starting May 2015 on ESA's Sentinel Online pages: <https://sentinel.esa.int>

TROPOMI's CO retrieval code for the Sentinel 5 Precursor mission tested on 10 years of SCIAMACHY's 2.3 μm measurements.

Borsdorff, Tobias; aan de Brugh, Joost; Tol, Paul; Aben, Ilse; Landgraf, Jochen

SRON Netherlands Institute for Space Research, Netherlands, The

In 2016, the Tropospheric Monitoring Instrument (TROPOMI) will be launched on board of the Sentinel 5 Precursor (S5-P) mission. For this mission, the highly efficient Shortwave Infrared Carbon Monoxide (CO) Retrieval algorithm (SICOR) was developed to meet the requirements of an operational data processing. In this contribution, we present the application of the SICOR algorithm to measurements of ESA's Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY) instrument. Both, SCIAMACHY and TROPOMI cover the 2.3 μm spectral range with the same spectral resolution but TROPOMI is distinguished by having an improved radiometric performance and a better spatial resolution. Using the same retrieval approach for both satellite instruments will ensure the comparability of the CO data sets of both missions. In the perspective of long-term data analysis, we derived a full-mission 10-year data set of CO vertical columns (2003-2012) from the short wave infrared (SWIR) measurements of SCIAMACHY. To account for SCIAMACHY's instrument degradation we used clear sky measurement over the Sahara region as a natural calibration target to determine spectral calibration, a spectral radiometric offset, the width of the instrument spectral response function for the entire mission. Finally, the 10 years CO dataset is validated with on-ground CO column measurements at several sites of the TCCON network.

Developments in the retrieval of NO₂ from OMI and TROPOMI observations

Eskes, Henk [1]; Boersma, Folkert [1,2]; Maasakkers, Johannes D. [1,3]; van Geffen, Jos [1]; Williams, Jason [1]; Veeffkind, Pepijn [1]

1: KNMI, The Netherlands; 2: Wageningen University, The Netherlands; 3: Harvard University, USA

A new version of the NO₂ retrieval for OMI - the KNMI DOMINO retrieval code, version 3 - has been recently developed. The modifications in this algorithm compared to the current DOMINO version 2 product will be discussed in our contribution. The spectral fitting to derive the DOAS slant column for NO₂ has been revised as explained in the paper by van Geffen et al., AMTD 2014, and the main modifications will be reviewed. The TM4 chemistry-transport model used for DOMINO-2 is upgraded to the latest TM5 release, and the resolution is

increased from 3x2 degree to 1x1 degree. Further aspects which were updated include the temperature dependence of the O2-O2 cloud retrieval, the error estimation and terrain height treatment, and newly developed air-mass factor lookup tables. The estimate of the stratospheric NO₂ column by means of data assimilation in TM5 is improved. Various aspects of these developments have been verified through intercomparisons with other retrieval approaches within the TROPOMI verification team and the European QA4ECV project. Finally we will discuss the future application of DOMINO-3 for TROPOMI.

Estimation of stratospheric NO₂ from nadir-viewing satellites: The MPI-C TROPOMI verification algorithm

Beirle, Steffen; Wagner, Thomas

MPI Chemistry Mainz, Germany

The retrieval of tropospheric column densities of NO₂ requires the subtraction of the stratospheric fraction from the total columns derived by DOAS. Here we present a modified reference sector method, which estimates the stratosphere over "clean" regions, as well as over clouded scenarios in which the tropospheric column is shielded.

The selection of "clean" pixels is realized gradually by assigning weighting factors to the individual ground pixels, instead of applying binary flags. Global stratospheric fields are then compiled by "weighted convolution". In a second iteration, unphysical negative tropospheric residues are suppressed by adjusting the weights respectively. This algorithm is foreseen as "verification algorithm" for the upcoming TROPOMI on S5p.

We show the resulting stratospheric estimates and tropospheric residues for a test data set based on OMI observations. The dependencies on the a-priori settings (definition of weighting factors and convolution kernels) are discussed, and the results are compared to other products, in particular to DOMINO v.2 (based on assimilation, similar to the TROPOMI prototype algorithm) and the NASA standard product (based on a similar reference-region-type approach).

Satellite-based Trends of Tropospheric NO₂ over Large Urban Agglomerations and an Approach Towards Their Validation

Schneider, Philipp [1]; Stebel, Kerstin [1]; Lahoz, William A. [1]; van der A, Ronald [2]

1: NILU - Norwegian Institute for Air Research, Kjeller, Norway; 2: Royal Netherlands Meteorological Institute (KNMI), De Bilt, The Netherlands

Nitrogen dioxide (NO₂) is one of the most prominent air pollutants and is of particular concern in densely populated urban areas. Here we present a study investigating recent trends in tropospheric NO₂ columns over 66 large urban agglomerations worldwide. These were derived using data from the Scanning Imaging Absorption spectroMeter for Atmospheric CHartography (SCIAMACHY) instrument onboard the Envisat platform for the period August 2002 to March 2012. A seasonal model including a linear trend was fitted to the satellite-based time series over each site. The results indicate distinct spatial patterns in trends. While agglomerations in Europe, North America, and some locations in East Asia/Oceania show decreasing tropospheric NO₂ levels on the order of -5 % yr⁻¹, rapidly increasing levels of tropospheric NO₂ are found for agglomerations in large parts of Asia, Africa, and South America. The site with the most rapidly increasing absolute levels of tropospheric NO₂ was found to be Tianjin in China with a trend of 3.04 (±0.47) × 10¹⁵ molecules cm² yr⁻¹, whereas the site with the most rapidly increasing relative trend was Kabul in Afghanistan with 14.3 (±2.2) % yr⁻¹. In total, 34 sites exhibited increasing trends of tropospheric NO₂ throughout the study period, 24 of which were found to be statistically significant. A total of 32 sites showed decreasing levels of tropospheric NO₂ during the study period, of which 20 sites did so at statistically significant magnitudes. Our study further examines the impact of the recent economic crisis on NO₂ time series and investigates the relationship between urban NO₂ trends and changes in population growth. We find that this

relationship is subject to substantial regional differences as well as influenced by economic and demographic factors.

In addition we present a methodology for directly validating satellite-based trends in NO₂ using the growing set of long-term Multi-Axis Differential Optical Absorption Spectroscopy (MAX-DOAS) stations worldwide. More specifically, MAX-DOAS instruments located in southern France and China (operated by BIRA) as well as multiple stations throughout Asia provided by the JAMSTEC network are used to provide reference information at various pollution levels. While the corresponding time series currently are still relatively short, several stations now have continuous time series of more than five years length and thus show potential to be used for direct trend validation. First results indicate that the method is feasible and provides similar trends from both data sources when the number of months with valid data is on the order of 50 or more. For stations at which this number is significantly lower, the trend uncertainties are currently too high to use them as a reference. However, these uncertainties in trends are bound to reduce rapidly with increasing time series length and it is anticipated that only 1-2 additional years of data are required to obtain statistically significant results in polluted regions. Within the next few years there are also likely to be more stations worldwide which provide operational long-term MAX-DOAS datasets with suitable record lengths for trend analysis. Once the MAX-DOAS time series are long enough for a larger number of stations worldwide it is anticipated that such as network will provide a method for directly validating the tropospheric NO₂ trends obtained from satellite-based platforms without the need for indirect validation using models or similar techniques, which introduce significant amounts of additional uncertainty.

Evaluation of Discrepancies in the Anthropogenic NO_x Emission Trends across Europe: Synergistic use of LOTOS-EUROS and NO₂ Tropospheric Columns from GOME-2 and OMI.

Curier, Lyana; Segers, Arjo; Timmermans, Renske

TNO, Netherlands, The

In Europe, establishing (long term) trends in pollutant emissions, and concentrations is a key part of evaluating the impact of policies. Traditionally, air pollutant concentrations are monitored using in-situ measurement, while emissions are estimated on annual basis. Unfortunately, in both cases the methodology used are not consistent across Europe. In the past decade, studies using spaceborne instruments have illustrated that the tropospheric column of nitrogen dioxide contains valuable information about its sources, transport and sinks. Consequently, inverse modelling using satellite observations of NO₂ columns to estimate anthropogenic NO_x emissions has been extensively used.

Various studies have focused on estimating the trends in NO_x emissions using the tropospheric NO₂ columns from OMI measurements, as it reaches global coverage on a daily basis with a 13 × 24 km² footprint at nadir. Across Europe, a significant negative trend of 5–6% per year in highly industrialized areas was identified. However, since all these studies make use of the same instrument, no information is provided on the impact of the instrument and its overpass time on the derived trends amplitude. In this study, we aim to quantify the discrepancies in the derived trends amplitude and provide significant information on the optimal overpass time to monitor the impact of the mitigation strategies across Europe. To this end, we compare trends in the anthropogenic NO_x emissions derived from OMI and GOME-2 observations.

In this presentation, first, the sensitivity of each instrument to relevant emission source sectors across Europe will be shown. The NO₂ column sensitivity to source categories will allow us to better understand the observed trends. Second, the trends derived across Western Europe from OMI and GOME-2 observations will be presented and, the discrepancies will be investigated. Finally, an attempt to reconcile the trend estimates from both instruments across Europe will be presented.

The S-5P/TROPOMI formaldehyde retrieval algorithm baseline and its application to OMI and GOME-2 measurements

De Smedt, Isabelle [1]; Van Roozendaal, Michel [1]; Danckaert, Thomas [1]; Theys, Nicolas [1]; Hendrick, François [1]; Stavrou, Trisisevgeni [1]; Müller, Jean-François [1]; Hilboll, Andreas [2]; Richter, Andreas [2]; Eskes, Henk [3]; Veefkind, Pepijn [3]

1: Belgian Institute for Space Aeronomy (BIRA-IASB), Brussels, Belgium; 2: Institute of Environmental Physics University of Bremen (IUPB), Germany; 3: Koninklijk Nederlands Meteorologisch Instituut (KNMI), De Bilt, the Netherlands

The TROPospheric Monitoring Instrument (TROPOMI) will be launched in 2016 onboard the ESA Sentinel-5 Precursor (S-5P) satellite. It will provide global and daily observations of atmospheric trace gases, with an unprecedented spatial resolution of 7×7 km². Formaldehyde (HCHO) is a central molecule of tropospheric chemistry. Its observation allows for the determination of non-methane hydrocarbon emissions, which are precursors of tropospheric ozone and biogenic aerosols and influence the oxidizing capacity of the troposphere. Measurements from TROPOMI will improve the monitoring capability of HCHO from anthropogenic and natural emissions, and will extend the long-term datasets from past and existing UV sensors (GOME, SCIAMACHY, OMI, GOME-2, OMPS).

Within the S-5P project, BIRA-IASB is in charge of the development of the prototype HCHO level-2 algorithm, while IUP-Bremen leads verification tasks. We present the algorithm baseline and results from its application to the complete series of OMI and GOME-2 measurements. This includes the validation of the resulting data products using MAX-DOAS measurements available in China, Burundi and Europe. We also present a global trend analysis of the tropospheric HCHO columns between 2004 and 2014. Furthermore the specificities of the TROPOMI algorithm are discussed in more details, in particular the impact of using state-of-the-art TM5 profiles at the spatial resolution of $1^\circ \times 1^\circ$ as a priori in the air mass factor calculation. Finally results from the scientific verification based on synthetic spectra and on OMI test data are discussed.

Shortwave infrared measurements of the TROPOMI instrument on the Sentinel 5 Precursor mission

Landgraf, Jochen [1]; aan de Brugh, Joost [1]; Hu, Haili [1]; Borsdorff, Tobias [1]; Scheepmaker, Remco [1]; Butz, Andre [2]; Hasekamp, Otto [1]; Aben, Ilse [1]

1: SRON Netherlands Institute for Space Research, Netherlands, The; 2: Karlsruhe Institute of Technology (KIT), Germany

In 2016, the Sentinel 5 Precursor mission will be launched with the TROPOMI instrument as its single payload. It will deliver daily global measurements of the atmospheric composition for air quality and climate application as part of the Copernicus atmospheric services. In this presentation, we focus on the measurements of the shortwave infrared (SWIR) spectral range providing global distributions of CH₄, CO, H₂O and its isotope HDO. Starting with the status of the SWIR instrument module and its calibration, we discuss the operational data processing of the SWIR trace gases including an estimate of the data quality. The main challenge is to account for scattering by water clouds, cirrus and tropospheric aerosols without exceeding the computational constraints of the processing facility. To demonstrate the maturity of the algorithms, we show applications of the algorithms to GOSAT and SCIAMACHY measurements and the verification with on-ground measurements.

Improving the NO₂ retrieval for S5P

Richter, Andreas; Hilboll, Andreas; Burrows, John P.

University of Bremen, Germany

Nitrogen dioxide is one of the key atmospheric trace gases which are detectable by UV/visible remote sensing from satellite. It plays an important role in stratospheric ozone chemistry, both by acting as ozone depleting catalyst and by removing reactive halogen oxides into less reactive reservoir substances. In the troposphere, NO₂ is a pollutant which adversely affects human health, leads to photochemical ozone smog formation and contributes to acidification of rain and surface waters.

Tropospheric nitrogen dioxide columns have been retrieved from measurements of the GOME, SCIAMACHY, and GOME-2 instruments, as well as from OMI observations and more recently OMPS data. For the upcoming TROPOMI instrument on S5P, two nitrogen dioxide retrieval algorithms are being developed, the prototype which will be used in the operational processor and the verification algorithm, which combines different approaches to the retrieval of tropospheric, stratospheric and total columns of NO₂.

Here, we report on work performed on improvements of the spectral retrieval including analysis of effects found at very large NO₂ absorptions and attempts to use the spectral information to derive a rough estimate of the vertical distribution of NO₂. The basic ideas of the selected approaches will be presented, sensitivity studies on synthetic data be reported and first applications on real GOME-2 data be shown.

Spectroscopic database for TROPOMI/Sentinel 5 precursor

Birk, Manfred [1]; Loos, Joep [1]; Wagner, Georg [1]; Campargue, Alain [2]; Mondelain, Didier [2]; Hase, Frank [3]; Orphal, Johannes [4]; Tran, Ha [9]; Perrin, Agnes [4]; Daumont, Ludovic [5]; Rotger, Maud [5]; Bigazzi, Alberto [6]; Zehner, Claus [7]; Cou

1: DLR/German Aerospace Center, Germany; 2: Universite Joseph Fourier, France; 3: KIT, Karlsruhe, Germany; 4: LISA, Paris, France; 5: Universite de Reims Champagne Ardenne, Reims, France; 6: Serco, Frascati, Italy; 7: ESA-ESRIN, Frascati, Italy; 8: CNRS 7

The ESA project „SEOM-Improved Atmospheric Spectroscopy Databases (IAS)“ will improve the spectroscopic database for retrieval of the data products CO, CH₄, O₃ and SO₂ column amounts measured by the TROPOMI instrument (TROPospheric Monitoring Instrument) aboard the Sentinel 5 precursor. The project was launched in February 2014 with 3 years duration. The spectroscopy of CO, CH₄ and O₃ in the 2.3 µm region is covered in the first 2 years, while UV measurements of SO₂ and UV/FIR/IR measurements of ozone will be carried out in the last year. User requirements for the spectroscopic database were obtained by retrieval simulations, indicating the need to take line mixing into account in case of CH₄, to measure HDO in case of water and even to measure line broadening of CH₄ lines by water vapor. A dedicated line model will be used to represent the laboratory spectra since the Voigt routine was found to be not sufficient to obtain the needed accuracy. Details on the retrieval simulations will be given together with the user requirements and the laboratory measurement plan. Measurements of pure water and ambient temperature air broadened measurements of water were finalized in March 2015 utilizing a high resolution Bruker IFS 125HR Fourier-Transform spectrometer at DLR. Complementary, continuous wave cavity ring-down measurements of pure water were also finalized in Grenoble, France. First quality checks and intercomparison of the data will be shown. Furthermore, the latest laboratory results will be presented.

Improved HCOOH retrieval from IASI measurements: Comparison with ground-based measurements

Pommier, Matthieu [1]; Clerbaux, Cathy [1,2]; Clarisse, Lieven [2]; Coheur, Pierre-Francois [2]; Mahieu, Emmanuel [3]; Clare, Paton-Walsh [4]; Vigouroux, Corinne [5]

1: Sorbonne Universités, UPMC Univ. Paris 06; Université Versailles St-Quentin; CNRS/INSU, LATMOS-IPSL, Paris, France; 2: Spectroscopie de l'Atmosphère, Chimie Quantique et Photophysique, Université Libre de Bruxelles (ULB), Brussels, Belgium; 3: Institut

Formic acid (HCOOH) is one among the most abundant volatile organic compounds (VOCs) present in the atmosphere. HCOOH sources include emissions from vegetation, soil and biomass burning. To a lesser extent, it is also produced by motor vehicles. It is mainly a secondary product from organic precursors.

HCOOH plays a role in the oxidizing capacity of the troposphere and on the global budget of tropospheric ozone (O₃), and it is also a source of rain acidity in remote areas. There are however large uncertainties on sources and sinks and HCOOH is misrepresented in the global emissions inventories.

In this work, we retrieve concentrations from spectra recorded by the IASI (Infrared Atmospheric Sounding Interferometer) instrument launched onboard the MetOp-A satellite in 2006. IASI is a nadir looking Fourier transform spectrometer, sounding the atmosphere with a global coverage twice per day. The HCOOH global distributions are derived using a new retrieval approach, based on conversion factors between brightness temperature differences and representative retrieved total columns.

We present global distributions and comparisons with FTIR measurements obtained at La Reunion, Wollongong and Jungfraujoch from 2008 to 2013. The IASI instrument provides a 6-year record for different regions, highlighting the signatures from biomass burning events and allowing the study of seasonal and interannual variations.

Revising the global budget of glyoxal (OCHCHO) based on OMI and GOME-2 vertical columns

Müller, Jean-François; Stavrou, Jenny; Lerot, Christophe; De Smedt, Isabelle; Van Roozendaal, Michel

Belgian Institute for Space Aeronomy, Belgium

Glyoxal is, like formaldehyde, a short-lived intermediate in the oxidation of non-methane volatile organic compounds (NMVOC) emitted by plants, vegetation fires and anthropogenic activities. It is also identified as a precursor of secondary organic aerosols (SOA). Both compounds absorb in the UV-visible spectral region and have been measured by the SCIAMACHY satellite sensor since 2003, and more recently, by OMI and GOME-2. Previous modelling studies using SCIAMACHY data have pointed to the existence of large additional sources, in particular over forests [Stavrou et al. 2009], and more recently over Eastern China, most likely due to aromatic hydrocarbons [Liu et al. 2012], suggesting that glyoxal can serve as an indirect estimator of urban VOC sources.

The current study is motivated by (i) recent advances in our understanding of chemical pathways leading to glyoxal formation, in particular from the oxidation of isoprene, the most largely emitted NMVOC, (ii) the existence of numerous in situ concentration measurements for the key anthropogenic glyoxal precursors (e.g. acetylene, aromatics) over industrialized areas, which can be used to narrow down the anthropogenic emission estimates in these regions, and (iii) substantial improvements in retrieval algorithms for glyoxal columns from UV-visible satellite instruments, which has led to a significant reduction of the number of unphysical negative columns over the oceans as well as to generally lower glyoxal columns over continents.

In this study, the chemical mechanism and NMVOC emission inventories of the global CTM IMAGESv2 are revised based on recent investigations. The relative importance and possible uncertainties of different chemical pathways leading to glyoxal formation in the oxidation of isoprene are determined by box model simulations. Next, GOME-2 and OMI glyoxal and formaldehyde data are used to constrain the emissions of biogenic, pyrogenic and anthropogenic VOCs. To that effect, the inverse modelling technique using the adjoint model of

IMAGESv2 is used. The role of model uncertainties is explored through a number of sensitivity studies. The model results are evaluated against selected ground-based observations. The consequences for e.g. SOA and O₃ formation in polluted areas are also briefly discussed.

Biomass burning emissions estimates from IASI CO satellite measurement

Krol, Maarten

Wageningen University, Netherlands, The

Biomass burning strongly affects the atmospheric composition. Also, biomass burning is strongly related to climate. Traditional methods to estimate biomass burning emissions are based on satellite measurements of burned area and fire radiative power. An alternative approach is the observation of trace gases from space. Carbon Monoxide (CO) is arguably the most interesting species in this respect. Its atmospheric lifetime of about 1-2 months ensures good traceability of biomass burning plumes in the atmosphere.

In the recent years, we developed a data assimilation system to ingest large amounts of IASI CO column measurements with the aim to improve biomass burning emission estimates. The system is based on the TM5 atmospheric chemistry transport model, coupled to a 4DVAR data assimilation system. We applied the system, zooming in on strong biomass burning areas in the tropics, viz. South America and Africa. We find that our system is able to capture the biomass burning CO plumes very well. However, we also find that the emissions from the GFED4 bottom up inventories have to be modified. In South America and South Africa, the GFED4 CO emissions in the early burning season appear to be too high. In contrast, emissions seem to be too low near the end of the biomass burning season. In Northern Africa, GFED4 emissions appear to be too high also.

In the presentation I will discuss the system, the results, and some uncertainties related to other sources of CO. Possible future applications of the system will also be discussed.

On the consistency of top-down hydrocarbon emission fluxes inferred from GOME-2 and OMI formaldehyde observations

Stavrakou, Jenny [1]; Müller, Jean-François [1]; Bauwens, Maite [1]; De Smedt, Isabelle [1]; Van Roozendael, Michel [1]; Georges, Maya [2]; Clerbaux, Cathy [2,3]; Coheur, Pierre-François [3]

1: Belgian Institute for Space Aeronomy, Belgium; 2: UPMC Univ. Paris 6, Univ. Versailles St. Quentin; CNRS/INSU, LATMOS-IPSL, 75252, Cedex 05, Paris, France; 3: Spectroscopie de l'Atmosphère, Service de Chimie Quantique et Photophysique, Université Libre

The vertical columns of formaldehyde (HCHO) retrieved from two satellite instruments, the Global Ozone Monitoring Instrument-2 (GOME-2) on Metop-A and the Ozone Monitoring Instrument (OMI) on Aura, are used to constrain global emissions of HCHO precursors from open fires, vegetation and human activities in 2010. To this end, the emissions are varied and optimized using the adjoint model technique in the IMAGESv2 global CTM on a monthly basis and at the model resolution. Given the different local overpass times of GOME-2 (9h30) and OMI (13h30), the simulated diurnal cycle of HCHO columns is investigated and evaluated against ground-based optical measurements at 7 sites in Europe, China and Africa. The agreement between simulated and ground-based columns is found to be generally better in summer (with a clear afternoon maximum at mid-latitude sites) than in winter, and the annually averaged ratio of afternoon to morning columns is slightly higher in the model than in the ground-based measurements.

Both optimizations infer reductions of the global biogenic and pyrogenic flux estimates compared to their a priori values and show a high degree of consistency. A reduction of the global annual biogenic emissions of isoprene is derived, by 9% and by 13% according to GOME-2 and OMI, respectively, compared to the a priori estimate of 363 Tg in 2010. The reduction is largest (up to 25-40%) in the Southeastern US, in accordance with earlier studies. The GOME-2 and OMI satellite columns suggest a global pyrogenic flux decrease by 36% and 33%, respectively, compared to the GFEDv3 inventory. This decrease is especially pronounced over tropical forests such as Amazonia and Thailand/Burma, and is supported by comparisons with IASI CO observations. In

contrast to these flux reductions, the emissions due to harvest waste burning are strongly enhanced in the Northeastern China plain in June, as well as over Indochina in March. Sensitivity inversions are conducted in order to explore the possible impact of uncertainties associated to the priori errors on the emission fluxes, the cloud fraction filter applied to the satellite data, and the isoprene oxidation mechanism on the inferred estimates.

Assessing the potential of TROPOMI for global monitoring of terrestrial chlorophyll fluorescence

Guanter, Luis [1]; Aben, Ilse [2]; Tol, Paul [2]; Krijger, Matthijs [2]; Hollstein, Andre [1]; Köhler, Philipp [1]; Damm, Alexander [3]; Joiner, Joanna [4]; Frankenberg, Christian [5]; Landgraf, Jochen [2]

1: GFZ Potsdam, Germany; 2: SRON Netherlands Institute for Space Research; 3: Remote Sensing Laboratories, University of Zurich; 4: NASA Goddard Space Flight Center; 5: Jet Propulsion Laboratory, California Institute of Technology

Sun-induced chlorophyll fluorescence (SIF) is an electromagnetic signal emitted in the 650-850 nm spectral range by the chlorophyll-a of assimilating plants. The monitoring of SIF from space can provide critical information about the photosynthetic functioning of terrestrial ecosystems. In fact, global retrievals of SIF from space have recently been achieved from a number of spaceborne spectrometers (namely, GOSAT, GOME-2, SCIAMACHY and OCO-2) originally intended for atmospheric research. Although not designed for land applications, those atmospheric instruments have turned out to provide the necessary spectral and radiometric sensitivity for SIF retrieval from space.

Despite these achievements, the exploitation of SIF measurements for most applications is strongly hampered by the coarse spatial resolution and low number of observations provided by existing instruments: most terrestrial ecosystems are highly heterogeneous at spatial scales larger than 5-10 km, whereas existing global SIF products are typically gridded in cell boxes with size ranging from 0.5 to 20. This issue will be greatly improved with the advent of the TROPospheric Monitoring Instrument (TROPOMI) onboard the Sentinel-5 Precursor.

TROPOMI is a push broom grating spectrometer combining a wide swath (2600 km) with high spatial resolution (7x7 km² at nadir) and daily global coverage. TROPOMI will perform nadir observations in the 675-775 nm spectral window with a spectral resolution of 0.5 nm. Because of the similar spectral characteristics, approaches for SIF retrieval from TROPOMI can be based on methods developed for GOME-2 and SCIAMACHY. However, TROPOMI's much finer spatial resolution promises to improve substantially the information content of the SIF data with respect to existing data sets, for example over fragmented agricultural areas and over tropical rainforest regions, which will especially benefit from the much higher frequency of clear-sky observations. It can be shown that TROPOMI can reduce global uncertainties in SIF mapping by more than a factor 2 with respect to GOME-2, which comes together with an about 5-fold improvement in spatial sampling. In addition, TROPOMI will be the first imaging spectrometer ever to deliver global data with a moderate spatial resolution and a continuous spectral sampling of the red and near-infrared spectral regions (the so-called red-edge). Red-edge reflectance measurements by TROPOMI can be used to monitor a number of vegetation geophysical parameters of great value to interpret the SIF measurements and to convert them into quantitative estimates of photosynthetic fluxes.

In this contribution, we will provide a short review of the state of the art of global terrestrial fluorescence monitoring and will present a sensitivity analysis illustrating the breakthrough in the field that we can expect from TROPOMI.

GlobEmission: applications of emission estimates from satellite

van der A, Ronald (1); Mijling, Bas (1); Ding, Jieying (1); Stavrakou, Jenny (2); Van Roozendael, Michel (2); De Smedt, Isabelle (2); Muller, Jean-Francois (2); Bauwens, Maite (2); Curier, Lyana (3); Veldeman, Nele (4); de Leeuw, Gerrit (5); Rodriguez, Ed

1: KNMI, The Netherlands; 2: BIRA-IASB, Belgium; 3: TNO, The Netherlands; 4: VITO, Belgium; 5: FMI, Finland

Emission inventories are developed for use in scientific applications and as input in urban, regional, continental or global scale air quality models. Furthermore, emission estimates are used by policy makers in order to evaluate progress towards emission abatement measures and to decide on future strategies.

Within the GlobEmission project (part of the Data User Element programme of ESA) emission estimates are developed from satellite observations of air constituents. The main advantage of space-based emission estimates are the spatial consistency, high temporal resolution and the rapid availability of these estimates to the user. The emission estimates are developed for specific applications of users that are involved in the project. A few examples of these applications are air quality modeling over China, monitoring emissions of the oil industry in the Middle East, isoprene emissions from the biosphere and the impact of fires. In this presentation examples will be given of those applications.

Monitoring air pollution at global scale using the IASI thermal infrared instrument

Bauduin, Sophie (1); Clarisse, Lieven (1); Clerbaux, Cathy (1,2); Hurtmans, Daniel (1); Coheur, Pierre-François (1)

1: Spectroscopie de l'Atmosphère, Service de Chimie Quantique et Photophysique, Université Libre de Bruxelles, Brussels, Belgium; 2: Sorbonne Universités, UPMC Univ. Paris 06 ; Université Versailles St-Quentin ; CNRS/INSU, LATMOS-IPSL, Paris, France

Air quality is a major health concern in most megacities and important industrial regions. It is therefore important to properly quantify the emissions of the main air pollutants and to understand their transport pathways and their reactivity in the atmosphere. In recent years, there have been important progresses to monitor near-surface atmospheric composition from satellites, which offer the possibility to draw spatial distributions from local to global scale as well as time evolutions for a series of regulated air quality species. Among the sounders currently in orbit, those operating in the thermal infrared have usually their maximum sensitivity in the mid-troposphere but have been shown to be able to monitor air surface pollution when the temperature contrast between the ground and the air above it is sufficiently large.

In this work, we will present a series of results demonstrating the capability of infrared sounders to measure surface air composition. We will focus the presentation on the measurements of sulfur dioxide (SO₂) and carbon monoxide (CO) from the IASI instrument. More specifically, the development of a new product allowing the retrieval of SO₂ from IASI observations at global scale will be briefly presented. Global distributions of anthropogenic SO₂ surface pollution will be shown, focusing on the identification of the principal hotspots and of exceptional pollution events. In addition, we will provide results of CO pollution from IASI and show how in favorable conditions, the surface CO concentration can be de-correlated from the free tropospheric abundance. We will put the results in the perspective of current and future missions, which, by combining infrared and UV sounding missions, offer improved possibilities for the global surveillance of air quality.

Global Distribution of Tropospheric BrO Observed from Satellite

kurosu, thomas p. [1]; natraj, vijay [1]; stutz, jochen p. [2]; kasai, yasuko [3]; theys, nicolas [4]; van roozendaal, michel [4]; canty, tim [5]; salawitch, ross j. [5]; saiz-lopez, alfonso [6]

1: jet propulsion laboratory/california institute of technology, usa; 2: university of california, los angeles, usa; 3: national institute of information and communications technology, japan; 4: belgian institute for space aeronomy, belgium; 5: university

We present global observations of tropospheric bromine monoxide (BrO) derived from the Ozone Monitoring Instrument (OMI) on the EOS-Aura satellite, based on cloud-slicing techniques.

BrO is a halogen oxide present mostly in the lower stratosphere, where it catalytically destroys ozone with about 25 times the efficiency of ClO. BrO also has a tropospheric component, where it is released from sea surfaces, at the interface of ocean water and sea ice in the polar spring, in volcanic plumes, and in the vicinity of salt lakes. Tropospheric BrO has been linked to mercury (Hg) deposition through BrO-induced conversion of gaseous Hg to reactive Hg, which is then deposited on the surface and enters the food chain, ultimately affecting human health.

As part of NASA's Aura Science Team, we are developing an OMI Tropospheric BrO data product that provides a unique global data set on BrO spatial and vertical distribution in the troposphere and stratosphere. Information of this kind is currently unavailable from any of the past and present bromine-monitoring instruments. We present first results of spatially and vertically resolved tropospheric BrO loading in equatorial to mid-latitudinal regions.

Seasonal variation of bromine monoxide over the Rann of Kutch salt marsh seen from space

Hörmann, Christoph [1]; Beirle, Steffen [1]; Penning de Vries, Marloes [1]; Sihler, Holger [1]; Platt, Ulrich [2]; Wagner, Thomas [1]

1: Max Planck Institute for Chemistry, Mainz, Germany; 2: Institute for Environmental Physics, University of Heidelberg, Germany

Bromine monoxide (BrO) is an important catalyst in the depletion of tropospheric and stratospheric ozone [O3]. In the troposphere, reactive bromine can be released from sea ice, volcanoes, sea-salt aerosol or salt lakes and high concentrations of BrO are associated with the autocatalytic 'bromine explosion' cycle. For all of these natural sources enhanced BrO vertical column densities (VCDs) have been successfully observed from ground using Differential Optical Absorption Spectroscopy (DOAS). Until now, satellite observations were only reported for polar regions during springtime and volcanic emissions (mostly for major eruptions).

We present the first satellite observations of enhanced monthly mean BrO VCDs over a salt marsh, the Rann of Kutch (India/Pakistan), during 2004-2014 as seen by the Ozone Monitoring Instrument (OMI). The Rann of Kutch is a so-called 'seasonal' salt marsh. During India's summer monsoon (June/July – September/October), the flat desert of salty clay and mudflats, which average 15 meters above sea level, fills with standing rain and sea water. With more than 7500 km² it is the largest salt desert in the world and additionally one of the hottest areas of India with summer temperatures around 50 °C and winter temperatures decreasing below 0 °C. Probably due to these rather extreme conditions, the Rann of Kutch has not been yet investigated for atmospheric composition measurements by ground-based instruments. Satellite observations, however, provide the unique possibility to investigate the entire area remotely over a long-time period.

The OMI data reveals recurring maximum BrO VCDs during April/May, but no enhanced column densities during the monsoon season while the area is flooded. In the following months the signal only recovers slowly while the salty surface dries up. We discuss the possible effects of temperature, precipitation and relative humidity on the release of enhanced reactive bromine concentrations. In order to investigate a possible diurnal cycle of the BrO concentration, the OMI results (at a local overflight time around ~13:30) are compared to corresponding results from the Global Ozone Monitoring Instrument (GOME-2, local overflight time at ~9:30).

Day 5, Friday 12 June 2015

Applications/Data Assimilation

Assimilating Satellite Data in the Copernicus Atmosphere Monitoring Service Global Data Assimilation System: Current Status and Prospects for the Sentinel Era

Engelen, Richard; Agusti-Panareda, Anna; Benedetti, Angela; Crepulja, Marijana; Flemming, Johannes; Inness, Antje; Jones, Luke; Massart, Sebastien; Parrington, Mark; Peuch, Vincent-Henri; Razinger, Miha; Suttie, Martin; Yang, Xiaobo

ECMWF, United Kingdom

This year, the Copernicus Atmosphere Monitoring Service (CAMS) is entering its operational phase. After many years of pioneering work through a series of EU and ESA funded projects (GEMS, Promote, MACC), a mature data assimilation and forecasting system for global atmospheric composition has been established. This system, which is based on the ECMWF numerical weather prediction system, forms one of the important core elements of the Service. It uses a wide array of satellite and in-situ data observing both meteorological and atmospheric composition variables to provide a best estimate of the current state of the atmosphere on a daily basis. These analyses are then used as initial conditions for 5-day global forecasts of atmospheric composition, covering aerosols, chemical species and greenhouse gases. The same system is also used to produce reanalyses allowing a wider range of data to be used, because there is no strict near real-time requirement.

CAMS forms an important component of the Copernicus programme adding significant value to the information coming from the current and future observing system. This presentation will provide an overview of the CAMS use of current satellite data, such as OMI, GOME-2, IASI, MOPITT, MLS, MODIS, and GOSAT. With the expected launch of Sentinel-3 and Sentinel-5p in the coming year crucial new information on atmospheric composition will become available, both for operational and research purposes. We will show how CAMS, in close collaboration with ESA, is preparing for these new observations to enable maximum benefit for the users of the atmosphere services as early as possible. We will also show how CAMS can provide important feedback about the data quality through careful data monitoring in the comprehensive data assimilation system. The latter information will be very beneficial for the scientific community to make more optimal use of the Sentinel data.

Sodankylä satellite data centre and almost real-time monitoring of atmospheric composition in Northern Europe

Tamminen, Johanna [1]; Hassinen, Seppo [1]; Ialongo, Iolanda [1]; Tukiainen, Simo [1]; Hakkarainen, Janne [1]; Kivi, Rigel [1]; Ryyppö, Timo [1]; Heilimo, Jyri [1]; Lindfors, Anders [1]; Levelt, Pieter [2]; Veefkind, Pepijn [2]; Krotkov, Nickolay [3];

1: Finnish Meteorological Institute, Finland; 2: KNMI, the Netherlands; 3: NASA, USA

Since 2006 the Sodankylä satellite data centre has utilized the direct broadcast data downlink of the NASA's Aura satellite to process Dutch-Finnish Ozone Monitoring Instrument (OMI) data and to distribute O₃, SO₂, UV-radiation and aerosol index observations within 20 min after the satellite overpass. These so called Very Fast Delivery OMI products have been used in monitoring and forecasting the transportation of volcanic plumes, observing ash clouds from forest fires and in following ozone abundance and UV-radiation. Since 2014 NASA's Suomi NPP/OMPS data has also been received and processed in addition to OMI. The upgraded system, named SAMPO, was operational just in time to monitor the Bárðarbunga/Holuhraun fissure eruption in Iceland, which started in September 2014.

In this presentation we demonstrate the direct broadcast products of the SAMPO service and applications of the data. In particular, the recent volcanic eruptions in Iceland are discussed. As the volcanic SO₂ plume in

2014 also reached Finland, the data have been compared to ground-based observations. Furthermore, future plans of the Sodankylä satellite data centre as the Copernicus Sentinel Collaborative Ground segment are discussed. The most recent plans include processing global TROPOMI/Sentinel 5 Precursor UV-radiation products.

Monitoring the changing environment of the 21st Century: the role of OSSEs in determining the future global observing system

Lahoz, William Albert [1]; Attie, Jean-Luc [2]; Ricaud, Philippe [3]; El Amraoui, Laaziz [3]; Hache, Emeric [4]; Tournier, Cyrille [5]

1: NILU, Norway; 2: University of Toulouse, France; 3: CNRM, Meteo-France, France; 4: Thales, France; 5: Astrium, France

A changing environment in the 21st Century, in particular because of constituents associated with air quality and climate change, and with consequences for societal well-being, illustrates the need to monitor the environment, including compliance with environmental regulations from societal actors such as public authorities, governments and industry. For air quality, this monitoring involves, inter alia, measurements of key pollutants (e.g., ozone and carbon monoxide) in the lowermost troposphere even in the atmospheric boundary layer at spatio-temporal scales relevant to policy makers (temporal frequencies of order less than 1 hour; spatial scales of order less than 10 km). Monitoring criteria also apply to greenhouse gases affecting climate change.

In this presentation, we identify the role of data assimilation observing system simulation experiments (OSSEs) in determining the future global observing system (GOS) to monitor atmospheric constituents in a changing environment. We describe requirements for constructing such OSSEs, and discuss caveats associated with setting up and interpreting the OSSEs. To illustrate the concept, we present OSSEs performed within the MUSICQA project to assess the added-value of planned and proposed geostationary satellite platforms to measure atmospheric constituents affecting air quality.

Added value and optimal design of future satellite observations for air quality applications - Observing System Simulation Experiments

Timmermans, Renske [1]; Attié, Jean-Luc [2,3]; Builtjes, Peter [1,4]; Curier, Lyana [1]; Edwards, David [5]; Eskes, Henk [6]; Kranenburg, Richard [1]; Lahoz, William [7]; Peuch, Vincent-Henri [8]; Schaap, Martijn [1]; Segers, Arjo [1]

1: Netherlands Organisation for Applied Scientific Research (TNO), The Netherlands; 2: University of Toulouse, France; 3: CNR-GAME, France; 4: Free University Berlin (FUB), Germany; 5: National Center for Atmospheric Research (NCAR), US; 6: Royal Netherl

Over the past few years a growing number of space observations focusing on atmospheric composition have become available and this trend will continue with the launch of new satellites (ESA-Sentinels, NASA-TEMPO, KARI-GEMS and JAXA air quality and climate mission) in the near future. To justify the production and launch of these expensive instruments, there is a need for determining the added value of future satellite instruments and their optimal design in an objective way. One methodology that can do so is the OSSE (Observing System Simulation Experiment). Although extensively used in the meteorological community, its use in the field of air quality and climate is still limited and a common approach is desirable.

A full and realistic OSSE consists of the following elements: (1) a realistic nature run to simulate the true state of the atmosphere; (2) an observation simulator including full instrument description, full radiative transfer models or scene-dependent averaging kernels, cloud information, product retrieval scheme, and realistic error and error correlation estimates; (3) a well-established data assimilation model different from the nature run model; (4) model independent results; (5) a calibration run; and (6) a dedicated quantitative evaluation focusing

on the driving science questions, and including statistical significance of the results. When containing this set of elements the OSSEs can be used to provide realistic answers on the added value and optimal design of future instruments for a specific application.

In this contribution we will present the methodology and the potential of OSSEs for satellite observations of atmospheric composition. Illustrative examples will be given from existing air quality OSSEs, amongst others an OSSE for the potential value of small satellite instruments observing NO₂ columns and the ESA-ISOTROP OSSE investigating the benefits of sentinel 4 (GEO) and 5 (LEO) measurements of ozone, CO, NO₂ and HCHO to better constrain pollutant concentrations and precursor emissions that influence air quality.

The atmospheric composition geostationary satellite constellation for air quality and climate science: Evaluating performance with Observation System Simulation Experiments

Edwards, David; Barré, Jérôme; Worden, Helen

NCAR, United States of America

Current satellite observations of tropospheric composition made from low Earth orbit provide at best one or two measurements each day at any given location. Coverage is global but sparse, often with large uncertainties in individual measurements that limit examination of local and regional atmospheric composition over short time periods. This has hindered the operational uptake of these data for monitoring air quality and population exposure, and for initializing and evaluating chemical weather forecasts. By the end of the current decade there are planned geostationary Earth orbit (GEO) satellite missions for atmospheric composition over North America, East Asia and Europe, with additional missions proposed. Together, these present the possibility of a constellation of GEO platforms to achieve continuous time-resolved high-density observations of continental domains for mapping pollutant sources and variability on diurnal and local scales. We describe Observing System Simulation Experiments (OSSEs) to evaluate the contributions of these GEO missions to improve knowledge of near-surface air pollution due to intercontinental long-range transport and quantify chemical precursor emissions. We discuss the requirements on measurement simulation, chemical transport modeling, and data assimilation for a successful OSSE infrastructure. Our approach uses an efficient computational method to sample a high-resolution global GEOS-5 chemistry Nature Run over each geographical region of the GEO constellation. The demonstration carbon monoxide (CO) observation simulator, which is being expanded to other chemical pollutants, currently produces multispectral retrievals and captures realistic scene-dependent variation in measurement vertical sensitivity and cloud cover. We use the DART Ensemble Adjustment Kalman Filter to assimilate the simulated observations in a CAM-Chem global chemistry-climate model Control Run. The impact of observing over each region is evaluated using data denial experiments. Finally, we report on international collaborations using the OSSE approach to determine expected performance of planned satellite systems and set requirements for future missions.

Fast emission estimates for rapidly changing economies constrained by satellite observations

Mijling, Bas [1]; van der A, Ronald [1]; Ding, Jieying [1,2]

1: KNMI, Royal Netherlands Meteorological Institute; 2: Delft University of Technology

Emission inventories of air pollutants are crucial information for policy makers and form important input data for air quality models. Unfortunately, bottom-up emission inventories, compiled from large quantities of statistical data, are easily outdated for regions such as China, the Middle East, India, and South Africa, where rapid economic growth changes emissions accordingly. Alternatively, top-down emission estimates from satellite observations of air constituents have important advantages of being spatial consistent, having high temporal resolution, and enabling emission updates shortly after the satellite data become available.

Constraining emissions from concentration measurements is, however, computationally challenging. Within the GlobEmission project of the European Space Agency (ESA) a new algorithm has been developed, specifically designed for fast daily emission estimates of short-lived atmospheric species on a mesoscopic scale (0.25×0.25 degree) from satellite observations of column concentrations. The algorithm needs only one forward model run of a chemical transport model to calculate the sensitivities of concentrations to emissions, using trajectory analysis to account for transport. By using a Kalman filter in the inverse step, optimal use of the a priori knowledge and the newly observed data is made.

We apply the algorithm for NO_x emission estimates to East China, the Middle East, India, and South Africa, using the CHIMERE model together with tropospheric NO₂ column retrievals of the OMI and GOME-2 satellite instruments. The observations are used to construct time series of monthly emissions, which reveal important local emission trends such as the effect of emission reduction measures during the 2014 Youth Olympic Games in Nanjing, and the impact and recovery from the global economic crisis. The algorithm is also able to detect emerging sources (e.g. new power plants) and improve emission information for areas where proxy data are not or badly known (e.g. shipping emissions). The new emission estimates result in a better agreement between observations and simulations of air pollutant concentrations, facilitating improved air quality forecasts.

Vertically resolved stratospheric ozone and nitrogen dioxide measurements used for surface air quality prediction

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For the past thirteen years the Canadian built OSIRIS instrument onboard the Swedish led Odin satellite has been collecting measurements of spectrally dispersed limb scattered sunlight and using these to retrieve information on the composition of the Earth's atmosphere in the altitude range from 7 km to 60 km. In particular OSIRIS measurements have been used to retrieve vertical profiles of the ozone and nitrogen dioxide number density and vertical profiles of the stratospheric aerosol extinction. Also, over the past decade OSIRIS measurements have been extremely useful in identifying the impact of volcanic eruptions on not only the stratosphere but on the atmosphere near the surface of the earth.

Recently Canada has begun studying the concept of a follow-on mission to the highly successful OSIRIS. This new mission, microCATS, will involve a modified versions of OSIRIS alone on a dedicated Canadian built micro-satellite platform. The modified OSIRIS has been named the Canadian Atmospheric Tomography System (CATS) and will make similar measurements to OSIRIS but with greater precision and higher spatial resolution, especially within the UTLS region.

This presentation will: describe the Odin instrumentation; discuss recent work on the OSIRIS data records that indicate both the nitrogen dioxide and ozone measured from Odin can be used for air quality analysis; introduce the CATS instrument; and discuss the potential of the microCATS measurements for air quality analysis and forecasting should these measurements be made available in near real time.

Benchmarking climate model top-of-atmosphere radiance in the 9.6 micron ozone band compared to TES and IASI observations

Worden, Helen Marie [1]; Bowman, Kevin W. [2]; Conley, Andrew [1]; Lamarque, Jean-François [1]; Shindell, Drew [3]; Clerbaux, Cathy [4]; Coheur, Pierre-François [5]; Doniki, Stamatia [5]

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Tropospheric ozone has the third highest radiative forcing (RF) for anthropogenic greenhouse gases since pre-industrial times, but high uncertainties and a large spread in model values remain in the IPCC AR5. These uncertainties, along with recent studies comparing climate models and satellite observations of tropospheric ozone provide motivation to benchmark the model-to-satellite differences in TOA ozone band flux and flux sensitivity. The TOA flux for the 9.6 micron ozone band is a fundamental quantity which is predicted by IPCC chemistry-climate models but has never been tested directly against satellite measurements. We also compute the sensitivity of TOA (top of atmosphere) flux to the vertical distribution of ozone, or Instantaneous Radiative Kernel (IRK), for both the Aura-TES and MetOP-IASI instrument. The IRK explicitly accounts for more dominant radiative processes such as clouds and water vapor due to the spectrally resolved absorption features and allows attribution of changes in ozone RF to vertical changes in ozone and ozone precursor emissions. The continuation of the TES record of infrared ozone spectra, TOA flux and IRKs with long-term IASI data will allow accurate predictions of future ozone forcing and an assessment of the feedback from changes in the hydrological cycle on ozone RF. Here we present initial comparisons of satellite observed TOA ozone band fluxes and IRKs with RRTMG (Rapid Radiative Transfer Model-GCM applications) in the NCAR CAM-chem chemistry/climate model and with the GISS radiative transfer model.

Poster Session

Volcanic ash retrievals using ORAC and satellite imager measurements in the visible and IR

McGarraugh, Gregory R. [1]; Thomas, Gareth E. [2]; Povey, Adam C. [1]; Poulsen, Caroline A. [2]; Grainger, Roy G. [1]

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The Optimal Retrieval of Aerosol and Cloud (ORAC) is a generalized optimal estimation system that uses visible to infrared measurements from a wide range of instruments including AATSR, AVHRR, MODIS, and SEVIRI. Recently, support to retrieve volcanic ash has been added to the ORAC community code for which it retrieves optical thickness, effective radius and cloud top pressure. Use of the same optimal estimation algorithm for different parameters provides a means to discriminate volcanic ash from aerosols and clouds using Bayesian statistics to determine the probability that a scene contains volcanic ash relative to aerosol or cloud. Use of the same algorithm for multiple sensors provides a basis for a more consistent comparison between retrievals from different instruments eliminating algorithmic differences that are unrelated to the instruments themselves.

In our presentation we will discuss the implementation of the volcanic ash retrieval in ORAC including the forward model, and the ancillary data, measurement wavelengths and optical parameters used. The benefits of using the VIS and the IR measurements in a combined retrieval will be discussed using both formal information content analysis and results from specific retrieval cases including that of the 2010 Eyjafallajökull and 2013 Etna eruptions. We will show that use of the wide range of channels of MODIS is beneficial but it is also possible to obtain valuable information using the limited number of channels on AVHRR taking advantage of a longer observation history. ORAC also benefits from the optical parameters recently determined at Oxford using techniques combining both laboratory measurements and computational models. The effects of using these new optical properties will be presented using results from supported instruments.

Improvements of the MPI-C water vapour retrieval in the red spectral rang

Lampel, Johannes [1]; Beirle, Steffen [1]; Mies, Kornelia [1]; Wagner, Thomas [1]; Grossi, Margherita [2]; Loyola, Diego [2]

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Water vapour plays an important role in the atmosphere, since its radiative forcing due to its infrared absorptions is three times as large the radiative forcing of CO₂ in the Earth's atmosphere. Its relation to air temperature makes it thus an important feedback mechanism for the Earth's climate and is therefore fundamental for climate analysis as well as for weather monitoring.

The observations of the spectrometers GOME, SCIAMACHY and GOME-2 allow retrieving total column water vapour from 1995 until today. Overlapping periods allow to validate the consistency of the time series and to evaluate instrumental and operational differences between the instruments. Changing instrumental properties such as slight changes in the spectral resolution and their effect on the resulting water column densities are evaluated in order to obtain trend information from this data-set.

The operational DLR/MPI-C water vapour retrieval uses the absorptions of water vapour and of molecular oxygen in the spectral range from 612-676 nm in order to obtain vertical column densities (VCDs) of water

vapour. From the O₂ slant column density (SCD) the air mass factor of the respective observation can be calculated, which is needed for the calculation of the vertical column density. This procedure is robust and easy to implement and is independent of cloud cover and other external data products. It is however subject to large errors for individual observations (especially if clouds are present) because of the different height profiles of water vapour and O₂. During overlap periods differences were observed. These observations are presented and their reasons are discussed.

In order to remove this limitation, a new water vapour retrieval is being developed. It is based on a look-up-table approach, based on radiative transfer modelling for each viewing geometry and atmospheric condition. It intrinsically corrects scan angle dependency, the influence of ground albedo and clouds. It will also intrinsically account for saturation effects due to radiative transfer as well as the instrumental resolution, since the calculations will be done at high spectral resolution. An outline of the new retrieval will be shown.

The vertical distribution of volcanic SO₂ plumes measured by IASI

Carboni, Elisa [1]; Grainger, Roy [1]; Mather, Tamsin A. [2]; Pyle, David M. [2]; Smith, Andrew [1]; Dudhia, Anu [1]; Thomas, Gareth [3]; Siddans, Richard [3]; Koukouli, Mariliza [4]; Balis, Dimitris [4]

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Sulphur dioxide (SO₂) is an important atmospheric constituent that plays a crucial role in many atmospheric processes. For example the current hiatus in global warming has been suggested to be caused by low level volcanic activity. Volcanic eruptions are a significant source of atmospheric SO₂ and its effects and lifetime depend on the SO₂ injection altitude. In the troposphere SO₂ injection leads to the acidification of rainfall while in the stratosphere it oxidises to form a stratospheric H₂SO₄ haze that can affect climate for several years. The Infrared Atmospheric Sounding Instrument (IASI) on the Metop satellite can be used to study volcanic emission of SO₂ using high-spectral resolution measurements from 1000 to 1200 cm⁻¹ and from 1300 to 1410 cm⁻¹ (the 7.3 and 8.7 μ m SO₂ bands). The scheme described in Carboni et al. (2012) has been applied to measure volcanic SO₂ amount and altitude for most explosive eruptions from 2008 to 2014, including large eruption such as Nabro and less intense events such as Etna lava fountains and the recent Bardabunga eruption. The work includes a comparison with independent measurements: (i) the SO₂ column amounts from the 2010 Eyjafjallajökull plumes have been compared with Brewer ground measurements over Europe; (ii) the SO₂ plumes heights have been compared with CALIPSO backscatter profile. The results of the comparisons show that IASI SO₂ measurements are not affected by underlying cloud and are consistent (within the retrieved errors) with the other measurements considered. The series of analysed eruptions, between 2008 and 2012, show that the biggest contributor of volcanic SO₂ was Nabro, followed by Kasatochi and Grímsvötn. Our observations also show a tendency of the volcanic SO₂ to be injected to the level of tropopause during many explosive eruptions. For the eruptions observed, this tendency was independent of the maximum amount of SO₂ erupted (e.g., 0.2 Tg for Dalafilla compared with 1.6 Tg for Nabro) and of the volcanic explosive index (between 3 and 5).

5 years of GOSAT target mode observations of volcanic CO₂ emissions, and first OCO₂ data

Schwandner, Florian M. [1]; Nguyen, Hai [1]; Kataoka, Fumie [2]; Kuze, Akihiko [3]; Shiomi, Kei [3]; Carn, Simon A. [4]; Goto, Naoki [3]

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Carbon dioxide (CO₂) emissions from volcanoes are subject of increasing attention over the past decade, for their use as earliest indicators of impending eruptions. Earliest indicators of volcanic unrest reflect deep processes, especially the ascent and emplacement of new basaltic magma at depth. These deep processes

result in transient increases of localized CO₂ emissions, preceding eruptions by weeks to months. Detecting such CO₂ precursors by continuous ground-based monitoring operations is unfortunately not a widely implemented method yet, and likely not feasible at all ~550 active volcanoes on Earth. Detecting CO₂ emissions from space offers obvious advantages – however it is technologically challenging, not the least due to the increasing atmospheric burden of CO₂, against which a surface emission signal is hard to discern.

In a multi-year project, we have investigated the feasibility of space-borne detection of pre-eruptive volcanic CO₂ point source anomalies using observations of column averaged CO₂ dry air mole fractions (XCO₂) from the Greenhouse Gas Observing SATellite (GOSAT). Since 2010, we have observed over 40 active volcanoes from space using GOSAT's special target mode. Over 72% of targets experienced at least one eruption over that time period. Several volcano targets have shown positive anomalies during eruptions. More significantly, as methods improved we more recently began to see a significant XCO₂ increase prior to eruptions.

In 2014, NASA launched its first satellite dedicated to atmospheric CO₂ observation, the Orbiting Carbon Observatory (OCO-2). Its observation strategy differs from the single-shot GOSAT instrument. At the expense of GOSAT's fast time series capability (3-day repeat cycle, vs. 16 for OCO-2), its 8-footprint continuous swath can slice through emission plumes, providing momentary cross sections. While GOSAT measured approximately circular ~10.5km diameter single-shot footprints, OCO-2 can provide hundreds more soundings per area at single kilometer scale footprint resolution. In this contribution, we summarize progress made over the past 5 years of CO₂satellite observations, and lessons learned toward detecting volcanic CO₂ eruption precursors from space.

Tropical Upper Tropospheric Ozone Volume Mixing Ratios Retrieved using the Cloud Slicing Method: SCIATRAN/WFDOAS Sensitivity Studies and Ozone Sonde Comparisons

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Total ozone retrieved with the weighting function DOAS using SCIAMACHY/GOME-2 data and operational cloud parameters (cloud fraction and cloud top height) were taken to derive tropical upper tropospheric ozone volume mixing ratios with the cloud slicing method [Ziemke, 2001]. This new retrieval code S5P_TROPOZ_CSA will be used in the operational processing of the TROPOspheric Monitoring Instrument (TROPOMI) on board the Sentinel 5 precursor (S5p), which is expected to be launched in 2016.

Here we present results from SCIAMACHY/GOME-2 and discuss the choice of parameters and the needed time/spatial resolution, which strongly depends on the instrument characteristics being used. We take modelled spectra from SCIATRAN and the WFDOAS algorithm to retrieve total ozone. With these results we analyse the impact of errors of parameters like cloud top height and cloud optical thickness on the retrieval accuracy. Furthermore a first verification using ozone sonde data from tropical stations will be shown.

Extension of the ESA CCI Total Ozone Climate Data Record with the Application of the GODFITv3 Algorithm to OMI Observations

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One of the great achievements of the first phase of the ESA Ozone Climate Change Initiative has been the release of new level-2 total ozone data sets from GOME, SCIAMACHY and GOME-2/Metop-A reprocessed with the latest GODFIT-3 algorithm. These data sets are characterized by unprecedented standards of consistency, stability and accuracy.

Recently, new algorithmic developments have been implemented within GODFIT in order to ingest and analyse backscattered light spectra measured by OMI (Ozone Monitoring Instrument), the hyperspectral imager launched as part of the AURA platform payload in 2004. In particular, a new look-up table version of GODFIT has been developed to process the massive OMI level-1 data set in a timely and fast manner. We show that this approach maintains a level of accuracy similar to that of the on-line GODFIT version, in addition to providing accelerated performance by a factor of 10. This fast algorithm has been recently used to reprocess the entire OMI time series, thus extending the ESA CCI Climate data record for total ozone

In this work, the OMI GODFIT-3 total ozone product is compared to the two operational products OMI-TOMS and OMI-DOAS, and also to the historical multi-sensor CCI data set. These comparisons clearly indicate that the new product is highly consistent with other data sets and is of very high quality, even in extreme geophysical conditions (ozone hole, Polar Regions, ...). We show that an optimization of the pre-flight instrumental slit functions has been necessary in the ozone fitting window (325-335 nm) in order to completely eliminate any row dependence in the product. With its remarkable long-term stability, OMI has the potential to be used in combination with GOME as a long-term reference for producing multi-sensor climate total ozone data record.

Validation of CO₂ Retrievals from GOSAT SWIR TANSO-FTS data, and Evaluation of Advanced spectral SWIR/TIR Synergistic Methodologies for Lowermost Tropospheric CO₂ Retrieval.

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The retrieval of the lowermost tropospheric content of greenhouse gases such as CO₂ and CH₄ is a critical issue for characterizing their sources and sinks. One key question lies in the methods to extract the best information of the concentration of these gases in the lower troposphere from satellite observations.

We present first a validation of our atmospheric CO₂ products retrieved from SWIR TANSO-FTS data on board GOSAT. This validation is based on the comparison between our CO₂ products with TCCON products and other CO₂ products from GOSAT data provided by several research groups (ACOS, NIES, SRON/KIT, and Univ. of Leicester).

Then, we present spectral synergy methodologies exploiting SWIR and TIR spectral bands of TANSO-FTS and we discuss their expected added value to improve the retrieval of the lower tropospheric CO₂ product. A specific approach combining SWIR and TIR level 2 products is compared with a more classical SWIR/TIR level 1 synergy algorithm and preliminary results are presented using synthetic TIR and SWIR GOSAT measurements.

GOME/ERS-2: new homogeneous Level 1b data from an old instrument

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DLR-IMF, Germany

The Global Ozone Monitoring Experiment (GOME) was launched on-board the ERS-2 satellite, in 1995, and operated until the switch-off of ERS-2 in 2011. GOME is a nadir-viewing, scanning spectrometer that measures the solar radiation scattered by the atmosphere in the ultraviolet, visible and near-infrared spectral region. The instrument can measure a range of atmospheric trace constituents, with the emphasis on global ozone distributions.

In the framework of ESA's "GOME Evolution Project", a reprocessing will be made of the entire 16 year GOME Level 1 dataset. The GOME Evolution Project further includes the generation of a new GOME water vapour product, and a public outreach programme.

The current GOME Level 1 products are not consistent because they were generated using different processor versions. Up to now a reprocessing covering the complete mission didn't take place. In this paper we will describe the reprocessing of the Level 1 data, carried out with the latest version of the GOME level-0-to-1 Data Processor at DLR. The reprocessing of the GOME Level 1 data comprises the following: improvement of the dark signal correction, especially during and following a transit through the South Atlantic Anomaly; extensive review of the wavelength calibration; improvement of the polarisation correction; consistent processing of calibration data optimized for the complete mission and including instrument degradation; and the development of a new Level 1b data product. The new data product is based on NetCDF-4, and will contain fully processed Level 1b data. This is in contrast to the existing data product, which contains the measured signals plus calibration data and needs a special software tool to be converted to Level 1b. The reprocessed product is accompanied by a new ATBD (Algorithm Technical Basis Document) and PUM (Product User Manual).

CCI-Ozone Fundamental Climate Data Records: Evaluation of compliance with GCOS requirements and research needs

Lambert, Jean-Christopher [1]; Balis, Dimitris [2]; Goutail, Florence [3]; Granville, José [1]; Hubert, Daan [1]; Keppens, Arno [1]; Koukoulis, MariLiza [2]; Laeng, Alexandra [4]; Pommereau, Jean-Pierre [3]; Rahpoe, Nabiz [5]; Sofieva, Viktoria [6]; Braesi

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Started in 2010 for a period of six years, ESA's Climate Change Initiative aims at establishing Fundamental Climate Data Records (FCDRs) from satellite data for a list of Essential Climate Variables (ECVs). In this context, the Ozone_cci project provides FCDRs on atmospheric ozone from data acquired by ESA, EUMETSAT and Third Party Missions. Atmospheric ozone is an important ECV as it controls the radiation budget of the Earth, interacts with atmospheric dynamics and climate, and influences chemically other radiatively active species. Ozone data requirements were collected from the Global Climate Observing System (GCOS), from WMO rolling requirements, and from the climate research community involved in CCI activities through the Climate Modelling User Group. After a first phase of three years during which most of the contributing ozone retrieval algorithms were revisited, the project delivered a Climate Research Data Package (CRDP) with improved and harmonised ozone total column, nadir ozone profile and limb/occultation ozone profile FCDRs, from ERS-2 GOME, Envisat (GOMOS, MIPAS, SCIAMACHY), Odin (OSIRIS, SMR), SCISAT-1 ACE-FTS, and MetOp-A GOME-2. Extension to other satellite missions like Aura OMI and MetOp IASI, as well as further improvements in the UT/LS, in the troposphere and in the mesosphere are ongoing.

In-depth characterisation and geophysical validation of FCDRs by independent teams play an essential role in the Ozone_cci project. First, in support to algorithm evolution and data improvement, e.g. via round-robin evaluation, to identify the most suitable retrieval algorithm or method for every ozone data set to be reprocessed. Later, to assess the quality of the reprocessed data sets and evaluate their compliance with user requirements. The objective of this paper is threefold: first, to show how the different categories of user requirements were translated into practical validation requirements; second, to provide an overview on the QA/validation system developed to meet objectives of the project and of the future Copernicus services; and third, to report on some already successful applications of the current ozone FCDRs in climate research. In particular, the current ozone FCDRs are shown to be well suited as core data sets for the evaluation of the climate and climate-chemistry models participating in CMIP6 and the next WMO ozone assessment. The paper concludes with a perspective on further developments of the project.

5 Years of GOSAT Column Averaged XCO_2 and XCH_4 Observations From the UoL Full Physics Optimal Estimation Retrieval

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We present an overview of the University of Leicester Full Physics (UoL-FP) retrieval algorithm as applied to short wave infra-red (SWIR) spectra recorded by the Japanese Greenhouse Gases Observing Satellite (GOSAT) between 2009 and the present day for GreenHouse Gas (GHG) retrievals.

UoL-FP retrieves dry column mole fractions of CO_2 (XCO_2) from SWIR atmospheric O_2 ($0.72 \mu\text{m}$) and CO_2 (1.61 and $2.06 \mu\text{m}$) windows over land only with a single sounding resolution diameter of $\sim 10.5 \text{ km}$. CH_4 (XCH_4) is retrieved with a proxy method applied on top of the UoL-FP algorithm.

Updates to the retrieval including application of improved aerosol, fluorescence and surface scattering terms are shown. A suite of product validation and error characterisation protocols have been applied to demonstrate UoL-FP's meeting of extremely high accuracy requirements for atmospheric XCO_2 as applied to projects such as the ESA Climate Change Initiative.

Comparisons with GHG observations from the ground based Total Column Carbon Observing Network (TCCON) are drawn to infer UoL-FP retrieval bias and error correlations with key retrieval interferences such as aerosol, cirrus cloud and surface albedo. Improvements to the co-location of GOSAT and TCCON observations to infer these comparisons are made and with the integration of model transport related fields for sounding selection.

Global monthly, seasonal and annual trends from the 5 year data-sets are reported with an emphasis on describing inter-annual variability of GHGs. Latitudinal gradients for the UoL-FP data-set are compared against state of the art global chemical transport model calculations for each GHG, along with detailed examinations of GHG relevant regions. Latest results from porting UoL-FP to the recently launched Orbiting Carbon Observatory 2 are also presented, focussing on retrieval quality over selected TCCON sites.

$\text{HDO}/\text{H}_2\text{O}$ Retrievals from ENVISAT to Sentinel-5P

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The relative abundance of the heavy water isotopologue HDO provides a deeper insight in the atmospheric hydrological cycle, because evaporation and condensation processes deplete heavy water in the gas phase. Measurements of the ratio $\text{HDO}/\text{H}_2\text{O}$ therefore provide a unique look at these processes, e.g. at their relative strength, location, and correlation with other processes in the hydrological cycle or large-scale events such as El Niño. This better understanding of the hydrological cycle leads to better General Circulation Models, which are crucial for climate predictions, climate reconstructions and water resources management.

We first show the global, near-surface distribution of $\text{HDO}/\text{H}_2\text{O}$ as measured with the 2.3 micron (SWIR) channel of the SCanning Imaging Absorption spectroMeter for Atmospheric CartograpHY (SCIAMACHY) on-board ENVISAT for the years 2003-2007. These measurements have been validated with ground-based measurements from the Total Carbon Column Observing Network (TCCON) and the Network for the Detection of Atmospheric Composition Change (NDACC). The measurements show a negative bias that increases with latitude, but local seasonal variations seem to agree well. Since most of the variations in the ratio $\text{HDO}/\text{H}_2\text{O}$ can be explained by variations in humidity (since the heavier HDO preferably rains out when an air mass dries), the real added information of $\text{HDO}/\text{H}_2\text{O}$ is shown when used in conjunction with humidity measurements. For certain locations SCIAMACHY observes the same asymmetries in the $\text{HDO}/\text{H}_2\text{O}$ vs humidity relationship throughout the season as observed by the higher-accuracy ground measurements, which shows the potential and needed extension of global $\text{HDO}/\text{H}_2\text{O}$ measurements from space.

Then we describe, using SCIAMACHY as a heritage, an HDO/H₂O retrieval algorithm for the TROPOMI instrument on-board Sentinel-5P. The algorithm is a simplified version of the operational TROPOMI CO algorithm, and will be able to provide accurate HDO/H₂O measurements above (almost) cloud-free conditions over land and above low-level clouds over oceans. Besides an expected lower noise sensitivity compared to SCIAMACHY, the TROPOMI HDO/H₂O measurements will have a much smaller ground footprint and a shorter revisit time, which all combined lead to many more cloud-free observations and therefore to less spatial and temporal averaging needed to do meaningful science. We show various sensitivity tests to showcase the performance of the retrieval, as well as the results of a case study over the southern USA and Mexico. For this case study the TROPOMI measurements were simulated very accurately by using realistic input data for the state of the surface (land/water coverage, albedo, altitude), the atmosphere (cloud coverage, profiles for temperature,

humidity, HDO/H₂O ratio, CO and methane) and the viewing geometry.

Ozone_CCI: Geophysical Validation of uncertainties of ozone vertical profiles

Laeng, Alexandra; Sofieva, V.; von Clarmann, T.; Walker, K.A.; Rozanov, A.; Weber, M.; Rahpoe, N.; Degenstein, D.; Roth, C.; Urban, J.; Clerbaux, C.; Coheur, P.; Hadji-Lazaro, J.; Zehner, Claus

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We present the results of unified geophysical validation of errors bars of individual Level 2 vertical ozone profiles, measured by limb and nadir sensors participating in the Ozone_cci Project: GOMOS, MIPAS, SCIAMACHY, ACE-FTS, OSIRIS, SMR and IASI. This work is a part of Comprehensive Error Characterization Report of Ozone_cci Project.

The validation is performed by comparing the squared mean error estimate with variance of a sample derived from the dataset, in a region with low natural variability, for different separation distances. The approach allows simultaneous validation of random component of uncertainty estimates and experimental estimate of the structure functions of ozone variations. In our presentation, we discuss how realistic we find the ozone profile uncertainties for different instruments to be.

Airborne Gimballed Limb Observer for Radiance Imaging of the Atmosphere (GLORIA) data for Sentinel 5P validation

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GLORIA is an infrared limb and nadir sounder. The purpose of GLORIA is to measure temperature and composition in the upper troposphere/lower stratosphere at high spatial resolution. The instrument was designed to be deployed on board different research aircraft, namely the Russian high-altitude research aircraft M55 Geophysica and the German High Altitude and Long Range (HALO) research aircraft.

GLORIA is able to measure infrared limb, nadir, and sub-zenith emissions between 780 and 1400 cm⁻¹ by means of a Michelson interferometer. The vertical resolution of the limb data is a few hundred meters. The application of tomographic reconstruction techniques to special limb observation modes allows for the derivation of 3-dimensional fields of atmospheric quantities with a resolution of up to 20km x 20 km in both horizontal dimensions or a few hundred meters in one horizontal dimension.

In this paper, we present GLORIA data obtained during two research flights in view of the geophysical validation of TROPOMI Level 1b and Level 2 products by this instrument.

Validation of OMPS LP Ozone Profiles with Satellite, Ozonesondes and Lidar Measurements

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The Ozone Mapping and Profiler Suite (OMPS) on board Suomi National Polar-orbiting Partnership (S-NPP) was launched on October 28, 2011. It consists of three instruments: Nadir Mapper (NM), Nadir Profiler (NP) and Limb Profiler (LP). The OMPS LP instrument is designed to provide high vertical resolution ozone profiles from measurements of the scattered solar radiation in the 290-1000 nm spectral range. It collected its first Earth limb measurement in January 10, 2012, and continues to provide daily global measurements of ozone profiles from the cloud top up to 60 km.

This presentation will describe the recent changes implemented for the OMPS LP ozone product and discuss the results of comparisons with co-located measurements from the MLS on-board Aura, GOMOS and SCIAMACHY on-board ENVISAT, and OSIRIS on-board ODIN, as well as ozonesondes and lidar measurements.

In general, the agreement with MLS and OSIRIS is within 5% over an altitude range of 20-40 km. Above 40 km, the difference is -5-10% in the southern and northern hemispheres. In the lower stratosphere above the tropopause, the lack of aerosol corrections is evident, where OMPS is 5-10% smaller in the tropics and northern hemisphere. The difference is smaller in the southern hemisphere, where the retrieval algorithm is less sensitive to aerosol due to the large single-scattering angle and small aerosol scattering phase function.

Calibration and monitoring of an operational UVN mission: Lessons learned from 8 years of GOME-2 operations on Metop.

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Since Metop-A and Metop-B were launched in October 2006 and September 2012 there are meanwhile two GOME-2 instruments in orbit providing operational UVN data to users. As of Summer 2013, the instruments are operated in a tandem operations configuration with GOME-2 on Metop-A and Metop-B covering a 960 km and a 1920 km swath, respectively. The latter is ensuring full daily coverage.

In order to ensure that level-1b radiance data from the two instruments can be used at similar levels of quality and with minimal systematic differences, a state of the art calibration and in-orbit monitoring of both sensors is needed. In achieving this, a continuous analysis from the individual flight-model on-ground calibration campaigns as well as from an advanced near-real-time in-orbit monitoring and data quality assurance system is required. Both tasks are specifically challenging for instruments like GOME, SCIAMACHY, and GOME-2, but as well for the forthcoming Sentinel-4, 5p and 5 missions. Here we need to handle very high information contents per individual measurement and deal with demanding requirements with respect to the accuracy of their differential spectral structures.

We present lessons learned from the on-ground calibration campaign of three GOME-2 flight models as well as methods to apply in-flight derived continuous calibration key data updates and adjustments making use of an advanced continuous monitoring approach. Further we show impacts of level-1 data quality issues on level-2 data retrieval results.

Mapping NO_x sources on high spatial resolution by combined measurements from OMI and GOME-2 narrow swath mode

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Due to the short lifetime of NO_x in the troposphere, maps of tropospheric NO₂ directly reflect the distribution of NO_x sources.

The level of detail depends on the spatial resolution of the satellite instruments, which improved over the years.

Currently, the best spatial resolution is provided by OMI, reaching 24x13 km² at nadir.

GOME-2 has larger footprints in standard mode (80x40 km²), but provides high cross-track resolution (10 km) during observations in the "narrow swath" mode (NSM).

Here we discuss selections of satellite observations (in particular small ground pixels and low wind speeds) in order to compile high resolution maps as proxy for the spatial distribution of NO_x sources. As OMI and GOME-2 NSM provide complementary ground pixel orientation, they can be used to resolve spatial patterns down to 10 km, if adequately combined.

Validation of Satellite AOD Uncertainties

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Knowledge of uncertainties is essential to understand observations. Uncertainty estimates are also crucial for data assimilation and data merging (e.g. uncertainty-weighted ensemble). During phase-1 of the Aerosol_cci project pixel level uncertainties based on error propagation, error parameterizations (using a posteriori validation results) or as simple approximation of uncertainty of AOD standard deviations within 10 x 10 km² super pixels were provided, and now, during phase-2 of the project, the harmonization of the uncertainties across all products is planned.

First efforts of validation of the AOD uncertainties were performed under the consideration that for all algorithms, the uncertainty should be dominated by the retrievals themselves. They are also expected to be much larger than the uncertainties in AERONET (direct) AOD observations, providing a straightforward means to check the consistency of the retrievals. Co-located AERONET observations were subtracted from retrieved values. When divided by the retrieved uncertainty, the results should form a Gaussian distribution with mean zero and width of unity. Significant deviations from that would indicate systematic errors in the existing error propagation that would require further characterization. During the Aerosol_cci phase-1, this evaluation mainly showed the need for harmonization. Estimating the uncertainties from the standard deviation within the 10 x 10 km² pixels was shown to greatly underestimate the uncertainties, and seems therefore not a recommended method for estimating uncertainties.

Here, we give a general overview of uncertainties given for the most used present satellite AOD sensor. We show results from the evaluation of the preliminary pixel error characterisation of the 17-year 1995 - 2012 ATSR-2 (ERS-2) and AATSR (ENVISAT) dataset (Level 2 v4.2 data, Univ. of Swansea retrieval). Furthermore, we give an evaluation of an AEROSOL CCI-2 4 month AATSR test data set (for March, June, September, December) to better understand the translation of pixel level uncertainties to Level 3 error.

microCATS – A Canadian Follow-On to the Still Operational OSIRIS Instrument

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The Canadian built Optical Spectrograph and InfraRed Imaging System (OSIRIS) has been in operation onboard the Odin spacecraft since the autumn of 2001. Since this time OSIRIS has routinely made measurements of the vertical distribution of ozone, nitrogen dioxide, stratospheric aerosol and bromine monoxide. These measurements have played a key role in recent international initiatives including the SPARC initiative SPIN, the SPARC Data Initiative, the Si2N Initiative and the ozone and aerosol cci initiatives. The OSIRIS measurements have made a valuable contribution to these initiatives due to their proven climate quality accuracy and precision as well as their overall stability with time. Along with this the OSIRIS measurements of nitrogen dioxide and ozone are now being used for air quality analysis through limb nadir matching with sensors that provide total columns of ozone and NO₂.

microCATS is a purely Canadian concept that is designed to provide continuity of the important OSIRIS measurements into the next decade. The Canadian Atmospheric Tomography System (CATS) is a follow-on to OSIRIS with minor design modifications intended to improve both the precision and spatial sampling of the retrieved constituent profiles. Canada is now studying the concept of deploying CATS on its own dedicated micro-satellite platform in order to continue the OSIRIS data records. Along with this the idea of limb nadir matching TEMPO and microCATS measurements in order to improve air quality and chemical weather forecasts over Canada is also under investigation through modelling and data analysis exercises. This paper will detail the microCATS mission and its expected scientific return.

OMI Total Ozone Column Product validated against UVMFR retrievals

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The Ozone Monitoring Instrument (OMI) is a spectroradiometer on board NASA Aura, providing Total Ozone Column (TOC), almost globally, every day, with a spatial resolution of 13kmX24 km, since July 2004. In the next few months Sentinel-5P will be launched, and carry TROPOMI, a spaceborne nadir viewing spectrometer which will cover the same spectral range, narrowing the spatial resolution to 7 km X 7 km and extending current data record. Studies have evaluated OMI's product using Brewer spectroradiometer measurements and found average biases to be less than 3%.

UVMFR (Ultraviolet Multifilter Radiometer) is an instrument designed to measure total and diffuse and calculate Direct solar Irradiance at 7 wavelengths in the UV spectrum, with high accuracy and very high frequency. Main advantages of this instrument is the portability, the automatic calibration procedure, simple operational use, unattended functionality and the relatively low cost. In that frame it could become a very effective solution to validate satellite products.

A method was developed to retrieve TOC, from UVMFR measurements combined with radiative transfer model calculations. Lookup tables of ratios of direct solar irradiance at 305nm and 325nm in respect to TOC, Solar Zenith Angle and Aerosol Optical Depth have been constructed and compared with UVMFR irradiance measurements in order to retrieve TOC. We used UVMFR measurements in Athens, Greece during the period July 2009 to May 2014 to create a TOC time series with high temporal frequency (1 minute for cloudless conditions). The validation of the method have been assessed using a Brewer spectroradiometer operating in parallel for the whole period.

In order to compare OMI-based and ground-based TOC measurements we have calculated UVMFR daily values of TOC averaging measurements in a 2 hour window around OMI overpass. This comparison revealed

differences up to 7%, with mean differences at 4.2 DU and standard deviation of 8.7%. Same seasonal cycle was observed in both data sets, with minimum values at October-November and maximum at April-May. Also a small seasonal dependent difference among the time series was observed. OMI retrieval permanently underestimated during spring months, and overestimated at summer months. We investigated this behavior by examining Ozone Effective Temperature influence by its effect on ozone absorption coefficient and detect a relation of 0.9% TOC change per K. We applied a correction to the data set using stratospheric temperature climatological values.

This method could be adopted in order to validate TROPOMI retrievals in places where Brewer instruments are not available, benefiting from instrument 's mobility and low cost and portability.

Closing the Error Budget of Atmospheric Data Comparisons: An Essential Prerequisite to Accurate and Informed Satellite Validation

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In recent years, driven by more and more stringent user requirements like the targets of the Global Climate Observing System (GCOS), the accuracy and resolution of atmospheric composition EO data have improved significantly, as evidenced through the ground-based validation of e.g. ERS-2, Envisat, OMI and MetOp-A/B IASI data products in ESA's CCI and Multi-TASTE projects. Upcoming missions such as the Sentinel-5 Precursor TROPOMI and the future Sentinels 4 and 5 will undoubtedly bring another step change in data quality and resolution, further emphasizing the importance of a reliable and appropriate validation infrastructure handling properly the always wider range of measurement characteristics, sensitivities and associated uncertainties (cf. recommendations R8 and R9 at ATMOS 2012). In particular, proper interpretation of validation results requires now a corresponding effort to understand the comparison error budget, including uncertainties associated with the comparison metrology: spatial and temporal mismatch in presence of atmospheric gradients and variability, differences in horizontal and vertical smoothing of atmospheric inhomogeneities and structures, and differences in pseudo-global sampling of patterns and cycles.

To this end we present here a versatile simulator of atmospheric remote sensing systems and their metrology, OSSSMOSE. Its architecture consists in the generation of multi-dimensional observation operators set up by the metadata of existing observing systems, followed by the application of those observation operators onto high-resolution atmospheric fields. In this way, the system quantifies smoothing and sampling errors associated with a list of remote sensing measurements of atmospheric composition. The system can also model the expected differences between the various measurement types due to differences in sampling and smoothing of atmospheric structures. The quality of these simulations is demonstrated on ozone and water vapour column and profile comparisons, such as those performed within ESA's Multi-TASTE and Ozone_cci. It is shown that metrology-related errors can be of a magnitude similar to - or even greater than - the measurement noise of the individual measurements under comparison. Further development and application of the OSSSMOSE simulator on GRUAN network and co-located satellite data constitutes a key work package in the new H2020 project GAIA-CLIM, and work being developed therein is summarized.

Gravity Waves Resolved by the High Resolution ECMWF Analysis Data

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Gravity waves (GWs) are atmospheric waves in temperature and wind. It is generally believed that major sources are located in the troposphere. Upward propagating GWs transport energy and momentum and deposit these in the stratosphere and mesosphere. Thereby they act as the major forcing of the circulation in the mesosphere, the QBO and the summer branch of the stratospheric Brewer-Dobson circulation and contribute to the forcing of the winter branch of the stratospheric Brewer-Dobson circulation, where they are chiefly

responsible for a predicted acceleration in Chemistry Climate Models (CCMs). Reliable climate predictions therefore require quantification of gravity wave momentum flux (GWMF) substantially better than a factor of 2. As recently assessed by the SPARC GW initiative we have a general consistent qualitative picture of the global distribution of GWMF, but quantitatively uncertainties are at least a factor of 3. One potential way to remedy this apparent clash between needs and actual knowledge are global GW resolving models.

Analysis data of the ECMWF in 2008 gained a sufficient resolution to resolve a large part of the GW spectrum. We analyze these data for GWMF and compare the results with observations from the HIRDLS satellite. High realism is found for winter mid and high latitudes. Main sources of a burst of GWMF in January 2008 are the south tip of Greenland, a storm approaching the Norwegian coast and orography of southern Norway. For low summer latitudes convection is the main source of GWs, both in the ECMWF model and in HIRDLS observations. However, the detailed source mechanism is different, which is expressed by longer horizontal wavelengths and slower phase speeds of the ECMWF resolved waves than found in reality.

An important advantage of the global model data is that sources can be identified by backward ray-tracing. This is not possible for current generation limb scanners such as HIRDLS, where sources have to be attributed by spatial collocation. Spatial collocation has been used also for other techniques in a number of studies. However, the current study demonstrates that this may be seriously misleading.

Both in global measurements from various satellites and in the ECMWF global model results, largest GWMF is found at the edge of the southern polar vortex. Previous investigations have provided evidence that the SH winter storm tracks and convection could provide important sources. However, backward ray tracing from ECMWF indicates that at least part of the GWMF is generated in the stratosphere. The importance of stratospheric GW sources will be discussed based on these model analyses.

Valuable as global GW modeling is, true ground-truth can be determined from measurements only. The results presented in this study are based on the sampling of a potential future infrared limb imager. They hence demonstrate the advances which could be achieved by global GW measurements with such kind of instrument: 1) reliable source identification by backward ray tracing, 2) GW momentum flux measurements with the accuracy required from CCM modeling and 3) direction information, calculation of net momentum fluxes and drag as required for studying the interaction between mean winds and GWs.

Sentinel-5 Precursor NO₂ and HCHO validation using NDACC and complementary FTIR and UV-Vis DOAS systems

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The NIDFORVal project (S5P NItrogen Dioxide and FORmaldehyde Validation using NDACC and complementary FTIR and UV-Vis DOAS ground-based remote sensing data) aims at providing an assessment of the quality of two mandatory S5P products: nitrogen dioxide (NO₂) and formaldehyde (HCHO). Two different and independent ground-based remote sensing techniques will be used: Fourier Transform Infrared (FTIR) and UV-Visible Differential Optical Absorption Spectroscopy (UV-Vis DOAS). These techniques can provide accurate NO₂ total (DirectSun DOAS), stratospheric (FTIR and ZenithSky DOAS) and tropospheric (Multi Axis (MAX) DOAS) columns, as well as HCHO total columns (FTIR and MAXDOAS). High quality measurements from over 60 ground-based stations and 80 instruments will be gathered from NDACC and complementary networks or recent infrastructures, extending the overall data set to a large range of observation conditions sampling high, mid- and low latitudes, as well as unpolluted, sub-urban and urban polluted sites. The first task of the project will be to provide homogenized and characterized FTIR and UV-Vis DOAS time-series (2016-2023) of NO₂ and HCHO data, and archive them in the ESA Cal/Val database or linked to it through the NDACC database at NOAA. Data retrieval homogenization will be based on the experience developed by project partners on NO₂ (e.g. Hendrick et al., ACP, 2012) and HCHO (e.g. Vigouroux et al., ACP, 2009, Pinardi et al., AMT, 2013). We will present here the state of the art of the NO₂ and HCHO products obtained by FTIR and UV-Vis (DirectSun, ZenithSky, and MAXDOAS) techniques. Based on the averaging kernels, we will show how the different vertical sensitivities of both measurement techniques can fulfill complementary S5P validation objectives.

The second task of the NIDFORVal project addresses the validation of the S5P products during the commissioning phase E1, making use of common tools derived from the experience developed in precursor projects (e.g., Multi-TASTE, O3M-SAF, GECA, NORS). For this task, we will use a subset of ground-based FTIR and UV-Vis DOAS stations ready for operational data submission in rapid delivery mode. Following phase E1, the S5P project will enter into the routine operations phase (E2). During this phase, the progressive accumulation of large data sets will allow for improved statistics, enabling a refinement of the validation: refined categorization of validation sites and search for patterns or specific behaviors in validation results, analysis of seasonal cycle effects and finally verification of long-term consistency throughout the mission. Also efforts will be made to improve collocation criteria, through an in-depth exploration of the representativeness of each validation site based on appropriate model data. We will present here the tools that are already available at BIRA-IASB as well as the plans to adapt and improve them for the purpose of NIDFORVal.

The BESD Algorithm for CO and CH₄ Retrieval from Sentinel-5 Precursor and Comparison with the Operational Prototype Retrieval Algorithms

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Scheduled for launch in 2016, the Sentinel-5 Precursor (S-5P) satellite mission with the TROPOMI instrument onboard will be monitoring the composition of the earth's atmosphere. The measurements that will be performed in TROPOMI's short wave infrared (SWIR) channel at about 2.3 μ m, for example, can be used to derive information on the anthropogenic greenhouse gas methane (CH₄) and on carbon monoxide (CO), an important contributor to air pollution.

In preparation for the S-5P mission, operational prototype algorithms for CH₄ and CO retrieval are being developed by the SRON Netherlands Institute for Space Research. Beside these prototype algorithms, which eventually will be applied for the operational data product, an independent scientific verification algorithm for the products CH₄ and CO is developed at the University of Bremen. As basis, the BESD (Bremen optimal estimation DOAS) retrieval algorithm, which previously has been applied successfully also to XCO₂ retrieval from SCIAMACHY and GOSAT, is adjusted to CH₄ and CO retrieval from S-5P. Beside measurements in the SWIR band, it leverages additional information from the oxygen A-band in the near infrared (NIR) channel to better constrain scattering parameters, in particular from thin clouds.

A wide range of synthetic retrievals were performed to assess the resulting retrieval precision and accuracy under different atmospheric conditions including various aerosol and cloud scenarios. This exercise was performed for the verification as well as the prototype algorithms. In general, it has been found that all retrieval algorithms perform well within the requirement for the investigated error components. The details of this comparison will be shown.

The Role of Vicarious Calibration in the OCO-2 Inflight Calibration Program

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NASA's Orbiting Carbon Observatory-2 (OCO-2) launched on July 2nd, 2014, and began observations in early August. During the earliest phase of the mission, intensive calibration measurements were performed to validate the stringent radiometric, spectral and spatial calibration requirements of the three-band spectrometer. The radiometric calibration program incorporates a combination of routine observations of on-board lamps, astronomical standards including the sun and the moon, and well-characterized ground-based, vicarious calibration targets.

Observations of well characterized surface targets provide a useful tool for monitoring the long-term performance of the space-based components of the radiometric calibration system. From 2009 to June 2014, a combined team from the Japan Aerospace Exploration Agency (JAXA), National Institute for Environmental Studies, Japan (NIES), and the NASA Jet Propulsion Laboratory (NASA JPL), together with collaborators from Colorado State University (CSU) and NASA Ames, have conducted 6 annual vicarious radiometric calibration field campaigns at a dry lakebed playa at Railroad Valley, NV, in support of in-flight calibration of the TANSO-FTS sensor aboard the Japanese Greenhouse gases Observing SATellite, GOSAT (nicknamed Ibuki). These intense, week-long campaigns returned observations of the spectral and angular dependence of the surface reflectance at several sites on the playa during GOSAT overpasses. They also returned measurements of atmospheric properties above the site, including the aerosol optical depth and profiles of pressure, temperature, relative and humidity and the concentrations of CO₂, CH₄, and O₃ (Kuze et al, 2013, Long-Term Vicarious Calibration of GOSAT Short-Wave Sensors: Techniques for Error Reduction and New Estimates of Radiometric Degradation Factors. IEEE 99:1-14).

In October 2013, we transitioned into a more agile and frequent short campaign mode, in support of OCO-2 readiness. After launch, we conducted a short campaign in late August 2014, in the first 30 days of In Orbit Checkout as planned, to establish a baseline for the post-launch Radiometric Degradation Factor (RDF). In 2015 we plan 3-4 short campaigns (March, June, August/Sept). JPL established an automated facility at Railroad Valley in 2011, to monitor ground reflectances in 8 different wavelengths at 4 cluster sites, plus soil moisture profiles, meteorology, and other data. All sensors are autonomously operating and data are telemetered via satellite to JPL. The code sets and analysis tools for data handling and processing were implemented into the automated data system beginning in November. Both field and automated data are used for deriving top-of-the atmosphere radiances and thus RDF with a high degree of operational automation.

Validation and Alternative Retrievals of GOMOS Ozone Profiles in the UTLS Altitude Region

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Global Ozone Monitoring by Occultation of Stars (GOMOS) is a satellite instrument onboard the ENVISAT platform that was in operation during 2002–2012. During this period, GOMOS observed about 880 000 vertical profiles of ozone, NO₂, NO₃ and aerosols. About half of these measurements were made during nighttime. The GOMOS measurement principle is based on the stellar-occultation technique.

In this paper, we present rigorous validation and characterization of operational GOMOS ozone profiles in the upper troposphere lower stratosphere (UTLS) altitude region. The GOMOS profiles are validated using ozone soundings from NDACC (Network for the Detection of Atmospheric Composition Change). The results show a strong ozone overestimation by GOMOS in the tropopause region and below. The median relative difference grows up to 100 % and is particularly large in the tropics. The influence of retrieval uncertainties and star properties on the high bias in the troposphere is also investigated.

In addition to the validation and characterization of the operational data product, we also show recent advantages of alternative retrieval algorithms that are designed in particular for processing the GOMOS measurements for UTLS applications. The retrievals are performed using re-designed two-step algorithm and alternative one-step algorithm. In one-step retrieval, the spectral and the vertical inversions of the two-step algorithm are executed simultaneously. This approach allows a better use of the smoothness prior information and the prior given for example to aerosol parameters affects the other species too. This feature is critical when going near the detection limit. The preliminary results show drastic improvement of the quality of the GOMOS profiles in the UTLS altitude region when compared against NDACC ozone soundings. To further evaluate the novel UTLS dataset (consisting of 171 233 profiles from 49 brightest stars in full dark), we perform a comparison against OSIRIS ozone dataset, which has shown reliable results in the UTLS altitude region.

Assimilating Volcanic SO₂ Satellite Data in the Copernicus Atmosphere Monitoring Service Global Data Assimilation System

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In the middle of September 2014 several European countries experienced high concentrations of sulphur dioxide at ground level. Due to strong European efforts over the last decades to reduce SO₂ emissions, high concentrations of SO₂ are now quite rare in Western Europe except in specific areas affected by industrial or shipping emissions.

French in-situ air quality stations observed high values of SO₂, especially along the northwestern coast. However, the hypothesis that these high values could be linked to ship emissions trapped in the lower atmosphere appeared unlikely because they were exceptionally high and observations in the United Kingdom, the Netherlands and Germany also showed high concentrations between 21 and 25 September.

The precursor Copernicus Atmosphere Monitoring Service near-real-time forecasting system, as provided by the Monitoring Atmospheric Composition and Climate (MACC) project, explained the situation thanks to its use of satellite observations to constrain the model forecasts. The OMI satellite instrument observed concentrations of volcanic SO₂, emitted by the Icelandic Bardarbunga volcano, and these observations were assimilated by the MACC system. The subsequent 5-day forecast then captured the transport of this plume of volcanic SO₂ southward.

While this case illustrated successful use of OMI satellite data in the data assimilation system, it also showed some of its weaknesses. Only one OMI observation was used for the specific forecast resulting in a plume with concentrations that were too low. OMI observations are only assimilated above a certain threshold value to limit the impact of noisy observations on the analysis, which significantly limits the spatial coverage.

GOME-2 also provides SO₂ retrievals in near real-time, but these suffer from even higher noise than the OMI observations, which limits the use of these retrievals in an operational assimilation system. Since the particular event in September, a specific volcanic SO₂ flag was introduced for the GOME-2 SO₂ retrievals allowing a much more optimal use of the observations in the data assimilation.

We will present both the original results from the pre-operational OMI assimilation and re-runs with the new GOME-2 SO₂ data. Significant improvement of the analysis and forecast will be shown. We will also show current work on and ideas for future improvements of both the modelling and data assimilation aspects of volcanic SO₂.

Remote Sensing of Stratospheric Trace Gases by TELIS

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TELIS (TErahertz and submillimeter LIMb Sounder) is a balloon-borne cryogenic heterodyne spectrometer with two far infrared and submillimeter channels (1.8 THz and 480--650 GHz developed by DLR and SRON, respectively). The instrument was designed to investigate atmospheric chemistry and dynamics with a focus on the stratosphere. TELIS participated in three scientific campaigns in Kiruna, Sweden between 2009 and 2011. The recent campaign took place in 2014 over Ontario, Canada. During previous campaigns, TELIS shared a balloon gondola with MIPAS-B and mini-DOAS. The primary scientific goal of these campaigns has been to monitor the time-dependent chemistry of chlorine and bromine, and to achieve the closure of chemical families inside the polar vortex.

In this work, we present retrieved profiles of ozone (O₃), hydrogen chloride (HCl), carbon monoxide (CO), and hydroxyl radical (OH) obtained by the 1.8 THz channel from the polar winter flights during 2009--2011. Furthermore, the corresponding retrieval algorithm is described. The quality of the retrieval products is

analyzed in a quantitative manner including: error characterization, internal comparisons of the two different channels, and external comparisons with coincident spaceborne observations. The errors due to the instrument parameters and pressure dominate in the upper troposphere and lower stratosphere, while the errors at higher altitudes are mainly due to the spectroscopic parameters and the radiometric calibration. The comparisons with other limb sounders help us to assess the measurement capabilities of TELIS, thereby establishing the instrument as a valuable tool to study the chemical interactions in the stratosphere.

Investigation of rain-induced emission pulses of NO and HCHO from soils as viewed by satellite sensors

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Outside industrial areas, soil emissions of NO_x ($\equiv$ NO + NO₂), stemming from bacterial emissions of NO, represent a considerable fraction of total NO_x emissions, and may even dominate in remote tropical and agricultural areas. Rain-induced spikes in NO_x have been observed by in-situ measurements and also satellite observations. However, the estimation of soil emissions over broad geographic regions remains uncertain using bottom-up approaches. Independent, global satellite measurements can help constrain emissions used in chemical models. Recent laboratory experiments on soil fluxes suggest that also significant HCHO emissions from soil can occur. This study addresses these issues by investigating the change of tropospheric NO₂ (as a proxy for NO_x) and HCHO column densities before and after the first rain fall event following a prolonged dry period with particular focus on semi-arid regions. Tropospheric NO₂ and HCHO columns retrieved from OMI, GOME-2 and SCIAMACHY are used to study and inter-compare the responses of the trace gases from space. At the beginning of the wet season in the Sahel in April/May/June strong NO₂ vertical column density (VCD) enhancements compared to the background levels are observed by all three satellite sensors. Further analysis shows that spatial patterns and the magnitude of such enhancements over regions in Africa and Australia are highly dependent on the season, prevailing soil temperatures and land cover types. The analysis of HCHO VCDs around the sudden dry-wet transition shows larger differences between the individual satellite instruments with no consistent enhancement potentially due to lower signal-to-noise ratios.

The Multi-TASTE validation system: Tasting the evolution of reactive and greenhouse gas data products from Envisat and Third Party Missions

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Over the past two decades the Multi-TASTE validation system has proven its value in the characterisation and the support to the development of atmospheric composition measurements by ESA's GOME, Envisat and Third Party Missions. We give an overview of the capabilities and the latest results of this comprehensive, versatile and semi-operational system and address its relevance regarding the recommendations voiced at ATMOS 2012.

Versatility has been a key driver for the design of the Multi-TASTE system, ever since its inception during the commissioning phase of GOME in the mid 1990s. Over the years the system was continuously expanded and improved to identify ever more subtle features in ever more mature satellite data sets. By now, it is capable of providing a suite of global, long-term validation analyses for column and/or vertical profile products of numerous reactive gases, greenhouse gases and temperature. The harmonised analysis framework furthermore allows to study the quality of subsequent data releases as well as the mutual consistency of different satellite missions. Multi-TASTE analyses contributed to the evolution and the characterisation of GOME, Envisat and TPM products in the context of the respective Quality Working Groups and ESA's Climate Change Initiative. The system is currently being prepared for upcoming challenges, e.g. adaptations to support the QA4ECV framework and guidelines, and the operationalization of the data processing flow for the Sentinel-5p TROPOMI mission.

The default operating mode of the Multi-TASTE system is based on community-agreed validation protocols and practices, but it can easily be tailored for applications with more specific demands since for most components in the analysis chain more advanced tools are selectable. These include for instance multi-dimensional observation operators which are used to define co-location criteria based on the actual measurement sensitivity rather than simple radius-based criteria. Also available are different unit conversion and smoothing routines, averaging kernel based analyses of information content, and a range of statistical methods to obtain robust estimates of the bias, short-term variability and long-term stability. The satellite data are typically compared to ground-based reference measurements obtained by UV-visible and FTIR spectrometers, microwave radiometers, ozonesondes and lidars, all operating within the NDACC, SHADOZ and WMO GAW networks. Analyses are not solely performed at the largest scale, but focus also on specific spatial regions, time periods or dependences on other geophysical parameters, whenever relevant.

After a description of the Multi-TASTE system, we summarize the latest results for operational Envisat products of ozone, temperature and greenhouse gases. We show the evolution in data quality of the GOMOS (IPF V5 to IPF V6), MIPAS (IPF V5 to ML2PP V6) and SCIAMACHY (SGP V3 to SGP V5) processors. Depending on data availability, first results will be shown as well for the upcoming MIPAS ML2PP V7 and SCIAMACHY SGP V6 processors. Our focus is on altitude and latitude-resolved estimates of bias, short-term variability and long-term stability. We conclude by reviewing the contribution of Multi-TASTE to the progress made since the ATMOS 2012 recommendations were drafted.

Validation of the new additions to the O³-CCI Multi-Sensor level-2 Total Ozone Climate Data Record.

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1: Laboratory of Atmospheric Physics, Aristotle University of Thessaloniki, Greece.; 2: Belgian Institute for Space Aeronomy, Brussels, Belgium; 3: German Aerospace Center, Remote Sensing Technology Institute, Wessling, Germany.; 4: ESA/ESRIN, Frascati,

During the second phase of the ESA's Ozone Climate Change Initiative project, O3-CCI, multi-sensor total ozone climate data records (CDRs) have been further improved with new algorithmic developments and extended in time by including new sensors. Apart from the original GOME/ERS-2, SCIAMACHY/Envisat and GOME-2/MetopA total ozone columns, analysed with the direct-fitting retrieval algorithm GODFIT-3, the OMI/Aura observations are now included in the Ozone CRD.

Validation against ground-based quality-assured Brewer and Dobson measurements, downloaded from the World Ozone and Ultraviolet Radiation Data Center, shows the resulting improvements to the Ozone CRD by optimising the instrumental slit functions. In order to assess the inter-consistency and long-term stability of the five sensors included in this data record, comparisons with existing datasets by the same sensors are also considered, always using as background "truth" the ground-based measurements. Possible remaining issues are also acknowledged and their reasons elucidated.

Operational aerosol products for Sentinel-5 Precursor: Aerosol Layer Height and UV Aerosol Index

Sanders, A.F.J.; de Haan, J.F.; Sneep, M.; Stein Zweers, D.C.; Apituley, A.; Stammes, P.; Tilstra, G.; Tuinder, O.; Levelt, P.F.; Veefkind, J.P.

Royal Netherlands Meteorological Institute (KNMI), Netherlands, The

Two operational aerosol products are prepared for TROPOMI on the Sentinel-5 Precursor mission: the well-known UV Aerosol Index (UV-AI) and a new Aerosol Layer Height (ALH) product. The UV Aerosol Index continues the long time series started by TOMS in the late seventies. It is an index calculated from reflectances in the ultraviolet wavelength range that provides information on the presence of elevated

absorbing aerosols. The Aerosol Layer Height product is targeted at providing the height of optically thick, localized aerosol layers in the free troposphere, such as volcanic ash plumes and desert dust. Retrieval of aerosol height is based on a spectral fit of reflectances in the oxygen A band in the near-infrared wavelength range. We will introduce current algorithm setups and the corresponding level-2 products. Particular attention will be given to the ALH product. A single uniform scattering layer with fixed geometric thickness is assumed and the height and aerosol optical thickness of this layer are retrieved. We will show case studies of the ALH algorithm applied to actual O2 A band observations from GOME-2 to illustrate the algorithm's expected performance. We will discuss among other things the role of the surface albedo and aerosol model. The case studies also include comparisons of the retrieved height parameter with lidar measurements. The substantially smaller footprint of TROPOMI and the availability of many more retrievals for increased statistics will help to further advance retrieval of aerosol height from passive satellite measurements in the coming years. Furthermore expected synergies between the two products will be discussed as well as synergies with aerosol products from VIIRS on Suomi-NPP, which will fly in close formation with Sentinel-5 Precursor. For example, aerosol height information will help to better interpret the Absorbing Aerosol Index and quantify absorbed radiation for climate applications. In case of wildfires and biomass burning, aerosol height may also improve estimates of injection heights for transport modeling.

Parametrization of Surface Albedo for Nadir Aerosol Retrieval SYNAER

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Aerosol retrieval working in the visible channels has to deal with an ill-posed problem. AOD and surface albedo are both unknown parameters within a nadir-only aerosol retrieval as the synergistic aerosol retrieval SYNAER. SYNAER is a retrieval algorithm using a combination of radiometer and spectrometer measurements onboard the same satellite platform. In a first step the aerosol amount can only be estimated with the knowledge of the surface albedo within the visible channel. Kaufman, et al.¹ introduced a linear parametrization of the albedo, which is dependent on the shortwave infrared radiometer measurement. This parametrization is a common way in the so called dark field method for aerosol retrievals².

For a general understanding of the dependences between red, near and shortwave infrared channels ASRVN datasets were analyzed. ASRVN is a MODIS based dataset of surface albedo, atmospheric corrected with adjacent AERONET aerosol measurements. Additionally measured surface spectra were investigated on synthetic radiometer channels. A linear relationship between shortwave infrared (1.6 μm) and red (670 nm) can be determined as Kaufman suggested, but the relationship is not constant. As suggested by Holzer-Popp

2, et al. for AATSR and by Mei et al.³ for AVHRR these linear relationship can be related to the NDVI (normalized differential vegetation index). By analyzing the ASRVN and spectrometer measurements it turned out that a simple linear relationship only by using the NDVI is not sufficient for a larger variety of surface types. In order to describe the SWIR to RED dependence an additional vegetation index has to be introduced. This index accounts not only for the vegetation amount of the surface as the NDVI does, but also allows a measure for the water amount of the surface, which affects the NIR and SWIR channels of a radiometer. Introducing the NDII (normalized differential infrared index) promises a more accurate determination of the RED surface reflectance based on the SWIR channel reflectance. Additionally, an analytical equation for the SWIR to RED reflectance can be derived including both vegetation indices NDVI and NDII.

Nevertheless it has to be considered that the vegetation indices themselves are affected by the aerosol amount, so the approach needs their iterative correction for the aerosol impact. The extended parametrization of surface albedo is used in the synergistic aerosol retrieval. Theoretical calculations and application to satellite datasets will be discussed in the presentation.

1

Kaufman Y., Remer L., 1994, Detection of Forests Using Mid-IR Reflectance: An Application for Aerosol Studies, IEEE Transactions on Geoscience and Remote Sensing, 32-3, 672-683 Holzer-Popp T., Schroedter-Homscheidt, M., Breitzkreuz, H., Klüser, L., Martynenko, D., 2008, Improvements of synergetic aerosol retrieval for ENVISAT, Atmospheric Chemistry and Physics, 8, 7651-7672 Mei L., Xue Y., Kokhanovsky A. A., Hoyningen-Huene von W.,

Leeuw de G., Burrows J. P., 2013, Retrieval of aerosol optical depth over land surfaces from AVHRR data, Atmospheric Measurement Technique Discussion, 6, 2227-2251

Angle Dependency of UV Aerosol Index and Sensitivity to SO₂ Preparations for the TROPOMI Mission

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The UV Aerosol Index (UVAI) is a useful metric for the detection of UV-absorbing aerosol plumes. It has been determined from UV-measuring satellite instruments starting in the 1970s with the TOMS series and will be continued with TROPOMI.

Although the UVAI is most sensitive to elevated absorbing aerosols, it can also be used to identify non-absorbing aerosols, e.g. sulfate droplets in a volcanic plume. Apart from its sensitivity to aerosol properties, the UVAI is also strongly dependent on the relative solar and viewing angles. We recently demonstrated this in a volcanic sulfate plume, where UVAI < 0 were found on one side of the OMI swath (correctly indicating the presence of non-absorbing aerosols), whereas the same plume viewed from the opposite direction yielded UVAI > 0 (seemingly indicating aerosol absorption). Calculations using a radiative transfer model (RTM) showed that this effect could be fully attributed to the viewing angle dependence of UVAI, which itself depends strongly on plume altitude.

In the current study we explore these effects in more detail using RTM calculations. The results could be used to estimate aerosol plume height and absorption from UVAI measurements alone.

In addition, we demonstrate the effect of very high SO₂ columns (which may occur in the course of a major volcanic eruption) on UVAI determined at 331 and 360 nm. This effect is significant for the TOMS instruments, particularly during the eruption of Pinatubo in 1991.

Preview of an ozone loss study based on data assimilation of Odin/SMR ozone

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Odin is a Swedish-led satellite project in collaboration with Canada, France and Finland and carries OSIRIS (Optical Spectro graph/InfraRed Imaging System) and SMR (Sub-Millimetre Radiometer). Odin is continuing to produce profiles of chemical species relevant to understanding the middle and upper atmosphere since it launched in February 2001. The long-term observation of stratospheric ozone can be useful for trend analysis of chemical ozone loss. This study concerns polar ozone loss over the Arctic and Antarctic hemisphere utilizing the 12 years (02-13) of ozone data from Odin/SMR. In order to quantify the chemical loss, it is necessary to clearly understand the contribution of dynamics in ozone changes. We have applied the data assimilation technique with a number of improvements to study the inter-annual variability during the entire Odin period.

The Technology and Atmospheric Mission Platform (TAMP) Project

Natali, Stefano [1]; Mantovani, Simone [1]; Triebnig, Gerhard [2]; Hirtl, Marcus [3]; Fehr, Thorsten [4]

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The scenario of data availability for the upcoming years will confront the scientific and industrial communities with a strong increase of satellite missions and related data. This is in particular the case for the Atmospheric Sciences communities, with the upcoming Copernicus Sentinel-5 Precursor, Sentinel-4, -5 and -3, and Earth

Explorers scientific satellites and their integration with ground based observations and models, and poses the basis for a new data exploitation paradigm opening new research and commercial opportunities.

As a preparation activity supporting scientific data exploitation for Earth Explorer and Sentinel atmospheric missions, ESA is funding the technology study and prototype implementation of the "Technology and Atmospheric Mission Platform" (TAMP).

The TAMP test-bed environment will allow handling, visualization and analysis purposes of the "data triangle" consisting of (1) EO satellite products (available within the system, generated inside the system, and user provided), (2) model data provided by chemical weather forecast models (e.g. hourly 3D distribution of ozone, NO₂, PM₁₀, and other pollutants at European and regional scales), and (3) reference / validation data sets (as standard validation datasets e.g. AERONET, EARLINET, NDAAC or Pandonia).

Services offered by the system will comprise data access, viewing, processing and analysis services. They will be developed along use cases defined with users from different scientific and operational fields and implemented according to their requirements to ensure acceptance of TAMP platform by the atmospheric community. These services and tools are provided following the "virtual workspace" concept: all resources (data, processing and collaboration tools) are provided as "remote services", accessible through a standard web browser, to avoid the download of big data volumes and for allowing utilization of provided infrastructure for computation.

The present work aims at presenting the TAMP concept to the Atmospheric Science community, introducing the platform and stimulating interest and discussions on the need of a thematic platform for atmospheric sciences to better exploit the upcoming missions data.

Development and verification of SCIAMACHY operational ESA Level 2 version 6/7 products

Azam, Faiza [1]; Noël, Stefan [1]; Eichmann, Kai-Uwe [1]; Richter, Andreas [1]; Wittrock, Folkard [1]; Hilboll, Andreas [1]; Schönhardt, Anja [1]; Buchwitz, Michael [1]; Reuter, Maximilian [1]; Rozanov, Alexei [1]; Bovensmann, Heinrich [1]; Burrows, John

1: Institute of Environmental Physics (IUP), University of Bremen, Bremen, Germany; 2: Belgian Institute for Space Aeronomy (IASB-BIRA), Brussels, Belgium; 3: Remote Sensing Technology Institute (IMF-DLR), German Aerospace Center (DLR), Oberpfaffenhofen,

The SCanning Imaging Absorption spectroMeter for Atmospheric CHartography (SCIAMACHY) aboard Envisat observed the Earth's atmosphere in nadir, limb and solar/lunar occultation geometries covering the UV-Visible to NIR (240-2380 nm) spectral range with a moderate spectral resolution of 0.2-1.5nm. The instrument provided decade long coverage (2002-2012) of various atmospheric parameters from the troposphere up to the mesosphere. These decadal datasets are important building blocks for long term assessments of climate relevance. The SCIAMACHY Quality Working Group (SQWG), formed in 2007, aims at improving the quality of the operational data products. University of Bremen (IUP), BIRA, DLR-IMF, SRON and KNMI are the members providing expertise in this group. Since the establishment of SQWG, the ESA operational Level 2 processor was significantly improved w.r.t. data quality and the product list was substantially enhanced with new parameters. The current project builds on the heritage of previous SQWG projects and has the following objectives: update the Level 0-2 processing chain, deliver the processor baseline enabling the generation of a quality controlled Level 1b and Level 2 dataset for the whole mission and to ensure long-term usability of the data. The SQWG Level 2 team is working on the improvement and implementation of processor Version 6 and the future Version 7. Under the SQWG framework, the main focus is on the following products: in nadir mode, total columns of O₃, NO₂, CO, IO and the tropospheric columns of NO₂, and O₃ (from limb-nadir matching) and the tropospheric columns of BrO and HCHO and, in limb, the aerosol and water vapour profiles and cloud flagging improvement and implementation. Here we present the key results of SCIAMACHY Level 2 Version 6 and Version 7 implementation and verification activities.

Improving Knowledge of Surface Emissions Using Observations from Satellite and Aircraft Campaigns

Frost, Gregory J. [1]; Granier, Claire [1,2,3]; Darras, Sabine [4]; Doumbia, Thierno [2]; Kim, Si-Wan [1,3]; Hassler, Birgit [1,3]; Sindelarova, Katerina [2]; Ryerson, Thomas B. [1]; Trainer, Michael [1]

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Recent satellite and aircraft observations have been integrated to better quantify the distribution and temporal variability of surface emissions at global and regional scales. This presentation will give examples of approaches using a combination of space-borne instruments, aircraft data collected during field campaigns, and atmospheric modeling. These methods have also been used to assess the capability of future space missions to provide a better understanding of emissions.

We discuss several case studies demonstrating an approach to evaluate NO_x emissions at a sector level by comparing satellite retrievals and in-situ aircraft sampling to regional and global chemical-transport model calculations of NO₂ columns. These studies address impacts of NO_x emissions controls at US power plants and the quantification of NO_x emissions from motor vehicles, industrial facilities, and ports in US cities and in megacities around the globe.

Space-borne instruments in geostationary (GEO) orbit will soon monitor major air pollutants across North America, Europe, and Asia. We investigate the possibility that GEO observations of formaldehyde (HCHO) columns can provide information about urban volatile organic compound (VOC) emissions. Aircraft observations constrain model simulations of the emissions of primary VOC species and their atmospheric oxidation to form HCHO. Model simulations of tropospheric HCHO columns are then compared with retrievals from current satellite instruments in low earth orbit and from proposed GEO instruments.

We conclude with a discussion of how better knowledge of surface emissions of atmospheric compounds can be integrated into the GEIA (Global Emissions Initiative, <http://www.geiacenter.org>) international project. GEIA provides access to information on global and regional emissions datasets through the ECCAD (Emissions of atmospheric Compounds and Compilation of Ancillary Data, <http://eccad.sedoo.fr>) database

Rescaling NO₂ satellite retrievals using OMI and SILAM model compared with zeppelin measurements

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Satellite-retrieval NO₂ column have been used in the Pan-European Gas-AeroSOIs-climate interaction Study (PEGASOS) EU project to provide a general context of the three field campaigns involved in the project: the Benelux area and the Po Valley in the spring and summer 2012, respectively, and western Finland during the spring 2013. In this work we use results from the Benelux and Po Valley campaigns. The OMI data are used together with model-simulated NO₂ profiles, using SILAM, to estimate the spatial variation of NO₂ at different altitudes. The method used here is based on the approach proposed by Lamsal et al. 2008 and 2013. OMI NO₂ concentrations were compared with collocated NO₂ measurement on the Zeppelin, within 2 hours close to the OMI overpass time. The results show the highest NO₂ concentrations over the Benelux area. The OMI NO₂ retrievals and the Zeppelin flight altitudes show favorable agreement and the vertical variation is well-reproduced with higher NO₂ concentrations near the surface. There are still some discrepancies between both retrievals that may be due to the time difference of up to 2 hours between the satellite overpass time and the Zeppelin measurements, while also the OMI pixel size used in this study is large compared with the time it took for the Zeppelin to sample the same area, in particular in view of the short atmospheric life time of NO₂. However, in general the NO₂ patterns in both the OMI and the zeppelin NO₂ observations are similar.

Lamsal, L. N., R. V. Martin, A. van Donkelaar, M. Steinbacher, E. A. Celarier, E. Bucsela, E. J. Dunlea, and J. P. Pinto, Ground-level nitrogen dioxide concentrations inferred from the satellite-borne Ozone Monitoring Instrument, *J. Geophys. Res.*, 113, D16308, doi:10.1029/2007JD009235, 2008.

L. N. Lamsal, R. V. Martin, D. D. Parrish, and N. A. Krotkov, Scaling Relationship for NO₂ Pollution and Urban Population Size: A Satellite Perspective. *Environ. Sci. Technol.*, 47, 7855–7861, 2013.

Tropical tropospheric ozone columns from nadir retrievals of GOME, SCIAMACHY and GOME-2

Leventidou, Elpida [1]; Weber, Mark [1]; Eichmann, Kai-Uwe [1]; Valks, Pieter [2]; Ebojie, Felix [1]; Burrows, John Philip [1]

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Tropospheric ozone columns can be retrieved with the Convective Clouds Differential (CCD) technique [Ziemke et al. 1998] using retrieved total ozone columns and cloud parameters from space-borne observations. We have developed a CCD-IUP algorithm which was applied to GOME/ERS (1995-2003), SCIAMACHY/Envisat (2002-2012) and GOME-2/MetOp (2007-2012) weighting function DOAS [Coldewey-Egbers et al., 2005, Weber et al., 2005] total ozone data. A unique long-term record of monthly averaged tropical tropospheric ozone columns (20°S – 20°N) was created starting in 1996. Here we present the monthly mean tropical tropospheric ozone columns dataset, including validation by comparisons with SHADOZ [Thompson et al., 2003] ozonesonde data and Limb-Nadir Matching [Ebojie et al. 2014] tropospheric ozone data. Within the framework of TROPOMI/S5P algorithms verification we will present the comparison between the verification (CCD-IUP) and the prototype (S5P_TROPOZ_CCD, developed by P. Valks) algorithms retrieving tropical tropospheric ozone columns using GOME-2 level-2 GDP 4.6 total ozone and cloud data.

Vertical Profiles of Volcanic Ash Aerosols: a Case Study with the Puyehue Cordón Caulle Eruption in June 2011

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Volcanic ash poses a non-negligible risk to humans and animals when present in the ambient air. It can also be a major threat to aviation, by reducing visibility, disturbing the functioning of the avionics and in the worst cases blocking the turbo engines. After the eruption of the Icelandic volcano Eyjafjöll in 2010 and the subsequent closure of the European air space for a few days, a lot of efforts have been undertaken by the scientific community to better characterize ash clouds, in order to provide better data to Volcanic Ash Advisory Centers, which deliver advisory and guidance. Current satellite-based measurements provide mostly aerosol optical depth (AOD) with no or very limited altitude information. The altitude of the ash plume is most often determined using transport models.

Here, we present for the first time retrievals of vertical profiles of volcanic ash aerosols from IASI thermal infrared radiances. The retrievals have been designed as an adaptation of the retrieval of desert dust vertical profiles that we have developed in the past years [Vandenbussche et al, AMT 2013]. The adaptation mostly has to cope with the fact that volcanic ash may be found much higher in the atmosphere (up to about 15km) with respect to desert dust (usually below 6km), and with the presence of ice particles together with ash aerosols. Ice particles, like ash, absorb, scatter, and emit in the thermal infrared spectral window. In particular ice aerosols lead to a positive slope in the 800-1000cm⁻¹ spectral window, where ash particles produce a negative slope. The presence of both ash aerosol and ice particles together is thus an additional challenge for ash retrievals from thermal infrared radiances.

In this contribution, we will first show the retrieval strategy, then discuss its application to the Puyehue Cordón Caulle eruption in June 2011. We will compare the plume location and AOD with previously published results [Klüser et al, AMT 2013]. We will also look at the vertical distribution of the ash cloud and its evolution in time and space. We will discuss the strengths and limitations of the presented retrieval strategy.

Cloud Fraction Determination for GOME-2 A/B with OCRA V3.0

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Retrieval of atmospheric trace gases requires a precise knowledge of the presence or absence of clouds, usually expressed as a cloud fraction. It is therefore extremely important to determine the degree of cloudiness of a measured scene as good as possible. In contrast to many cloud detection algorithms working on sounders or on imagers in the infra-red or micrometer range, the Optical Cloud Recognition Algorithm (OCRA) is designed for

spectrometers operating in the UVN part of the spectrum. By design, it can be applied to both, broad and narrow optical wavelength ranges. For GOME-type sensors, OCRA uses the information provided by the Polarization Measurement Devices (PMD), but its concept can easily be transferred to other sensors, e.g. OMI on AURA or the upcoming TROPOMI on Sentinel-5 Precursor. The basic idea behind OCRA is to split the measurement of a scene into contributions of clouds and a cloud-free background, i.e. the top-of-atmosphere reflectance in the absence of clouds. OCRA uses the general assumption that clouds have a higher reflectivity than the surrounding ground,

in all optical wavelengths. In the UVN spectral range part, the cloud reflectivity is almost wavelength-independent and therefore clouds appear as "white" regions in the normalized RGB color space. The scene which is furthest away from the "white" situation is the one where we expect the least possible amount of cloud contamination. Merging all these scenes on a global grid then provides the cloud-free background map. The comparison

of a measured reflectance with the corresponding cloud free reflectance can then be used to derive a radiometric cloud fraction for this given scene. In contrast to earlier versions, OCRA V3.0 now also includes degradation corrections for the PMD reflectances as well as corrections for viewing zenith angle dependencies, latitudinal and seasonal dependencies. Another new feature is an improved Sun-glint detection and removal scheme.

The cloud fractions obtained with OCRA for GOME-2 on MetOp-A and -B are compared with the cloud fractions from the Advanced Very High Resolution Radiometer (AVHRR) sensor also flying on the MetOp satellites. Finally, we expand on how we plan the transition and adaptations from the GOME-2 based OCRA towards the OCRA version algorithm to be used for the generation of the official cloud products for TROPOMI/Sentinel-5P,

including selection of optimal wavelength ranges, generation of new cloud-free maps, adapted Sun-glint removal and snow-vs-cloud discrimination.

Level 2 processing for the imaging Fourier transform spectrometer GLORIA: Derivation and validation of temperature and trace gas volume mixing ratios from calibrated dynamics mode spectra

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The Gimbalbed Limb Radiance Imager of the Atmosphere (GLORIA) is a newly developed unique instrument that combines for the first time a classical Fourier transform spectrometer (FTS) with a 2-D detector array.

Imaging allows the spatial sampling to be improved by up to an order of magnitude when compared to a limb scanning instrument. GLORIA is designed to operate on various high altitude research platforms. The instrument is a joint development of the German Helmholtz Large Research Facilities Karlsruher Institut fuer Technologie (KIT) and Forschungszentrum Juelich GmbH (FZJ). GLORIA builds upon the heritage of KIT and FZJ in developing and operating infrared limb sounders (CRISTA, MIPAS).

In Summer 2012, GLORIA was an integral part of the first large HALO missions dedicated to atmospheric research, TACTS and ESMVAL. The data span latitudes from 80°N to 65°S and include several tomographic flight patterns that allow the 3-D reconstruction of observed air masses.

We describe the retrieval of temperature and trace gas (H₂O, O₃, HNO₃) volume mixing ratios from GLORIA dynamics mode spectra. 26 integrated spectral windows are employed in a joint fit to retrieve seven targets using consecutively a fast and an accurate tabulated radiative transfer model. Typical diagnostic quantities are provided including effects of uncertainties in the calibration and horizontal resolution along the line-of-sight. Simultaneous in-situ observations by in-situ instruments aboard HALO allow a validation of retrieved values for three flights in the upper troposphere/lowermost stratosphere region spanning polar and sub-tropical latitudes. A high correlation is achieved between the remote sensing and the in-situ trace gas data, and discrepancies can to a large fraction be attributed to differences in the probed air masses caused by different sampling characteristics of the instruments.

We thus provide an overview of the heterogeneous structure of the upper troposphere/lower stratosphere (UTLS) as observed over Europe. Retrieved water vapor and ozone are used to identify the tropospheric or stratospheric character of air masses and can thus be used to visualize the multi-species 2-D (and partly 3-D) chemical structure of the UTLS. A highly intricate structure is found consisting often of fine-scale layers extending only several hundred meters in the vertical. These horizontally large-scale structures are thus below the typical vertical resolution of current chemistry climate models.

This 1-D processing of GLORIA dynamics mode spectra provides the basis for tomographic inversions from circular and linear flight paths to better understand selected dynamical processes of the upper troposphere and lowermost stratosphere. We also show first 3-D results and diagnostic quantities from a tomographic flight over Scandinavia.

A different way to look at the intercomparison of datasets – illustrated with SCIAMACHY v5.02 versus lidar ozone profiles

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In traditional validations of atmospheric profiles, the intercomparison of two datasets is usually carried out in predefined groups of observational characteristic like longitude, stellar magnitude or solar zenith angle. Here we present an alternative method in which we trained a self organizing map (SOM) with a full time series of relative difference profiles of SCIAMACHY limb v5.02 and ozone profiles from seven NDACC lidar. For each individual observation, a set of observations characteristics from the SCIAMACHY and lidar data was mapped to the trained SOM. These maps were studied to see if the variation for a given characteristic corresponds to the variation seen in the SOM map. For the studied datasets, altitude-dependent relations for the global dataset were found between the difference profiles and studied variables. From the lowest altitude studied (18 km) ascending, the most influencing factors were found to be longitude, followed by solar zenith angle and latitude, sensor age and again solar zenith angle together with the day of the year at the highest altitudes studied here (up to 45 km). Clustering into three classes showed that there are also some local dependencies, with for instance one cluster having a much stronger correlation with the sensor age (days since launch) between 36 and 42 km. The validation approach based on using SOM proved to be a powerful tool for the exploration of differences between datasets without being limited to a-priori defined data subsets.

Hemispheric Distributions and Solar-Induced Variability of NO_y Produced by Energetic Particle Precipitation in 2002-2012 as Measured by MIPAS

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The MIPAS Fourier transform spectrometer on board Envisat has measured limb emission spectra in the mid-IR for a 10-year period (2002-2012) which have been used to retrieve vertical profiles of the six principal reactive nitrogen (NO_y) compounds (HNO₃, NO₂, NO, N₂O₅, ClONO₂, and HNO₄) with global coverage and independent of illumination conditions. From these data, the contribution of NO_y produced by energetic particle precipitation (EPP) has been discriminated from the background NO_y by using a tracer correlation method based on co-located MIPAS CH₄ and CO measurements. The obtained EPP-NO_y distributions demonstrate a regular indirect EPP impact on the entire stratosphere (down to 22-25 km) by polar winter descent and show a clear solar cycle signal in consonance with the change in the geomagnetic activity. Furthermore, a pronounced hemispheric asymmetry is observed, with higher concentrations of EPP-NO_y in the Southern Hemisphere (SH) and a larger variability in the Northern Hemisphere (NH). In this paper, possible drivers of the observed hemispheric asymmetry are discussed. We also show by multi-linear regression of the temporal evolution of EPP-NO_y with the Ap index that 80-90% of the SH inter-annual variability (excluding direct contributions by Solar Proton Events) can be attributed to changes in the geomagnetic activity. This tight relationship holds throughout the winter season and at all vertical levels. In the NH, a similar well-correlated relationship is found until mid-winter. Afterwards, the Ap correlation breaks down above the 2 hPa level in years with elevated stratopause occurrence.

Retrieval of Tropospheric Columns from Ground-Based MAX-DOAS Measurements Performed in the Greater Area of Thessaloniki and Comparison with Satellite Products

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Phaethon is a ground-based MAX-DOAS system developed at the Laboratory of Atmospheric Physics (LAP) in Thessaloniki, Greece. The instrument, which consists of a cooled miniature CCD spectrograph (AvaSpec-ULS2048LTEC), is capable of performing both direct solar irradiance and sky radiance spectral measurements at any elevation angle and produces total and tropospheric columns of atmospheric trace gases which absorb in the region 300-450 nm, such as NO₂, O₃, HCHO and SO₂. Phaethon, can be easily moved and installed at different locations for air quality monitoring and support satellite validation studies. In the framework of the Optimization and expansion of ground infrastructure for the validation of satellite-derived column densities of atmospheric species, AVANTI project, the prototype Phaethon was upgraded and two new clone systems were developed. The three Phaethon systems have been operated for a few days in parallel at the Aristotle University campus and they were found to agree very well in the derived tropospheric column measurements with no systematic differences. Subsequently, they were deployed at different sites in the greater area of Thessaloniki, Greece, characterized by diverse local pollution sources representing urban, industrial and rural conditions in order to test their performance under different atmospheric loadings and to link modeling of tropospheric trace gases with satellite products. Tropospheric columns derived at these different sites which are located within an area of about 15 km by 40 km, comparable to the size of a satellite pixel, are presented and compared with retrievals from OMI/Aura and GOME-2/MetopA and /MetopB satellite sensors that represent the average pollution levels in the sub-satellite pixel area. One of the Phaethon systems will be deployed for about one year in the Guangzhou region in China performing measurements for the validation of satellite derived tropospheric NO₂ within the EU FP7 Monitoring and Assessment of Regional air quality in China using space Observations, Project Of Long-term sino-european co-Operation, MarcoPolo project.

Simulations of 3D Tomographic Measurements of Gravity Waves with the IR Limb Sounder GLORIA

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The forcing of gravity waves (GWs) is an important coupling mechanism in the atmosphere. They are a major driver of the middle atmosphere circulation and may play a role, for instance, in sudden stratospheric warmings and the rebuilding of the stratopause afterwards. To get a better understanding of GWs, airborne 3D tomographic measurements of mountain waves with the German research aircraft HALO are planned. A central question concerns the achievable accuracy of the 3D wave vector, GW temperature amplitude, and the associated momentum flux derived from the measurements.

To answer this, we study, based on GW resolving model data, which GW parameters can be retrieved from 3D temperature distributions measured by the airborne infrared limb sounder GLORIA.

GLORIA is a joint development of the Helmholtz Research Facilities Karlsruher Institut für Technologie and Forschungszentrum Jülich and combines a classical Fourier Transform Spectrometer with a 2D detector array. GLORIA is a demonstrator for a future infrared limb imager satellite as a follow up concept to PREMIER (EE7 candidate). The capability of GLORIA to image the atmosphere and thereby take up to 16384 spectra simultaneously improves the spatial sampling of conventional limb sounders by an order of magnitude. Furthermore GLORIA is able to pan the horizontal view direction and therefore measure the same volume of air under different angles. Due to these properties 3D tomographic methods can be applied and temperature and tracer fields with spatial resolutions of better than 30km x 30km x 300m can be achieved. To obtain these resolutions a tomographic retrieval scheme is used, which is able to fully exploit the manifold radiance observations of the GLORIA limb sounder. The algorithm is optimized for large scale 3-D retrievals of several hundred thousands of measurements and atmospheric constituents. It can efficiently solve the problem by quasi-Newton type methods, in our case a truncated conjugate gradient-based trust region scheme.

We will present simulated measurements and retrievals for both circular and linear flight patterns and deduce GW parameters from these data. The determined GW momentum flux will be compared to the one estimated from the original model data. Based on these data, an optimal flight strategy for the upcoming POLSTRACC/GW-LCycle campaign is developed.

Study of Seasonal and Interannual Variabilities of Tropospheric Ozone and CO over Indian Ocean from 2008 to 2013 with IASI-SOFRID Data

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Tropospheric O₃ over the Northern Indian Ocean has been shown to be controlled by the Indian outflow of pollution but also to stratosphere to troposphere exchange and more recently to African lightning NO_x (LiNO_x). A recent study [Zhang et al., 2012] also highlighted strong maxima of tropospheric O₃ over the Equatorial Southern Indian Ocean in May from multi annual (2005-2009) observations from the TES space borne sensor. These seasonal maxima were shown to be caused by the production of LiNO_x over Africa. Important interannual variability was observed with larger maxima in 2006 and 2008 related to anomalous anti-cyclonic circulation over central Africa. Nevertheless, many aspects concerning the factors controlling the variability and evolution of O₃ over the Indian Ocean region remain unclear.

In this study we use O₃ and CO dataset retrieved from the IASI-A sensor with the Software for a Fast Retrievals of IASI Data (SOFRID) to document the seasonal and interannual variability of tropospheric O₃ and CO over the Indian Ocean region. The SOFRID database also allows us to document the evolution of O₃ and CO over this region in the most recent period, namely from 2008 to 2013. We will show that both the interannual

variability and the evolution of CO and O₃ concentrations strongly depend on the part of Indian Ocean region we are looking at. To the north of the domain, the wintertime maxima of O₃ over the Bay of Bengal are much stronger in 2009 than for the other years. Over the Arabian Sea the O₃ wintertime maxima does not display such interannual variability. To the south, anomalously large concentrations of O₃ are detected north of Madagascar during the austral fall season of 2008. IASI CO data are used to complement the information provided by the O₃ data allowing for instance targeting air masses impacted by biomass burning.

In order to understand the observed seasonal and interannual variabilities, we have performed simulations with the GEOS-Chem global chemistry transport model. We will present the comparisons between the simulated and observed O₃ and CO distributions and a preliminary discussion concerning the source regions and transport processes responsible for the observed variabilities.

Mesospheric Hydroxyl and Ozone Response to Energetic Electron Precipitation over the Solar Cycle

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Energetic electron precipitation (EEP) from the Earth's outer radiation belt continuously affects the chemical composition of the mesosphere in the polar regions. At altitudes below about 80 km, EEP leads to odd hydrogen (HO_x) enhancements following ionisation and ion chemical reactions, which is expected to contribute to ozone balance in the mesosphere. Using measurements from the Microwave Limb Sounder (MLS/Aura) and Medium Energy Proton and Electron Detector (MEPED/POES) between 2004-2009 we show that EEP significantly affect mesospheric HO_x about 35% of the time. The largest EEP-induced HO_x effect is found at 70-80 km, caused by electrons with energies between 100-300 keV. Finally, utilising 11 years of observations from the Global Ozone Monitoring by Occultation of Stars (GOMOS/ENVISAT), Sounding of the Atmosphere using Broadband Emission Radiometry (SABER/TIMED), and Microwave Limb Sounder (MLS/Aura) instruments, we show that the EEP induced increases in OH are typically accompanied by decreases in ozone at altitudes between 60-80 km. EEP leads to extremely large (up to 90%) short term (days) ozone depletions in the atmosphere. The magnitude of these short term effects is comparable to those caused by large but much less frequent solar proton events. On solar cycle time scales, we find that EEP causes significant ozone variations of up to 34% at 70-80 km. Since ozone is important to atmospheric heating and cooling rates, such variation could imply significant, EEP-driven modulation of mesospheric temperature balance.

SCIAMACHY Operations History and the New Level 1b Product - an Approach for Long-term Data Preservation

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SCIAMACHY on ENVISAT has acquired, over a period of 10 years, a wealth of high quality measurement data. After the end of the SCIAMACHY/ENVISAT mission it has become a paramount goal to ensure long-term availability of this dataset. Even well into the future we expect to retrieve new insights into the Earth's atmosphere from the existing dataset.

One of the challenging properties of SCIAMACHY was its sophisticated command & control scheme which resulted in complex operation scenarios. This was partially due to the unique viewing capabilities – nadir, limb and solar and lunar occultation. In order to understand measurement data from the various observation modes, a comprehensive but still clear description of the underlying instrument operations is needed. Usually,

operations information is one of the items of a space-borne scientific mission which vanishes first after the end of the mission and little is kept for future usage.

For SCIAMACHY we plan to implement a different approach. It is our intention to store essential operations information in the new level 1b product, which will be developed in the framework of the SQWG phase F. Then, as long as the SCIAMACHY level 1b products are preserved, the operations information is maintained as well. This approach not only ensures long-term availability of SCIAMACHY's operations know-how but also avoids the problem of generating dedicated operations I/O software tools. Since the routines for reading the new level 1b product will be a generic tool, they also will allow accessing the operations information.

In the new concept an operations section is added to the level 1b product. It consists of several areas, all covering a certain aspect of SCIAMACHY operations. The areas include ENVISAT Platform status with reference orbit (with relevance for SCIAMACHY), SCIAMACHY instrument status, SCIAMACHY monitoring status, SCIAMACHY instrument configuration and the acquired HK telemetry. Since the level 1b products are orbit oriented, the operations information has to reflect the same structure. Thus it is required to collect all the items listed above on an orbit-by-orbit basis in databases with absolute orbit numbers starting at 2204 (2 August 2002 – start of quasi-routine operations) and ending at 52868 (8 April 2012 – ENVISAT anomaly). The entire volume of the new operations section will amount to about 5 MB, i.e. it only adds a small amount of data to the level 1b product with a total size of about 300 MB.

We report on the overall concept of operations information in the SCIAMACHY level 1b product and on the current status of its implementation.

SCIAMACHY: New Level 0-1 Processor and Plans for the Future

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SCIAMACHY (SCanning Imaging Absorption spectroMeter for Atmospheric CHartography) was a scanning nadir and limb spectrometer covering the wavelength range from 212 nm to 2386 nm in 8 channels. It is a joint project of Germany, the Netherlands and Belgium and was launched in February 2002 on the ESA's ENVISAT platform. After the platform failure in April 2012, the space agencies continue to support the operational product evolution in the frame of the SCIAMACHY Quality Working Group and Expert Support Laboratory.

Note that SCIAMACHY's in-orbit lifetime was twice the planned lifetime. The instrument was designed to measure column densities and vertical profiles of trace gas species in the troposphere, in the stratosphere and in the mesosphere (Bovensmann et al., 1999). It can detect a wide range of trace gases and can provide information about aerosols and clouds.

The operational processing of SCIAMACHY aims to deliver continuously high quality data products to the scientific community. It is split into Level 0-1 processing (essentially providing calibrated radiances) and Level 1-2 processing providing geophysical products. The operational Level 0-1 processor has been completely re-coded and embedded in a newly developed framework that speeds up processing considerably.

A better degradation correction was implemented that now takes into account the dependence of transmission on the incidence angle of light on the mirror. The stray light correction now uses a matrix correction scheme for all channels. The handling of calibration data was completely overhauled: instead of using a collection of files we use a database that allows proper traceability of used calibration data for any given Earth measurement and that allows immediate quality checks. With the improved Level 1 products it is expected that the Level 2 products are also improved (see related contribution on operational Level 2 products from SCIAMACHY). Both datasets were re-processed. Here we will report on the quality of the Level 1 data. In addition future planned improvements such as a new bad pixel mask in the SWIR channel will be discussed.

The use of Sentinel-3 synergy products for physically based automatic atmospheric correction of Sentinel-2 imagery

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The present study describes the development, the implementation and the automation of a physically-based atmospheric correction method for ESA's high resolution mission Sentinel-2, by exploiting atmospheric products of the Sentinel-3 synergy. It is investigated to what extent atmospheric properties from Sentinel-3 products can be considered with fine-resolution land imagery, in order to improve the estimates of surface reflectance through physically based atmospheric correction.

The 6s (Second Simulation of Satellite Signal in the Solar Spectrum vector code) radiative transfer model is used for simulating the interaction between land and atmosphere. It enables accurate simulations of satellite and plane observation, accounting for elevated targets, use of anisotropic and Lambertian surfaces and calculation of gaseous absorption. The 6s is chosen among others, as in many independent publications provides more accurate than other models for atmospheric correction of high resolution optical imagery.

Since neither Sentinel-2, nor Sentinel-3 data/products are available at the moment, alternative data are used in this study. Aerosol optical thickness at 550nm from the MODIS (Moderate Resolution Imaging Spectroradiometer) Aerosol Product (MOD02_L2) is used instead of the Sentinel-3 Level-2 SYN product (SY_2_SYN) for atmospheric correction of Sentinel-2 simulated data. The Level-2 SYN product (SY_2_SYN) will be produced by the Global Synergy Level-1/2 software and contains surface reflectance and aerosol parameters over land. Simulated data from the Sentinel-2 APEX campaign are used. Data was acquired on a clear day from a flight altitude of 4600m above sea level in Zurich, Switzerland and its simulation includes all spectral and spatial characteristics of all 13 Sentinel-2 bands and contains top-of-atmosphere radiance data, corresponding to a Sentinel-2 level 1C product.

Since, the Sentinel-2 mission will provide global coverage of the Earth's land surface every 5 days with 2 satellites, its data will be of great use in several studies, for the majority of which, accurate atmospherically corrected products are essential. The Sentinels constellation is designed to support synergistic use, therefore this study highlights the use of Sentinel-3 atmospheric products for improving the accuracy of Sentinel-2 derived surface reflectance.

Towards a Near Operational Validation of IASI level 2 trace gas products

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Earth observation data sets are fundamental for investigating the processes driving climate change and thus for supporting decisions on climate change mitigation strategies. Atmospheric remote sounding from space is an essential component of this observational strategy, since it allows for a global coverage. However, for a correct scientific interpretation of these observational records a continuous documentation of their quality is required. An optimal method would be a continuous inter-comparison of the space-based observations to high quality reference observations made at the Earth's surface. In this context, this work will exploit the high potential of the Spanish atmospheric super-site IARC (Izaña Atmospheric Research Centre, Tenerife), as a ground-based reference site, to perform a comprehensive validation of the operational atmospheric level 2 trace gas products water vapour, ozone, methane, nitrous oxide, carbon monoxide and carbon dioxide of the remote sensor IASI (Infrared Atmospheric Sounding Interferometer).

We will document to what extent the ground-based data can be used as a reference for the space-based observations. To do so, we will analyse the temporal and spatial variability of the atmospheric parameters at IARC in order to decide about the appropriate temporal and spatial coincidence criteria for the validation of

space-based measurements with ground-based observations. Based on our studies about the required coincidence criteria, firstly, we will address the documentation of the quality of the whole IASI-A/IASI-B time series (2007-2014 and 2013-2014, respectively) by using the IARC's ground-based FTS (Fourier Transform Spectrometer) experiment. It will be our core reference technique since it is the only measurement technique that can comprehensively validate many different atmospheric trace gas products. Secondly, we will establish the methodology to perform the comparison IASI and ground-based FTS products shortly after the measurement. Such near operational validation of satellite sensor products is strongly requested by the satellite operators and the climate research community. Furthermore, it will be a good strategy for validating the huge amount of data series that will be produced by the next generation of satellite sensors. For instance, besides the three IASI sensors (A, B, and C) there will soon be MTG-IRS (Meteosat Third Generation – Infra Red Sounder) or Sentinel 5P-Tropomi producing trace gas time series with unprecedented high temporal and spatial resolution.

Using Sentinel 5 precursor Level 2 Data: File Format and Metadata

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This contribution is an introduction to the Sentinel 5 precursor (S5P) level 2 data files. This will help users to prepare for the new mission. Some choices were made to make it easy to read the data for new users, but this will require some adaptation by existing users of previous atmospheric missions. The file format for S5P is based on netCDF-4. The contribution will focus on the structure of the file and the metadata that comes with the data. We will provide some background for the choices we have made, to help users understand where to find the data they need after launch for S5P.

Given that S5P is the first of the upcoming atmospheric missions within the Copernicus framework, the file formats of Sentinel 4 and Sentinel 5 will be very similar, if not identical. The choices we have made for S5P will likely stick with us for the next few decades. On the other hand, the phase-F projects of GOME and SCIAMACHY also look into the work done for Sentinel 5 precursor, and are likely to end up with a file format that is also very similar.

A project-wide decision has been made to use SI units for S5P/TROPOMI. We follow the IUPAC recommendations made 20 years ago. As a consequence familiar units for a column amount of a trace gas such as "DU" and "molecules cm⁻²" are not used in the level 2 output. Instead the unit "mol m⁻²" shall be used. Conversion factors to transform the provided value into traditional units are attached to the variables. This should ease the transition while at the same time stimulating the use of SI units.

Remote Sensing of Small Scale Emissions of CO₂ and CH₄ using Airborne Solar Absorption Spectroscopy – the MAMAP Experience

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1: University of Bremen, Germany; 2: METAIR AG, Switzerland; 3: Earth Science Division, NASA Ames Research Center (ARC), USA; 4: Center for Interdisciplinary Remotely-Piloted Aircraft Studies (CIRPAS), USA; 5: Bubbleology Research International (BRI), USA

Very often natural and anthropogenic emissions of CO₂ and CH₄ occur on small scales (several km down to a few meters). Examples are the CO₂ release by volcanoes and power plants, as well as CH₄ emissions from large seeps, landfills, coal mine venting and oil/gas production. Quantifying and verifying these emissions by independent, non-intrusive (remote sensing) techniques is required in the context of a better understanding and management of these sources. Recent achievements using the Methane Airborne MAPper (MAMAP) sensor - developed by the University of Bremen in cooperation with the GFZ Potsdam - show that CO₂ as well as CH₄ point-source emissions can be derived from column-averaged dry air mole fractions of CO₂ and CH₄ retrieved from airborne passive nadir remote sensing measurements. This new method allows the independent verification of strong point source emissions. In 2012 (CMAPEX) and 2014 (COMEX) two campaigns were executed in support of the CarbonSat Earth Explorer mission definition activities, to validate the new method by combined remote sensing and in-situ data collection over and around power plants, coal mine ventilation shafts, landfills as well as oil/gas fields. The paper will summarise results of the campaigns and will give an outlook on the future development of this unique remote sensing technique, which is also highly relevant in the context of the validation and data interpretation of future CO₂ and CH₄ satellite missions like OCO-2, Sentinel-5P, MERLIN and CarbonSat.

Overview of the Atmospheric Composition Sentinel Missions S5P, S4 and S5

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Under the leadership of the European Commission (EC), a series of Copernicus Atmospheric Monitoring Service (CAMS) Missions is in preparation by ESA. The programme basically consists of a geostationary element called Sentinel-4 (S4) and a low-Earth orbiting element called Sentinel-5 (S5). The S4 ultraviolet-visible-near-infrared (UVN) instrument will be embarked on Eumetsat's MTG-S satellite and the S5 UVN short-wave-infrared (UVNS) instrument will be embarked on one of the MetOp-SG/EP-SG satellites. The corresponding Sentinel missions consist of the following elements:

Sentinel-4 comprises a UV-visible-near IR spectrometer monitoring diurnal variation in regional air quality complemented by the IR sounder on-board of MTG-S;

Sentinel-5 includes a UV-visible-near-IR-shortwave-IR spectrometer observing atmospheric composition in support of global air quality and climate assessments, from near-polar orbit. This sensor is complemented by the IASI-follow-on IR sounder and visible/thermal IR and (polarisation) imagers on-board of the same MetOp-SG/EP-SG satellite in the series;

In view of bridging the data gap between OMI on EOS-Aura, S5 will be preceded by a simplified instrument, the Tropospheric Monitoring Instrument (TROPOMI), carried on board a dedicated, near-polar orbiting platform. This mission, called "Sentinel-5 Precursor" (S5P), will be operated in loose formation with NOAA's Suomi-NPP (SNPP) spacecraft. This concept will allow utilization of cloud image data provided by the VIIRS instrument on board SNPP for use in routine processing tasks.

The presentation will address the scientific and programmatic background for all three missions. To complement this, there will be dedicated presentations on each of the atmospheric composition Sentinels.

A climatology of global aerosol mixtures to support Sentinel-5P and EarthCARE mission applications

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In support of atmospheric composition studies that are planned for Sentinel-5P and EarthCARE, we present a newly-derived global climatology of aerosol mixtures. Constraining aerosol type with satellite remote sensing continues to be a challenge and the global climatology presented here can help inform the choice of components and mixtures in aerosol retrieval algorithms used by instruments such as TROPOMI and ATLID and to test retrieval results.

The global climatology was obtained via application of cluster analysis to seven years of 3-hourly, gridded 2.5 x 2 degree aerosol optical depth (AOD) data (for sulfate, biomass burning, mineral dust and marine aerosol) from the Goddard Chemistry Aerosol Radiation and Transport (GOCART) model, led to a spatial partition of the global aerosol distribution into ~10 aerosol mixtures. Analysis of the percentage contribution of each of the four different aerosol types to mixtures then allowed development of a straightforward naming convention and taxonomy. In addition, assignment of primary colours to the constituent types enabled true colour-mixing and the generation of easy-to-interpret maps. To further help characterize the mixtures, aerosol robotic network (AERONET) Level 2.0 Version 2 inversion products were extracted from within the mean global multiyear and seasonal partition of each cluster. The AERONET data were used to estimate the values of key optical and microphysical parameters. In the context of the observational constraints and uncertainties associated with AERONET retrievals, bivariate analysis of different parameter pairs suggests that mixtures dominated by mineral dust and marine aerosol can be detected with reference to their single scattering albedo and Angstrom exponent at visible wavelengths in conjunction with their fine mode fraction and sphericity. Multivariate approaches at classification in the literature appear to be more ambiguous.

The aerosol type climatology represents current knowledge that would be enhanced, possibly corrected, and refined by high temporal and spectral resolution, cloud-free observations produced by Sentinel-5P and EarthCARE instruments. The multiyear mean and seasonal gridded global partitions of AOD and compositional aerosol mixtures comprise a preliminary reference framework that can: i) enable tests of the effect on look-up table derived retrievals of initializing retrieval algorithms used by OMI/TROPOMI or CALIOP/ATLID with aerosol type mixtures, ii) help fine-tune aerosol type selection methods used in existing algorithms by referring to mean and seasonal optical and microphysical properties of aerosol mixtures, iii) allow comparison of retrieved aerosol types with those expected from the climatology and iv) contribute to the assessment of region and season-specific aerosol type assumptions.

A linear method for the retrieval of sun-induced chlorophyll fluorescence from GOME-2 and SCIAMACHY data

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Global retrievals of near-infrared sun-induced chlorophyll fluorescence (SIF) have been achieved in the last several years by means of space-borne atmospheric spectrometers. SIF is an electromagnetic signal emitted by the chlorophyll-a of photosynthetically active vegetation in the 650–850 nm spectral range. It represents a part of the excess energy during the process of photosynthesis and provides a measure of photosynthetic activity. Furthermore, SIF fills-in the O2-A band up to a level at which it can lead to biases in aerosol or XCO2 retrievals making use of the O2-A band. Including SIF in these retrievals, either as a priori information or an extra element in the state vector, can help to reduce those biases.

The key challenge to retrieve SIF from space is to isolate the signal from the about 100 times more intense reflected solar radiation in the measured top of atmosphere (TOA) radiance spectrum. Nevertheless, it has been

demonstrated that a number of satellite sensors provide the necessary spectral and radiometric performance to evaluate the in-filling of solar Fraunhofer lines and/or atmospheric absorption features by SIF.

We will present recent developments for the retrieval of SIF from medium spectral resolution space-borne spectrometers such as the Global Ozone Monitoring Experiment (GOME-2) and the Scanning Imaging Absorption SpectroMeter for Atmospheric Chartography (SCIAMACHY).

Building upon the previous work by Joiner et al. 2013, our approach solves existing issues in the retrieval such as the arbitrary selection of the number of free parameters. In particular, we use a backward elimination algorithm to optimize the number of coefficients to fit, which reduces also the retrieval noise and selects the number of state vector elements automatically. A sensitivity analysis with simulated spectra has been utilized to evaluate the performance of our retrieval approach. The method has also been applied to estimate SIF from real spectra acquired from GOME-2 and SCIAMACHY.

We are able to present a time series of GOME-2 SIF results covering the 01/2007–01/2012 time period and SCIAMACHYSIF results between 08/2002–03/2012. This represents an almost one decade long record of global SIF.

We compare SIF retrieval results from GOME-2 and SCIAMACHY data and find a good correspondence of the SIF values and the spatial patterns from the two sensors, which suggests the robustness of the proposed retrieval method. In addition, we examine uncertainties and use our retrieval results to show empirically the low sensitivity of the SIF retrieval to cloud contamination.

Applications of Satellite Observations of Tropospheric NO₂ at High Latitudes for Monitoring Air Quality (ILMA): objectives and first result

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Climate change scenarios foresee increasing anthropogenic activities and their environmental effects at high latitude regions (especially in the Arctic). In particular, nitrogen oxides (NO_x = NO + NO₂), mainly generated by anthropogenic combustion, play an important role in tropospheric chemistry and have harmful effects on human health. Satellite observations are best suited for atmospheric composition monitoring over large regions where ground-based measurements are only scarcely available or difficult to maintain. However, satellite observations are not yet extensively applied for air quality monitoring at high latitudes.

Total and tropospheric NO₂ columns are currently provided for example by OMI (Ozone Monitoring Instrument), flying onboard NASA's Aura satellite, which is included in the ESA Third Party mission. The upcoming TROPOMI (TROPOspheric Monitoring Instrument) on Sentinel 5 Precursor will produce NO₂ observations similar to OMI but with improved spatial resolution (7 × 7 km² instead of OMI's 16 × 24 km²) and signal-to-noise ratio. OMI data can be used to evaluate the algorithm's performance at high latitudes and to develop applications for the upcoming TROPOMI observations.

In this context, ILMA-project (supported by the ESA Living Planet fellowship programme) aims at:

Increase the scientific exploitation of the existing satellite data for air quality monitoring at high latitudes, with specific focus on tropospheric NO₂ observations in Arctic region.

Evaluate the satellite data quality at high latitudes through validation and comparison with auxiliary data.

Prepare for TROPOMI data validation and exploitation at high latitudes

Develop a data user network for air quality monitoring at high latitudes using satellite data, including a pilot demonstration study for urban pollution monitoring in Finland.

The first results of the project show for example that OMI NO₂ data and the ground-based observations from Pandora spectrometer in Helsinki (Finland) differ on average by -6% and 1% for all skies and clear sky

conditions, respectively. The clear sky overpasses mainly correspond to summer days and, thus, to smaller solar zenith angles.

The NO₂ surface concentrations available from Kumpula air quality station in Helsinki are also analysed in order to evaluate the capability of satellite data to monitor air quality. The NO₂ seasonal and weekly cycles from OMI, Pandora and surface concentration data show a similar wintertime peak and a lower signal during the weekend, as compared to the other weekdays. Also, OMI tropospheric columns in Helsinki show about 20% decrease over the last 10 years, corresponding to a reduction in the surface NO₂ concentrations during the same period.

Satellite & in-situ Information for Advanced Air Quality Forecast Services – SiAiR

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The ESA funded SiAiR project addresses a theme of high socio-economic relevance - namely the numerical forecast of pollution from particulate matter PM₁₀. Although a minor constituent of the atmosphere, the PM₁₀ particles are linked to visibility reduction, adverse health effects and heat balance of the Earth. Moreover, airborne particles play an important role in the spreading of biological organisms, reproductive materials, and pathogens (pollen, bacteria, spores, viruses, etc.), and they can cause or enhance respiratory, cardiovascular, infectious, and allergic diseases (Shiraiwa et al., 2012). The characteristics of an aerosol population (total number concentration, size distribution, chemical composition etc.) depend on the location: urban or remote rural; continental or marine; boundary layer or higher up; as well as on the season and even the time of the day (e.g. Poschl, 2005).

Atmospheric models constitute an important tool for simulations of transport and transformation of aerosols and gases and thus they can improve our knowledge about aerosol particles primary and secondary sources of aerosol particles.

The regional air quality models are typically conducted using climatologies for the input parameters. However, satellite remote sensing products provide two important sources of information compared with surface and aircraft monitoring data: the more complete spatial coverage and the vertically integrated measure of atmospheric components (Edwards, 2006). An increasing number of studies have recently focused on air quality applications of satellite remote sensing, including identifying specific air quality events such as forest fires (Mazzoni et al., 2007), characterizing the long-range transport of some pollutants in combination with global-scale modeling (Heald, 2006), and evaluating regional air quality model simulations (Hodzic et al., 2006, Kondragunta et al., 2008). There is clearly an enormous potential for using satellite data to improve air quality modeling.

Therefore it is of particular interest to investigate and understand how satellite measurements can be used to improve our characterization of the atmosphere. One of the key advantages of assimilating satellite products in the air quality models is the availability of data aloft. These data may be available as a total atmospheric column, tropospheric column, and/or vertical profile.

The overall scope of the project is to define the assimilation of observations (satellite products and ground measurements) into the numerical modeling of the Romanian National Meteorological Administration (NMA) for air quality purposes.

In order to achieve this goal, based on a critical examination of successful implementations of the concept, an observational data assimilation methodology has been defined and implemented in a prototype system. Support Vector Regression technique is applied to derive highly-resolved PM₁₀ initial fields for air quality modeling from satellite measurements of the Aerosol Optical Thickness.

Additionally, PM₁₀-ground measurements are assimilated using optimum interpolation.

The WRF/Chem model is run in data assimilation enabled/disabled configurations and the observational data assimilation impact on the PM10 forecast performance is evaluated.

This presentation describes the prototype system used for the data assimilation experiments in the SiAIR project, and the results obtained so far.

Tropical Tropospheric Ozone observed from GOME-2 and perspectives for TROPOMI

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Tropospheric Ozone is of particular interest not only because it is a greenhouse gas, but also because it directly affects human health and causes agricultural damage. There is still a large uncertainty about the global distribution of tropospheric ozone, because ground-based measurements like ozonesondes are sparse. Therefore global distribution patterns as observed from satellites are an excellent tool to monitor the evolution of tropospheric ozone and to increase our knowledge and understanding of the underlying processes.

The presented data are based on the ozone and cloud products from the GOME and GOME-2 measurements and retrieved by a convective cloud differential (CCD) algorithm. The stratospheric ozone column is estimated by vertical column above large convective clouds. The difference between the total column for cloud free observations and the stratospheric column equals the tropospheric column. One of the underlying assumption is that the stratospheric column does not vary with longitude for certain latitude bands. Due to this assumption this method can only be applied in the tropics (20°S to 20°N).

The results compare well with the ozone soundings from the SHADOZ network. The average bias between the tropospheric columns from the GOME observations and the ozone sondes is below 1 DU and the standard deviation is about 5 DU. For some stations the tropospheric columns deviated in the mean by less than 0.1 DU, only for the northern and southern most stations (Hanoi and Réunion island) average discrepancies of 5 DU and more were found.

The CCD tropospheric ozone shows similar distribution patterns as other satellite based tropospheric ozone products. In particular a comparison with the tropospheric ozone contained in the GOME-2 profile retrievals from RAL proves the good quality of both products.

For the non tropical regions a new product is under development. This tropospheric data results from the difference of GOME-2 total ozone column and AURA / MLS stratospheric column. It compares well with OMI/MLS and within the tropics also with CCD method.

With the current satellites the CCD tropospheric ozone data is provided on a grid of 2.5° longitudinal by 1.25° latitudinal and monthly averaged to get a reasonable signal to noise ratio. With the upcoming TROPOMI/S5P missions the spatial and temporal resolution of the CCD data might be significantly improved as it will be shown using sensitive analysis.

Accuracy of OMI Tropospheric NO₂ retrievals in the presence of Aerosols: how good is the Aerosol Correction based on a Cloud Model?

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Nitrogen oxides (NO_x = NO + NO₂) play a key role in tropospheric chemistry. They regulate amongst others the ozone level, the formation of nitrate aerosols and they are seen as indicators of air pollution in general. Global quantification of the atmospheric NO₂ amount is obtained through measuring the back-scattered sunlight within the UV-Vis spectral domain by satellite sensors at the top of the atmosphere. Often, the Differential

Optical Absorption Spectroscopy (DOAS) technique is used to derive Slant Column densities from reflectance spectra. Subsequent retrieval of the NO₂ tropospheric Vertical Column density requires the characterization of the geophysical conditions (surface properties, vertical distribution of trace gases particles, clouds, etc...) as they impact the length of the light path followed by the back-scattered sunlight. This is achieved by computing the tropospheric NO₂ Air Mass factor (AMF) with radiative transfer models.

The present operational NO₂ product (DOMINO v2, [Boersma et al., 2011]) from the Ozone Monitoring Instrument (OMI) on board the NASA EOS-AURA satellite, does not explicitly account for aerosol effects. Instead, the OMI cloud retrieval is applied also to cloud free scenes with aerosols and scenes where both clouds and aerosols are present. In other words: aerosols are treated as clouds, and both are modeled through the so-called effective cloud parameters.

These effective cloud parameters are then used to compute the tropospheric NO₂ AMF in presence of aerosols. The errors induced by this approach on the accuracy of the retrieved NO₂ columns are unclear. A study has been performed to understand in detail the net sensitivity of the effective cloud parameters to aerosols as well as the impact on the tropospheric NO₂ AMFs of assuming a Lambertian cloud model. A model vs. observations approach is followed by confronting the OMI tropospheric NO₂, clouds and MODIS aerosol products, and by characterizing the key drivers of the aerosol net effects, compared to a signal from clouds, in the UV-Vis spectra. Then, a comprehensive NO₂ error budget, related to effective cloud parameters can be obtained. This study focused on large industrialised areas like China.

In average, the DOMINO tropospheric NO₂ AMFs show that over China, in Summer time, a shielding effect is applied in the current NO₂ retrieval algorithms (i.e. the tropospheric NO₂ is implicitly assumed, in average, located below the cloud layer, which results in a decreased sensitivity to the gas absorption below the cloud particles layer). However, simulations based on TM5 NO₂ and aerosol profiles have demonstrated that the direct effect of aerosol particles on the NO₂ absorption (shielding effect or enhancement effect) depends actually on their optical properties and their altitude relative to the NO₂. These variables need to be combined to provide more insight into the exact influence that aerosols exert on cloud and trace gas retrievals.

The comparison of the OMI cloud and MODIS aerosol products indicates a strong correlation between the effective OMI cloud fraction and cloud top pressure values w.r.t. the aerosol amount (AOT). The OMI cloud retrieval [Acarreta et al., 2004] exploits the O₂-O₂ spectral range through the DOAS approach, assuming an opaque Lambertian cloud model. Simulated retrievals, based on the configuration of the operational OMI cloud chain as achieved at KNMI, show that the increase of the effective cloud fraction w.r.t AOT represents the net effect (scattering or absorbing) of aerosols on the continuum reflectance. Aerosol perturbation of the cloud fraction can reach 0.1 for AOT=1. The effective cloud pressure is derived from the O₂-O₂ absorption line at 475 nm. Aerosols contribute to a shielding effect on the O₂-O₂ slant column density: i.e. in the presence of aerosols, more photons are absorbed instead of being scattered back to the satellite sensor, and less absorption by O₂-O₂ is observed. This results in a decrease of the length of the light path and so of the retrieved cloud pressure (between 600 and 700 hPa for absorbing aerosols). The decrease of the effective cloud pressure w.r.t. AOT is sensitive to the effective cloud fraction value, and therefore to the amount of aerosols as well. Indeed, small effective cloud fractions (i.e. small AOTs) have little effects on the average light path; the effective cloud pressure stays then close to the ground pressure.

Finally, the implicit (based on retrieved effective cloud parameters in the O₂-O₂ spectral band) and explicit aerosol corrections are confronted through the related tropospheric NO₂ AMFs. This exercise is based on global TM5 simulations for the year of 2006. This allows then to quantify the tropospheric NO₂ biases induced by the presence of aerosols in the OMI observation pixels.

Evaluation of the effect of strong aerosol loads on satellite retrievals of tropospheric NO₂, SO₂ and HCHO using MAX-DOAS observations in Wuxi, China

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For the analysis of satellite observations of the tropospheric vertical column density (VCD) of trace gases (such as NO₂, SO₂ and HCHO), the air mass factor (AMF) is used and calculated by radiative transfer models. For these calculations input parameters like the observation geometry, atmospheric properties (e.g. air density, trace gas profiles, cloud and aerosol properties) and surface properties (e.g. terrain height and albedo) are needed. In particular, the effects of aerosols in the boundary layer on the AMF can be substantial in the polluted region, especially in many megacities of China, where the aerosol load is quite high and changes rapidly. However the aerosol effect on the AMF is not considered in the published products of tropospheric VCD of NO₂, SO₂ and HCHO from the Ozone Monitoring instrument (OMI), the Global Ozone Monitoring Experiment (GOME-2) and the Scanning Imaging Absorption spectrometer for Atmospheric Chartography (SCIAMACHY). In addition, the different layer heights of the trace gases, such as NO₂, SO₂ and HCHO because of their different sources and life time make the performance of the aerosol effect probably different with each other. To evaluate the effect of strong aerosol loads on the tropospheric VCDs of NO₂, SO₂ and HCHO, we use long-term (about four years) observations of the Multi-Axis-Differential Optical Absorption Spectroscopy observations in Wuxi, China. To minimise the influence of clouds we select clear days with either low or high aerosol load. On these days, we compare the tropospheric VCDs from different satellite instruments with those from MAX-DOAS observations. Further, the tropospheric vertical profiles of the trace gases and aerosol extinction derived from the MAX-DOAS observations are used as input for the radiative transfer simulations to calculate improved AMFs. The differences of the improved AMFs compared to the original AMFs indicate the effect of the aerosols and trace gas profiles on the retrieval of tropospheric trace gas VCDs.

Metop/IASI CH₄ profiles : Retrieval and Validation

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Methane (CH₄) is the second most important greenhouse gas contributing to human-induced climate change. It is produced at the surface by both natural (wetlands, termites, geological sources) and anthropogenic (rice agriculture, ruminants, mining...) processes. Although most sources and sinks of CH₄ have been identified, their relative contributions to atmospheric CH₄ levels are highly uncertain (Kirschke et al., 2013). Long-term monitoring of CH₄ is therefore of crucial importance and can provide important insight in estimating long-term trends of fluxes and concentrations.

The IASI instrument onboard the ESA MetOp platforms is the ideal candidate for long-term monitoring of climate variables. It has been providing data since 2006 and has demonstrated the ability to retrieve a series of chemistry and climate variables from thermal infrared data on both regional and global scales (Hilton et al., 2012). In addition, with the launch of three successive IASI-NG instruments starting from 2020, more than 20 years of observations will be added to the 15 years from IASI.

The Belgian Institute for Space Aeronomy (BIRA-IASB) has developed a IASI-CH₄ product retrieved with the ASIMUT radiative transfer and retrieval software (Vandaele et al., 2008). In this paper, we will analyze the quality of the retrieved IASI-CH₄ profiles by a comparison with the high precision ground-based TCCON measurements and airborne in-situ CH₄ observations. In addition, we will show first results from an comparison with the LMD mid-tropospheric IASI-CH₄ data product; work which is part of the ESA GHG-CCI project.

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Parallel Retrieval of Aerosol and Cloud

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Due to similarities in their radiometric signature, it is not possible to retrieve aerosol and cloud properties simultaneously from satellite imagery. A plethora of filtering techniques have been developed to ensure aerosol and cloud are analysed separately, but this neglects the scientifically interesting regions of interaction between the two. It also limits the spatial coverage of such products, with up to 20% of the planet neglected because it is considered too cloudy to be suitable for an aerosol retrieval but insufficiently so for a cloud retrieval.

The Optimal Retrieval of Aerosol and Cloud (ORAC) is a single algorithm that can retrieve the aerosol or cloud properties consistent with a single measurement. By performing radiative transfer calculations via look-up tables, various types of particle can be considered in parallel – such as liquid-phase cloud, different models of ice nuclei, and various clean and polluted aerosols – by simply running the program repeatedly using tables assuming different microphysical properties and vertical distributions. Bayesian statistics can determine the probability that the scene contains a specific species, classifying it as aerosol, cloud, or uncertain. The important but infrequently discussed 'uncertain' region can then be used to investigate the impact of contamination and data coverage on existing products by, for example, observing how retrieved aerosol optical thickness varies as a function of the distance from the nearest cloud. It also provides a potential window for the study of aerosol-cloud interactions.

Stratospheric Ozone Trends Derived From a 30 year Combined SAGE II and OSIRIS Time Series

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Stratospheric ozone profile measurements from the Optical Spectrograph and InfraRed Imager System (OSIRIS) instrument on the Odin satellite (2001–Present) are merged with those from the Stratospheric Aerosol and Gas Experiment (SAGE) II satellite instrument (1984–2005) to calculate decadal trends in stratospheric ozone between 60°S and 60°N. A multi-instrument, multi-decade, deseasonalized and merged stratospheric ozone record (1984–present) is produced by analyzing the measurements during the operational overlap of both satellites (2001–2005). The deseasonalized monthly time series is fit using linear regression with six non-linear predictor basis functions: three quasi-biennial oscillation proxies, the El Niño–Southern Oscillation index, a solar activity proxy, and the NCEP pressure at the tropical tropopause; and two linear trends: before and after 1997, which give the decadal trends in ozone. From 1984–1997, statistically significant negative trends of 5–10% per decade exist throughout the stratosphere (30–50 km). From 1997–present, statistically significant recovery rates of 3–8% per decade exist throughout most of the stratosphere. Below 22 km and between 40°S–40°N a negative trend is measured before and after 1997. The recovery is not significant in the tropical stratosphere between 25–35 km.

Validation of Retrieved Volcanic Ash Properties from the Infrared Atmospheric Sounding Interferometer (IASI)

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The Infrared Atmospheric Sounding Interferometer (IASI), on board both the MetOp-A and MetOp-B platforms, is a Fourier transform spectrometer covering the mid-infrared (IR) with a spectral resolution of 0.5cm^{-1} (apodised) and a pixel diameter at nadir of 12km. These characteristics allow global coverage to be achieved twice daily for each instrument and make IASI a very useful tool for the observation of larger aerosol particles (such as desert dust and volcanic ash) and the tracking of volcanic plumes.

In recent years, following the eruption of Eyjafjallajökull, interest in the the ability to detect and characterise volcanic ash plumes has peaked due to the hazards to aviation. The thermal infrared spectra shows a rapid variation with wavelength due to absorption lines from atmospheric and volcanic gases as well as broad scale features principally due to particulate absorption. The ash signature depends upon both the composition and size distribution of ash particles as well as the altitude of the volcanic plume.

An optimal estimation (OE) algorithm for the retrieval of volcanic ash properties has been developed for use with hyperspectral satellite instruments such as IASI, which analyses the brightness temperature spectra in the wavenumber range $680\text{--}1200\text{cm}^{-1}$. Initially, IASI pixels are flagged for the presence of volcanic ash using a linear retrieval detection method based on departures from a background state. Given a positive ash signal, the RTTOV output for a clean atmosphere (containing atmospheric gases but no cloud or aerosol/ash) is combined with an ash layer using the same scheme as for the Oxford-RAL Retrieval of Aerosol and Cloud (ORAC) algorithm. The retrieved parameters are ash optical depth (at a reference wavelength of 550nm), ash effective radius, plume altitude and surface temperature. A comprehensive error budget is also obtained for each pixel.

The use of different measurement error covariance matrices is explored, comparing the results from a sensitivity study of the retrieval process using covariance matrices trained on either clear-sky or cloudy scenes. The result exhibited that, due to the smaller variance contained within it, the clear-sky covariance matrix is preferable. However, if the retrieval fails to pass quality control tests, the cloudy covariance matrix is implemented.

The retrieval algorithm is applied to scenes from the Eyjafjallajökull eruption in 2010 and the Grimsvötn eruption in 2011 and the retrieved parameters have been validated against alternative sources: The plume altitudes are compared to derived cloud-top altitudes from the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) instrument and the effective radius is compared to aircraft measurements from the Facility for Airborne Atmospheric Measurements (FAAM).

Characterization and uncertainty budget of surface-based array spectrometers used for validation of satellite-derived trace gases

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The ESA funded project a pulsed tuneable laser system for the characterisation of spectrometers (ATLAS) aims at improving the accuracy of surface based networks based on array spectroradiometers that are widely used for satellite validation of various atmospheric products. The project has started on March 2015, has an initial duration of one ½ years and is coordinated by PMOD/WRC at Davos, Switzerland.

Ground-based measurements of solar radiation are a key requirement for the validation of remote-sensing atmospheric products from satellites (e.g. NO_2 , O_3 , Aerosols, e.t.c.). State-of-the-art systems consist of array spectroradiometers measuring spectral solar radiation in the UV-VIS-NIR range in order to determine a large range of parameters, from surface radiation to atmospheric composition products such as total and tropospheric concentrations of trace gases, as well as their profiles. In order to fulfil their role as reference

systems for the validation of satellite products, traceable surface-based measurements to the international system of units are required, including a comprehensive uncertainty budget based on an extensive characterisation of each measuring system. One key aspect in this chain is the radiometric characterisation of the optical system, including its stray-light characteristics and nonlinearities in order to produce correction functions for these parameters, as the quality and uncertainty of the measurements and of their derived atmospheric products is a direct consequence of the care taken in the characterisation and calibration of the whole system.

The quantification of the whole uncertainty budget requires a thorough radiometric characterisation of the measurement system which needs to be embedded in a comprehensive quality control and quality assurance system comprising the whole measurement chain starting from the initial characterisation and calibration in the laboratory, to the field measurement, and finally ending in the retrieval model required to determine the final product. More specific the project will use a tunable laser system in order to measure the stray light and linearity of spectroradiometers and to develop algorithms and post correction functions in order to deal with major instrumentation uncertainties such as stray light and linearity.

The scope of the project is to use the infrastructure and experience of PMOD-WRC in order to characterise two systems belonging to two different networks for surface based validation of atmospheric trace gases (Pandonia and Phaeton). This in order to demonstrate the inherent uncertainty improvements possible with such radiometric characterisations and their implications to satellite validation activities concerning past and future satellite missions.

Estimation of NO^x emissions from NO² hotspots in polluted background using satellite observations

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Satellite observations have been widely used to study NO_x emissions from power plants and cities, which are major NO_x sources with large impacts on human health and climate. The quantification of NO_x emissions from measured column densities of NO₂ requires information on the NO_x lifetime, which is typically gained from atmospheric chemistry models. But some recent studies determined the NO_x lifetime from the satellite observations as well by analyzing the downwind plume evolution; however, this approach was so far only applied for strong isolated “point sources” located in clean background, like Riyadh in Saudi Arabia.

Here we present a modified method for the quantification of NO_x emissions and corresponding atmospheric lifetimes based on OMI observations of NO₂, together with ECMWF wind fields, but without further model input, for hot spots located in polluted background. We use the observed NO₂ patterns under calm wind conditions as proxy for the spatial patterns of NO_x emissions; by this approach, even complex source distributions can be treated realistically. From the change of the spatial patterns of NO₂ at larger wind speeds (separately for different wind directions), the effective atmospheric lifetime is fitted. Emissions are derived from integrated NO₂ columns above background by division by the corresponding lifetime.

NO_x lifetimes and emissions are estimated for 19 power plants and 50 cities across China and the US. The derived lifetimes are 3.3 ± 1.2 hours on average with extreme values of 0.9 to 7.7 hours. The resulting very short lifetimes for mountainous sites have been found to be uncertain due to the potentially inaccurate ECMWF wind data in mountainous regions. The derived NO_x emissions show overall good agreement with bottom-up inventories.

Current status of ENVISAT ozone and temperature profile validation

van Gijsel, Anne; Stammes, Piet; VALID, Team

KNMI, Netherlands, The

The latest analysis results of the most recent processing algorithms for MIPAS, GOMOS and SCIAMACHY will be presented on this poster. The analyses are performed as part of the VALID CCN inside the Multi-TASTE phase F project in support of the algorithm developers and the quality working groups. For MIPAS, both full resolution and optimized resolution ozone and temperature profiles will be compared to collocated lidar profiles. Distinction will be made between day and nighttime observations. GOMOS ozone profiles as well as high resolution temperature profiles are also compared to lidar profiles and results will be grouped by star and observation characteristics. For SCIAMACHY, we will be looking at the comparison of ozone profiles of the operational processor with lidar ozone profiles. Special focus will be on the temporal stability to see if the new level 1b data improves the previously observed difference between scan directions.

The IUP Nadir Ozone Profile Retrieval as a Verification Algorithm for TROPOMI

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TROPOMI (TROPOspheric Monitoring Instrument) on Sentinel 5 precursor is expected to be launched in 2016. It is an imaging nadir spectrometer with a total swath width of 2600 km measuring radiances, irradiances and reflectances using 4 channels covering the wavelength ranges from 270 nm to 2385 nm with some gaps in between. Channel UV1 is split into two virtual channels. UV1-A (270-300 nm) has a spectral resolution of 1 nm and a spatial sampling of 21 x 28 km and UV1-B (300-320 nm) a spectral resolution of 0.5 nm and a spatial sampling of 7 x 7 km. Both virtual UV channels are used to retrieve ozone profiles using an optimal estimation retrieval with Tikhonov regularisation. This algorithm is one of two algorithms used to verify the operational ozone profile prototype algorithm and has been successfully applied to GOME (Global Ozone Monitoring Experiment), SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric Cartography) and GOME-2 (Global Ozone Monitoring Experiment-2). With the very high spatial resolution it will not only be possible to extend the time series of globally measured ozone further but also to investigate processes occurring on very small scales.

In addition to highlighting the key differences between the IUP ozone profile retrieval algorithm and the prototype algorithm, results from the verification under-way will be shown. These results will include comparisons from linear retrievals using a limited set of test scenarios and comparisons from non-linear retrievals both including estimated sub-column errors and the expected contribution of the expected maximum noise to these.

Furthermore the performance of the IUP retrieval when applied to real data will be shown by comparisons of GOME, SCIAMACHY and GOME-2 with ozonesonde and lidar measurements.

SCIAMACHY: Impact of calibration changes on SCIAMACHY CH₄ and CO retrievals

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SCIAMACHY (SCanning Imaging Absorption spectroMeter for Atmospheric CHartography) was a scanning nadir and limb spectrometer covering the wavelength range from 212 nm to 2386 nm in 8 channels. It is a joint project of Germany, the Netherlands and Belgium and was launched in February 2002 on the ESA's ENVISAT platform. After the platform failure in April 2012, the space Agencies continue to support the operational

product evolution in the frame of the SCIAMACHY Quality Working Group and Expert Support Laboratory.. Note that SCIAMACHYs originally specified in-orbit lifetime was twice the planned lifetime.

The instrument was designed to measure column densities and vertical profiles of trace gas species in the troposphere, in the stratosphere and in the mesosphere (Bovensmann et al., 1999). It can detect a wide range of trace gases and can provide information about aerosols and clouds. For the next Level 1 processor several improvements that concern the SWIR products CH₄

and CO are planned like a better dark correction, an improved spectral calibration and a better bad pixel mask. Using the BIRRA (the Beer InfraRed Retrieval Algorithm) retrieval scheme which is also the basis of the operational processing, we will analyse the impact of the various Level 1 improvements on the CH₄ and CO products. The results of this sensitivity study will be shown in this contribution.

Results from the second SPARC water vapour assessment (WAVAS II) on satellite data quality

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Water vapour is one of the most important trace constituents of the Earth's atmosphere and plays a fundamental role in the climate system. The second SPARC water vapour assessment on satellite quality focuses on the observations that have become available since the start of the new millennium. Overall more than 30 data sets from 15 individual instruments are considered. They are compared in comprehensive way ranging from profile-to-profile comparisons to comparison of climatologies and time series. Besides that secondary parameters as tropopause ascent rates or amplitudes of various variability patterns are compared. Here the latest results will be presented and the quality of the current set of data discussed.

Improved Ozone and Carbon Monoxide Profile Retrievals Using Multispectral Measurements from NASA "A Train", Suomi-NPP, and TROPOMI Satellite Instruments

Fu, Dejian [1]; Bowman, Kevin [1]; Kulawik, Susan [1,2]; Worden, John [1]; Luo, Ming [1]; Veefkind, Pepijn [3]; Luo, Ming [1]; Aben, Ilse [4]; Landgraf, Jochen [4]; Flynn, Lawrence [5]; Yong, Han [5]; Liu, Xiong [6]; Worden, Helen [7]; Strow, Lawrence [8]

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Tropospheric ozone is at the juncture of air quality and climate. Ozone directly impacts human health, is a phytotoxin that undermines carbon uptake, and directly forces the climate system through absorption of thermal radiation. Carbon monoxide is a chemical precursor of greenhouse gases CO₂ and tropospheric O₃, and is also an ideal tracer of transport processes due to its medium life times (weeks to months).

The Aqua-AIRS and Aura-OMI instruments in the NASA "A-Train", CrIS and OMPS instruments on the NOAA Suomi-NPP, IASI and GOME-2 on METOP, TROPOMI aboard the Sentinel 5 precursor (S5p) have the potential to provide the synoptic chemical and dynamical context for ozone necessary to quantify long-range transport at global scales and as an anchor to the near-term constellation of geostationary sounders: NASA TEMPO, ESA Sentinel 4, and the Korean GEMS. We introduce the JPL Multi-Spectral, Multi-Species, Multi-Satellite (MS)³ retrieval algorithm, which ingests panspectral observations across multiple platforms in a non-linear optimal estimation framework. It incorporates the advances in remote sensing science developed during EOS-Aura era including rigorous error analysis diagnostics and observation operators needed for trend analysis, climate model evaluation, and data assimilation. Its performances have been demonstrated through prototype studies for multi-satellite missions (AIRS, CrIS, TROPOMI, TES, OMI, and OMPS). We present the preliminary joint tropospheric ozone retrievals from AIRS/OMI and CrIS/OMPS, and demonstrate the potential of joint carbon monoxide profiles from TROPOMI/CrIS. These results indicate that ozone can be retrieved with ~2 degrees of freedom for signal (dofs). The joint ozone retrievals are closer to ozone retrieved from the NASA Tropospheric Emission Spectrometer than any single instruments retrievals. Joint CO profiles have a dofs similar to the

MOPITT multispectral retrieval. Consequently, multispectral retrievals show promise in providing continuity with NASA EOS observations and paving the way towards a new advanced atmospheric composition constellation.

Internal Gravity Wave Activity Hotspot and Implications for the Middle Atmospheric Dynamics

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Internal gravity waves are widely recognized to contribute significantly to the energy and angular momentum transport. They play significant role in affecting many of the middle atmospheric phenomena (like QBO or Brewer-Dobson circulation). Using the GPS RO density profiles, we have discovered a localized area of enhanced IGW activity and breaking in the lower stratosphere of Eastern Asia/North-western Pacific region.

With a mechanistic model for the middle atmosphere we studied the effects of such a localized breaking region on a large-scale dynamics and transport. Possible formation and propagation directions of planetary waves caused by such a localized forcing were investigated and consequences for the polar vortex stability and stratosphere-troposphere exchange in the tropical region were discussed.

Finally, applying 3D EP flux and 3D residual circulation diagnostics, we investigated possible role of this area in longitudinal variability of the Brewer-Dobson circulation with a hypothesis of its enhanced downwelling branch in this region. In the process, model results were compared with the ozone and tracer distribution data from GOME, GOMOS, MIPAS and SCIAMACHY instruments further confirming the importance of the Eastern Asia/North-western Pacific region for middle atmospheric dynamics.

SIROCCO, a study on retrievals of CO and CH₄ in the atmospheres of Earth and Mars

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1: NOVELTIS, France; 2: ULB, Brussels, Belgium; 3: IASB-BIRA, Brussels, Belgium; 4: SRON, Leiden, the Netherlands; 5: IAPS, Rome, Italy; 6: ESA/ESTEC, Noordwijk, the Netherlands

The SIROCCO (Synergistic IR Retrieval Of CO and CH₄ Observations) study was performed under ESA guidance by a consortium led by NOVELTIS and including four partners: ULB (Belgium), IASB-BIRA (Belgium), SRON (Netherlands) and IAPS (Italy). The goal of the study was to review in a multidisciplinary context (Earth Observation and Planetary Science) the status of existing retrieval algorithms and to extend their capabilities by exploiting instrument synergies when applied to remote sensing data collected (or to be collected in the near future) by instruments in orbit around the planets Earth and Mars, with atmospheric carbon monoxide (CO) and methane (CH₄) as specific targets. A special focus was placed on spectral and/or geometrical synergies for deriving the near-surface concentrations of these two species (i.e. getting information on the atmospheric region called the planetary boundary layer or PBL). This specific objective is related to the detection and quantification of CO and CH₄ sources which are located at the surface, but which impact (through atmospheric transport and photochemical processes) the composition of the global atmosphere of these two sister planets of our solar system.

An overall review of the tasks covered in this project will be presented. In the first one, the existing requirements, algorithms and data sets related to the retrieval of CO and CH₄ in the atmospheres of the two planets have been reviewed. In a second task, specific algorithms have been selected as effectively running at the academic institutes participating in the study. The satellite data sets (Level 1 or L1 products i.e. spectra) available for testing the retrieval algorithms have been identified and collected (in some cases with a pre-processing as the spectral calibration of GOSAT spectra performed by NOVELTIS). The correlative

measurements (other satellites, aircraft and ground-based stations) appropriate for validating the retrieved concentrations (Level 2 or L2 products) have also been chosen and collected. A third task was devoted to real retrievals and comparison exercises and have been separated by planet (Earth and Mars) and by type of retrieval (stand alone or non-synergistic and synergistic). Indeed for getting the best information on the full atmospheric profile of the target species (including their concentration in the PBL) it is expected that the combination (at the input of the inversion process) of L1 information originating from different sensors could be more efficient to generate reliable L2 products, than the separate generation of L2 products (total column, partial columns or sub-columns, profiles) with their strength and weaknesses. Many of the possible spectral L1/L1 or L1/L2 synergies have been studied: L1(TIR,GOSAT)/L1(SWIR,GOSAT) or L1(TIR,IASI-NG)/L1(SWIR,S5) for Earth, L1(TIR,PFS)/L2(TIR T(z),PFS) or L1(SWIR,NOMAD)/L1(SWIR,ACS) for Mars. Remaining difficulties have been identified for CH₄ (with recommendations to solve them), but promising results have been obtained both for CO and CH₄ and for both planets, an additional demonstration of the benefit of the cross-fertilisation resulting from this ESA sponsored study. A synthesis of the main results obtained for Earth will be presented, as more specific results will be covered during this conference by other members of the SIROCCO consortium.

Broadband surface solar irradiance derived from satellite measurements of effective cloud fraction

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Surface solar irradiance (SSI) is an important component of the surface energy budget. Measuring SSI from satellites is therefore needed as one element in the monitoring of climate change from space. We have developed a method to estimate broadband surface solar irradiances (0.2 - 4 μm) from effective cloud fraction measurements by SCIAMACHY on ESA's Envisat satellite (2002-2012) and OMI on the NASA Aura satellite (2004-present).

The SSI retrieval algorithm is based on the Heliosat method in which the cloud index is replaced by the effective cloud fraction. The effective cloud fraction is retrieved from SCIAMACHY using the FRESCO 02 A-band algorithm and from OMI using the 02-02 algorithm, respectively. The MAGIC (Mesoscale Atmospheric Global Irradiance Code) algorithm is used to calculate the clear-sky SSI.

The SSI products have been validated against the globally distributed BSRN (Baseline Surface Radiation Network) measurements and compared with the ISCCP-FD (International Satellite Cloud Climatology Project Flux Dataset) surface shortwave downwelling fluxes. The SCIAMACHY and OMI SSI show good agreement with BSRN and ISCCP radiation products. These SSI products are available from the TEMIS website, www.temis.nl. Since the FRESCO effective cloud fraction will also be processed for TROPOMI on Sentinel-5P, the SSI product can also be derived from TROPOMI.

ESA Earth Explorer 8 Candidate Mission CarbonSat: Error Budget for Atmospheric Carbon Dioxide and Methane Retrievals

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CarbonSat is one of two candidate missions for ESA's Earth Explorer 8 (EE8) satellite, one of them to be launched around 2022. The primary atmospheric data products of CarbonSat are near-surface-sensitive column-averaged dry-air mole fractions of CO₂ and CH₄, i.e., XCO₂ and XCH₄. These products will be used to generate higher level source/sink data products via inverse modelling such as regional-scale surface fluxes of CO₂ and CH₄ and emissions of localized CO₂ and/or CH₄ emission sources such as cities, power plants, volcanos and oil

and gas fields. In order to minimize XCO₂ and XCH₄ retrieval errors it is important to simultaneously retrieve information on aerosols and clouds, Vegetation Chlorophyll / Solar Induced Fluorescence (VCF/SIF) and other atmospheric and surface parameters in addition to XCO₂ and XCH₄. VCF/SIF will be a secondary product of CarbonSat to be used to maximize the information on terrestrial vegetation carbon fluxes. A retrieval algorithm is used to retrieve these parameters from the CarbonSat spectral observations. Whereas CO₂ and methane information stems from near-infrared/shortwave-infrared (NIR/SWIR) spectral regions located at 1.6 and 2 micro-meter, VCF/SIF will be retrieved from clear solar Fraunhofer lines located around 755 nm. Atmospheric scattering information will mainly be provided by the strong O₂-A absorption band and the strong absorption bands of H₂O and CO₂ located around 2 micro-meter. The CarbonSat CO₂ and methane source/sink applications require high precision and accuracy. Random and systematic errors of the retrieved data products are expected to result from various geophysical, instrument related and other error sources. Using the latest specification of CarbonSat and the latest version of the retrieval algorithm we present an error budget focusing on XCO₂ and XCH₄ errors for CarbonSat nadir mode observations over land. This includes updates of error estimates for cloud and aerosol related XCO₂ and XCH₄ errors and the estimation of various instrument related errors such as errors due to inhomogeneous scenes and radiometric errors caused by various error sources such as residual polarization related errors.

The operational Near-Real-Time Total Ozone Retrieval Algorithm for GOME-2 on MetOp-A & MetOp-B and perspectives for TROPOMI/S5P

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The Montreal Protocol and its amendments were designed to reduce the production and consumption of ozone depleting substances and thereby introducing a gradual recovery of the Earth's fragile ozone layer. However, the exact timing of the expected ozone recovery and the inter-relationship between the ozone layer and on-going climate change are still under investigation. Therefore, long-term satellite total ozone datasets of high accuracy and stability are essential for monitoring the evolution of the stratospheric ozone layer.

The TROPOMI (Tropospheric Monitoring Instrument) is the payload instrument for the Sentinel 5 Precursor (S5P) mission which will provide atmospheric composition products including ozone during the time frame from 2016 to 2022. It will consequently extend the data record initiated with GOME/ERS-2 and continued with the SCIAMACHY/ENVISAT, OMI/AURA and GOME-2/MetOp missions.

Here we present the Near-Real-Time (NRT) TROPOMI/S5P total ozone retrieval algorithm which is based on the "DOAS-style" GOME Data Processor (GDP) algorithm Version 4.x. The DOAS technique for total ozone retrieval was deployed from the start of the GOME/ERS-2 mission in 1995 and is currently being used for the generation of the ESA SCIAMACHY and EUMETSAT O3M-SAF GOME-2 operational products. The enhancements in GDP 4.8 (the latest version of the GDP 4.x algorithm) are described first, and then we present the Global validation results for GOME-2/MetOp-A (GOME-2A) and GOME-2/MetOp-B (GOME-2B) total ozone measurements using Brewer and Dobson measurements as references. It is concluded that total ozone columns (TOCs) retrieved from GOME-2 using GDP 4.8 show very good agreement with ground-based measurements. TOCs from GOME-2A and GOME-2B are consistent with each other and may be used simultaneously without introducing trends or other systematic effects.

One of the major challenges for the operational processing of TROPOMI/S5P measurements is the high data rate - two orders of magnitude more data than that from GOME-2. Here we discuss performance enhancements of the retrieval algorithms such as the development of an acceleration method for Radiative Transfer Model (RTM) simulations.

GOME-2A and GOME-2B total ozone data have been used operationally in the Copernicus atmospheric service project MACC-II/III (Monitoring Atmospheric Composition and Climate - Interim Implementation) NRT system since October 2013 and May 2014 respectively. It is expected that the follow-on Copernicus Atmosphere Monitoring Service (CAMS) project will use NRT TROPOMI/S5P in addition to GOME-2 total ozone data.

Improved correction for contamination-induced in-flight instrument degradation of SCIAMACHY

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SRON Netherlands Institute for Space Research, Netherlands, The

As reported earlier, SCIAMACHY suffers from degradation due to contamination of the scan mirror surfaces and diffuser surface, among others.

We have improved the polarisation and degradation description of the instrument as well as the optical ground support equipment used for initial on-ground instrument calibration. This allows for a consistent model of the instrument for both on-ground and in-flight conditions, and for arbitrary amounts of contamination of the instrument. Using this model we have re-analysed the in-flight calibration and monitoring data to arrive at an improved description of the throughput and polarisation sensitivity of SCIAMACHY, for any time during its mission. We present the results and a selection of validation measurements.

The IGAC/SPARC Chemistry Climate Model Initiative (CCMI): What is it? How can ESA help?

Young, Paul

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CCMI is an international global atmospheric modeling project, organized under the auspices of both IGAC and SPARC. Its goal is improved understanding of processes driving recent and future changes in tropospheric and stratospheric composition, including how these two regions interact, and how their composition is coupled with climate. A crucial feature of CCMI is that it is giving central involvement to measurement and data scientists, as well as the modelers. This brings in dedicated expertise, and provides a deeper interpretation and understanding of model and observational data, and more opportunities to progress the science. In addition, the entire research community – including measurement and data scientists – was involved in suggesting sensitivity studies and specifying model output.

The core of CCMI is a series of chemistry-climate model simulations, covering 1960 to 2100. Many modeling groups have already completed the hindcast experiment (1960-2010) and the first phase of multi-model analyses are about to get underway. For the troposphere, for example, the community identified three broad research areas for CCMI to make progress in: (1) understanding long-term trends and variability in tropospheric ozone, (2) exploring links between chemical constituents and climate variability, and (3) a deep exploration of the drivers of the hydroxyl radical (Eyring et al., 2014).

Tackling these questions (and others) will require collaboration between modelers and observational scientists, using a variety of data from a variety of platforms, combining measurements in novel ways (e.g. species ratios, cluster analysis, exploring the frequency domain). It is in this area that CCMI hopes to engage the ESA community: defining research questions, exploiting rich and varied datasets, identifying new data needs, and making progress on the science.

For more information on CCMI, see <http://www.met.reading.ac.uk/ccmi/>

References

Eyring et al. (2014), Report on the IGAC/SPARC Chemistry-Climate Model Initiative (CCMI) 2013 Science Workshop, SPARC Newsletter No. 42.

Tropospheric Ozone Monitoring with IASI/MetOP Using a Self-Adapting Regularization Method

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Tropospheric ozone is a key species for tropospheric chemistry and air quality. Its monitoring is essential to quantify sources, transport, chemical transformation and sinks of atmospheric pollution. Accurate data are required for understanding and predicting chemical weather. Space-borne observations are very promising for these concerns, especially those from IASI/MetOp. However, their sensitivity near the surface remains limited and advanced retrieval methods are needed to access to the information from the lowest troposphere.

Ill-conditioning is a well-known issue of the retrieval of vertical atmospheric profiles. It produces oscillations in the retrieved profiles beyond the error margins defined by the mapping of the measurement noise onto the solution. Tikhonov regularization is often used to improve the conditioning of the inversion. As for any regularization scheme, a crucial step is the choice of the strength of the applied constraint. This choice depends on the measurement errors and on the sensitivity of the measurements to the target parameters at the different altitudes. For this reason a self-adapting and altitude-dependent regularization scheme is likely preferable over a fixed strength determined apriori, on the basis of sensitivity tests. Such a scheme was already introduced in 2009 and applied to atmospheric profiles retrieved from MIPAS/ENVISAT.

The implementation of this method on nadir IASI retrievals required the appropriated definition of the target function used to optimize the constraint for lower tropospheric retrievals. The challenge for this new retrieval algorithm is to limit the use of a priori constraints to the minimal amount needed to perform the inversion. Since the sensitivity of the observations to the ozone amount in the lowest layers depends on the atmospheric and surface conditions, it is crucial for the inversion algorithm to tune accordingly the contribution of the a priori information.

We apply the method first on simulated observations of tropospheric ozone for August 20th, 2009 over Europe. A first evaluation of the method is discussed in the paper. Significant improvements in terms of degrees of freedom (DOF) for the solution are achieved with a 15% increase on average. The error estimate during the retrieval is in better agreement with the true error, calculated as the difference between the retrieved ozone and the true ozone. The spatial distribution and the dispersion of the error are better described. Finally, a first attempt to apply the method to actual IASI measurements is presented.

Validation of GOME-2A and GOME-2B Ozone Profiles and Tropospheric Ozone Column Products

Delcloo, Andy [1]; Tuinder, Olaf [2]; Loyola, Diego [3]; Valks, Pieter [3]

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Respectively more than eight and two years of GOME-2A- and GOME-2B ozone profiles- and tropospheric ozone column data have been processed at KNMI and DLR.

GOME-2 vertical ozone profiles are given as partial ozone columns [in DU per layer] between varying pressure levels (40 levels between surface and 0.001 hPa). The ozonesonde data has a vertical resolution of about 100 m and is measuring ozone from the surface up to about 30 km. To validate the satellite derived ozone layers with the ozonesonde data, we integrate the ozone measured by the balloon ozone soundings between the corresponding GOME-2 pressure levels.

GOME-2A and GOME-2B ozone profile data was made available by KNMI at pre-selected sites. The reference data includes a global coverage of ozonesonde stations. We take into account the GOME-2 averaging kernels in our analysis to smooth the ozonesonde data towards the resolution of the satellite data. We will discuss the degradation of the GOME-2A instrument and its influence on the ozone profile product and make a comparison with the updated GOME-2B high resolution ozone profile product.

Validation results from the tropospheric ozone column products from GOME-2A and GOME-2B will be shown. To verify if the accuracy is within predefined error bounds given by user requirements, the tropospheric column values will be validated against ozonesonde data. Validation needs to establish the tropospheric ozone column accuracy for the complete range of observing and geophysical conditions that may affect it. Observing conditions include viewing and solar angles, instrument settings.

These GOME-2A and GOME-2B tropospheric ozone column data will be made available by DLR and KNMI in the framework of the O3M-SAF project. It includes further development and improvement of the CCD and cloud-slicing method for GOME-2, residual method using GOME-2 ozone profile and total column products and tropospheric column from GOME-2 ozone profile retrieved with total column constraint.

Assessment of GOMOS stratospheric aerosol extinction coefficients retrieved from the AerGom algorithm using contemporaneous satellite experiments

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AerGom, a stratospheric aerosol retrieval algorithm dedicated to the GOMOS experiment, enhances the quality of the official retrieval due to the extension of the spectral range used, a refinement of the aerosol spectral parameterisation, the simultaneous inversion of all atmospheric species as well as an improvement of the Rayleigh scattering correction. The retrieval algorithm allows for a good characterisation of the stratospheric aerosol extinction for a wide range of wavelengths.

In this work, we present the results of stratospheric aerosol extinction comparisons between AerGom and various spaceborne instruments (SAGE II, SAGE III, POAM III, ACE-MAESTRO and OSIRIS) for different wavelengths. Due to the unique observational technique of GOMOS, some of the results appear to be dependent on the star occultation parameters such as star apparent temperature and magnitude, solar zenith angle, latitude and obliquity. A systematic analysis is therefore carried out to identify biases in the dataset, using the various spaceborne instruments as reference. This bias characterization is extremely important for data users and might prove valuable for the production of unbiased long-term merged dataset.

An Instrument Independent Radiance Soft Calibration as a Tool for the Validation of Measured UV Radiance

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The monitoring of the state of calibration of any space borne spectrometer is highly important for a number of trace gas retrievals. Particularly retrievals using absolute radiances are susceptible to changes in the spectral calibration. One such algorithm is the optimal estimation based retrieval of ozone profiles from UV nadir sun-normalised radiances. In order to improve the performance the IUP (Institute of Environmental Physics, Bremen) nadir ozone profile retrieval, which depends primarily on absolute sun-normalised radiances, an instrument independent soft calibration has been set up at the IUP for GOME (Global Ozone Monitoring Experiment), SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric ChartographY) and GOME-2 (Global Ozone Monitoring Experiment-2). This soft calibration can be used to recalibrate radiances relative to pre-launch as well as calibrating radiances relative to post-launch by using simulated radiances assuming a reasonable state of the atmosphere and calculating ratios between measured and simulated

radiances. These comparisons are conducted over ocean and land ice using both dark and bright surfaces. The soft calibration is a useful tool to measure and evaluate degradation and degradation corrections implemented. As such it is used as a part of the GOME-Evolution project to validate the reprocessed reflectances in the UV channels 1A (237 nm – 307 nm), 1B (307 nm – 315 nm) and 2 (312 nm – 406).

In addition to an overview of the methodology of the radiance soft calibration its results will be shown GOME, SCIAMACHY and GOME-2. The effects of the soft calibration on ozone profiles retrieved using the IUP nadir ozone profile retrieval will be shown in comparisons with ozonesonde and lidar measurements. Furthermore preliminary results from the validation of the newly processed GOME level 1c radiances will be shown.

Updated HICRU Cloud Fraction Retrieval to Comply with Satellite Instruments Featuring Large Viewing Angles

Sihler, Holger; Beirle, Steffen; Hörmann, Christoph; Penning de Vries, Marloes; Wagner, Thomas

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Clouds play an important role in meteorology and climate. Furthermore, by altering the measurement sensitivity, clouds strongly affect satellite measurements of tropospheric trace gases relevant to environmental and climatological issues. The accuracy of tropospheric trace gas retrievals depends on the availability and accuracy of the cloud information. Especially for small cloud fractions, the accuracy of the the cloud fraction information is crucial.

The HICRU Iterative Cloud Retrieval Utilities (HICRU) algorithm has been specifically developed for the retrieval of small cloud fractions at high accuracy. This is achieved by inferring a ground albedo map from the dataset itself, minimising the influence of instrument degradation and/or insufficient calibration. HICRU thus requires a minimum of a-priori knowledge. So far, this approach is limited to measurements at sufficiently small viewing angles, such as from GOME and SCIAMACHY, for which the use of a single, viewing-angle independent background albedo map is justified. In this presentation, we demonstrate how this empirical approach may be extended to satellite instruments like GOME-2 and OMI, with viewing angles up to ± 45 or even ± 70 degrees, by parametrising the viewing angle dependence of the TOA reflectance. The presented work is part of the Sentinel-5 Precursor/TROPOMI verification activities.

Validation of SCIAMACHY cloud height products using ground-based Cloudnet observations

Wang, Ping; Stammes, Piet

KNMI, Netherlands, The

The FRESKO algorithm is a fast cloud retrieval algorithm using reflectances inside and outside the O2 A-band at 760 nm. The SCIAMACHY FRESKO cloud product, consisting of effective cloud fraction, cloud (mid-)pressure and broadband surface solar irradiance, is available on the TEMIS website (www.temis.nl) for the whole SCIAMACHY mission period (2002-2012). SCIAMACHY ESA Level 2 cloud top height product is also derived from the O2 A band by using the SemiAnalytical Cloud Retrieval Algorithm (SACURA). The two SCIAMACHY cloud height products have been validated using the ground-based Cloudnet observations at Cabauw and Lindenberg for the whole SCIAMACHY ten-year period.

Cabauw and Lindenberg are two Cloudnet sites where cloud and aerosol vertical profiles are measured at high temporal and vertical resolutions from groundbased lidar and radar. The cloud profiles are averaged for 1 hour centered at SCIAMACHY overpass time to make an optimal time-location match. In total we got about 650 collocated cases. The FRESKO cloud height and ESA L2 cloud top height are compared with lidar/radar cloud products for single-layer clouds and multi-layer clouds, respectively. The validation shows that for single layer clouds below 4 km, FRESKO retrievals have good agreement with the lidar/radar cloud top height; for high clouds, FRESKO cloud height is more close to the middle of the clouds. The ESA L2 cloud top height has good agreement with the Cloudnet cloud top height for middle-level clouds.

The FRESCO algorithm for SCIAMACHY is the same as that used for GOME-2 in the L1 product and in the O3M SAF of EUMETSAT. The FRESCO algorithm will also be applied to TROPOMI measurements.

A 30 year record of stratospheric aerosol from merged OSIRIS and SAGE II measurements

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We present a consistent 30 year record of zonally averaged stratospheric aerosol optical depth and extinction profiles through the development of a merging technique for SAGE II and OSIRIS measurements. Coincident measurement from the two instruments are shown to agree to within typically 10% throughout the aerosol layer, after conversion of the OSIRIS version 5.07 product at 750 nm to 525 nm, which is measured by SAGE II (version 7.0). The four year overlap between the missions is used to derive scaling factors for merging of the two time series from the probability distributions of the extinction measurements as a function of latitude and altitude. The resulting record is compared to other records that have been used in recent study to investigate the impact of the climate effects of increases in the stratospheric aerosol optical depth. Additionally, although study of the aerosol load in the UTLS is difficult with OSIRIS due to cloud contamination, this record shows that up to half of the aerosol load can occur below 15 km altitude, especially at higher latitudes, which is consistent with recently reported results from ground based observations.

Carbon dioxide observation from IASI and comparison with TANSO-FTS

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The ESA research project "Application of KLIMA Algorithm to CO₂ Retrieval from IASI/METOP-A Observations and Comparison with TANSO-FTS/GOSAT Products" aimed to develop a dedicated software, based on the KLIMA inversion algorithm (originally proposed by IFAC-CNR for the 6 cycle of ESA Earth Explorer Core Missions), suited for CO₂ retrieval and integrated into the ESA grid-based operational environment Grid Processing On-Demand (G-POD) to process Level 1 data acquired by the infrared atmospheric sounding interferometer (IASI) and to perform a comparison with Thermal And Near-infrared Sensor for carbon Observation Fourier Transform Spectrometer (TANSO-FTS), on board of the Greenhouse gases Observing SATellite (GOSAT), Level 2 data.

In order to obtain a reasonable capacity to bulk processing IASI data, we choose to integrate the KLIMA code into the G-POD system. For this reason, we investigated an optimized version of the KLIMA algorithm, aiming at developing a nonoperational retrieval code with adequate features for the integration on the G-POD system. The optimized version of KLIMA retrieval code has been completed and integrated on the G-POD operational environment and is available for bulk processing of IASI data. Using the KLIMA inversion code integrated into the ESA G-POD, it was possible to perform an extensive comparison of a selected set of IASI measurements collocated with TANSO-FTS observations. We performed an extensive comparison of the column-average CO₂ dry air mole fraction (XCO₂) retrieved from IASI measurements by using the KLIMA/G-POD inversion code with the operational Level 2 products from collocated TANSO-FTS observations. In this work, we show the results of this activity.

Energetic Particle Precipitation Indirect Effect During the Arctic Winter 2012/2013: Odin/SMR vs. WACCM-SD

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Energetic Particle Precipitation (EPP) refers to the process by which energetic protons and electrons affect the Earth's atmosphere. It is an important source of ionization in the polar mesosphere and lower thermosphere, leading to the formation of nitric oxide (NO). During polar winter, EPP-generated NO can be transported downward into the lower mesosphere and the stratosphere by the meridional circulation, where it can affect the ozone concentration. This solar-terrestrial coupling mechanism is called the EPP indirect effect (EPP-IE). It is observed every winter in both hemispheres. In the Northern Hemisphere (NH), the high dynamical variability makes its representation in current atmospheric models particularly challenging. Much less NO is generally transported down to the stratosphere in the simulations than what is actually seen in the observations. We are investigating these deficiencies by comparing NO mixing ratios observed by Odin/SMR with NO mixing ratios simulated by WACCM-SD. The Sub-Millimetre Radiometer (SMR) onboard the Odin platform, launched in 2001, is a limb emission sounder measuring trace gases in the middle atmosphere. Odin is a Swedish-led satellite project which is part of the ESA third party mission programme. SMR observations are compared with simulations by the NCAR Whole Atmosphere Community Climate Model with Specified Dynamics (WACCM-SD), which are constrained by meteorological reanalyses below 1hPa.

This paper is focused on the NH winter 2012/2013, which was characterized by an unusually strong NO descent due to a high dynamical activity (major stratospheric warming followed by an elevated stratopause event) and to a relatively high geomagnetic activity. That makes this event a very good example to study the EPP-IE. This detailed comparison study helps to clearly characterize the deficiencies of the model in order to improve the understanding of the impact of EPP on the atmosphere.

EVDC - ESA Validation Data Centre

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Introduction: The ESA Validation Data Centre (EVDC) is the official ESA repository for validation and campaign dataset.

EVDC is built to assist ESA and scientists with archival and exchange of correlative data for validation of Earth Observation of satellite instrument atmospheric composition products and provides the final archive for the data. EVDC builds on the previous ENVISAT Cal/Val database system in operation at NILU since the early 2000s, and includes tools for extraction, conversion and archival of a large amount of EO data.

Thanks to the EVDC project on behalf of ESA, the system is now in preparation for future satellite missions such as Sentinel-5P and ADM-Aeolus. An advantage with using EVDC is the possibility of sharing data within the campaign consortium – both during the campaign and in the analysing phase, the portal can be easily expanded to support new campaigns and missions.

Method: To facilitate exchange of validation data among investigators and missions a common effort between the GEOMS group that consists of representatives of NASA, ESA, the NDACC and related universities and organizations, has led to a set of harmonized guidelines, The Generic Earth Observation Metadata Standard (GEOMS) guidelines. EVDC is fully compatible with GEOMS. Through collaboration with the ECMWF, EVDC is providing access to daily updated analyses and forecast data files of global gridded meteorological parameters.

Results: EVDC provides a final archive for the data and has several 100s of users from all over the world. Data originates from a wide range of measurements principles and atmospheric disciplines like e.g. LIDAR, RADAR, uv-vis and spectrometer data from multiple sensors, including aircraft, balloon and ground based platforms,

uploaded to EVDC on a daily basis. An important part of the EVDC operation is provision of user support and advisory to data managers on how to archive data and what types of data they should store. The EVDC web pages include search and browse functionalities for atmospheric data, data upload and download facilities, documents, links and access to ECMWF data and plots, and other user relevant information.

Discussion & Conclusion: EVDC provides the final archive for the data. EVDC offers easy access to a wide range provision of user support and advisory to data managers on how to archive data and what variables they should store.

Development and characterisation of a state-of-the-art GOME-2 formaldehyde air-mass factor algorithm

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Space-borne observations of formaldehyde (HCHO) are frequently used to derive surface emissions of isoprene, an important biogenic volatile organic compound. The conversion of retrieved HCHO slant column concentrations from satellite line of sight measurements to vertical columns is determined through application of an air mass factor (AMF), accounting for instrument viewing geometry, radiative transfer, and vertical profile of the absorber in the atmosphere. This step in the trace gas retrieval is subject to large errors.

We present the AMF algorithm in use at the University of Leicester (UoL), which introduces scene specific variables into a per-observation full radiative transfer AMF calculation, including increasing spatial resolution of key environmental parameter databases, input variable area weighting, instrument specific scattering weight calculation, and inclusion of an ozone vertical profile climatology.

Application of these updates to HCHO slant columns from the GOME-2 instrument is shown to typically adjust the AMF by $\pm 10\%$, compared to a reference algorithm without these advanced parameterisations. Furthermore, the new UoL algorithm also incorporates a full radiative transfer error calculation for each scene to help characterise AMF uncertainties. Global median AMF errors are typically 50–60%, and are dominated by uncertainties in the HCHO profile shape and its corresponding seasonal variation.

Impact of Spectroscopic Line Data on Carbon Monoxide Column Density Retrievals from Shortwave Infrared Nadir Observations

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Among the various input data required for retrieval of atmospheric state parameters from infrared remote sensing observations molecular spectroscopy line data have a central role, because the data quality is critical for the quality of the retrieval product.

Here we discuss the impact of the line parameters on vertical column densities (VCD) estimated from short wave infrared nadir observations.

Using BIRRA (the Beer InfraRed Retrieval Algorithm) comprising a line-by-line radiative transfer code (forward model) and a separable nonlinear least squares solver for inversion we retrieve carbon monoxide from observations of SCIAMACHY aboard Envisat.

Retrievals using the recent versions of HITRAN and GEISA have been performed and the results are compared in terms of residual norms, molecular density scaling factors, their corresponding errors, and the final VCD product.

The retrievals turn out to be quite similar for all three databases, so a definite recommendation in favor of one of these databases is difficult for the considered spectral range around 2.3 μm .

Nevertheless, HITRAN 2012 appears to be advantageous when evaluating the different quality criteria.

AATSR-based Volcanic Ash Plume Top Height Estimation

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The AATSR Correlation Method (ACM) height estimation algorithm is presented. The algorithm uses Advanced Along Track Scanning Radiometer (AATSR) satellite data to detect volcanic ash plumes and to estimate the plume top height. The height estimate is based on the stereo-viewing capability of the AATSR instrument, which allows to determine the parallax between the satellite's 55° forward and nadir views, and thus the corresponding height.

Besides the stereo view, AATSR provides another advantage compared to other satellite based instruments. With AATSR it is possible to detect ash plumes using brightness temperature difference between thermal infrared (TIR) channels centered at 11 and 12 μm . The automatic ash detection makes the algorithm efficient in processing large quantities of data: the height estimate is calculated only for the ash-flagged pixels. In addition, it is possible to study the effect of using different wavelengths in the height estimate, ranging from visible (555 nm) to thermal infrared (12 μm). The ACM algorithm can be applied to the Sea and Land Surface Temperature Radiometer (SLSTR), scheduled for launch at the end of 2015.

The method has been used to study several eruptions in Europe and South-America (Etna 2002, Chaiten 2008, Eyjafjallajökull 2010, Grimsvötn 2011 and Puyehue-Cordon Caulle 2011). Results are compared to other satellite-based and land-based measurements. In addition to volcanic plume heights, the algorithm can be used to estimate the heights of other dense aerosol plumes such as smoke and dust plumes, as well as clouds.

Accurate information on the volcanic ash position is important for air traffic safety. The ACM algorithm can provide valuable data of both horizontal and vertical ash dispersion. These data may be useful for comparisons with existing volcanic ash dispersion models and retrieval methods. We present ACM plume top height estimate results for the Eyjafjallajökull eruption, and comparisons against available ground based and satellite observations.

East Asian Monsoon and Tropospheric Ozone from IASI/MetOp

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As an important greenhouse gas and air pollutant in the troposphere, monitoring of tropospheric ozone (O₃) is essential to understand its impact on air quality, chemical composition and climate. In this presentation, two independent studies using O₃ measurements from the Infrared atmospheric Sounding Interferometer (IASI) are presented. First, sensitivity studies are performed to investigate the origin of the systematic IASI O₃ positive bias with respect to independent observations, which is reported in the literature. Second, the East Asian monsoon variability is assessed using six years of IASI tropospheric O₃ columns. The study shows the ability of the instrument to detect the effect of the monsoon on the tropospheric ozone column and to reproduce the strength of the monsoon from one year to the other. Focusing on the period of May-August 2011, the WRF-Chem model is used at the surface and in the troposphere in conjunction with IASI to assess the meteorological and dynamical effects during the monsoon period on the tropospheric ozone column.

Evolution of the Chemical Composition of the Atmosphere over the Past Decades: Comparisons between Chemistry-Climate Model Simulations and Satellite Observations

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Global chemistry-climate models have been used to simulate the evolution of the atmospheric composition over the past decades. These simulations have been performed using the Community Atmosphere Model included in the NCAR Community Earth System Model: this model includes a full tropospheric and stratospheric chemical scheme.

We have analyzed the long-term changes as well as the interannual variability of several atmospheric compounds with a focus on ozone, carbon monoxide and nitrogen dioxide. We have investigated the behavior of these species by focusing on three regions, Europe, North America and Asia. In Europe and North America, surface emissions have decreased significantly since the 1980s, which have led to a decrease in the concentrations of several tropospheric compounds. On the contrary, emissions in Asia have dramatically increased, particularly during the past two decades, which has resulted in large increases in the atmospheric content of several species. Several issues have been raised from this analysis, i.e. an inconsistency between trends provided by different inventories of anthropogenic CO emissions in Asia and trends obtained from satellite observations since 2000. The simulations results have been compared with different satellite observations of tropospheric columns of NO₂, which indicate large differences between spaceborne instruments and different retrievals of the same instrument. Differences have also been identified by the simulations in NO₂ tropospheric columns since 1996 in different parts of the world, which are not always consistent with our current knowledge of surface emissions and their trends in these regions.

The analysis has also used in-situ observations of O₃, CO and NO₂ from different monitoring networks to analyze the model results in different stations in the regions under consideration.

The model simulations were performed in free-running and specified dynamic modes. The simulation with specified dynamic was forced by the Modern Era Retrospective Analysis for Research and Applications (MERRA) provided by the NASA Global Modeling and Assimilation Office. The free-run mode includes three ensemble members with prescribed sea surface temperature and perturbed spin-up climate conditions. We will discuss comparison of tropospheric concentration of atmospheric compounds calculated by different model simulations.

The results of the simulations will also be compared with results from high-resolution regional models, i.e. the CHIMERE model for Europe and the WRF-Chem model for Asia.

This work is performed as part of the MACC-III (Monitoring Atmospheric Composition and Climate) European project and of the international CCMi (Chemistry-Climate Model Initiative) project.

MIPAS vM21 temperatures: Comparison of version vM21 with ACE-FTS, MLS, OSIRIS, SABER, SOFIE and lidar measurements

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We present the recently released version M21 of MIPAS temperatures and line of sight information from the lower stratosphere to the lower thermosphere, which cover measurements performed by MIPAS in its MA, UA and NLC modes from January 2005 to March 2012. We will present the main upgrades with respect to the

previous version (TLOS_M11) and their effect on retrieved temperature fields. The MIPAS vM21 temperatures correct the main systematic biases of previous versions, leading to a remarkable improvement of their comparisons with ACE-FTS, MLS, OSIRIS, SABER, SOFIE and the two Rayleigh lidars at Mauna Loa and Table Mountain. We will show comparisons for the whole data set with these instruments as a function of season and latitude.

Combined use of satellite-derived AOT with urban surface morphology and cover to estimate PM10 and PM2.5 concentrations by employing mixed-effects models

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Linear mixed effects models were developed for the estimation of the average daily Particulate Matter (PM) concentration spatial distribution over the area of Greater London (UK). Both fine (PM2.5) and coarse (PM10) concentrations were predicted for the 2002-2014 time period, based on satellite data. The latter included Aerosol Optical Thickness (AOT) at 3x3 km spatial resolution, as well as the Surface Relative Humidity, Surface Temperature and K-Index derived from MODIS (Moderate Resolution Imaging Spectroradiometer) sensors. For meaningful interpretation of the association among these variables, all data were homogenized with regard to spatial support and geographic projection, thus addressing the change of support problem and leading to a valid statistical inference. To this end, spatial (2D) and spatio-temporal (3D) kriging techniques were applied to in-situ particulate matter concentrations and the leave-one-station-out cross-validation was performed on daily level to gauge the quality of the predictions. Satellite-derived covariates displayed clear seasonal patterns; in order to work with data which is stationary in mean, for each covariate, deviations from its estimated annual profiles were computed using nonlinear least squares and nonlinear absolute deviations. High-resolution land-cover and morphology static datasets were additionally incorporated in the analysis in order to catch the effects of nearby emission sources and sequestration sites. For pairwise comparisons of the particulate matter concentration means at distinct land-cover classes, the pairwise comparisons method for unequal sample sizes, known as Tukey's method, was performed. The use of satellite-derived products allowed better assessment of space-time interactions of PM, since these daily spatial measurements were able to capture differences in particulate matter concentrations between grid cells, while the use of high-resolution land-cover and morphology static datasets allowed accounting for local industrial, domestic and traffic related air pollution. The developed methods are expected to fully exploit ESA's new Sentinel-3 observations to estimate spatial distributions of both PM10 and PM2.5 concentrations in arbitrary cities.

Equivalence of Data Fusion and Simultaneous Retrieval

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Remote sensing observations of chemical and physical processes occurring in the atmosphere are presently made from space by several instruments and more instruments will be available in the future. We present a new data fusion method that can be used for the combination of two or more atmospheric vertical profiles measured by different instruments in the same location. The algorithm used for the fusion takes into account both the covariance matrix and the averaging kernel matrix of the fusing profiles and can be considered to be a generalization of weighted and arithmetic means. In turn, these means can be considered approximations of the new data fusion method, which for its comprehensive approach is referred to as complete fusion. The complete fusion method uses standard retrieval products and has very simple implementation requirements.

We compare the performance of complete fusion with those of weighted and arithmetic means using the measurements of the MIPAS (Michelson Interferometer for Passive Atmospheric Sounding) instrument onboard the ENVISAT satellite. A MIPAS limb sounding sequence is divided in two complementary data sets and two profiles are independently retrieved from the two sets of observations. The two profiles are fused using

complete fusion as well as weighted and arithmetic means. The results of these fusions are compared with the profile retrieved using simultaneously all the observations of the sequence.

The complete fusion perfectly reproduces the results of the simultaneous retrieval from the point of view of values, of error estimates and of number of degrees of freedom. Weighted and arithmetic means differ from simultaneous retrieval and are characterized by errors that are smaller than observed differences. This apparent contradiction is explained, as shown by the analysis of the number of degrees of freedom, by the poor vertical resolution of weighted and arithmetic means that prevents an adequate representation of the shape of the profiles.

GOMOS Measurements of O₃, NO₂ and NO₃ Compared to Model Simulations by Two Versions of the Specified Dynamics WACCM-model

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The Global Ozone Monitoring by Occultation of Stars (GOMOS) instrument on board the European Space Agency's ENVISAT satellite measured 880 000 stellar occultations during 2002–2012. From UV-Visible and IR spectra of the horizontal transmission vertical profiles of O₃, NO₂, NO₃, H₂O, O₂ and aerosol extinction can be retrieved. In addition two 1 kHz photometers at blue and red wavelengths make it possible to retrieve high resolution temperature profiles as well as gravity wave and turbulence parameters. Measurements cover altitude region from the cloud top up to 150 km. Atmospherically valid data are obtained generally in 15–100 km. Profile resolution is 2–4 km.

GOMOS ozone profiles have been successfully validated using ground-based instruments. Ozone and other retrieved data have also been compared to other satellite measurements. The best quality of GOMOS observations is achieved during nighttime, when only few other measurements are available for comparison. High resolution atmospheric models provide an interesting additional possibility for GOMOS measurement comparisons. In the past we have used NCAR ROSE and FinROSE models, now we use the more comprehensive Whole Atmosphere Community Climate Model (WACCM) from the National Center for Atmospheric Research.

WACCM is a chemistry - climate model spanning the range of altitude from Earth's surface to the thermosphere (approximately 140 km) with 88 vertical levels of variable vertical resolution of 1.1 km in the troposphere to 3.5 km above 65 km. Horizontal resolution is 1.9 latitude by 2.5 longitude and the model time step is 30 minutes. In the present analysis version 4 of WACCM was run in 'specified dynamics' mode by constraining dynamical fields to Modern-Era Retrospective Analysis for Research and Applications (MERRA) meteorological reanalyses below 1 hPa. We have completed two WACCM simulations: 1) with ionisation rates from solar proton events (SPE), 2) with ionisation rates from SPE and medium energy electrons (MEE).

In this work we show an inter-comparison of GOMOS O₃, NO₂ and NO₃ profiles with the collocated WACCM profiles. The results provide important new quality information about GOMOS data products. They also indicate probable development targets for the future WACCM evolution.

Long-term changes in tropospheric ethane measured by MIPAS

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Ethane is the most abundant hydrocarbon in the Earth's atmosphere, after methane, and acts as a precursor to tropospheric ozone. Sources of ethane include fossil fuels, the flaring of natural gas, biomass burning and biofuel use, with minor oceanic and biogenic sources. Its relatively long lifetime of 2 months is sufficient to allow mixing of the compound throughout the troposphere and lowermost stratosphere (when conditions allow). The main sink is through reaction with the hydroxyl radical in the troposphere.

Recent studies (e.g. Simpson et al., Nature, 2012) have highlighted a long-term decline of global atmospheric ethane concentrations and discuss implications for methane abundance. The most likely cause of the decrease was inferred to be from decreased venting and flaring from oil fields as other sources were likely to have remained fixed. Their work focussed solely on surface sites across the Pacific Ocean. In this study, we investigate the changes in ethane occurring in the upper troposphere and lower stratosphere, from a global perspective, utilising MIPAS data between 2002 and 2012.

By using a simple linear approximation, taking into account variability to define errors on the fit, we derive largest decreases of ethane in the upper troposphere (300K-340K) of up to 23 ppt/yr, with the Northern hemisphere changes significantly larger than the Southern Hemisphere. Although smaller, the southern hemisphere decreases are significant (up to 5 ppt/yr). As there is likely to be a minimal contribution from venting, this is most likely linked to changes in biomass burning over that period. The stability of MIPAS data is confirmed by analysis of N₂O which shows a similar modest increase compared to surface sites. There exists a relationship between MIPAS ethane and methane growth rate in the upper troposphere, with peaks in ethane concentration linked to methane growth rate increases. Reduced atmospheric ethane concentrations are likely to account for the slowing of methane's atmospheric growth rate over the past decade.

Total Column Water Vapour Product from the GOME, SCIAMACHY and GOME-2 Instruments: Comparison with Independent Data Sets

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Water vapour is a key component of the Earth's atmosphere and has a strong impact on the Earth's radiative balance. Therefore, observations of the effective distribution of total column water vapour (TCWV) on global scales are fundamental for climate analysis and weather monitoring as well as for the improvement of the water vapour product derived by post-processing of satellite data.

In this contribution we present the TCWV data sets from the GOME/ERS-2, SCIAMACHY/ENVISAT, GOME-2/MetOp-A and GOME-2/MetOp-B instruments generated by DLR using the GOME Data Processor algorithm and we perform an extensive comparison with independent data sets in order to evaluate their consistency and temporal stability. The GOME-type spectrometers lay the foundation for a consistent data record of H₂O observations, which spans almost 20 years already and will be further extended by GOME-2/MetOp-C, a third satellite which is planned to be launched in 2018.

The algorithm we use for the retrieval is based on a classical DOAS method (developed by MPI-Mainz) and combines H₂O and O₂ retrieval for the computation of the trace gas vertical column density. The atmospheric modelling is deliberately kept to a minimum. Although this may compromise the accuracy of each individual measurement, it makes the product more suited for long-term climatological studies.

Total column water vapour estimates from the GOME/SCIAMACHY/GOME-2 instruments are collocated and compared with MERIS, SSM/I and SSMIS satellite measurements and with model data from the ECMWF ERA-Interim reanalysis. We find global mean biases as small as 0.05 g/cm² between the GOME-type product and all other data sets. Larger regional differences are observed over ocean and land areas with high humidity or a relatively large surface albedo. Finally, we investigate the error associated to the satellite sampling. Besides intrinsic errors in the satellite retrievals themselves, spatial and temporal samplings strongly affect the quality and representativeness of long-term essential climate variables.

Stratospheric CH₄ and CO₂ Profiles Retrieved with Onion Peeling DOAS from SCIAMACHY Solar Occultation Measurements

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Stratospheric profiles of methane and carbon dioxide derived from solar occultation measurements of the SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY) on ENVISAT are part of the Climate Research Data Package (CRDP) generated in the context of the ESA GHG-CCI project.

These stratospheric data have been retrieved using the 'Onion Peeling DOAS' (ONPD) method, which combines an onion peeling approach with a weighting function DOAS (Differential Optical Absorption Spectroscopy) fit. The ONPD approach can in principle be applied to all gases measured by SCIAMACHY; we concentrate here on stratospheric methane and carbon dioxide.

The derived data sets cover the whole SCIAMACHY time series (August 2002 to April 2012), but due to the sun-fixed orbit of ENVISAT the solar occultation measurements are restricted to the latitudinal range between about 50°N and 70°N.

Nevertheless, the new SCIAMACHY data sets, which cover almost ten years, have the potential to provide valuable information about stratospheric changes, because measurements of the stratospheric distribution of greenhouse gases are generally sparse. In this presentation, we will show actual retrieval results and time series of the SCIAMACHY products. Furthermore, the quality of the newly derived data sets will be assessed by comparison with independent sources.

Validation of GOMOS High Resolution Temperature Profiles using Wavelet Analysis - Comparison with Thule Lidar Observations

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The Continuous Wavelet Transform (CWT) is a powerful tool to locate and characterise non-stationary signals. The time/space-spectral decomposition (scalogram), obtained using the "Morlet" wavelet transform [Torrence and Compo, 1998], allows the unambiguous detection of local properties of a signal across different scales. The perturbation profiles, defined as the signal components of the non-stationary phenomena only, can be calculated and subtracted from the original temperature profile, thus providing "wave-free" profiles. This procedure minimises the impact of atmospheric fluctuations in the framework of the validation of profile data. This approach has been shown to improve the accuracy of the Envisat Global Ozone Monitoring by Occultation of Stars (GOMOS) High Resolution Temperature Profiles (H RTP) validation, by significantly reducing the uncertainty on bias estimates [Iannone et al., 2014].

In the present work, the wavelet technique is applied to temperature and density vertical (stratospheric) profiles from Rayleigh Lidar measurements at Thule, Greenland (76.5°N, 68.8°W, operated by the University of Rome, "La Sapienza") and collocated Envisat GOMOS-H RTP occultations. The validation methodology and results will be discussed in detail, along with gravity waves case studies.

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Using Satellite Observations and Models to Understand Processes in the Composition-Climate System: Some Examples

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In recent years, a wealth of satellite observations has brought a new era in climate science as it has provided the opportunity for continuous monitoring of the state of the atmosphere on large spatial scales. There is enormous unexplored potential in using such data for understanding large-scale processes in the Earth system, even in parts of the globe where virtually no observations existed in the past. Here, I will present two examples of how we have used such satellite information to go beyond conventional model-observation comparisons, focusing on the underlying processes. Initially, I will demonstrate how satellite measurements (TES, MODIS, MISR) in conjunction with global composition-climate model sensitivity experiments can contribute to examining and understanding the interannual variability of important tropospheric constituents such as ozone, CO, OH, and aerosols. Particular focus will be placed on the influence of biomass burning emissions, which is found to be particularly strong, especially for CO, OH, and aerosols. The important implications for air quality and radiative forcing will also be demonstrated. Subsequently, I will discuss the value of using multiple satellite datasets in combination rather than individually, in order to investigate and evaluate processes in composition-climate models. The focus will be on a study where we examined the global and regional correlation between tropospheric ozone and CO, two important atmospheric constituents that are interrelated in a complex way. Observed (TES) ozone-CO correlations are found to be positive over extensive areas in pollution outflow regions in the northern mid-latitudes, but are even stronger in the tropical and subtropical Pacific, a remote region away from pollution sources. We use two global composition-climate models and find a contrasting ability in capturing the ozone-CO correlation, which appears unrelated to how well they capture the actual ozone and CO levels individually (suggesting underlying deficiencies and compensation of errors). I will discuss how this type of metric can assist process-oriented model evaluation, and present some preliminary results of our evaluation of models participating in the Chemistry-Climate Model Initiative (CCMI) in terms of capturing the ozone-CO correlation. Future plans and directions on how such satellite-based analysis can be expanded using more observational datasets (e.g. our recently initiated project in cloud-constituent relationships) will be presented. Finally, I will discuss the potential of using ESA satellite datasets for such process-based analyses in the future.

Optimization of Radiative Transfer Model Calculations for the Atmospheric Sentinel Missions

Efremenko, Dmitry S. [1]; Loyola, Diego [1]; Doicu, Adrian [1]; Trautmann, Thomas [1]; Spurr, Robert J.D. [2]

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Massive amounts of spectral information are expected from the new generation of European atmospheric sensors (Sentinel 5 Precursor, Sentinel 4 and Sentinel 5), so a fast processing of the data in the UVNS spectral domain is required. The major performance bottle-neck for the retrieval algorithms is the time-consuming radiative transfer model (RTM) simulations. In this context, we have developed several techniques for RTM performance enhancement with particular application to trace gas retrievals. The "telescoping" technique simplifies the RT solution by avoiding calculations in Rayleigh-only scattering layers for Fourier-azimuth components $m > 2$, while the "left-eigenvector" matrix approach enables efficient computation of the matrix exponential in the discrete ordinate method.

To optimize performance over spectral loops, we extended the RTM with principal component analysis (PCA) of optical parameters. This approach has the following features: (a) a two-stream model is used to compute the approximate spectrum; (b) differences (or "correction factors") between the approximate and exact solutions are expressed through a second-degree polynomial in the optical parameters; (c) PCA is used to map the initial data set of optical properties to a lower-dimensional subspace, in which the computation of the correction

factors is performed. A similar approach can be used to compute derivatives of the radiance (Jacobians) with respect to atmospheric parameters. Forward-model RTM simulations for total ozone retrieval in the wavelength domain 325–335 nm (Huggins bands) containing 88 spectral points were obtained by calling the multi-stream model with 8 streams per hemisphere only 5 times and the faster two-stream model 93 times. The speed improvement was about 8, with the maximum radiance error smaller than 0.2%.

To optimize the loop over ground pixels, we designed a RTM code using the GPU architecture of modern graphical cards. To reduce the CPU/GPU communication overhead, we exploited the asynchronous data transfer between host and device. To obtain optimal performance, we also used overlapping of CPU and GPU computations by distributing the workload between them. With GPUs, we achieved a 20x-40x speed-up for the multi-stream RTM, and 50x speed-up for the two-stream RTM, these figures with respect to performance with the original single-threaded CPU codes.

In the independent-pixel approximation for cloud-contaminated scenes, radiances are computed as a linear superposition of two solutions for the clear-sky and fully-cloudy scenarios, requiring two RTM calls. We developed two methods based on the re-use of results from clear-sky RTM calculations to speed up corresponding calculations for the cloud-filled scenario. The first approach is numerically exact, in that results from the clear sky computation can be saved in memory and reused for all non-cloudy layers in the second computation involving clouds. The second approach is (for the cloudy scenario) to generate a spectral correction applied to the radiation field from a fast two-stream RTM. Although this method involves some approximation, it still provides radiance accuracy better than 0.2%, with a speed-up factor of approximately 2 compared with time taken for two separate RTM calls.

High spatial resolution daily mapping of surface-level NO₂ using satellite and in-situ measurements

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Monitoring surface-level air quality is often limited by in-situ instrument placement and issues arising from harmonisation over long timescales. Satellite instruments can offer a synoptic view of regional pollution sources, but in many cases only a total or tropospheric column can be measured. The measured column therefore requires partitioning to separate the free tropospheric and stratospheric influences from the boundary layer contribution. Typically this partitioning is performed using a chemical transport model, which can introduce additional biases arising from model accuracy and the often coarser grid resolution compared with the nadir satellite footprint.

This work describes an empirical technique to estimate daily surface-level NO₂ through combining tropospheric columns measured by OMI and surface in-situ measurements. Tropospheric NO₂ columns retrieved by OMI over China and the UK are combined with in-situ measurements to derive surface-level NO₂ pollution maps. Conversion to surface concentrations achieved through ratioing columns with in-situ measurements taken within the nadir footprint during the satellite overpass. These ratios are then applied to adjacent local satellite ground pixels, allowing for daily high-resolution (13 x 24 km²) mapping of surface NO₂.

Validation of these maps is achieved through comparisons with in-situ measurements and model data. Surface concentrations derived with this technique show better correlation than direct comparisons with the raw column data.

Modelled Ozone Bias near the Stratopause using ESA CCI Limb Ozone Data

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Photochemical models are known to underestimate the observed ozone in the upper stratosphere and lower mesosphere (USLM), i.e. above 45 km of altitude. In the present study, we evaluate this issue within the state-of-the-art stratospheric chemistry transport model (CTM) of BASCOE (Belgian Assimilation System for Chemical Observations). First, we investigate the impact of the chemical scheme used in our model. We compare gas-phase chemical reaction rates and photodissociation cross-sections, compiled by the Jet Propulsion Laboratory (JPL) reported in 2006 with the latest JPL recommendations published in 2011.

Second, a sensitivity test to the solar activity rate is also carried out. Third, the impact of the temperature field on the modelled ozone deficit is studied. To this end, we compare the temperature field used in our model (operational ECMWF analyses up to 0.01 hPa) with temperature profiles provided by limb satellite data. The results of our experiments are evaluated using the ESA CCI limb level 2 ozone data to better understand and document the ozone underestimation issue.

SO₂ plume height retrieval from GOME-2 satellite measurements in support to aviation control.

van Gent, Jeroen; Brenot, Hugues; Theys, Nicolas; Van Roozendaal, Michel

BIRA-IASB, Belgium

The Support to Aviation Control Service (SACS), operated at our institute, uses multi-sensor UV-visible and infrared satellite measurements to provide near real-time information on volcanic ash and SO₂ concentrations. In case of enhanced SO₂ concentrations, notifications are sent out to subscribing organisations and individuals, with details regarding the volcanic event. This information may be used by aviation control organisations to judge the risk to air traffic and provide possible alternative routing.

One of the latest additions to the system is information on the altitude of SO₂ plumes, based on UV measurements of the GOME-2 sensors on the platforms METOP-A and METOP-B.

This poster shows examples of plume height retrieval from GOME-2 (METOP-A and -B). Results are shown for a number of recent major volcanic eruptions, each with different characteristics. The applied technique to retrieve altitude information will be discussed, as well as the applicability, quality and limitations of the method.

Extreme fast volcanic SO₂ plume height retrieval from UVN sensors

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Volcanic eruptions pose a major threat not only to the local population but also to aviation. The knowledge of the exact location and height of the SO₂ plume is essential for forecast models and also for aviation control since SO₂ causes sulfidation in the aircraft engines which might lead to a total engine failure if exposed over a long time. Furthermore for some volcanic events SO₂ was found to be a proxy for the much harder to detect volcanic ash, which melts in the airplane engines eventually also leading to a total engine failure. The near-real-time (NRT) information about the amount and location of volcanic SO₂, obtained for example from GOME-2, is currently being used by the Volcanic Ash Advisory Centers (VAACs). What is not available today is the near-real-time information about the altitude of the SO₂ plume detected by UVN sensors.

The published SO₂ plume height retrieval algorithms from UVN data are very time consuming and therefore not adequate for NRT applications. In this work we present a novel algorithm called Inverse Learning Machine (ILM) for the extremely fast and accurate retrieval of SO₂ plume height.

The basic idea of ILM is to find canonical correlations between spectral radiance and the geophysical parameters of interest using radiative transfer model (RTM) simulations. In the case of the SO₂ plume height problem, we use LIDORT-LRRS to simulate radiances in the wavelength range 310 to 335 nm for different SO₂ amounts and plume height scenarios and then we compute an inversion operator relating radiances with the plume height.

The time consuming part of ILM requiring RTM simulations, computation of canonical correlations and determination of inversion operator is performed off-line. The application of the resulting inversion operator to real measurements is extremely fast because it only involves the computation of a few simple matrix operations.

The inversion operator found with ILM is then applied to GOME-2 on MetOp-A and -B measured spectra for a number of volcanic scenarios including Kasatochi [2008], Nabro [2011], and Bardarbunga [2014]. The SO₂ plume height obtained with ILM agrees well with published results from other algorithms and sensors.

Finally we show that the accuracy of the volcanic SO₂ columns is significantly improved by using the plume height retrieved with ILM to compute appropriate Air Mass Factors.

Improved Pointing Knowledge for SCIAMACHY by Evaluating Solar and Lunar Measurements

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Satellite observations in limb or occultation geometry provide height resolved information about the atmospheric state. A critical point here is always the pointing knowledge, i.e. the precise knowledge of the viewing direction which determines the observed tangent height.

The SCanning Imaging Absorption spectroMeter for Atmospheric CHartography (SCIAMACHY) on ENVISAT (2002-2012) performed nadir, limb, solar/lunar occultation and various monitoring measurements. The pointing information of the instrument is determined by the attitude information of the ENVISAT platform and its star tracker together with the encoder readouts of both the azimuth and elevation scanner of SCIAMACHY.

In this work, we present additional sources of attitude information from the SCIAMACHY measurements itself. The basic principle is the same as used by the star tracker: We measure the viewing direction towards celestial objects, i.e. sun or moon. In solar occultation, we utilise the vertical scans over the solar disk. In horizontal direction, SCIAMACHY's Sun Follower device (SFD) is used to adjust the viewing direction.

Lunar occultation measurements use for both vertical and horizontal direction the adjustment by the SFD. Images from the USGS Robotic Lunar Observatory (ROLO) are used to simulate the adjustment of the SFD, taking into account the varying lunar libration and phase. Solar observations through SCIAMACHY's so-called sub-solar port provide an additional piece of attitude information in a very different viewing direction.

Overall goal is to determine improved mispointing parameters for the level 0-1b processing of SCIAMACHY measurements. All retrieved products from SCIAMACHY's limb and occultation measurements will benefit. This work is embedded in the SCIAMACHY Quality Working Group.

A novel ozone profile shape retrieval algorithm from UV/VIS sensors

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We report on the design and validation of a novel algorithm called ROPSMML for the very fast retrieval of the ozone profile shape information from UV/VIS nadir satellite measurements. The key idea of ROPSMML is to transform the ozone profile retrieval problem into a classification problem using machine learning techniques.

As a first step we used unsupervised learning to group a set of ozone measurements into clusters according to the profile shapes. After learning, all ozone data in a cluster has similar profiles shapes.

Then we selected representative ozone profiles from each cluster and used them as input for VLIDORT radiative transfer simulations in the UV spectral range and covering all feasible viewing geometries and surface conditions.

A set of training examples was then created with the simulated UV measurements and the labels of the corresponding profile clusters. Finally supervised learning algorithms were applied to the training examples in order to find the mapping between UV measurements and ozone profile shapes.

The application of the resulting mapping operator to UV measurements is very fast. The learning parts of ROPSMML including the radiative transfer model simulations are very time consuming but these tasks are performed only once and off-line.

In order to assess the goodness of the new algorithm we used GOME-2 measurements and compared the ROPSMML predicted ozone profile shapes with the corresponding profiles retrieved with classical inversion algorithms.

New Strategy for the Measurement of the CO₂ Distribution in Stratosphere and Upper Troposphere

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In the Thermal InfraRed region, the spectral features generated by vibro-rotational transitions of CO₂ have been exploited to retrieve pressure (P) and temperature (T) distributions by space-borne experiments that investigate the atmospheric composition. Besides its intrinsic importance, the knowledge of P and T is necessary in the data analysis of the experiment to retrieve the distribution of any target molecule from its spectral features. The P, T retrieval process is based on the assumption that the CO₂ atmospheric distribution is known. Therefore the role assigned to CO₂ in the data analysis prevents its spectral features to be used for the retrieval of its distribution. The accuracy of the CO₂ distribution obtained by simultaneously retrieving it with P and T did not meet the required accuracy (> 10%).

In this study we propose a new strategy for the measurement of the CO₂ distribution using a passive orbiting limb sounder. The idea is to exploit the pure rotational transitions of molecular oxygen in the far-infrared region for the retrieval of P and T. As these transitions originate from a magnetic dipole moment their line strength is very low. Nevertheless, due to the huge abundance of oxygen and to the large optical path of limb sounding observation geometries, they are among the most prominent features of the far infrared atmospheric spectrum.

The experiment considered for this study exploits a FT spectrometer with two output ports hosting respectively a far-infrared detector devoted to measure oxygen, and a mid-infrared detector devoted to measure CO₂ in the 700 cm⁻¹ region. In this study we consider different spectral resolutions of the spectrometer and different options for the far-infrared detectors (that are a crucial aspect of the experiment due to the challenge of cooling in a space experiment).

We use retrievals on simulated observations to assess the performance of the different options considered, in terms of precision of the retrieved CO₂ distributions. Since the oxygen transitions occur at frequencies where the Plank function is rather weak at atmospheric temperatures, we had to verify whether their spectral features contain enough information to determine temperature parameters. Preliminary tests indicate satisfactory precision for the P and T distributions retrieved from 70 km down to the tropopause.

Total Column Water Vapour from Along Track Scanning Radiometer Series: The design and application of the Advanced Infra-Red Water Vapour Estimator (AIRWAVE) tool

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Total Column Water Vapour (TCWV) global distribution is a key parameter for climate analysis and weather monitoring. We have designed a new algorithm that enables an accurate and precise estimate of Total Column Water Vapour (TCWV) using the Thermal Infra-Red (TIR) channels of all the Along Track Scanning Radiometer (ATSR) series of instruments. The new algorithm, called Advanced Infra-Red Water Vapour Estimator (AIRWAVE) has been developed in the frame of the ESA contract 'ATSR Long Term Stability (ALTS)' in the optic of a better exploitation of the (A)ATSR instruments and can be easily adapted to work with the Sea and Land Surface Temperature Radiometer (SLSTR) on board the Copernicus Sentinel 3.

The retrieval method does not require any tuning or adjustments to independent water vapour datasets and is based on: 1) calculations from a radiative transfer model that was specifically developed to simulate ATSR radiances, 2) informations on instrumental parameters, 3) sea surface spectral emissivity. AIRWAVE exploits the simultaneous use of forward and nadir measurements in the Thermal Infra-Red channels on ocean cloud-free scenes to produce day-time and night-time TCWVs.

In order to process the whole ATSR missions (1991-2012), the AIRWAVE prototype processor (AIRWAVE-PP) has been designed and integrated in the ESA GRID environment (GPOD). AIRWAVE-PP decodes each (A)ATSR Level 1 orbit file selecting sea and cloud-free radiances, retrieves TCWV at two different spatial resolution (1x1 km² and 0.25°x0.25°) and exports the results into NetCDF-CF files and PNG quick-look plots.

The physical derivation of the AIRWAVE retrieval method and its implementation will be presented. Preliminary results of the inter-comparisons between ATSR and Special Sensor Microwave/Imager (SSM/I) coincident TCWVs will be shown.

Low latitude seasonal variability of the mesosphere as observed by MIPAS

Garcia-Comas, Maya [1]; Lopez-Puertas, Manuel [1]; Funke, Bernd [1]; Gardini, Angela [1]; Jurado-Navarro, Aythami [1]; Stiller, Gabriele [2]; von Clarmann, Thomas [2]

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The intra-annual variability of the mesosphere and lower thermosphere near the equator is dominated by a strong semiannual oscillation (MSAO), plausibly originated by a differential filtering of the vertically propagating gravity waves by the semi-annually oscillating wind in the stratosphere. The effects of the MSAO are printed on the atmospheric temperature and on the species concentrations, which accompany the changes in the mean flow. Among other species and together with kinetic temperature, we derive water vapor and carbon monoxide abundances from MIPAS spectra using the Institut für Meteorologie und Klimaforschung und Instituto de Astrofísica de Andalucía (IMK/IAA) data processor. This scientific processor, which includes the GRANADA non-Local Thermodynamic Equilibrium algorithm, is able to deal with atmospheric emissions affected by non-LTE, particularly important for the IR emissions in the mesosphere and thermosphere. We will run our eyes over temperature, H₂O and CO time series retrieved from MIPAS measurements from the stratosphere to the upper

mesosphere over the equator and discuss their seasonal variations. We will focus on the MSAO morphology (vertical shape and seasonal and interhemispheric asymmetries), its inter-annual variability and its correlation with its stratospheric counterpart in order to better quantitatively understand the mechanism controlling it.

Stochastic Radiative Transfer and More Accurate Models for the Trace Gas Retrieval under Broken Cloud Conditions

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Trace gas retrievals from nadir sounding instruments are hindered by the presence of clouds. For satellite instruments with a high spatial resolution like the atmospheric Sentinel missions, it is important to properly account for the sub-pixel cloud inhomogeneities to assess their effect on the radiances at the top of the atmosphere, and ultimately to develop accurate cloud models for the trace gas retrieval. For this purpose we have designed a novel stochastic model for solving the solar radiation problem under broken cloud conditions and a molecular atmosphere with its underlying surface (Doicu et al. 2014). This model allows the probabilistic computation of the mean radiance at the top of the atmosphere as it is intended to be used for trace gas retrievals.

By representing the radiance and the geometric fields as the sum of their mean values and their random fluctuations, we derived an n th-order stochastic model for the solar radiation problem and arbitrary statistics. The stochastic model is expressed in matrix form, and is equipped with appropriate closure relations for the higher-order covariance terms. For broken clouds, the n th-order stochastic model reduces to a first-order stochastic model for a two-dimensional radiance vector, whose entries are the mean radiance field and the covariance of the radiance and the indicator fields.

Both external and internal mixing models have been introduced by considering zeroth-order stochastic models and by imposing closure relations for the covariance of the fluctuations of the radiance field and the indicator field. The closure relations involve constant and angular-dependent correlations with a closure coefficient which minimizes the discrepancy between the radiance fields computed by an internal mixing model and a reference model. For this reason, the internal mixing models belonging to the category of homogenization approaches can be regarded as parametrization of the reference model.

We show that the internal mixing models provide more accurate results. An important aspect of our analysis is the efficient computation of the closure coefficient for the internal mixing models by taking the stochastic model as a reference. This approach allows to efficiently process atmospheric data with high spatial resolution by using 1D radiative transfer models together with pre-computed look-up tables for the closure coefficient under realistic conditions.

References

Doicu A., Efremenko DS, Loyola D., Trautmann T. Discrete ordinate method with matrix exponential for stochastic radiative transfer in broken cloud fields. *J.Quant. Spectrosc. Radiat. Transfer*. 2014. V.138, P.1-16.

Analysis of Aerosol Properties over Jambi (Indonesia) using Remote Sensing

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Indonesia is an archipelago containing many active and dormant volcanoes. Aerosols erupted from volcanoes have significant effects on the climate and air quality of the region. These effects can be better understood if optical properties of aerosols are known. In the present study aerosol optical properties have been analyzed during July 2012-January 2013 using AERONET (aerosol robotic network) and MODIS (Moderate Resolution Imaging Spectro-Radiometer) data over the Jambi, a capital city of province Jambi. Jambi province is

surrounded by coasts from two of its sides while the other two are surrounded by Sumatra province. Mount Sinabung is an active volcano located in Sumatra at a distance of approximately 400 km from Jambi city. The study area lies at and near equator so the climate is tropical and its geographical location is very important for climate change and global pollution research because if any haze event occurs here it can affect both hemispheres. Aerosol properties like aerosol optical depth (AOD), Angstrom Exponent (AE), Single Scattering Albedo (SSA), Asymmetry Parameter (ASY) and volume size distribution were analyzed. HYSPLIT model (Hybrid Single Particle Lagrangian Integrated Trajectory) trajectories were drawn both for Sinabung's ash plumes and Jambi's local winds. The highest value of AOD was observed to be 1.54 ± 0.79 in the month of September 2013 while lowest value (0.12 ± 0.06) of AOD was observed in February 2013. AE was observed to be always greater than 1 except for November 2013 (0.90 ± 0.17). Water Vapor Content (WVC) remained very high throughout the study period. SSA and real part of refractive index were found to be higher in wet season (October to April) while imaginary part of refractive index and ASY were observed to be higher in dry season (May to September).

Harmonised Validation System for Tropospheric Ozone and Ozone Profile Retrievals from GOME to the Copernicus Sentinels

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Research addressing air pollution, the maintenance of the stratospheric ozone layer, and global climate change requires global and long-term monitoring of the vertical distribution of atmospheric ozone at ever-improving resolution and accuracy. Global tropospheric and stratospheric ozone profile measurement capabilities from space have therefore improved substantially over the last two decades, among others with new generation hyperspectral instruments measuring backscattered UV-visible sunlight (GOME, SCIAMACHY, OMI, GOME-2) and thermal emission (TES, IASI) at the nadir of the satellite. Enhanced versions of those instruments are now being developed within EU's Copernicus Earth Observation programme: the UV-visible-NIR TROPOMI instrument on board of the mid-afternoon satellite Sentinel-5P, to be launched in 2016, and both UV-visible and infrared instruments of the GOME and IASI types on board of the geostationary Sentinel-4 and polar orbiting Sentinel-5, to be launched at the end of the decade. Additionally, stringent climate research user requirements like e.g. the Global Climate Observing System (GCOS) targets call for continuous quality assessment and evolution of ozone data and their associated retrieval algorithms over the whole relevant spatial domain, vertical range, and mission lifetime. The fitness-for-purpose of tropospheric ozone column and ozone profile data products must thus be warily verified by means of in-depth QA/validation studies of the satellite data and associated retrieval algorithms before being used in scientific research and operational applications.

To that purpose, an extensive validation system has been developed on the heritage of various validation activities, starting in the 1990s with the first GOME ozone profile validations and progressively extending up to the current ESA Multi-TASTE Phase F data evolution and Ozone_cci production of multi-mission climate data records on ozone. Currently this validation system is being further consolidated with metrological traceability practices and with generic QA guidelines established within the FP7 QA4ECV project. The end-to-end approach of this system combines preliminary QA/QC procedures, data content studies, in-depth information content studies, information-content based co-location procedures, data homogenisation, and the more traditional data comparisons with respect to reference measurements acquired by ground-based networks of ozonesondes and lidars (NDACC, SHADOZ, WMO GAW). An OSSE system with detailed metrology of the remote sensing data is thereby used to assess the propagation of errors associated with differences in smoothing and with mismatches in space and time between the various measurements.

In this paper we briefly describe the principles and implementation of this QA/validation system, now in pre-operational phase. Through illustrative evaluation activities from ESA's Ozone_cci project we demonstrate its broad applicability to virtually all ozone (partial) column and profile datasets. We conclude with a perspective on current developments of this system required to address the specific challenges of the upcoming TROPOMI

ozone data validation as envisaged in the S5PVT A0 project CHEOPS-5p (Validation of Copernicus HEight-resolved Ozone data Products from Sentinel-5P TROPOMI).

Monsoon outflow observation in the tropical upper troposphere with the infrared limb imager GLORIA

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GLORIA (Gimbalbed Limb Observer for Radiance Imaging of the Atmosphere) is an airborne imaging Fourier Transform Spectrometer enabling measurements in limb and nadir geometry. In previous flight campaigns GLORIA has been operated in two different observational modes: the chemistry mode (CM) with higher and the dynamics (DM) mode with lower spectral resolution (0.125 cm⁻¹ vs. 1.25 cm⁻¹). While the DM is dedicated to obtain a high along-track sampling and tomographic applications, the CM is used to identify an enlarged set of trace gases.

During the TACTS/ESMVal flight over Arabian Sea and Arabian Peninsula on 18th September 2012, GLORIA detected layers and vertical plumes of enhanced ethane (C₂H₆), methane (CH₄), PAN (CH₃CO₃NO₂) and other gases indicating polluted tropospheric air. Based on the LaMS backward trajectory calculations, climatology and the spatial distribution cross sections retrieved from GLORIA chemistry mode measurements, we evaluate here the sources of the enhancements and the dynamics of the sampled air masses. The results are used to estimate an impact of outflow of pollutants from the Asian summer monsoon on the chemical composition of the UTLS in the flight region.

Non-LTE Retrievals of CO₂ Collisional Rates and VMRs using Limb Emission High Resolution Spectra from MIPAS/ENVISAT

Jurado-Navarro, A. Aythami [1]; López-Puertas, Manuel [1]; Funke, Bernd [1]; Garcia-Comas, Maya [1]; Gardini, Angela [1]; Stiller, Gabriele [2]; von Clarmann, Thomas [2]; Grabowski, Udo [2]; Glatthor, Norbert [2]

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The MIPAS instrument on Envisat has a large spectral coverage (15--4.3 μm) measuring the most important IR emissions of CO₂, i.e., the 15 μm, 10 μm and 4.3 μm bands. Additionally, it has a very high spectral resolution (0.0625 cm⁻¹). These characteristics make it an ideal instrument for studying the non-LTE processes of CO₂ emissions and measuring the CO₂ VMR, as well as for the temperature retrieval. In this presentation we focus on the retrieval of non-LTE collisional rates and CO₂ VMR using emission spectra at 10 and 4.3 μm in the mesosphere and lower thermosphere (MLT). The unprecedented spectral coverage and spectral resolution of MIPAS allow us to study in depth the non-LTE emission of CO₂ in the 4.3 μm, discerning the individual contributions to the limb emission of several tens of bands, including optically thick and thin bands in this altitude range. These measurements thus allow us to acquire unique information of the non-LTE processes driving the populations of the CO₂ vibrational levels which are applicable not only to MIPAS but also to other limb emission instruments like SABER. We present here new information about the non-LTE collisional processes as well as retrieved CO₂ VMR profiles in the MLT region.

Tomographic Retrieval for Scattered Light Limb Measurements: Multiple Spectral Fit Windows to Improve the Spatial Resolution

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The Scanning Imaging Absorption spectroMeter for Atmospheric CHartography (SCIAMACHY) on the ENVISAT satellite probed the atmosphere at the day side of Earth in alternating sequences of nadir and limb measurements from August 2002 to April 2012.

Limb measurements allow the retrieval of stratospheric profiles of various trace gases on a global scale. It has been shown that combining measurements of the same air volume from different viewing positions along the orbit, 2D distribution fields of stratospheric trace gases can be acquired in one inversion step.

Since the atmospheric scattering and absorption processes are wavelength dependent, the spatial sensitivity for limb observations also varies with wavelength. In general, for longer wavelengths, photons from more remote areas along the line of sight are contributing stronger to the measurement than for shorter wavelengths because of the lower probability of Rayleigh scattering. In addition, the radiative transfer is modified by the ozone absorption structures making longer light paths less probable within strong ozone absorption bands.

In this study, additional information on the spatial distribution of NO₂ is investigated by analysing results obtained by Differential Optical Absorption Spectroscopy (DOAS) in various spectral fit windows. Combining the fit results in one profile retrieval algorithm helps to improve the spatial sensitivity and resolution of the measurements.

The largest improvements for the spatial resolution and sensitivity are expected for the upper troposphere/lower stratosphere (UTLS) region where the variation of the spatial sensitivity with wavelength is strongest.

Trace gas column observations from GOME-2

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This contribution focuses on the GOME-2 trace gas column products developed in the framework of EUMETSAT's Satellite Application Facility on Atmospheric Composition and UV Radiation (O3M-SAF). We present an overview of the retrieval algorithms for ozone, NO₂, SO₂, formaldehyde (CH₂O) and water vapour, and we show examples of various applications such as air quality and climate monitoring, using observations from the GOME-2 instruments on MetOp-A and MetOp-B.

The retrieval of total ozone columns from GOME-2 uses an optimized Differential Optical Absorption Spectroscopy (DOAS) algorithm, with air mass factor conversions calculated using the LIDORT model. Total and tropospheric NO₂ is retrieved with the DOAS method in the visible wavelength region around the 435 nm. SO₂ emissions from volcanic and anthropogenic sources can be measured by GOME-2 using the UV wavelength region around 320 nm. The ozone, NO₂ and SO₂ column products are available for the users in near real time, i.e. within two hours after sensing by GOME-2. For CH₂O, an optimal DOAS fitting window around 335 nm has been determined for GOME-2. The GOME-2 trace gas column products have reached the operational O3M-SAF status, and are routinely available to the users.

The use of trace gas observations from the GOME-2 instruments on MetOp-A and MetOp-B for air quality and climate monitoring purposed will be illustrated, e.g. for South-East Asia and Europe. Furthermore, comparisons of the GOME-2 satellite observations with ground-based measurements will be shown. Finally, the use of GOME-2 trace-gas column data in the Copernicus atmospheric service project MACC-III will be presented.

Monitoring volcanic SO₂ emissions using GOME-2/Metop-A & -B

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SO₂ emissions are a good indicator for volcanic activity, since besides weak anthropogenic emissions there are no other known sources for atmospheric SO₂. Furthermore it can be a proxy for the much harder to detect volcanic ash, which can be hazardous not only for the local population but also for aviation.

Under the leadership of IMF, DLR-EOC provides operational trace gas measurements, including total SO₂ columns, in near-real-time (i.e., within 2 hours of recording) in the framework of EUMETSAT's Satellite Application Facility on Ozone and Atmospheric Chemistry Monitoring (O3M-SAF).

We will present here latest results of recent volcanic eruptions detected by GOME-2 aboard MetOp-A & -B as well as latest updates and developments of our operational GOME-2 SO₂ retrieval.

In-flight Spectral Calibration of the APEX Imaging Spectrometer using Fraunhofer Lines

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The Airborne Prism EXperiment (APEX) is an imaging spectrometer primarily designed for environmental remote sensing of the land surface but also allows observing atmospheric trace gases such as nitrogen dioxide (NO₂). The NO₂ retrieval places high demands on an accurate wavelength calibration and determination of the instrument function.

APEX centre wavelength positions (CW) and full widths at half maximum (FWHM) depend, among other factors, on the ambient air pressure. Therefore, a calibration model was developed which calculates CW and FWHM as function of air pressure. We validated this model by performing a DOAS wavelength calibration which aligns Fraunhofer lines present in the in-flight APEX spectrum with a high-resolution solar reference spectrum. The DOAS calibration was applied to individual 30nm wavelength windows between 385 and 600nm. In each window, CW and FWHM were fitted to minimise the difference between solar and APEX spectrum. We used two at-sensor radiance cubes (APEX Level 1 product) obtained over Zurich in 2013. The cubes differ by correcting CCD readout smear either in the forward (FOR) or reverse (REV) direction. Furthermore, NO₂ fitting windows were tested to find the optimal wavelength range for the APEX NO₂ retrieval algorithm. The current algorithm uses 470 to 510nm.

Our DOAS based spectral calibration worked best between 385 and 450nm and between 500 and 550nm in presence of strong Fraunhofer lines. Outside these windows, CWs and FWHMs could not be retrieved accurately. The fitting errors were larger in the FOR cube than in the REV cube, in particular below 420nm. The smaller errors suggest that the reverse readout smear correction improves the APEX Level 1 product at wavelengths relevant for the NO₂ retrieval, i.e. in the UV and blue range of the visible spectrum. The fitted CWs are in good agreement with the CWs predicted by the pressure model (accuracy <0.2nm) but depend on the across-track position. The fitted FWHMs are 10 to 80% larger than the modelled FWHMs depending on wavelength and across-track position. Since fitted and modelled FWHMs are highly correlated ($r > 0.95$), a simple linear scaling of the modelled FWHMs was applied to correct FWHMs for the full wavelength range. The optimal NO₂ fitting window was identified to be 440 to 510nm, reducing the slant column density errors from 38 to 22% as compared to the previously used window from 470 to 510nm. The smear correction algorithm, on the other hand, had only a small influence on the retrieved NO₂ slant columns.

In conclusion, spectral calibration with Fraunhofer lines can be used to understand in-flight changes of the calibration. The results will be used to improve the APEX Level 1 product and the APEX NO₂ retrieval.

Neural-network Approach to Hyperspectral Data Analysis for Volcanic Ash Clouds Monitoring

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This work presents a Multi Layer Perceptron Neural Network (MLPNN) approach that has been used to simultaneously retrieve volcanic ash Aerosol Optical Depth (AOD), effective radius, and ash cloud height using measurements from the Infrared Atmospheric Sounding Interferometer (IASI). Here we show the results of the network, considering the 2011 Grímsvötn eruption as a test case.

A network has been built for each parameter that is to be retrieved. The neural networks for the quantitative estimation of the parameters associated with volcanic ash were trained using example results from retrievals carried out using an optimal estimation (OE) technique. The OE retrieval method analyses brightness temperature spectra from IASI and the NN uses the corresponding spectral data as inputs. Assuming a single infinitely thin ash plume and combining this with the output from the radiative transfer model RTTOV, the OE algorithm produces probable values for the ash optical depth (AOD), particle effective radius, plume height and surface temperature, which are the target outputs of the NN.

Concerning the training phase and networks validation, a set of IASI images was selected covering the Grímsvötn May events. Neural networks were trained with a time series of IASI images collected from 21st-23rd May 2011, and were validated on one independent image belonging to the 23rd May eruption and an independent IASI image that occurred on May 24th. These images were not considered during the training phase in order to evaluate the generalization capability of neural networks.

The validation carried out on the scenes from the Grímsvötn eruption show that the Root Mean Square Error (RMSE) of the outputs remained lower than the Standard Deviation (STD) of the targets for both dates, which demonstrates a good performance in network generalization capability. In particular, the NNs show high accuracy in retrieving ash cloud height but reveal a loss of accuracy for AOD and effective radius when the values are statistically not well characterized during training phase.

The networks proved to be very effective in solving the inversion problem related to the estimation of the parameters of the volcanic cloud once the training phase is complete. NNs provide a fast inversion technique, which is useful for the application to volcanic monitoring. From this point of view the technique satisfies the need to respond quickly as a result of disastrous natural hazards, such as volcanic eruptions.

Future activities will include testing the effectiveness of the technique under cloudy conditions.

Development of a Web GIS Data Visualization Viewer for remote sensing MODIS cloud and aerosol data using OGC standards and Open Source Technologies

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The study presents the development of an interactive Earth Observation (EO) data visualization viewer used for the MODIS cloud and aerosol datasets in a study of the urban clusters impact on regional air pollution and climate (AEROVIS project: A bilateral cooperation between Greece and China). The EO data viewer has been developed using OGC standards and open source technologies. It is an interactive web GIS application that currently serves about 30 MODIS parameters, derived from the TERRA and AQUA satellites, for a 12 years data period with a one month interval.

Formation and maintenance of a lower stratospheric cirrus cloud over the tropics: Possible link with Kelud eruption

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A rare occurrence of stratospheric cirrus persisting for about 5 days is inferred from the combination of ground-based Mie-lidar observations over Gadanki (13.5°N, 79.2°E) and spaceborne Cloud-Aerosol Lidar Orthogonal Polarization (CALIOP) and Moderate Resolution Imaging Spectroradiometer (MODIS) observations. The deep convection (which is probably induced due to a potential vorticity intrusion event occurred on day of cirrus formation), might have transported water vapor to the lower stratosphere. Coincidentally, an ash cloud of high SO₂ content generated by the Kelud volcanic eruption gets transported to India, which is confirmed by using a trajectory analysis. It is suggested that the sulfate particles formed after the Kelud volcanic eruption are transported to India could homogeneously nucleate ice to form cirrus particles in the lower stratosphere, where the temperature is below 235 K. In addition, the cold anomaly associated with the presence of a 4-day wave is suggested as a reason for the cirrus persistence for about 5 days.

Statistical Modelling in Problems of Lidar Remote Sensing of Aerosol Cloudy Atmosphere

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Laser sensing is an effective way of studying optical properties of various atmospheric structures. If we consider strongly scattering media, like clouds, there arises the necessity of taking into account the effects of multiple scattering which changes the space and time characteristics of the light pulse. The Monte Carlo method is the most convenient one for obtaining practical results in such problems.

The aim of the present paper is to determine the connections between the characteristics of a light pulse reflected from cloudiness and certain parameters of the cloudy medium. Knowing these connections will give us the possibility to find out which cloudiness parameters may be obtained from the reflected signal with a given degree of confidence. Also an important problem is taking into account thin clouds in remote sensing of the ocean with optical methods. To solve these problems, the data about the form and magnitude of the time base of the light pulse reflected from cloudiness illuminated by an impulse source should be obtained. This task was resolved for the space and aircraft variants in the conditions of single and double layer continuous and broken cloudiness for various optical parameters of the clouds and various characteristics of the light source and receiver. For this problem's solution in the conditions of stochastic cloudiness special weight algorithms of the Monte Carlo method were developed.

The form and duration of light pulses reflected by clouds are obtained by the Monte Carlo method. Calculation results allow investigating the possibility to determine cloud height from satellites and finding relations between light pulse characteristics and certain cloud properties. A numerical model of a laser echo-signal is constructed in the case of single layer continuous and broken cloudiness (drop cloud of the lowest cloud level of St type) and double layer continuous cloudiness (a crystal cloud Ci of highest level is located above a drop cloud).

Hurricanes and Climate Change: A Case of United Kingdom

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Uncharacteristically strong storm activity in the UK during recent years has focussed attention once again upon climate change impacts. Rapid climate change, which in turn affects sea surface temperatures (SST), ocean circulation, mean temperatures, and wind speed patterns, is most likely contributing to these unprecedented and prolonged storm events. Previous studies focused on individual factors rather than cumulative effects of climate change: however, a knowledge gap exists. Consequently, this quantitative study analysed consequences of the current effect of climate change on United Kingdom sea surface and mean temperatures, along with mean wind speeds. It also assessed whether climate change scenarios will create favourable conditions for the genesis of catastrophic hurricanes in the UK by using a 3-Pathway Analysis (SST, Wind Speed, Temperatures). Accordingly, in-situ SST, mean wind speed, and mean temperatures for the period 2000 to 2014 are analysed. Primary results revealed increasing trends in regional SST (0.1°C to 0.7°C), mean temperature (0.4°C to 0.8°C), and wind speed (0.2 m/s to 2 m/s) patterns. It is expected that significant changes in climate will cause increases in sea surface temperature of between 1°C and 4°C , which will accelerate temperature and wind speed further. These adverse changes would negatively affect future weather patterns of the United Kingdom and create positive conditions for the formation of super storms and high winds by 2100, although not necessarily hurricanes.

Observing Sulphur Dioxide and Sulphate Aerosol in the Stratosphere using MIPAS

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The Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) was operational from 2002 to 2012 on the Envisat platform, measuring atmospheric limb emission spectra from $685\text{--}2410\text{ cm}^{-1}$. This range makes it possible to measure the ν_1 and ν_3 SO_2 bands as well as less well defined broadband aerosol features.

In order to investigate SO_2 to sulphate stratospheric decay, the time periods immediately after two large volcanic eruptions are inspected: Sarychev Peak, Russia in June 2009 and Nabro, Eritrea in June 2011. Using the MORSE sequential estimation retrieval, stratospheric loadings of SO_2 and aerosol extinction can be obtained. After conversion of the extinction measurements to aerosol mass, these show the decay of SO_2 to sulphate over the months following a volcanic eruption and are used to obtain decay rates.

Limb-Nadir Matching for Tropospheric NO_2 : A New Algorithm in the SCIAMACHY Operational Level 2 Processor

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SCIAMACHY (SCanning Imaging Absorption spectroMeter for Atmospheric CHartography) aboard ESA's environmental satellite ENVISAT observed the Earth's atmosphere in limb, nadir, and solar/lunar occultation geometries covering the UV-Visible to NIR spectral range. Limb and nadir geometries were the main operation modes for the retrieval of scientific data. The new version 6 of ESA's level 2 processor now provides for the first time an operational algorithm to combine measurements of these two geometries in order to generate new products. As a first instance the retrieval of tropospheric NO_2 has been implemented based on IUP-Bremen's reference algorithm [1]. We will detail the single processing steps performed by the operational limb-nadir matching algorithm and report the results of comparisons with the scientific tropospheric NO_2 products of IUP and TEMIS [2]. The operational limb-nadir matching has been programmed in a generic way, meaning that

the application to further trace gas species will require moderate adaptations only. Retrieval of tropospheric BrO by limb-nadir matching is planned for the next operational processor version.

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A Study of Carbonaceous Aggregates: Simplifying the Method of Calculation of Fractal Dimension

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Increasing urbanization, burning of fossil fuels along with vehicular emissions around the globe are a major source of aerosols which have different morphological properties, generally exhibiting fractal like geometry, as compared to natural aerosols. Coupled with their complicated shapes it becomes computationally difficult to calculate fractal dimension which is needed to quantify such aggregates.

The particle collection was done at Delhi and Kanpur in the Indo-Gangetic Plain (comprising of highly urbanized areas) in Northern-India to maximize probability of collection of carbonaceous aggregates. The individual particles were collected on Cu-TEM grids for individual particle morphology using High Resolution Transmission Electron Microscope (HRTEM). Further image analysis was done using ImageJ.

The particles collected at above mentioned sites exhibited fractal like morphology each composed of 110-150 spherical monomers (with monomer radius varying from 25nm-50nm) while shapes varied from chain-like shape to aggregates coagulated into almost spherical ones.

The empirical relation given by Lewis F. Richardson (reinstated by Mandelbrot, 1967) was used in the calculation of fractal dimension-

$$L(r) = a \cdot r^{(1-D_f)}$$

where $L(r)$ is the length of the aggregate taken along its periphery/perimeter, a is any positive constant, r is the length of the measuring scale or span and D_f is the fractal dimension.

Other recent studies have also used this empirical relation for its simplicity (Brown, 1987; Bo-An Jang, 2006).

The perimeter of the aggregates was calculated using ImageJ. An aggregate is "profiled" or a circumference is created using measuring spans of 50nm, 75nm, 100nm and 125nm in ImageJ to obtain perimeter $L(r)$ as a function of measuring span r .

A log-log plot of the empirical relation between perimeter $L(r)$ and measuring spans r is plotted. The slope of the plot is calculated (using a simple math software) to obtain fractal dimension.

The method developed gives satisfactory results within an error of 5%-10% when 4 to 5 different cases of measuring spans are used to measure perimeter of the profile.

By making the calculations of fractal dimension computationally less tedious it has become easier for us to understand the behavior and ageing mechanisms of carbonaceous aerosols.

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Interannual variations in VOC flux estimates inferred from OMI formaldehyde columns through 2005-2013

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Emission estimates for volatile organic compounds (VOCs) suffer from substantial uncertainties and may strongly differ between bottom-up inventories. Among VOCs, isoprene is the most importantly emitted hydrocarbon in the atmosphere, with global annual emissions estimated at about 500 Tg, but with large uncertainties associated to them (Arneth et al., 2011). Besides the variation due to differences in emission models and assumptions in their driving variables, emissions from open fires do have a strong natural interannual variability. Here we use an inverse modeling scheme constrained by formaldehyde columns retrieved from the Ozone Monitoring Instrument (OMI) to improve the biogenic and pyrogenic NMVOC emission estimates for the period between 2005 and 2013. To this purpose, we employ the IMAGESv2 global chemistry-transport model and its adjoint module (Stavrakou et al. 2015). The MEGAN-MOHYCAN-v2 updated model is used as bottom-up inventory for biogenic emissions (Stavrakou et al., 2014) and fire fluxes are taken from the GFEDv3 inventory (van der Werf et al., 2010). The inversions are realized per year and monthly emissions are derived per emission category and for every model grid. The inversion results are compared to (i) independent isoprene emissions from GUESS-ES (Arneth et al., 2007) and MEGAN-MACC (Sindelarova et al., 2014), (ii) global fire emission inventories, FINNV1.5 (Wiedinmyer et al., 2011) and GFASv1.0 (Kaiser et al., 2012), and (iii) fire counts from the MODIS sensor.

The mean annual OMI-based isoprene flux for the period 2005-2013 is estimated at 307 Tg, with small interannual variation in the global flux between a minimum of 294 (in 2008 and 2013) and a maximum of 317 Tg in 2010. This is found to be ca. 30 Tg/yr lower than the priori inventory, but substantially lower than the MEGAN-MACC and the GUESS-ES inventory, however, in terms of interannual variability all inventories show similar patterns. On the global scale all inventories agree on lower isoprene emissions in 2008 and 2013 and higher in 2010.

The OMI-derived fire flux estimates exhibit strong interannual variability, varying between 1300 (in 2009 and 2011) and 1800 TgC/yr in 2005 and 2007 on the global scale. The interannual variability of the a priori inventory is generally well preserved, but the global annual emission estimates are by 100 to 500 TgC lower depending on the year. The strongest decreases in fire emissions are suggested over northern Africa and southern America, where the space-based estimates are found to be in better agreement with the independent inventories. Over regions impacted by small fires, e.g. due to agricultural practices, a better correlation with MODIS fire counts is found after the inversion.

Updated pyrogenic and biogenic emission estimates are available at a resolution of $0.5^{\circ} \times 0.5^{\circ}$ at a monthly basis for all years between 2005 and 2013 on the GlobEmission website (<http://www.globemission.eu/>).

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Methane and carbon dioxide total columns over oceans measured by shortwave infrared satellite sounders

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The current spaceborne shortwave infrared (SWIR) spectrometer GOSAT and OCO-2 and the future CarbonSat mission focus on the retrieval of methane and carbon dioxide total column densities from cloud free observation over land. Moreover, the Sentinel 5 Precursor mission and its successor mission Sentinel 5 comprise a SWIR spectrometer to infer CH₄ columns as one of its target products. Generally, sea surfaces are very dark in the SWIR spectral range and so the low measurement signal over clear sky ocean scenes does not provide any information on both CO₂ and CH₄. Therefore, exploiting SWIR ocean measurements relies on sun glint observation geometries with high sea surface reflectivity. This observation mode requires clear sky conditions and reconciled solar and observation geometry and by that limits the number of useable observations over oceans. To complement on this, we present a novel physics-based method for retrieving methane XCH₄ and carbon dioxide XCO₂ total column mixing ratios over ocean areas covered by low clouds. The method is based on the existing RemoTeC algorithm that is extensively used to retrieve CH₄ and CO₂ columns from GOSAT SWIR measurements over land. For ocean pixels, we describe light scattering by clouds and aerosols by a single-layer water cloud with Gaussian height distribution. We infer the height and the geometrical thickness of the cloud layer jointly with the droplet size and the number density of the cloud and the column abundances of CO₂, CH₄ and H₂O. The CO₂ and CH₄ column product is validated with ground-based total column measurements performed at 8 stations from the TCCON network that are geographically close to an ocean coastline. For the TCCON sites with the most robust statistics, we find a retrieval bias of 0.29% of the total column-mixing ratio for XCH₄ combined with a standard deviation of retrieval errors of 1.15%. For XCO₂, the bias is 0.47 % combined with a standard deviation of 1.02%. Averaged over all TCCON sites, our retrievals are biased -0.04% for XCO₂ and -0.36% for XCH₄. The standard deviation of station biases amounts to 0.42% for XCO₂ and 0.31% for methane total column mixing ratio. In summary, the proposed approach

amends current and future physics-based CH₄ and CO₂ satellite products from SWIR measurements and enhances the geographical coverage over ocean areas without relying on sun glint geometry.

Retrieval of Atmospheric Temperature from Airborne Microwave Radiometer Observations

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Atmospheric temperature is a key geophysical parameter associated with fields such as meteorology, climatology, or photochemistry. There exist several techniques to measure temperature profiles.

In the case of microwave remote sensing, the vertical temperature profile can be estimated from thermal emission lines of molecular oxygen. The MTP (Microwave Temperature Profiler) instrument is an airborne radiometer developed at the Jet Propulsion Laboratory (JPL), United States.

The instrument passively measures natural thermal emission from oxygen lines at 3 frequencies and at a selection of 10 viewing angles (from near zenith to near nadir). MTP has participated in hundreds of flights, including on DLR's Falcon and HALO aircraft. These flights have provided data of the vertical temperature distribution from the troposphere to the lower stratosphere with a good temporal and spatial resolution. In this work, we present temperature retrievals based on the Tikhonov regularized nonlinear leastsquares fitting method. In particular, Jacobians (i.e. temperature derivatives) are evaluated by means of automatic differentiation. The retrieval performance from the MTP measurements is analyzed by using synthetic and real data. Besides, the vertical sensitivity of the temperature retrieval is studied by weighting functions characterizing the sensitivity of the transmission at different frequencies with respect to changes of altitude levels.

The ADM-Aeolus mission – Summary of the Science and Cal/Val Workshop held in February 2015

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ADM-Aeolus is an Earth Explorer mission of ESA's Living Planet Programme, carrying a Doppler wind lidar, called Aladin. It is designed to measure the lowermost 30 km of the atmosphere to provide profiles of wind, aerosols and clouds along the satellite's path.

As the first wind lidar in space, Aladin's measurements and global wind profile will be an important input for the NWP community, contributing to improve the forecast accuracy further.

In February 2015 ESA organised the ADM-Aeolus Science and Cal/Val workshop in ESRIN, Frascati, Italy, with the objective to bring scientists and Cal/Val Principle Investigators together to present and discuss the Aeolus mission and products, science applications and Calibration and Validation aspects.

During the workshop the value of the ADM-Aeolus data sets for example for NWP, climate re-analysis, climate modelling was highlighted through a number of presentations.

This presentation will provide an overview and summary of the ADM-Aeolus Science and Cal/Val workshop.

Validation of Thermodynamic Profiles from MIPAS and GOMOS against Radiosondes and Radio Occultation Reference Data

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Instrument keywords: MIPAS, GOMOS, CHAMP, COSMIC, GRACE, MetOp, GRUAN

Specific keywords: validation, T, p, thermodynamic profiles

In the ESA atmospheric Cal/Val context we prepared long-term radio occultation (RO) reference data from a variety of RO missions (including up to about 2500 profiles per day) in Generic Earth Observation Metadata Standard (GEOMS) format. Applications of the data include use in the long-loop monitoring of trends related to other spaceborne instruments but also to climate change and variability, in routine validation of atmospheric satellite products, in the validation of geophysical retrieval algorithms, and in scientific study of atmospheric processes. The RO data provided are suitable for in-depth examination of tropospheric and stratospheric fundamental state profiles, such as of temperature, pressure, and humidity as function of altitude, from satellite observations. This undertaking is highly worthwhile since the unique combination of global coverage, high accuracy and vertical resolution, long-term stability, and virtual all-weather capability makes, in the free atmosphere, the validation with RO data preferable to other methods. We will briefly discuss the setup of the system for multi-mission validation by RO, and the quality and availability of the reprocessed RO datasets. We will then focus on the discussion of results of the multi-year validation of temperature and pressure profiles over the upper troposphere and lower stratosphere (UTLS) from Envisat MIPAS data against collocated RO data from CHAMP, Formosat-3/COSMIC, GRACE-A, and MetOp-A. We will also provide results of temperature and density validation of Envisat GOMOS data against the RO dataset. In addition, for a further independent high-quality data source, the RO and Envisat datasets are compared with Radiosondes data from Vaisala RS90/92 sondes from the "standard" global radiosonde network. Additionally, we include the first years of GRUAN data (using Vaisala RS92), available since 2009. We show how these results help to obtain quantitative estimates on the quality of the data (e.g., systematic error bounds) and underline the utility of RO to serve as reference data for validation and climate monitoring applications.