ADVANCED ATMOSPHERIC TRAINING COURSE 2014

IR Nadir/Limb Viewing Instruments/Data (IASI, MIPAS)

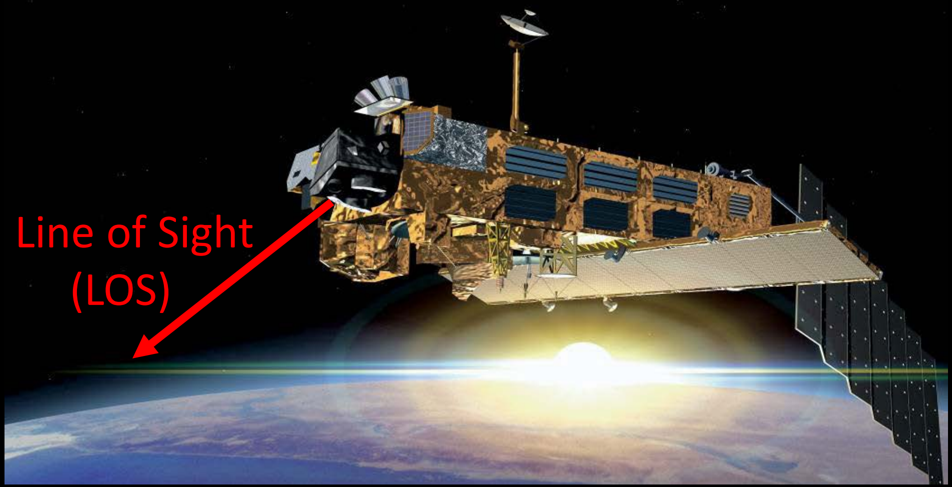
Michael Höpfner

Karlsruhe Institute of Technology

IMK-ASF

MIPAS on Envisat

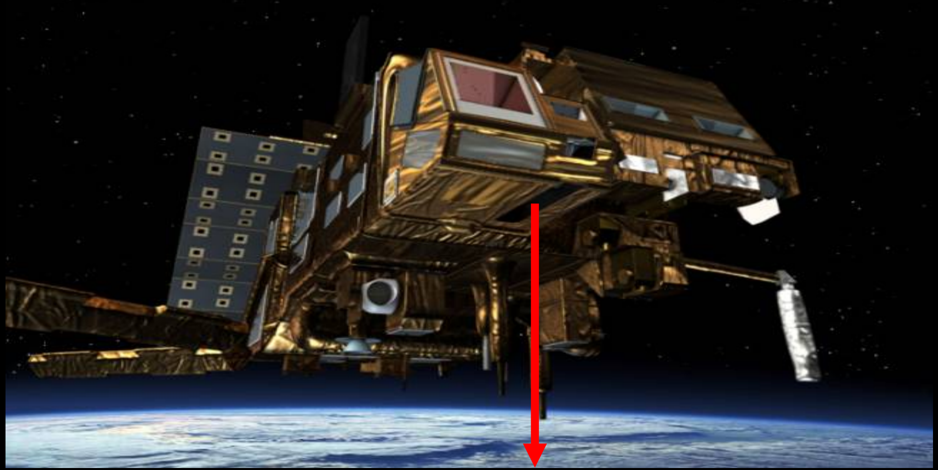
Michelson Interferometer for Passive Atmospheric Sounding



2002 – 2012

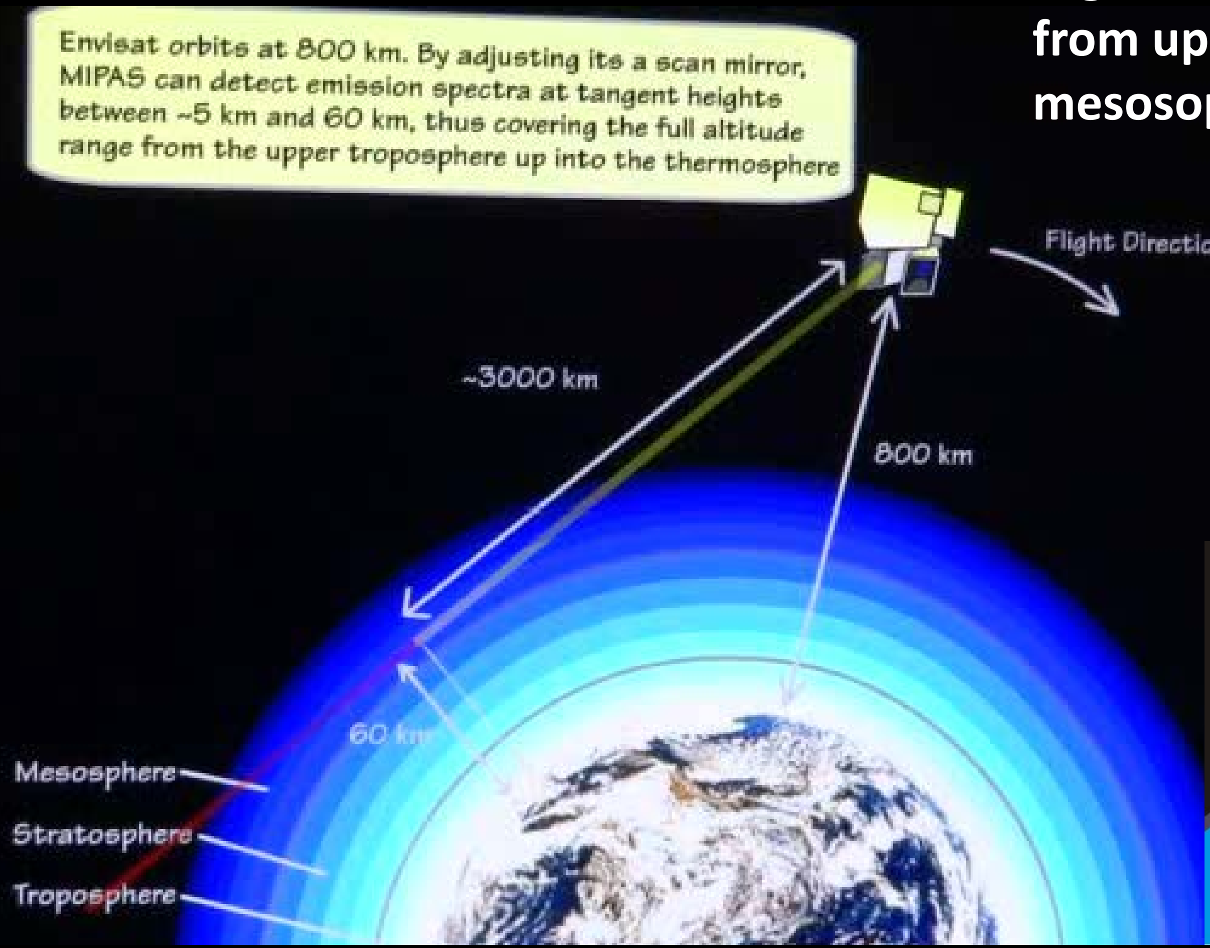
IASI on Metop

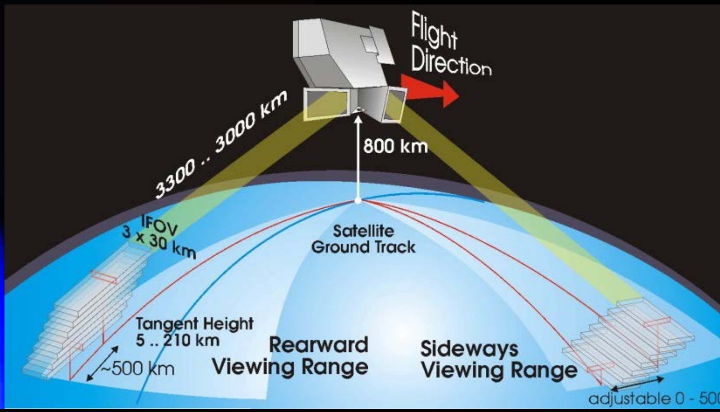
Infrared Atmospheric Sounding Interferometer



Metop A: 2006 –
Metop B: 2012 –

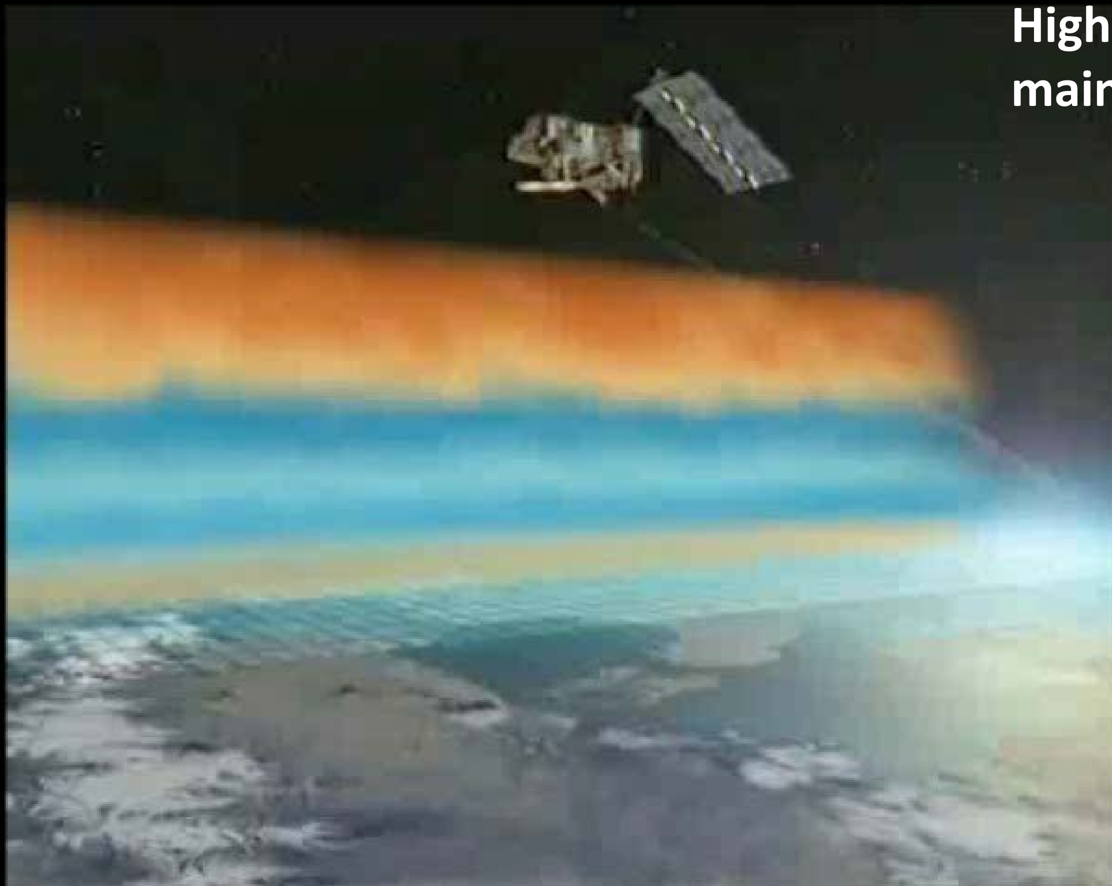
High vertical resolution and sensitivity from upper troposphere to mesosophere

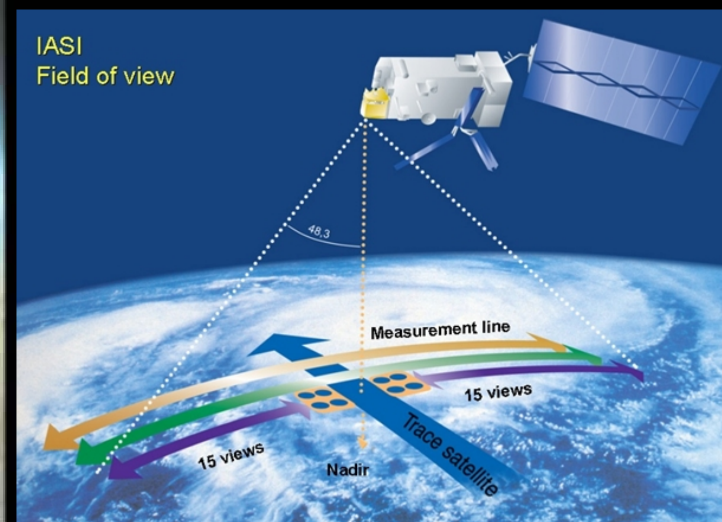




http://earth.esa.int/instruments/mipas/descr/flash.html

High horizontal resolution and coverage mainly of mid - upper troposphere



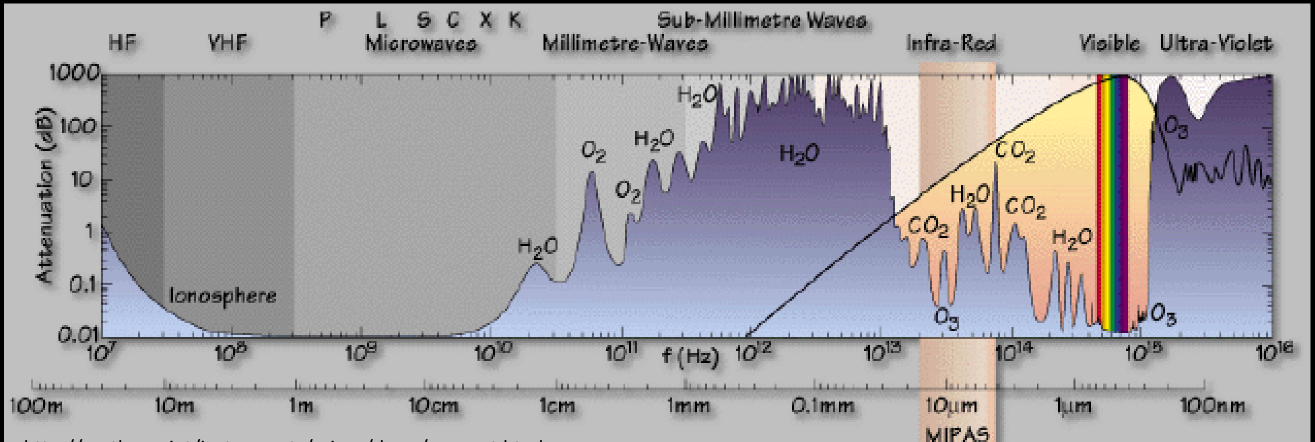


http://www.eumetsat.int/website/home/Satellites/CurrentSatellites/Metop/MetopDesign/IASI/index.html

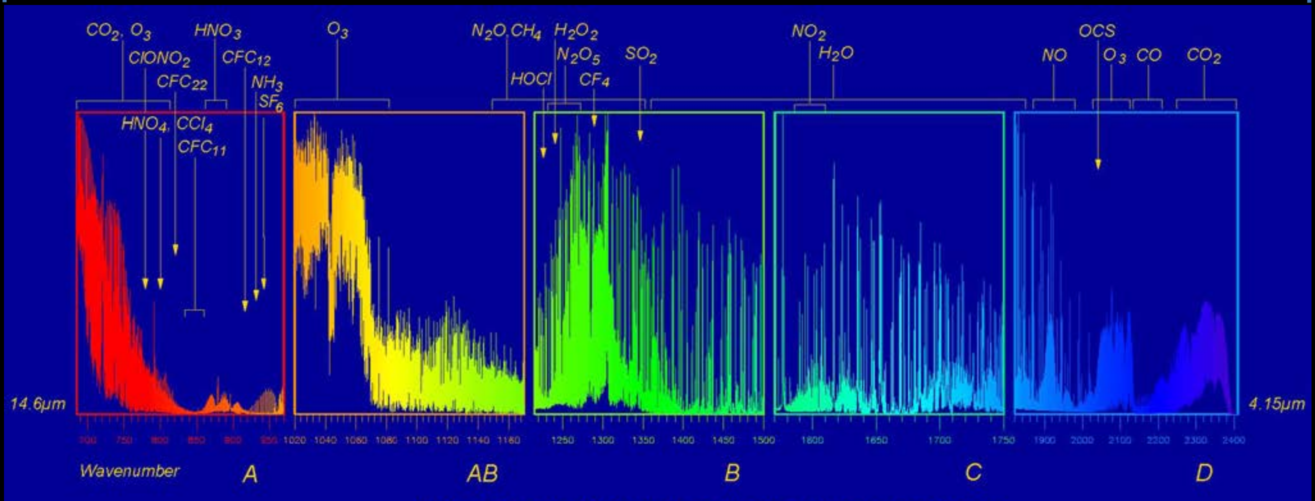
MIPAS

IASI

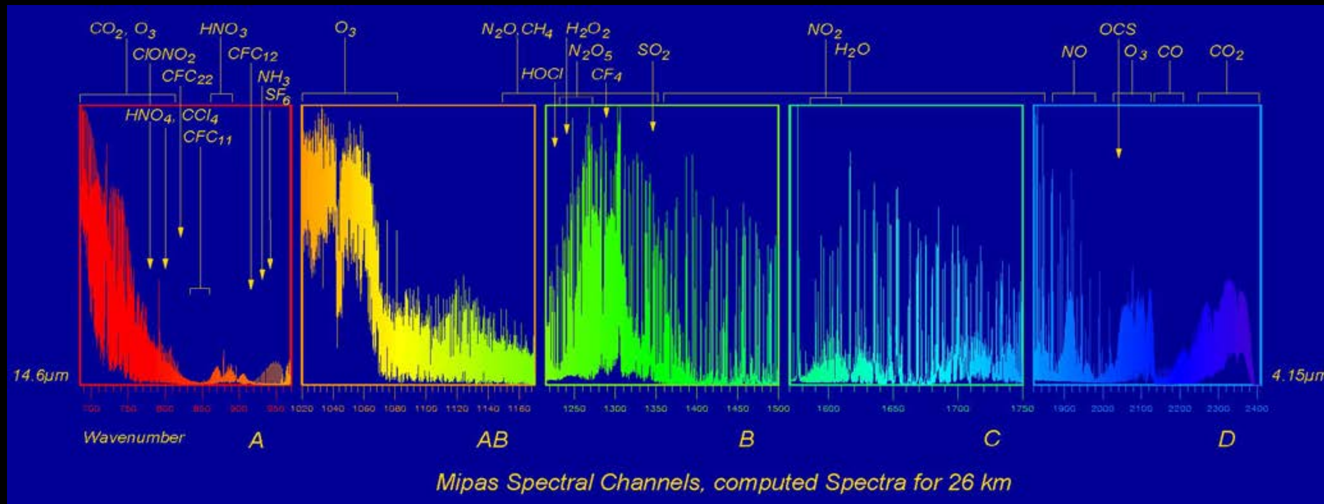
	MIPAS	IASI
Spectral range	685 – 2410 cm^{-1} 14.6 – 4.1 µm	645 – 2760 cm^{-1} 15.5 – 3.6 µm
Spectral sampling	0.025/ 0.0625 cm^{-1}	0.25 cm^{-1}

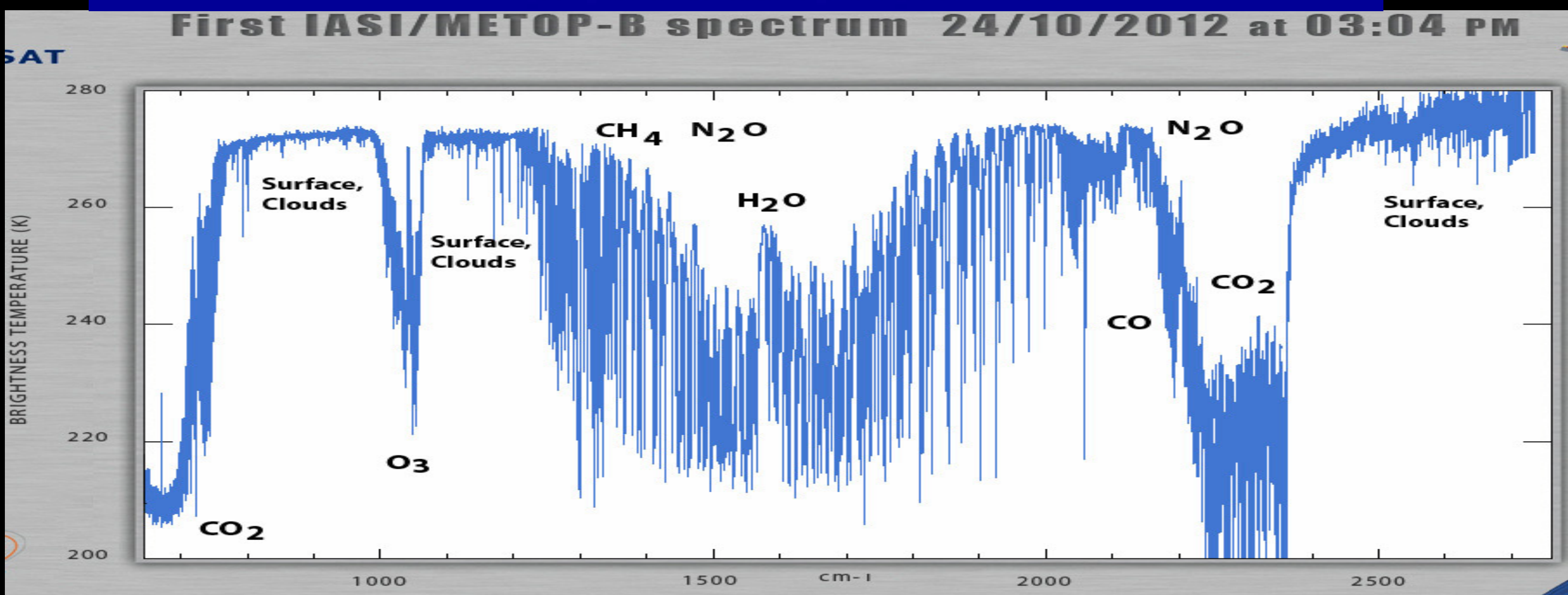


http://earth.esa.int/instruments/mipas/descr/concept.html

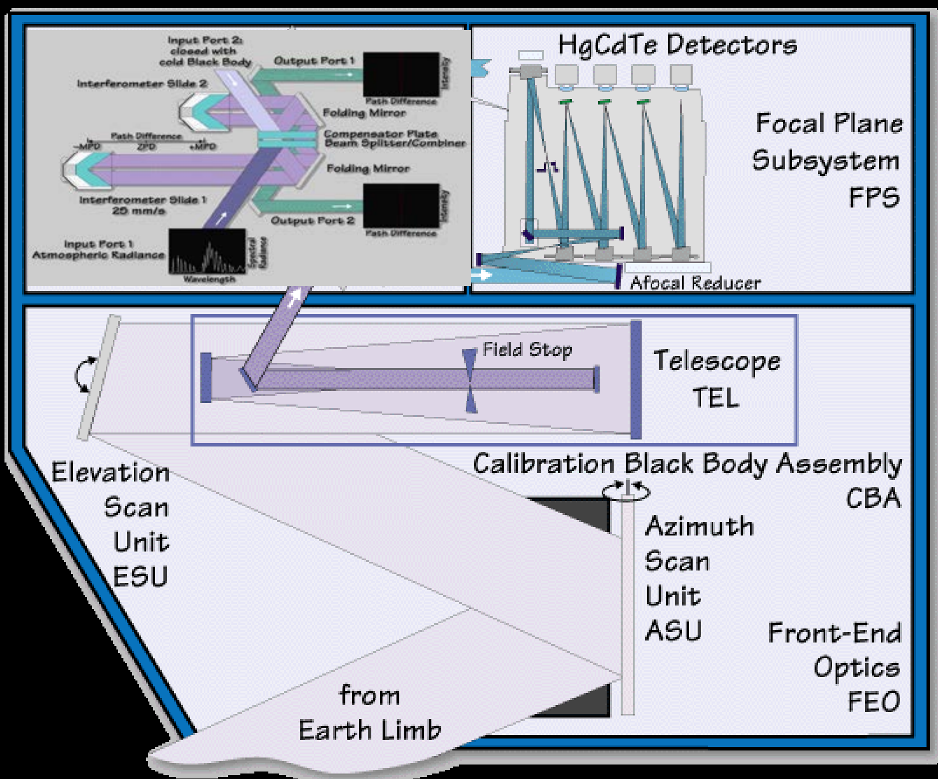


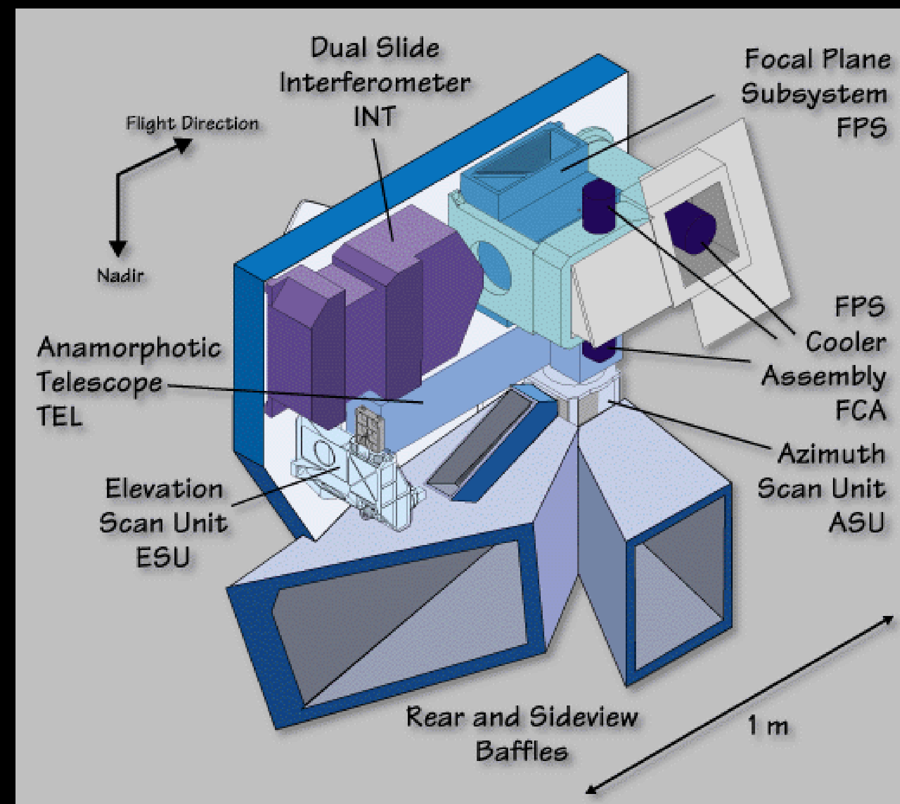
Mipas Spectral Channels, computed Spectra for 26 km


CO2, O3
HNO3
O3
N2O,CH4
H2O2
NO2
OCS
ClONO2
CFC12
N2O5
SO2
H2O
NO
O3
CO
CO2
CFC22
NH3
SF6
HOCl
CF4
HNO4, CCl4
CFC11
14.6µm
4.15µm
Wavenumber
A
AB
B
C
D
Mipas Spectral Channels, computed Spectra for 26 km


First IASI/METOP-B spectrum 24/10/2012 at 03:04 PM
BRIGHTNESS TEMPERATURE (K)
280
260
240
220
200
1000
1500
2000
2500
cm-1
CO2
Surface, Clouds
O3
Surface, Clouds
CH4
N2O
H2O
N2O
CO
CO2
Surface, Clouds

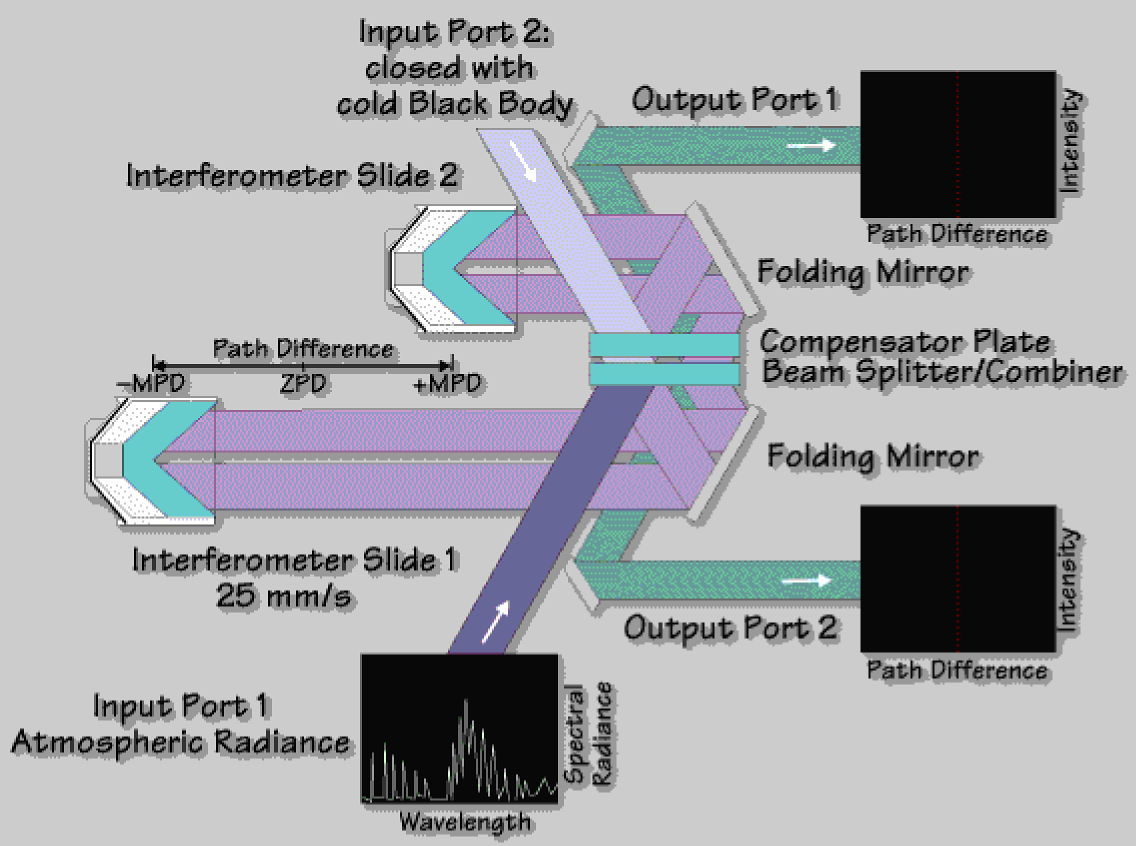
MIPAS - instrument

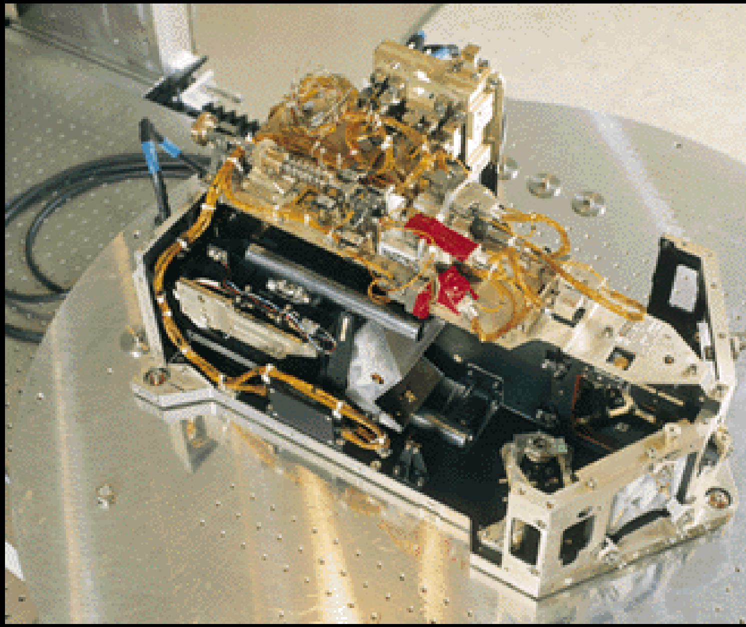




http://earth.esa.int/instruments/mipas/descr/concept.html

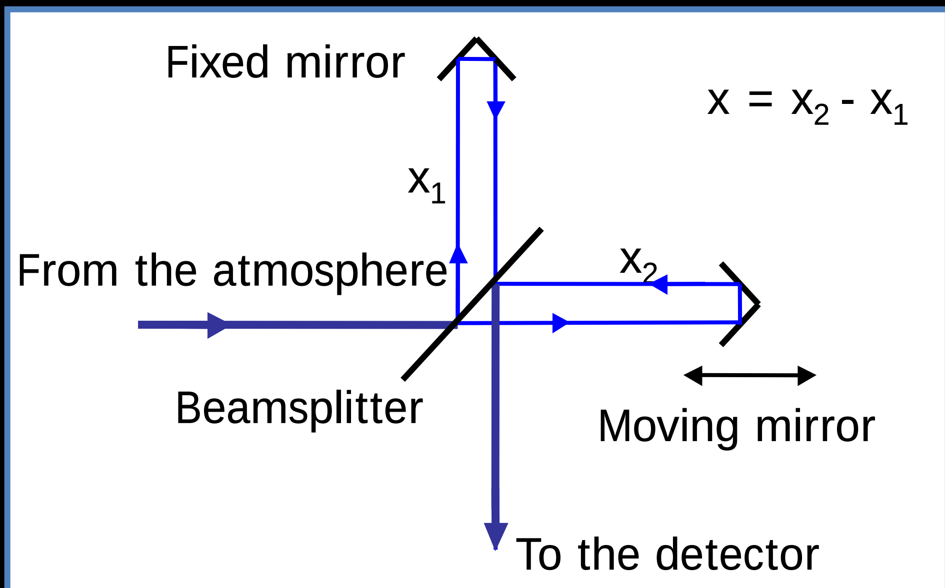
MIPAS - interferometer





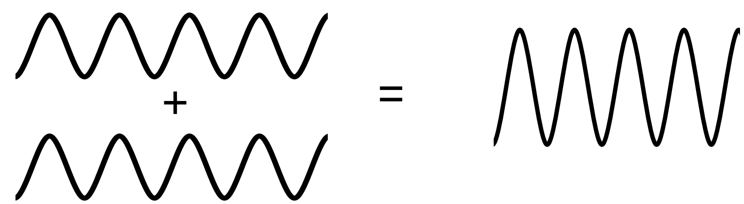
http://earth.esa.int/instruments/mipas/descr/concept.html

FTS - principle

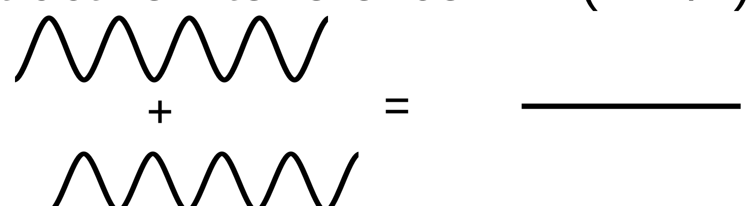



Albert Abraham Michelson (1852-1931)

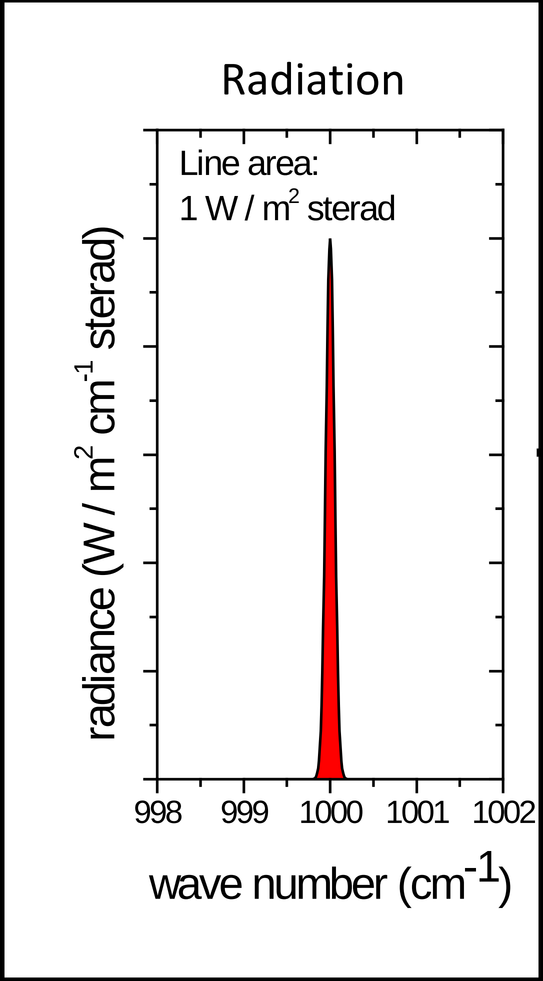
Constructive interference: $x = n\,\lambda$



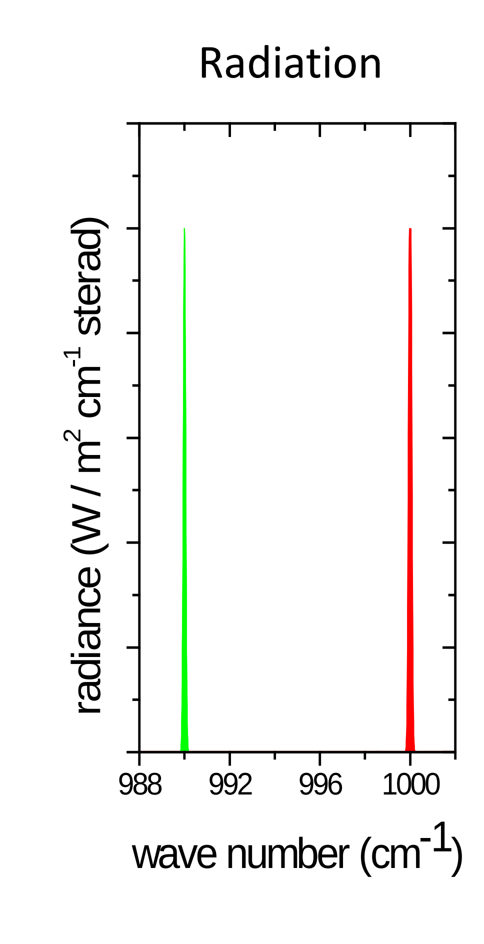
Destructive interference: $x = (n+1/2)\,\lambda$

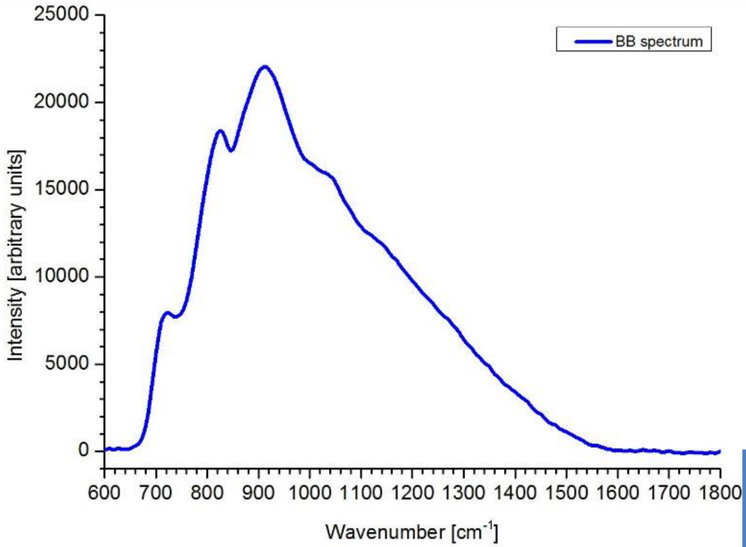


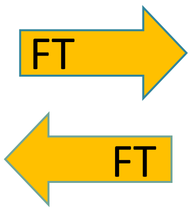
Interferogramm: one spectral line

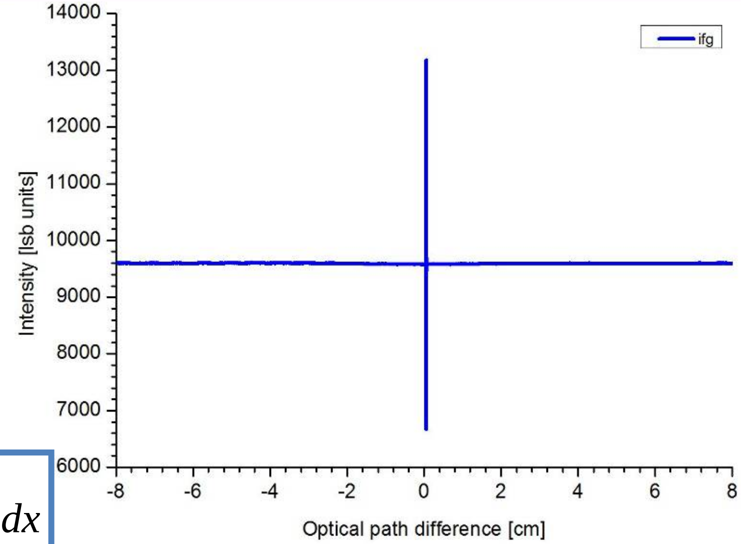


Interferogramm: two spectral lines

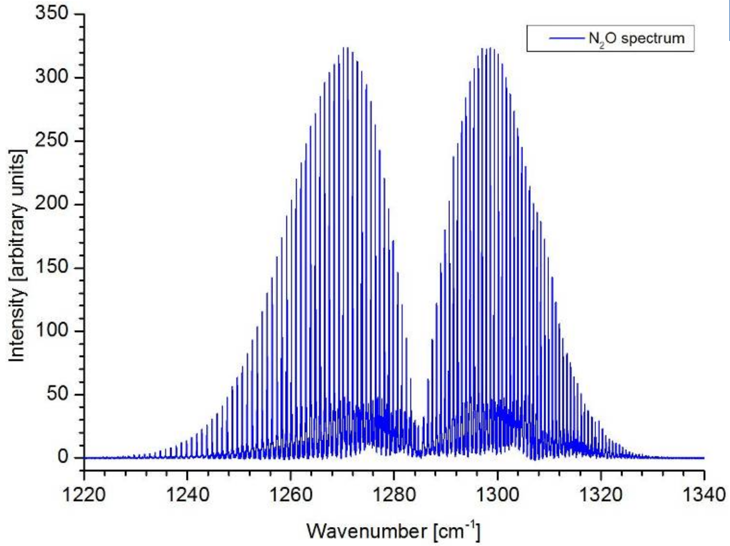


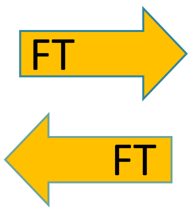


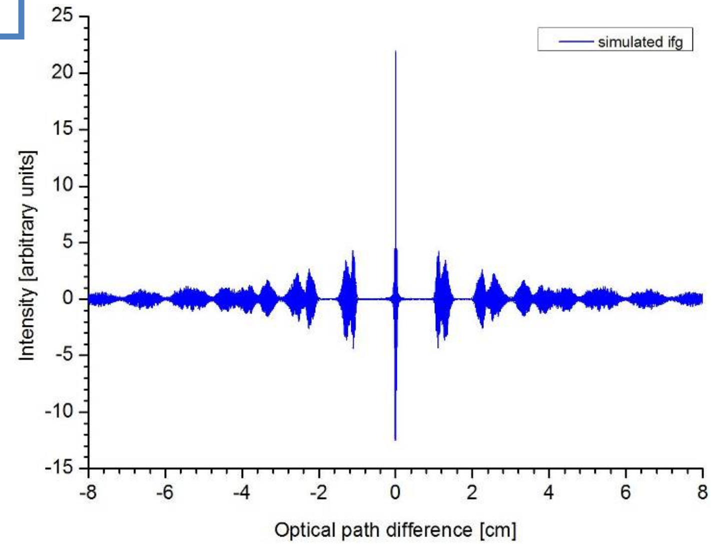




$$F(\sigma) = \int_{-\infty}^{\infty} f(x) e^{-2\pi i \sigma x} dx$$







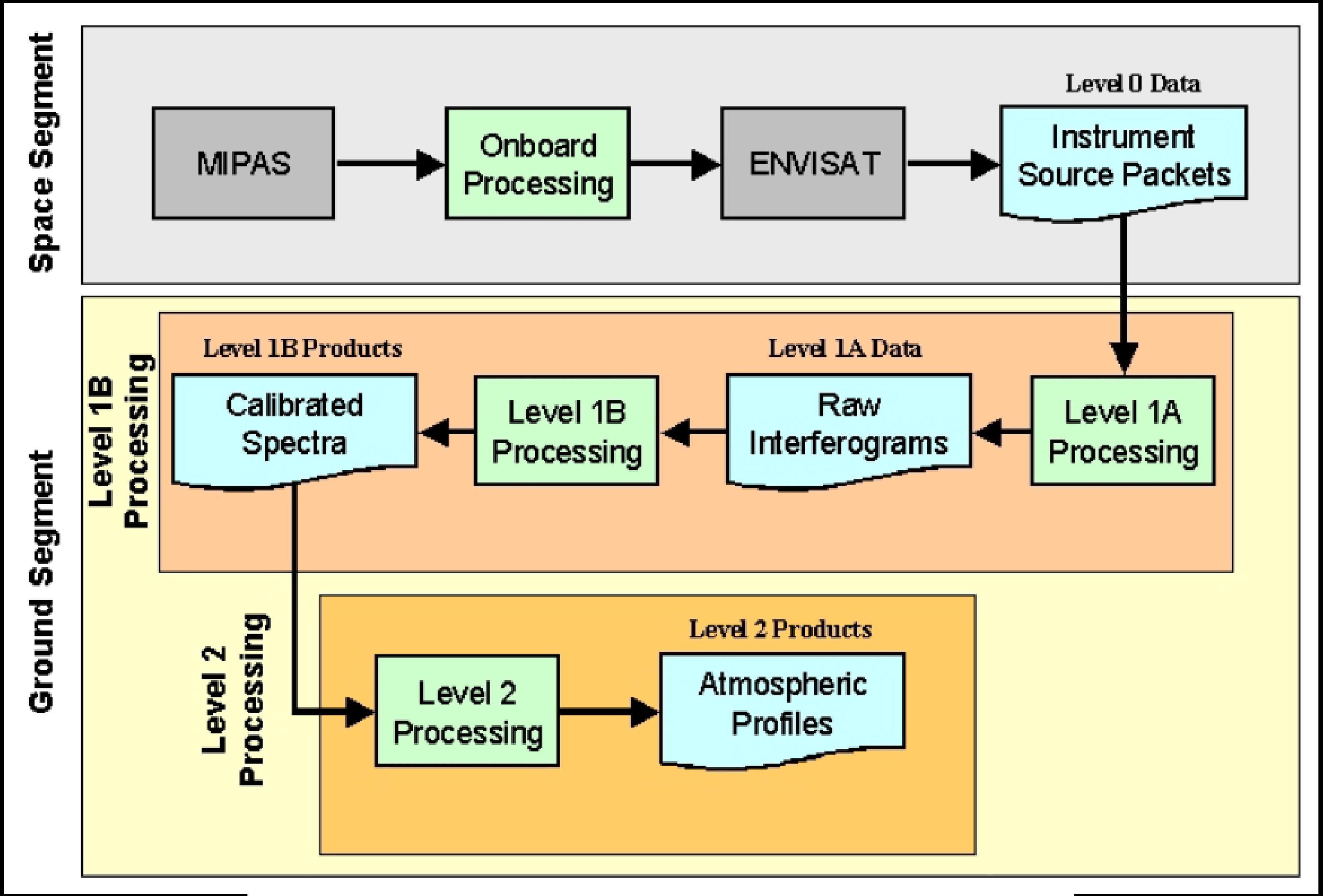
Pros and Cons of FTS

Advantages:

- No slit required: it can accept a large beam of light (throughput or Jacquinot's advantage)
- Only one detector required, not one detector per spectral interval; broad spectral coverage
- Spectral resolution not limited by size of detector but by maximum path difference: easy to achieve fine spectral resolution
- Good calibration – spectral and radiometric

Disadvantages:

- Mechanism necessary to produce optical path difference (but space-proven in the meantime)
- Very high data rates (but good compression algorithms)
- Complex processing (fast computers)



European Space Agency-EnviSat MIPAS Product Handbook, Issue 2.2, 27 February 2007

IASI Products

Level 0 : **Raw IASI measurement data**, after on-ground demultiplexing; level 0 includes pre-calibrated spectra, the corresponding non calibrated images, calibration images, verification data and auxiliary data necessary for further processing.

Level 1a : **Non apodised calibrated spectra and corresponding images** ; this step of processing comprises data decoding, radiometric post-calibration, spectral calibration, IASI/AVHRR coregistration via IASI images, geolocation and dating.

Level 1b : Level 1a **resampled**.

Level 1c : Level 1b **apodised** to obtain a nominal Instrument Spectral Response Function ; this level includes also an analysis of the **AVHRR radiances** over the IASI pixels.

Level 2a : **Geophysical products** derived from IASI in a self-standing mode (profiles of temperature, humidity, surface temperature, trace gas distribution, cloud parameters, etc.). Level 2a data may exist as interim geophysical products during the commissioning and pre-operational IASI mission phases and as geophysical products after upgrading of the processing software at the end of the pre-operational phase. Some of them might be merged into a more limited number of geophysical product records depending on the processing architecture and needs of users.

Level 2b : **Geophysical products** derived **after co-processing** of data from IASI and the METOP meteorological instruments. These products may be similar to level 2a products but with higher accuracy, resolution and/or extracted over a wider range of cloudiness.

Level 3 : **Gridded and time-averaged geophysical products** derived from level 2b products possibly in combination with information obtained from sources other than EPS system.

Level 4 : **Multisensor geophysical products** for instance as results of assimilation in meteorological or chemical transport models.

IASI mission requirements

Geophysical variables	Vertical resolution	Horizontal resolution	Accuracy
Temperature profile	1 km (low Troposphere)	25 km (cloud free)	1K (cloud free)
Humidity profile	1-2 km (low Troposphere)	25 km (cloud free)	10% (cloud free)
Ozone total amount	Integrated content	25 km (cloud free)	5% (cloud free)
CO, CH_4, N_2O	Integrated content	100 Km	10% (cloud free)

Nadir sounding weighting functions

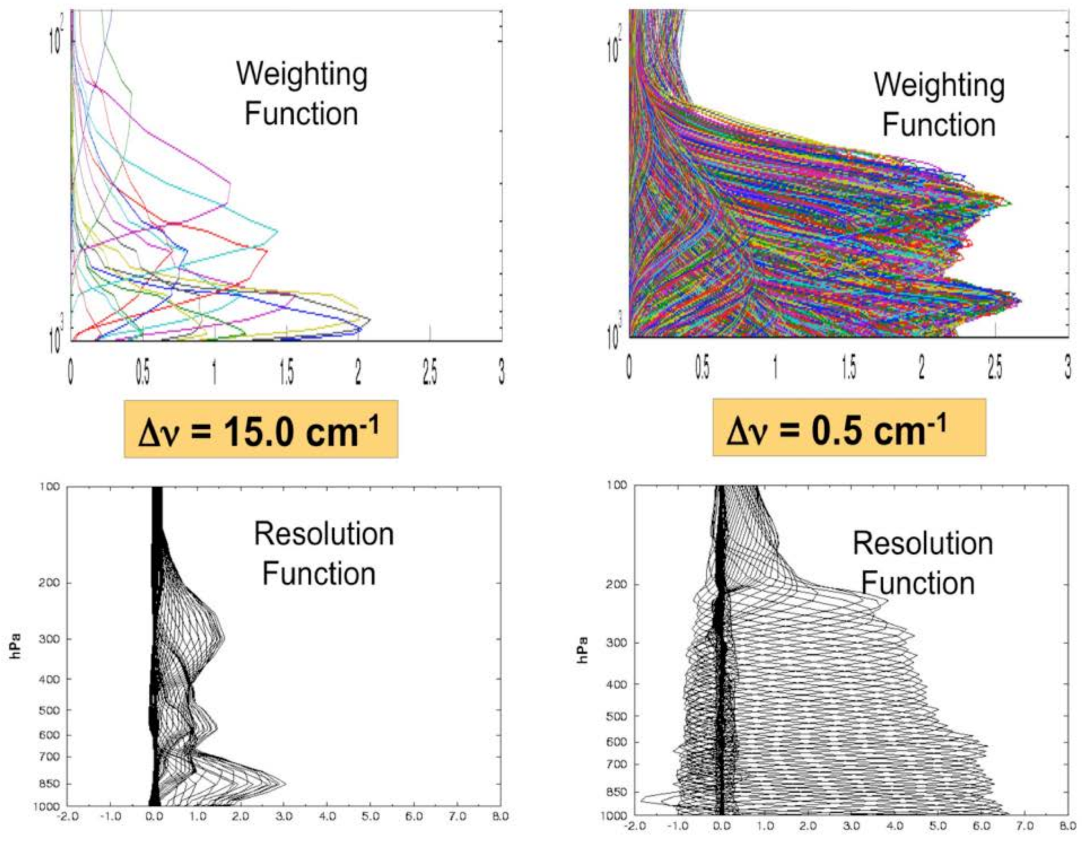
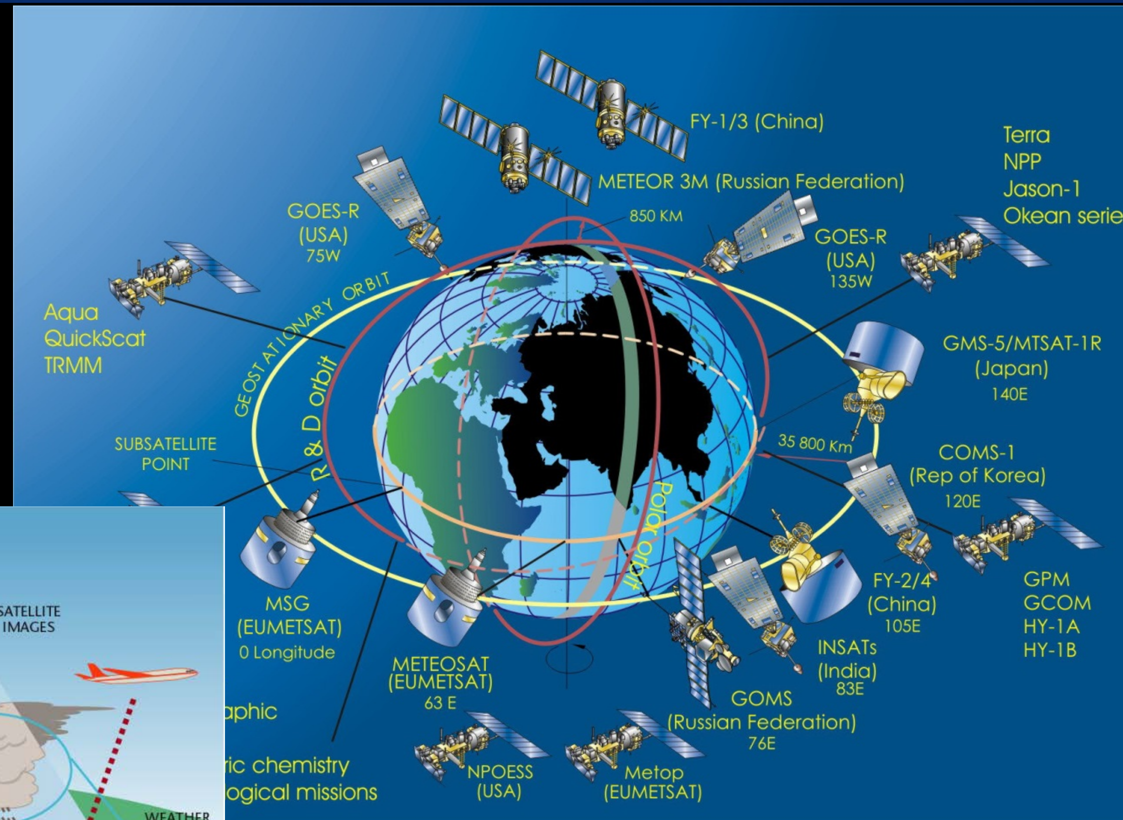
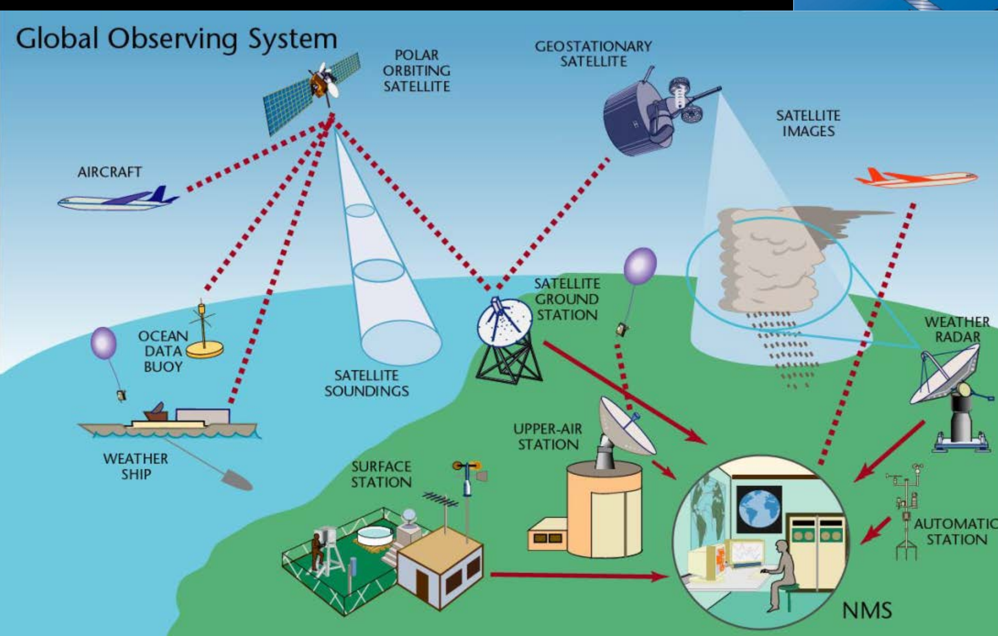


Fig. 2. The weighting functions and vertical profile resolution functions (i.e., averaging kernals) for two different instrument spectral resolutions.

Smith et al., 2009

Numerical weather prediction





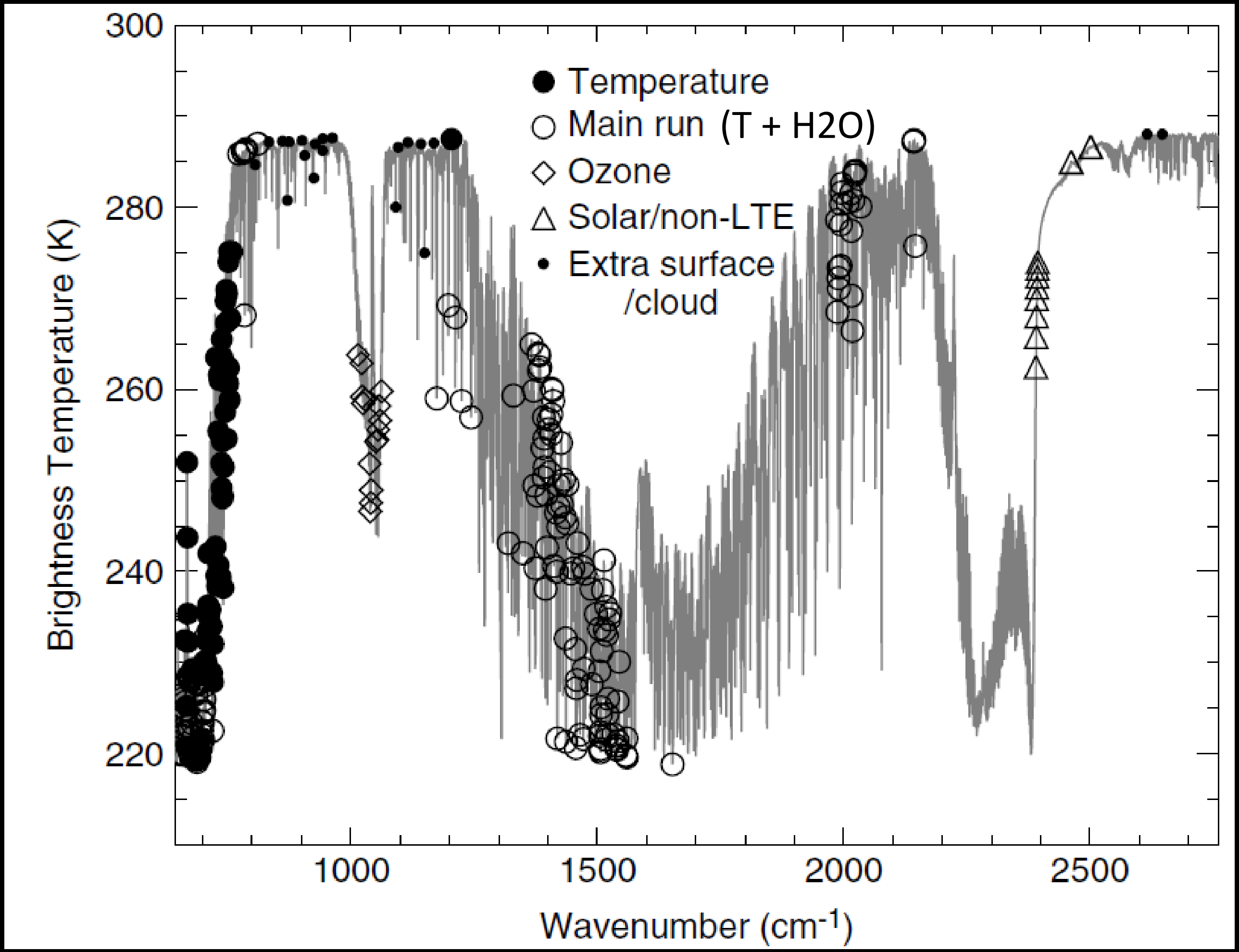
http://www.wmo.int/pages/prog/sat/images/

The first IASI instrument aboard Metop-A has delivered such essential improvements for Numerical Weather Prediction that some weather services consider IASI to be "the best meteorological sounder ever developed" (Météo France).

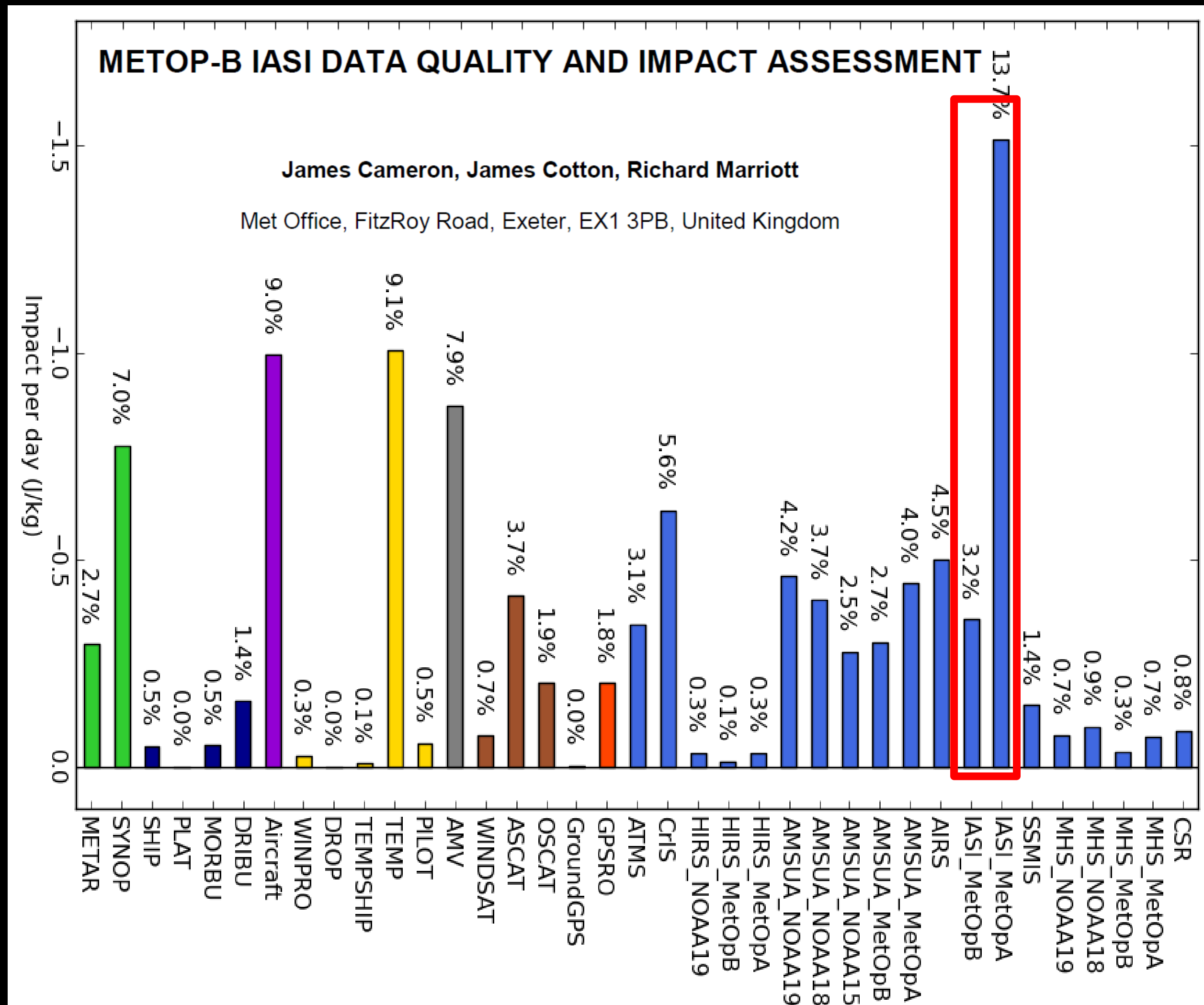
Andy Brown, Deputy Director of Foundation Science at the Met Office said: "Data from satellites plays a vital role in weather forecasting. A recent Met Office study found that satellites contributed about 65% of the total impact of observations on the performance of global weather forecasting models. IASI on Metop-A has given us the largest impact of any single satellite instrument, and we look forward to continued improvements provided by data from IASI on Metop-B."

http://www.eumetsat.int/website/home/News/DAT_2041275.html

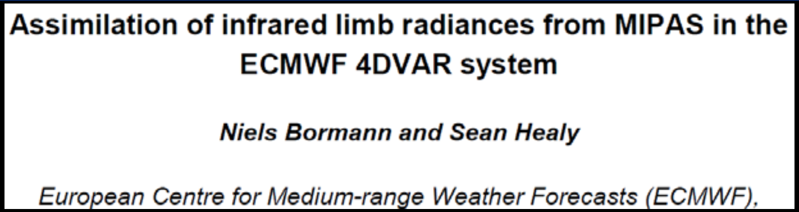
IASI NWP channel selection

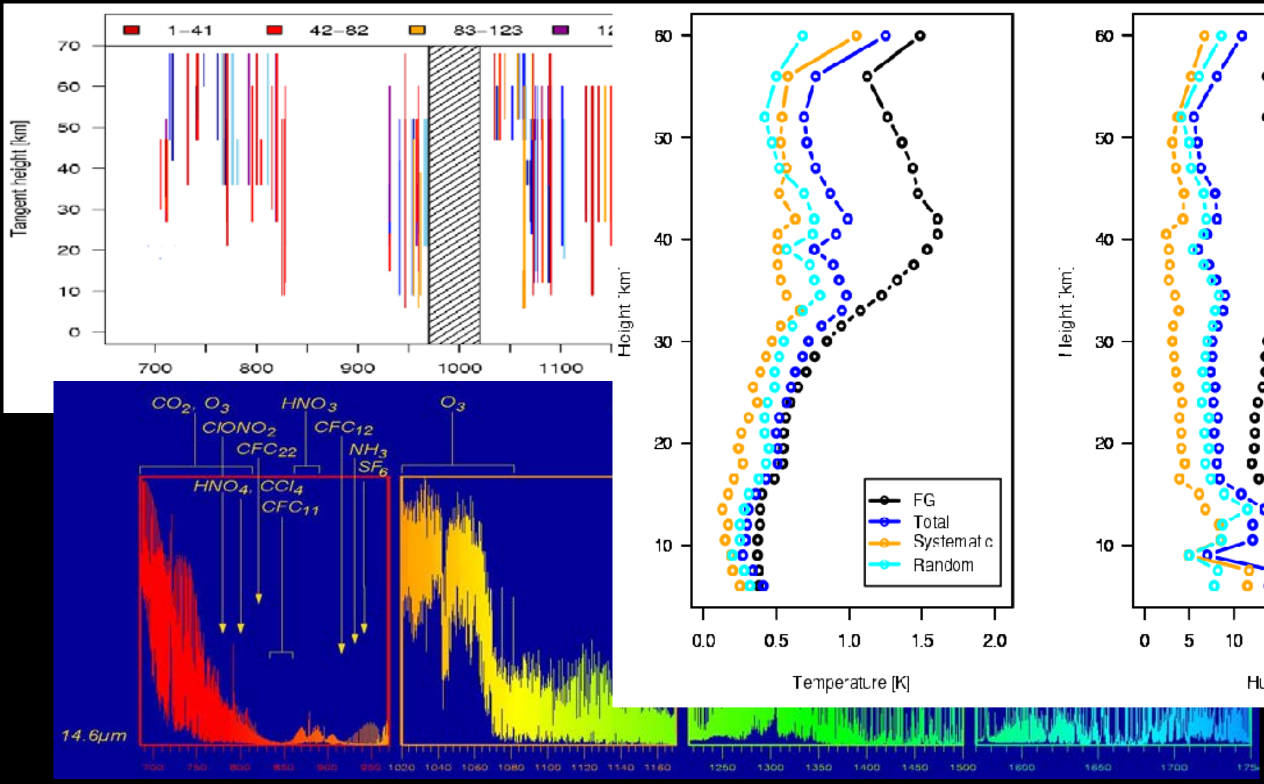


Collard, QJRMS, 2007

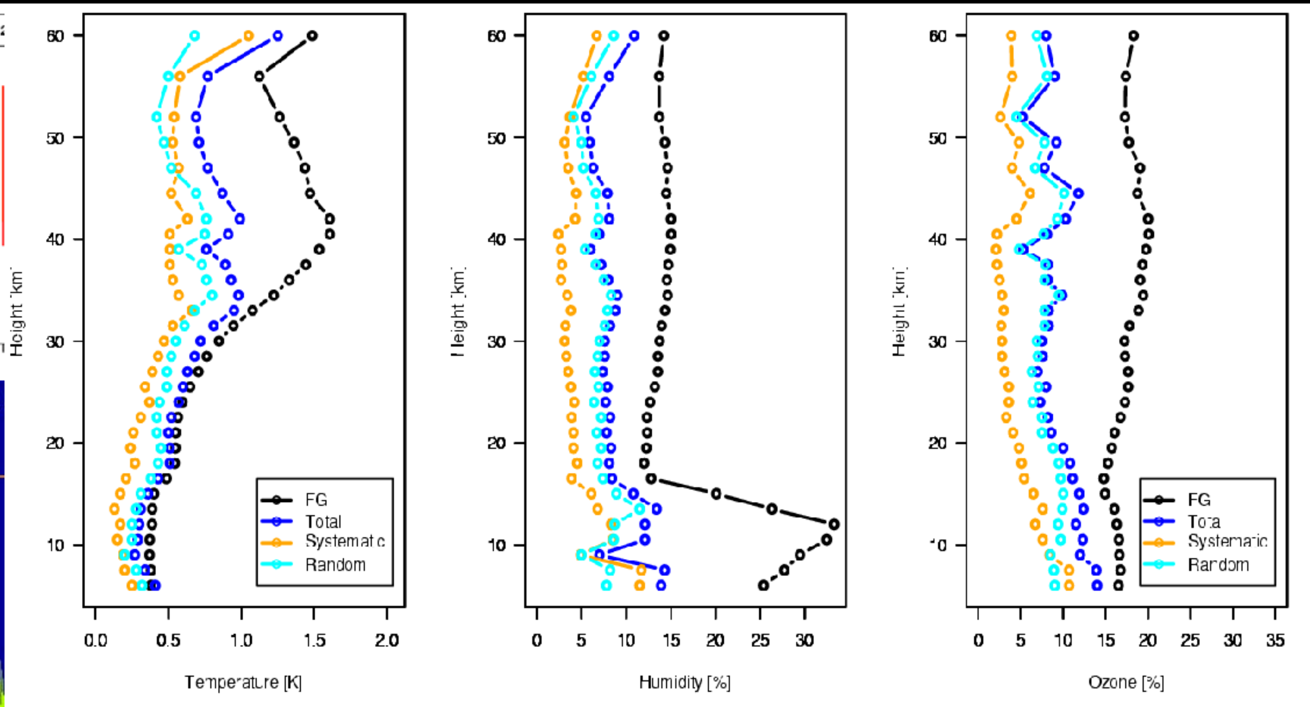


Mean impact per day of different observation types as derived from a forecast sensitivity experiment





Window selection



Theoretical reduction of analysis error

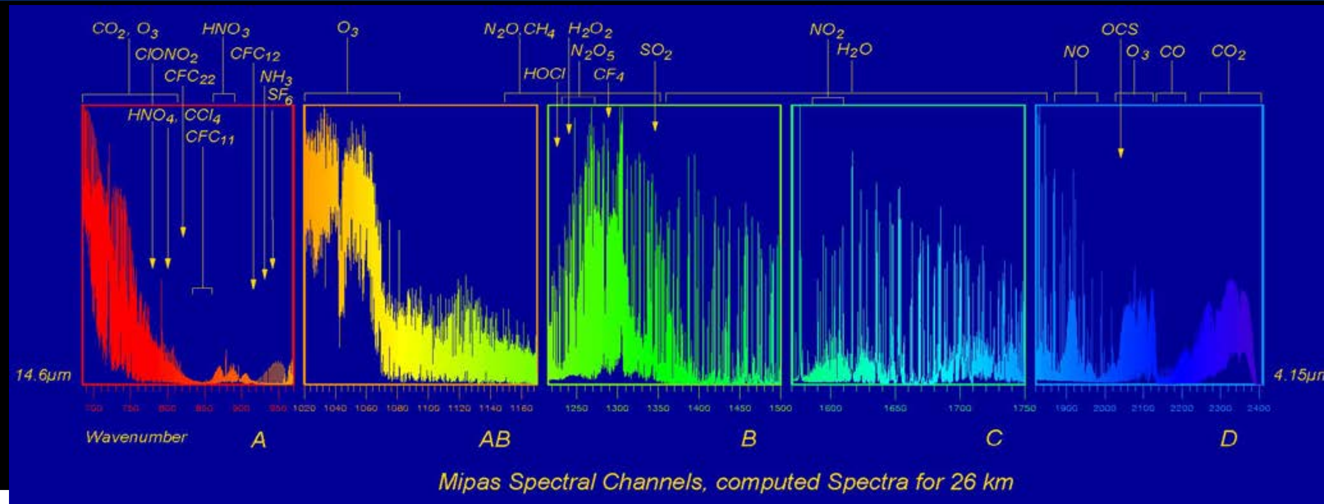
See also: N. Bormann* and J.-N. Thépaut
QUARTERLY JOURNAL OF THE ROYAL METEOROLOGICAL SOCIETY
Q. J. R. Meteorol. Soc. **133**: 309–327 (2007)

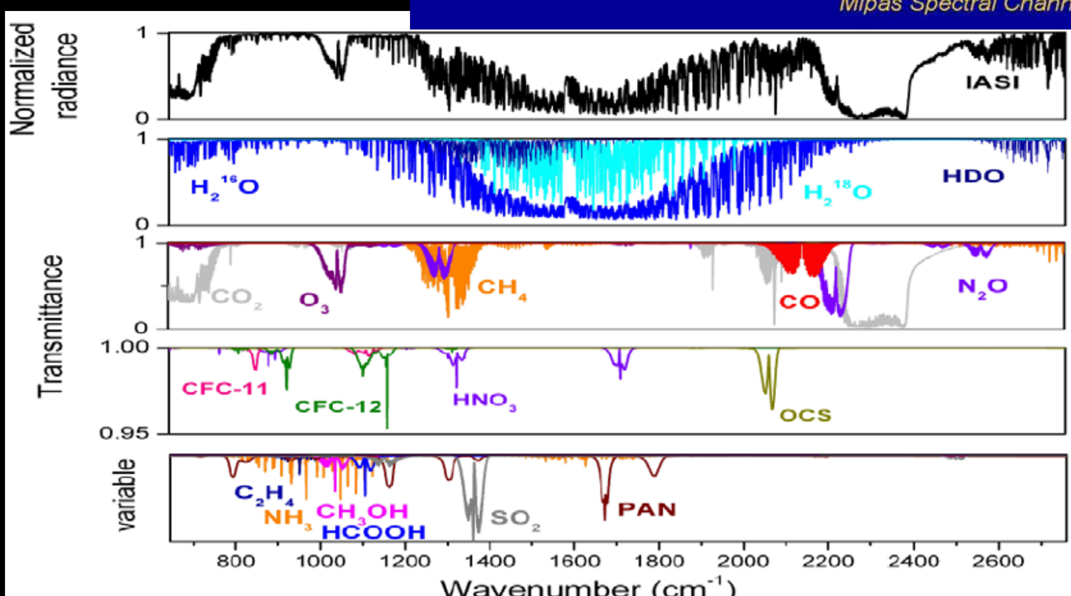
Table 1. List of IASI products available from EUMETSAT.

	Measured/retrieved parameters	EUMETCast		EUMETSAT data center		GTS	
		Filename patterns BUFR	NRT timeliness	Filename patterns native EPS / HDF5	Timeliness	Bulletin headers BUFR	NRT timeliness
L1	L1B full spectra–8,461 channels	NA	NA	IASI_xxx_1B_Mnn	8 h	NA	NA
	L1C full spectra–8,461 channels	*.l1_bufr	2 h 15 min	IASI_xxx_1C_Mnn	8 h	NA	NA
	L1C reduced spectra–316 channels	*300.l1_bufr	2 h 15 min	NA	NA	IEIX[01–99]	2 h 15 min
L2	Temperature profile–90 levels	*twt.l2_bufr	3 h	IASI_SND_02_Mnn	8 h	IEDX[01–19]	3 h
	Water-vapour profile–90 levels						
	Surface skin temperature						
	Retrieval error	NA				NA	
	Emissivity–12 channels	*ems.l2_bufr				NA	
	Fractional cloud cover	*clp.l2_bufr				IEDX[61–79]	
	Cloud-top temperature/pressure						
	Cloud phase						
	Ozone total column	*ozo.l2_bufr				IEDX[21–39]	
	Ozone partial column 0–6 km						
	Ozone partial column 0–12 km						
	Ozone partial column 0–18 km						
	CO total column	*trg.l2_bufr				IEDX[41–59]	
	N_2O total column						
	CH_4 total column						
	CO_2 total column						

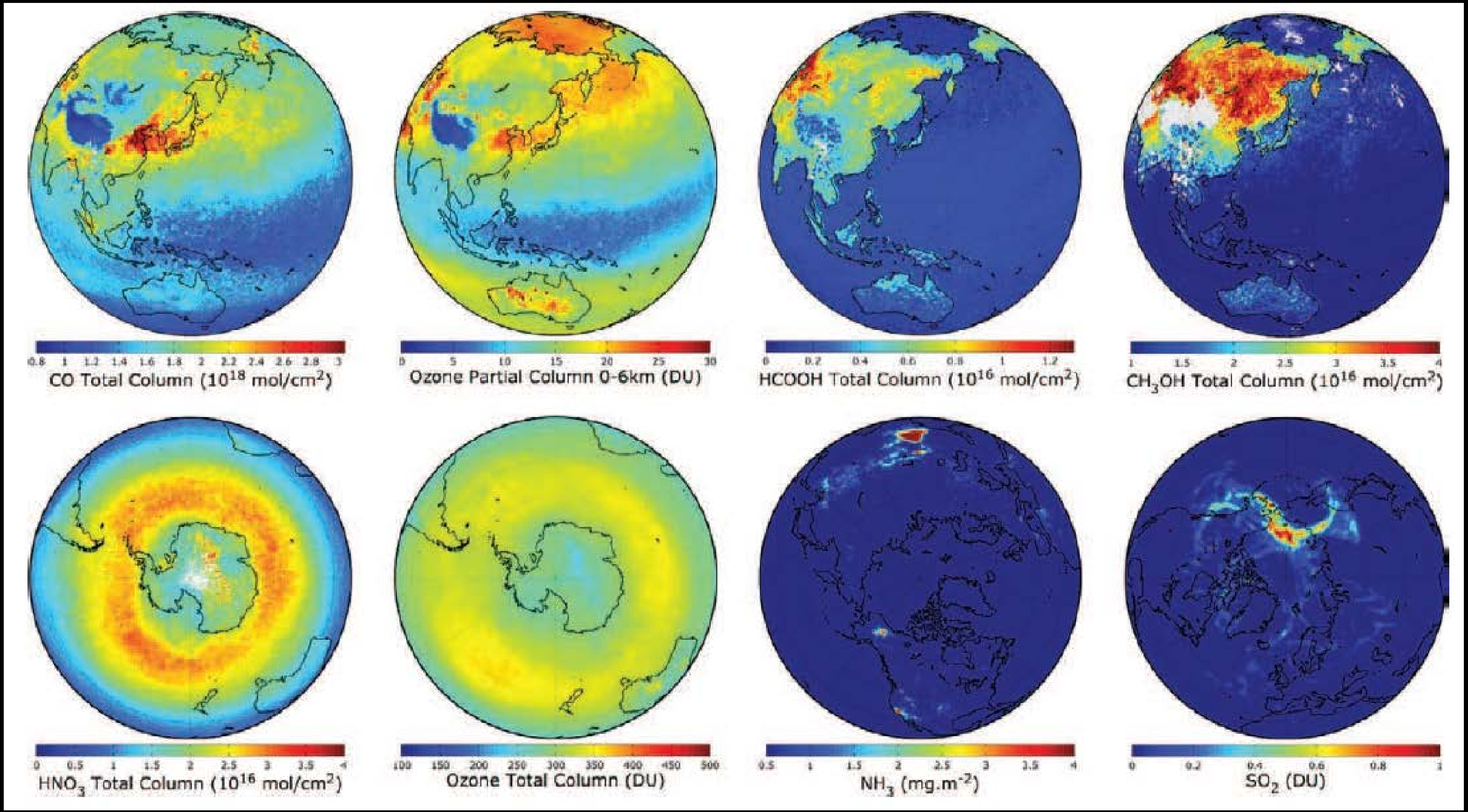
Hilton et al., BAMS, 2012

NA: Not available
NRT: Near-real time
BUFR: Binary universal form for the representation of meteorological data (www.wmo.int/pages/prog/www/WMOCodes.html)
GTS: WMO Global Telecommunication System (www.wmo.int/pages/prog/www/TEM/GTS/)
EUMETCast: EUMETSAT multi-service dissemination system (www.eumetsat.int/Home/Main/DataAccess/EUMETCast/index.htm)
EUMETSAT Data Centre: www.eumetsat.int/Home/Main/DataAccess/EUMETSATDataCentre/index.htm
IASI L1 product guide: http://oiswww.eumetsat.org/WEBOPS/eps-pg/IASI-L1/IASIL1-PG-0TOC.htm
IASI L2 product guide: http://oiswww.eumetsat.org/WEBOPS/eps-pg/IASI-L2/IASIL2-PG-index.htm





Clerbaux et al., ACP, 2009

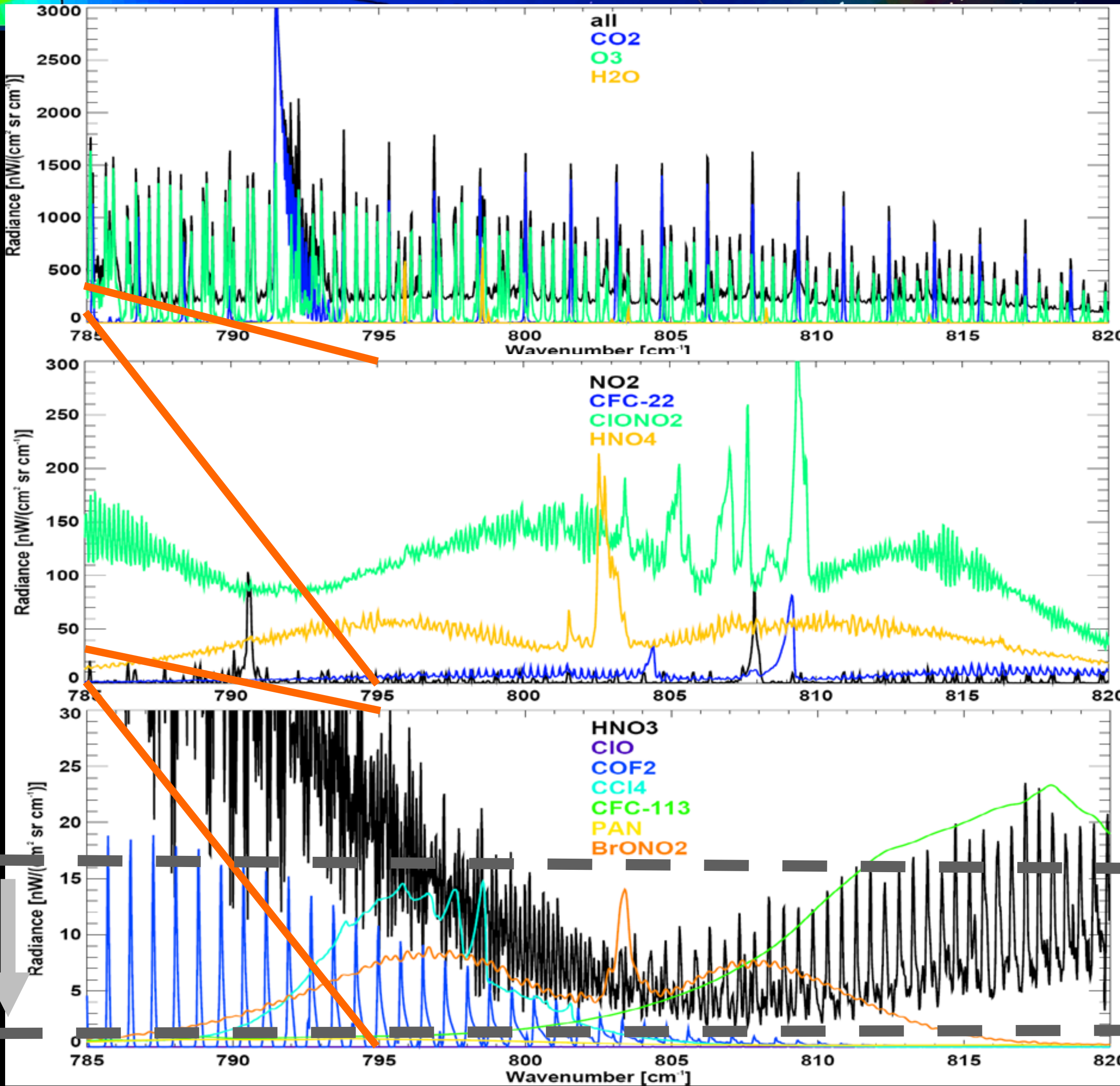


Hilton et al., BAMS, 2012

Ozone

www.die-zeitungen.de

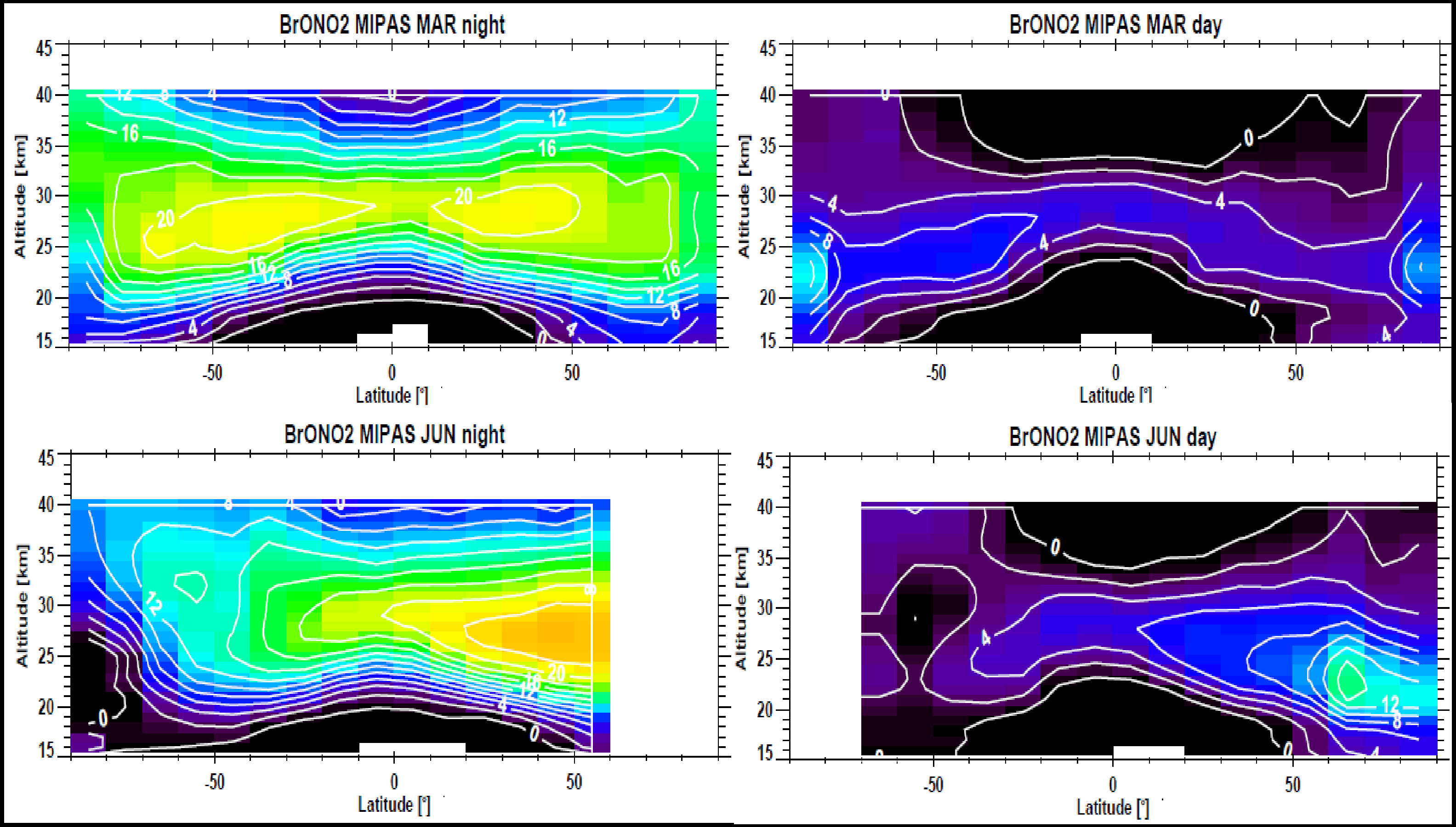
MIPAS: discovery of bromine nitrate



MIPAS noise level single spectra

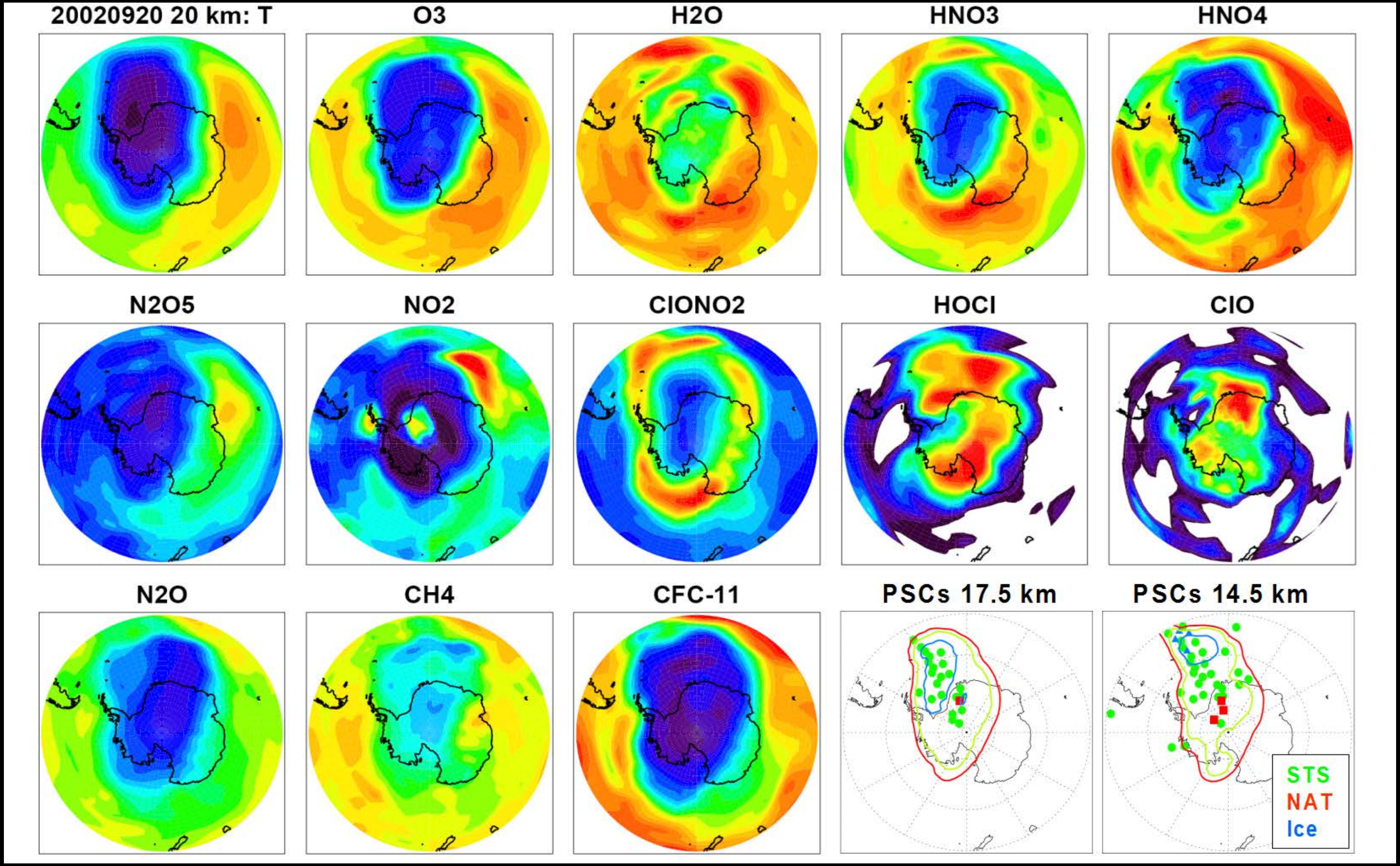
MIPAS noise level monthly mean spectra

MIPAS: discovery of bromine nitrate

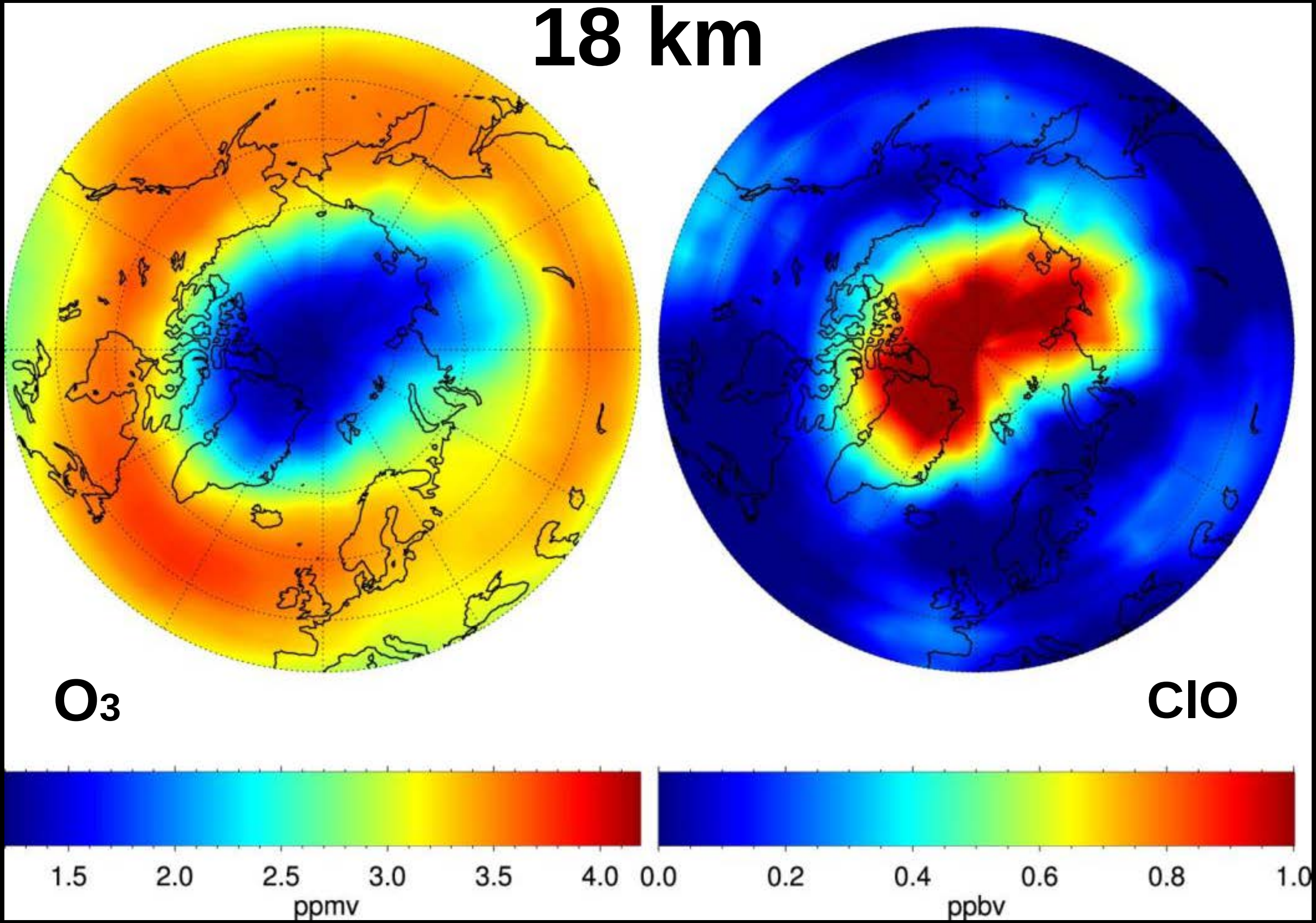


Höpfner et al., ACP, 2009
Höpfner et al., in prep.

MIPAS: southern hemisphere, 20. September 2002: 20 km

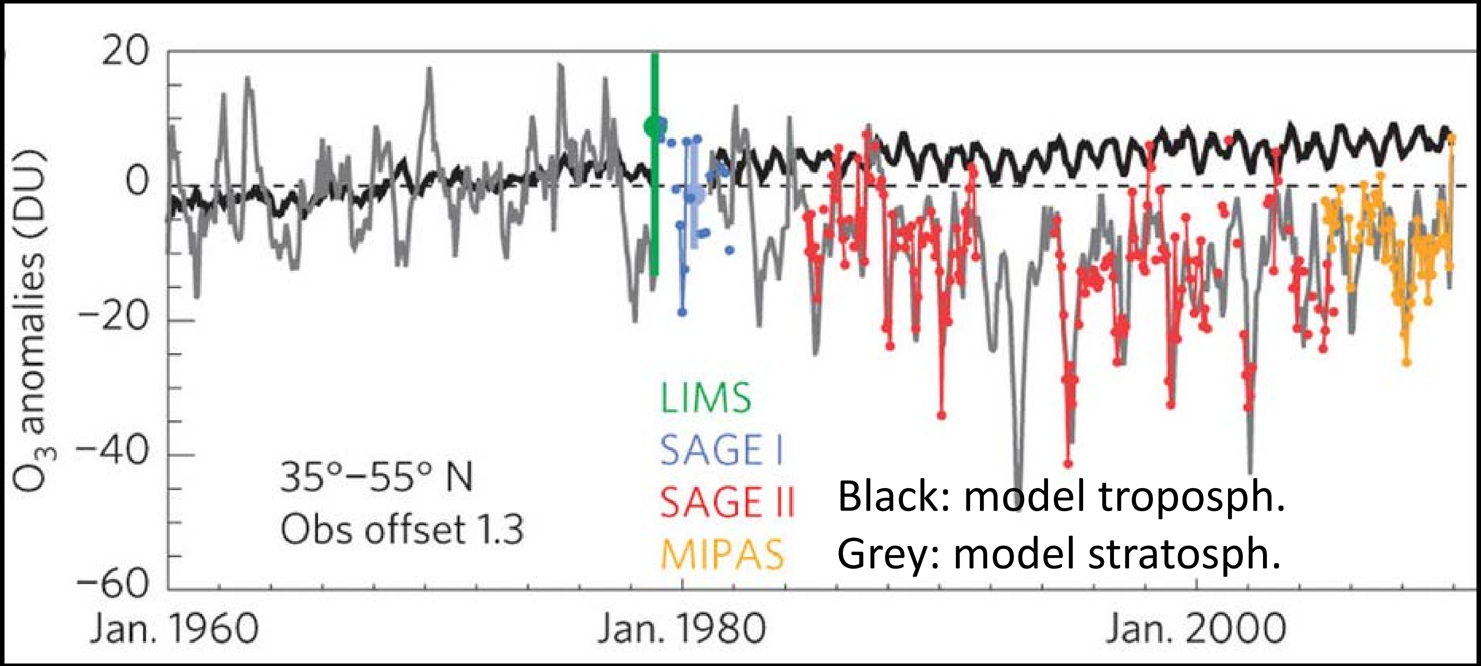


MIPAS: Ozone destruction over the Arctic, 18 March 2011



Sinnhuber et al., GRL, 2011

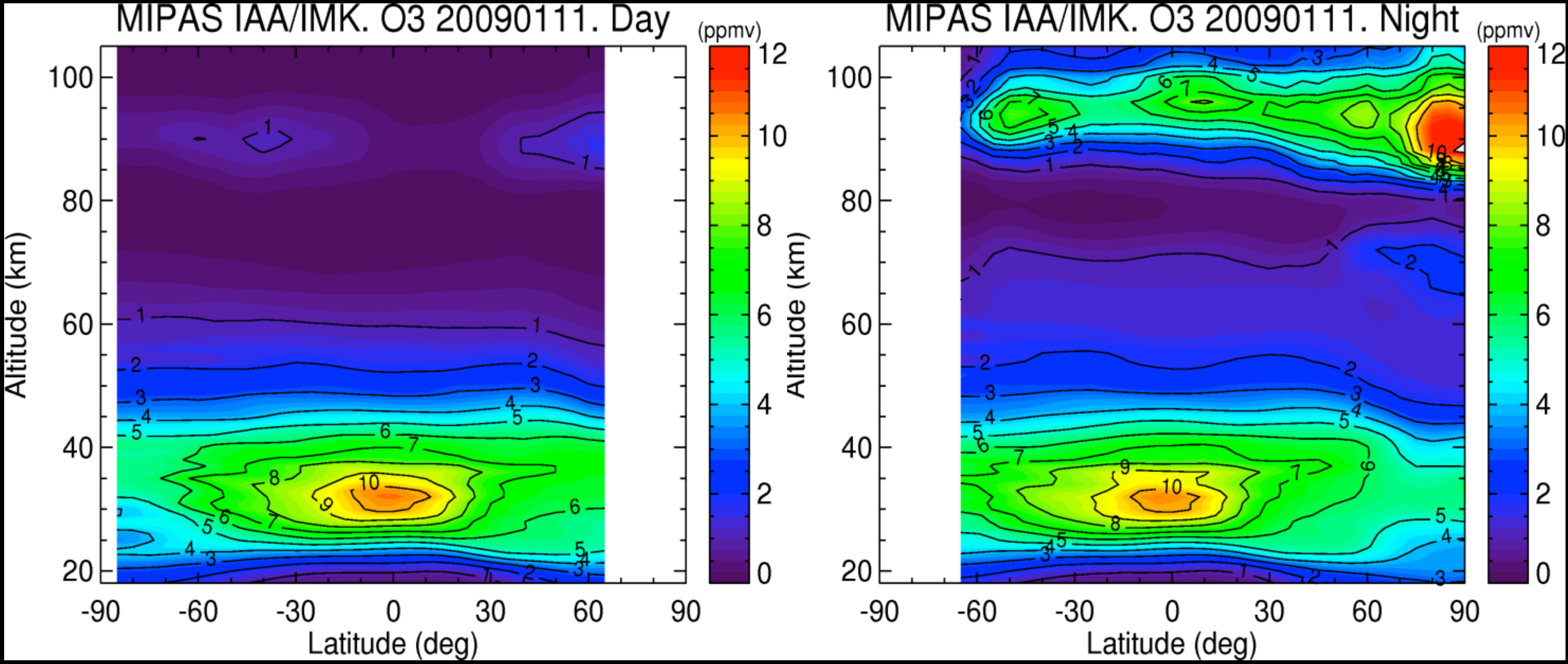
MIPAS+other limb-sounders: Reconciliation of halogen-induced ozone loss



Shepherd et al., Ngeo, 2014

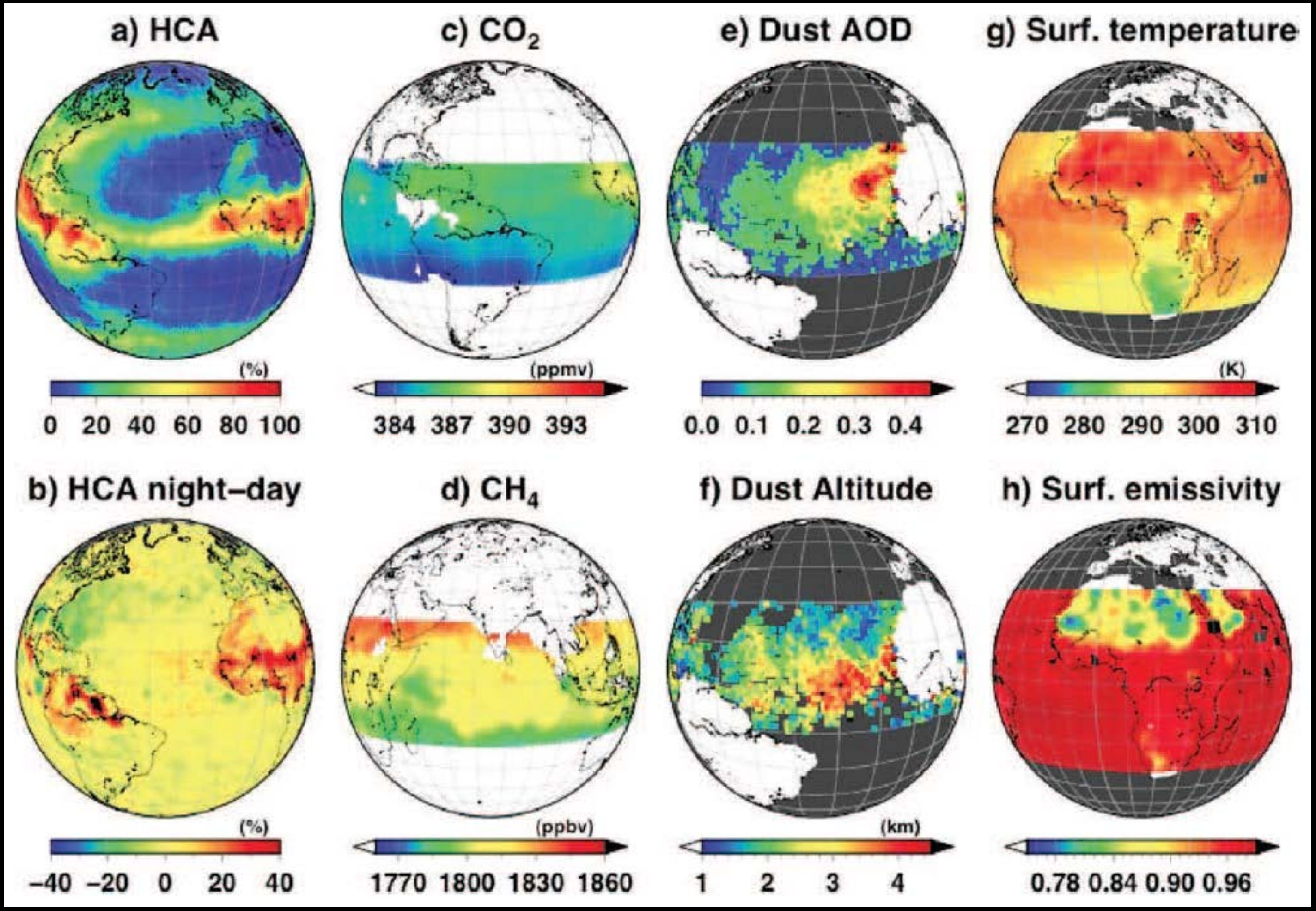
MIPAS: Diurnal variation of ozone in the upper atmosphere

NH Winter, Day | NH Winter, Night



Climate

IASI climate variables

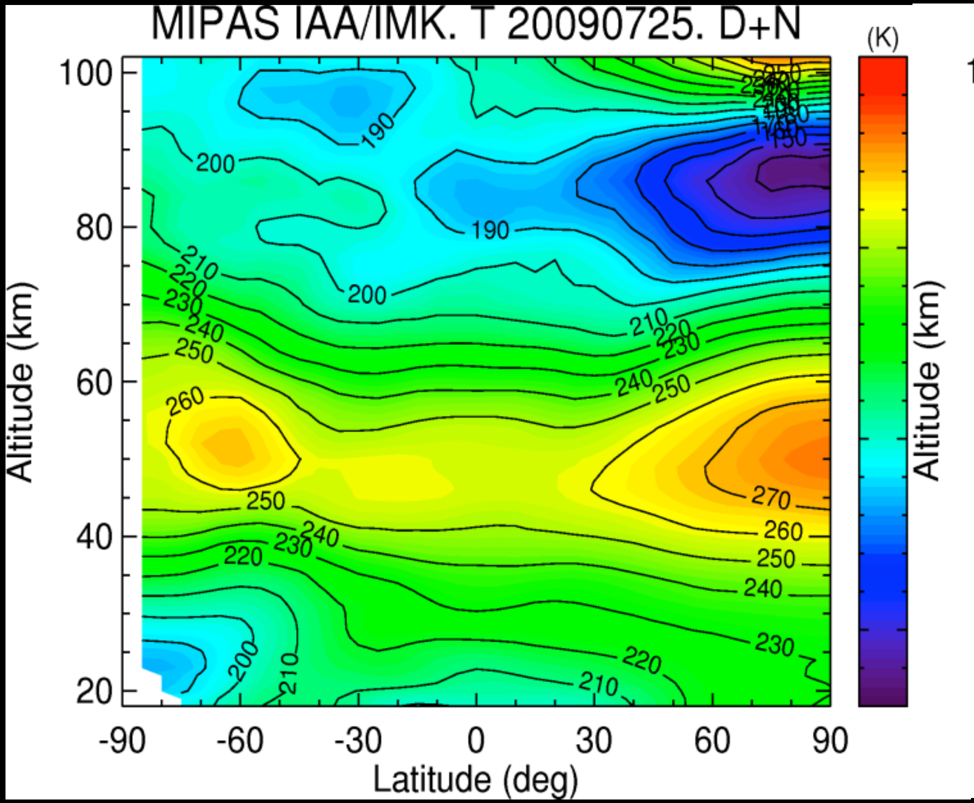


HCA: High Cloud Amount, AOD: Aerosol Optical Depth

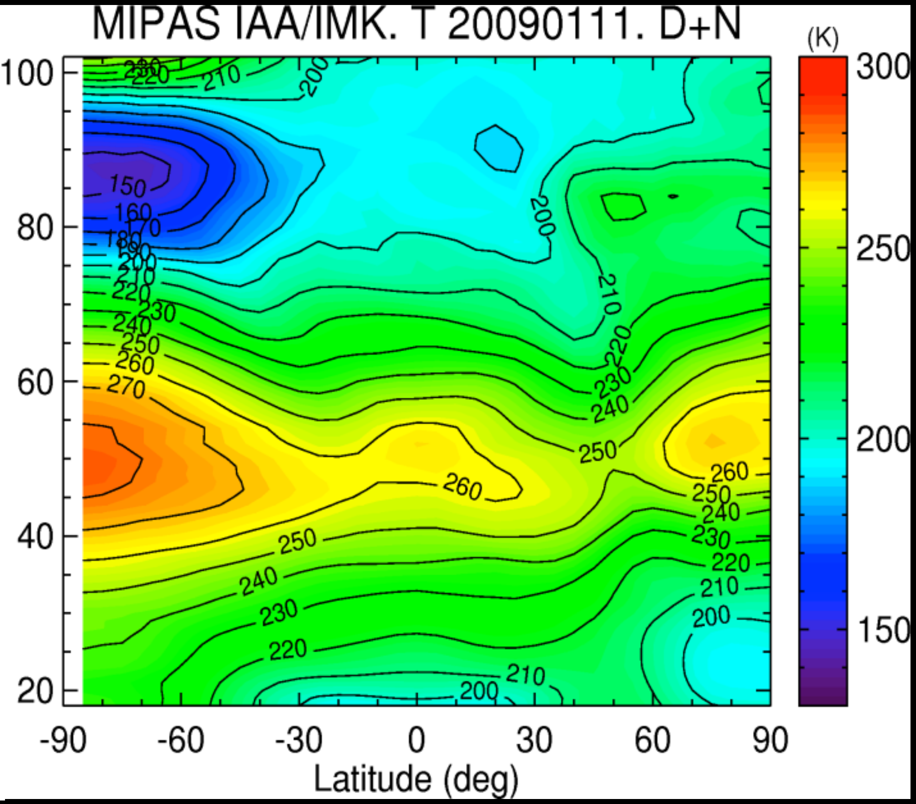
Hilton et al., BAMS, 2012

MIPAS Vertical temperature profiles in the middle atmosphere

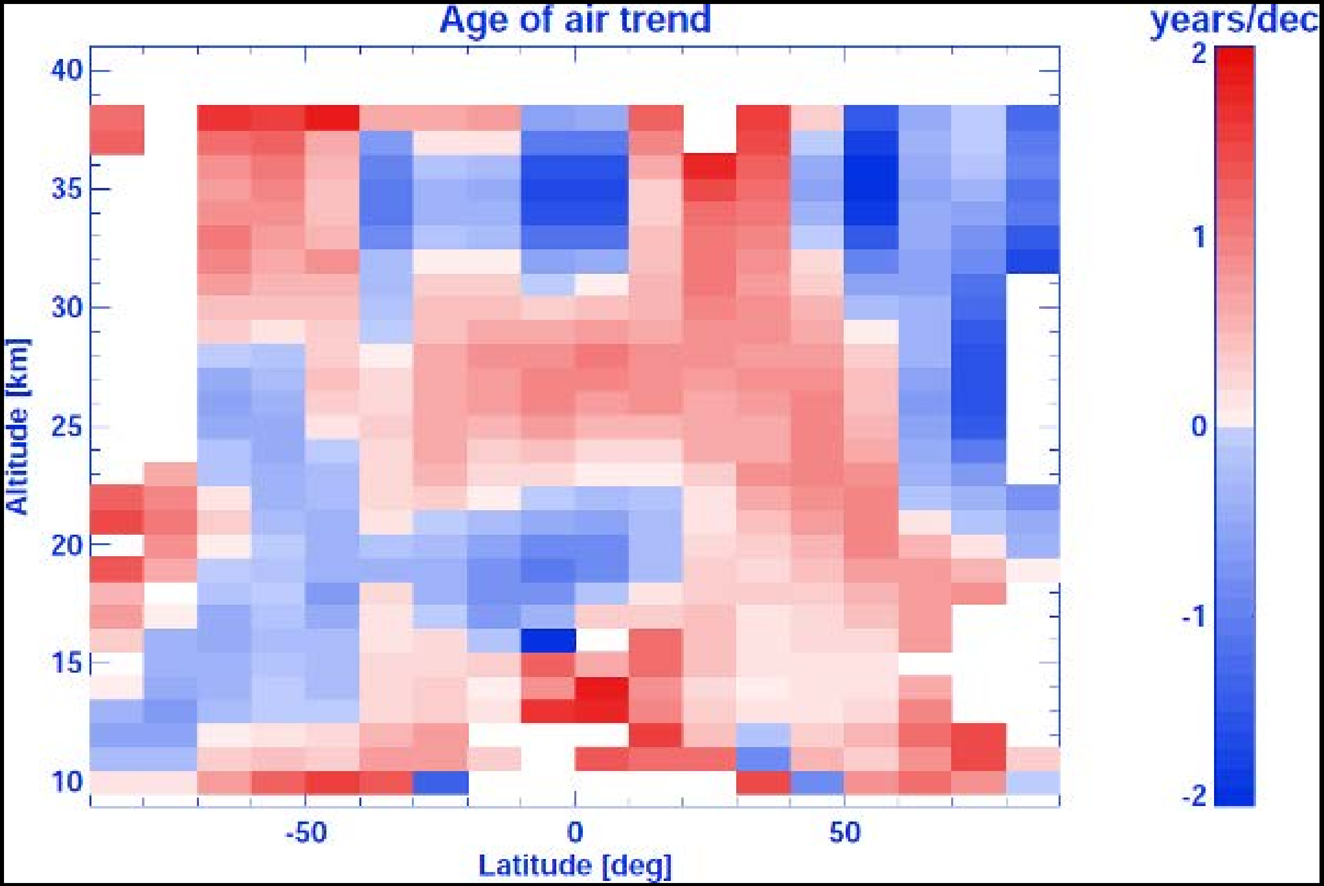
NH Summer



NH Winter

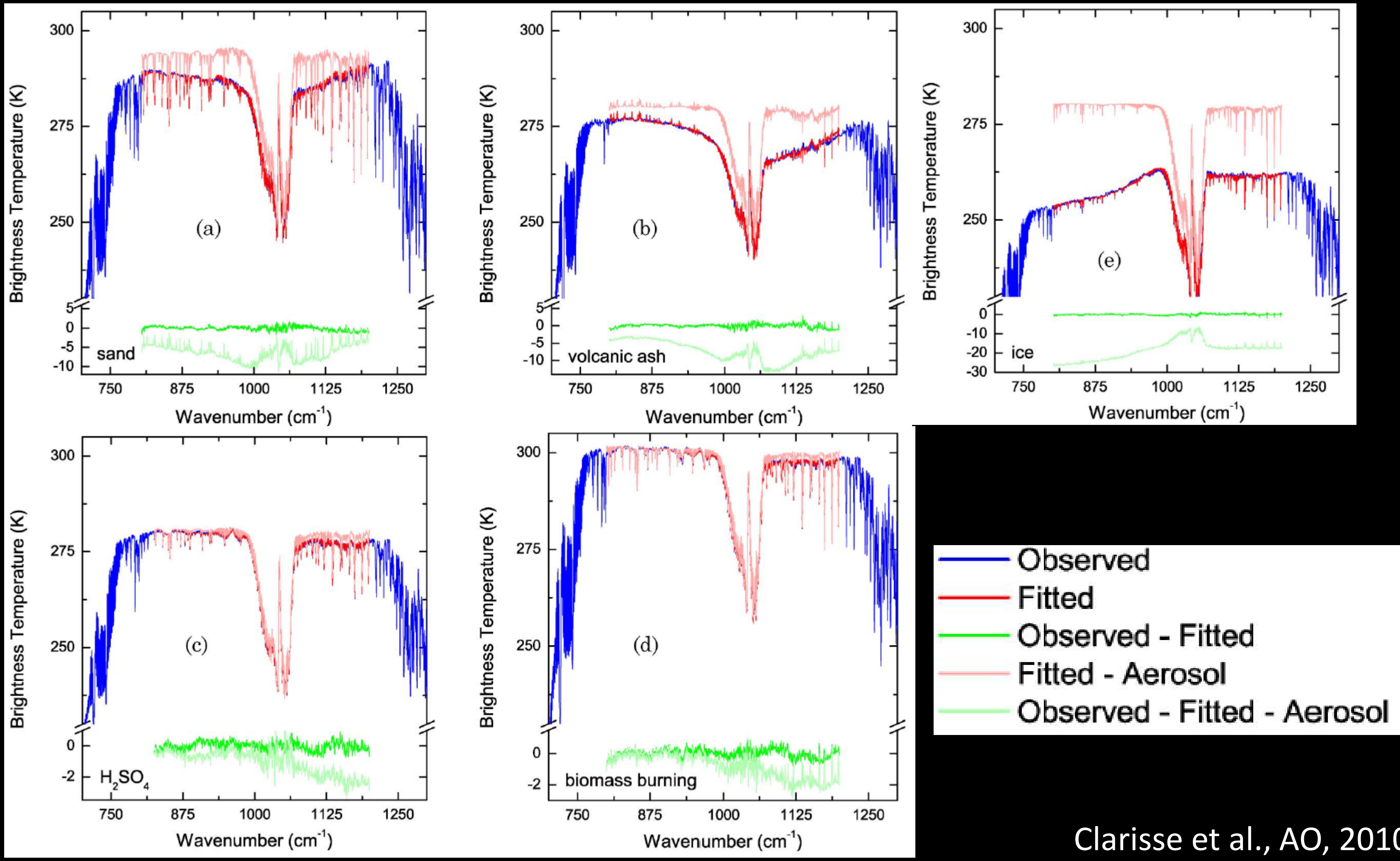


MIPAS: Age of stratospheric air and its trend from SF6



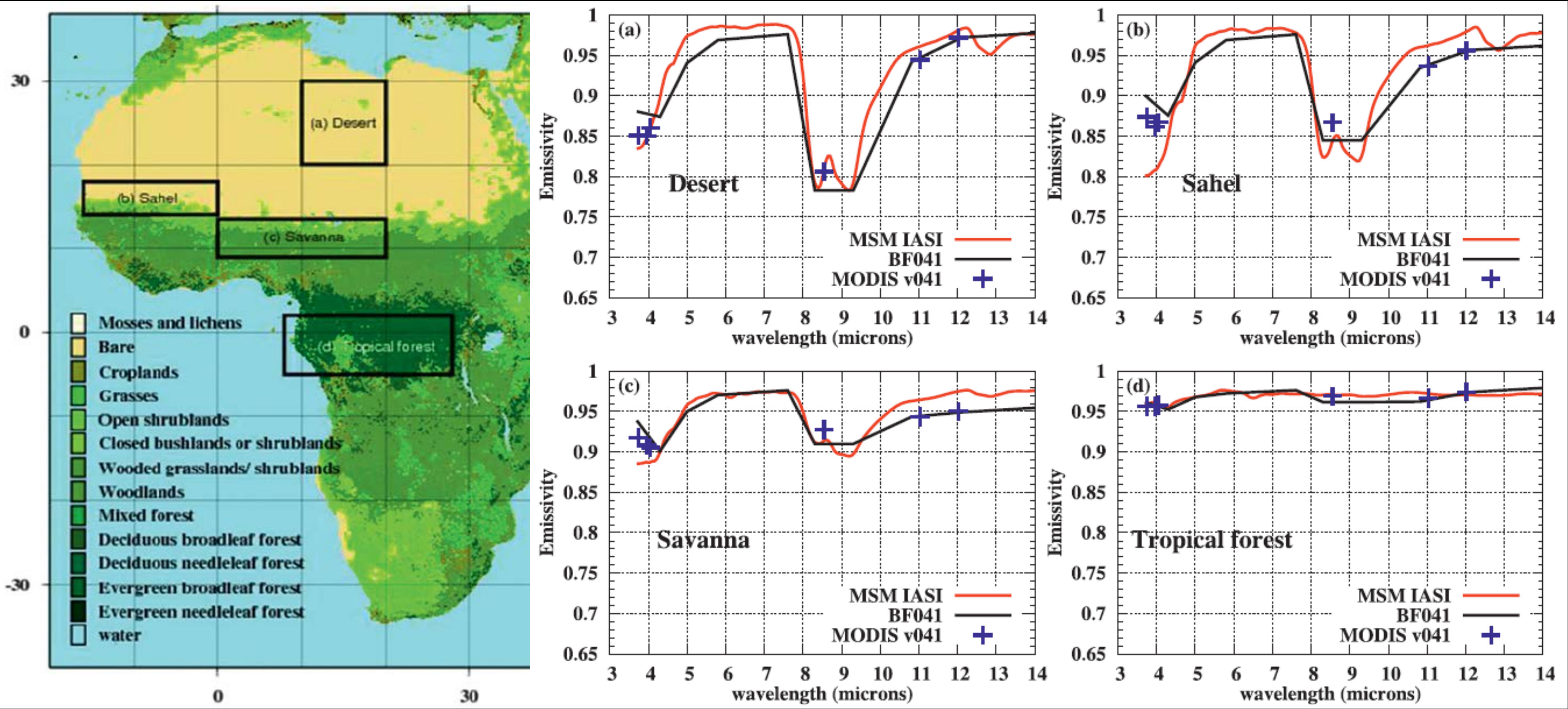
Stiller et al., ACP, 2012

IASI climate variables: aerosol



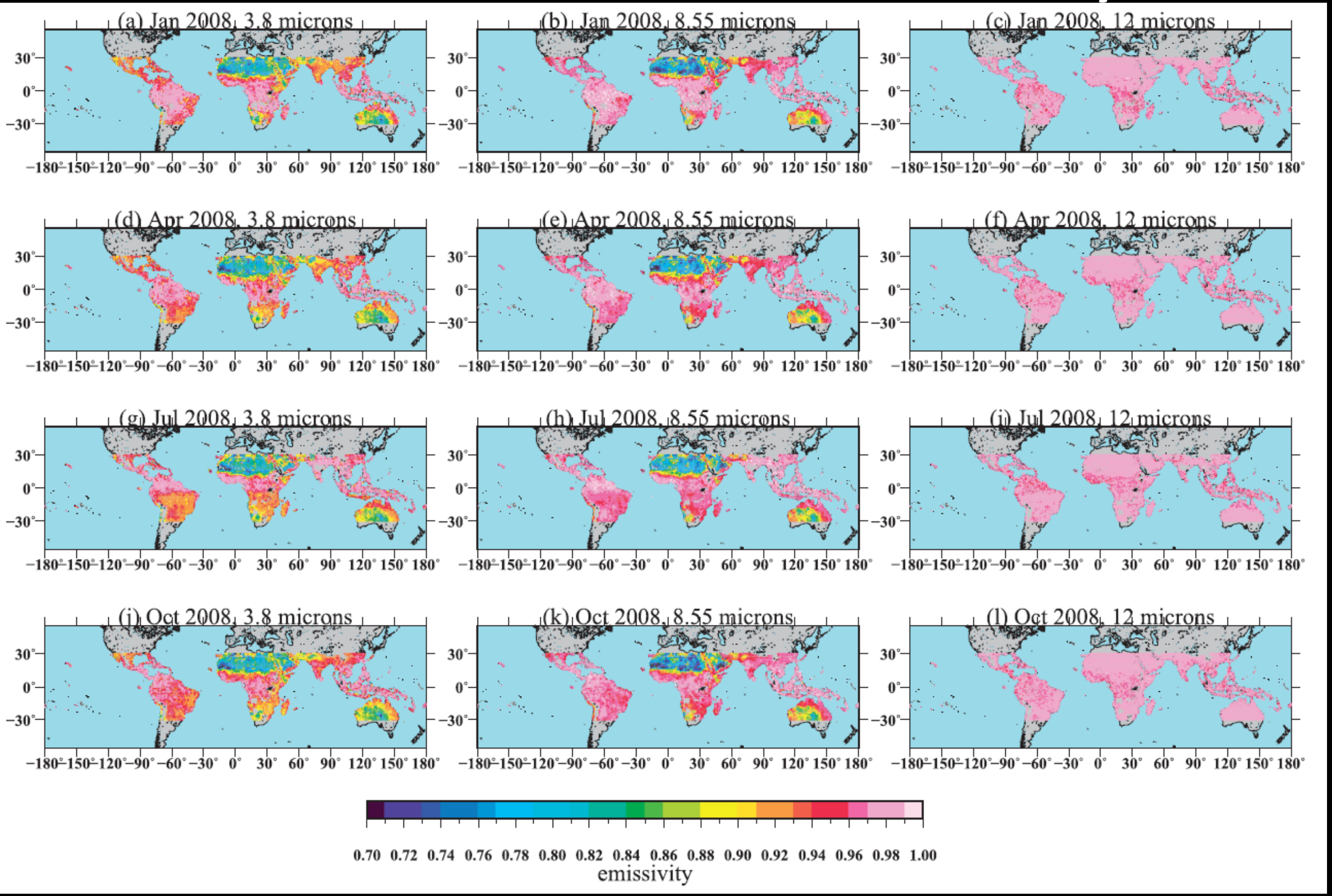
Clarisse et al., AO, 2010

IASI climate variables: surface emissivity



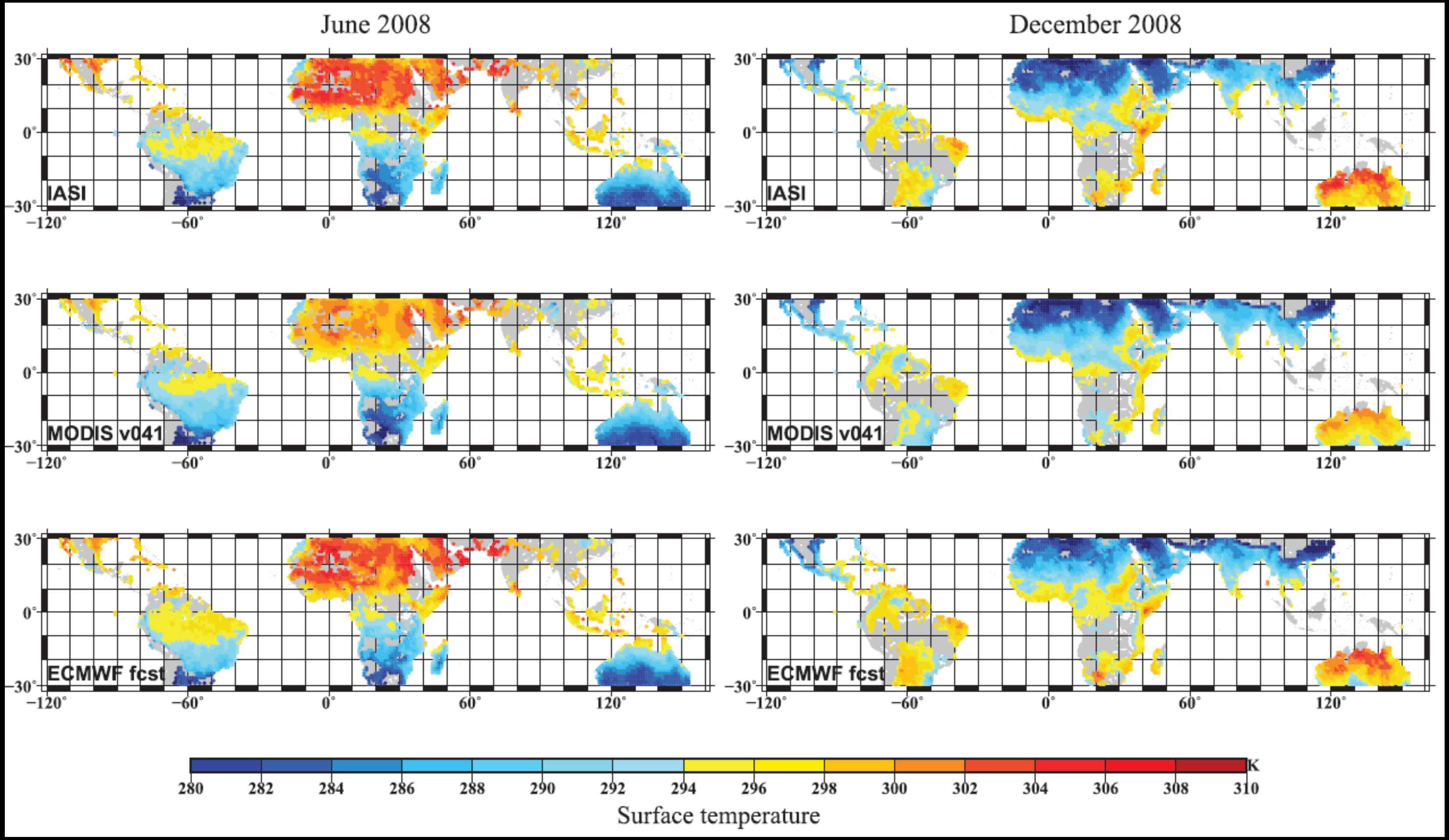
Capelle et al, JAMC, 2012

IASI climate variables: surface emissivity

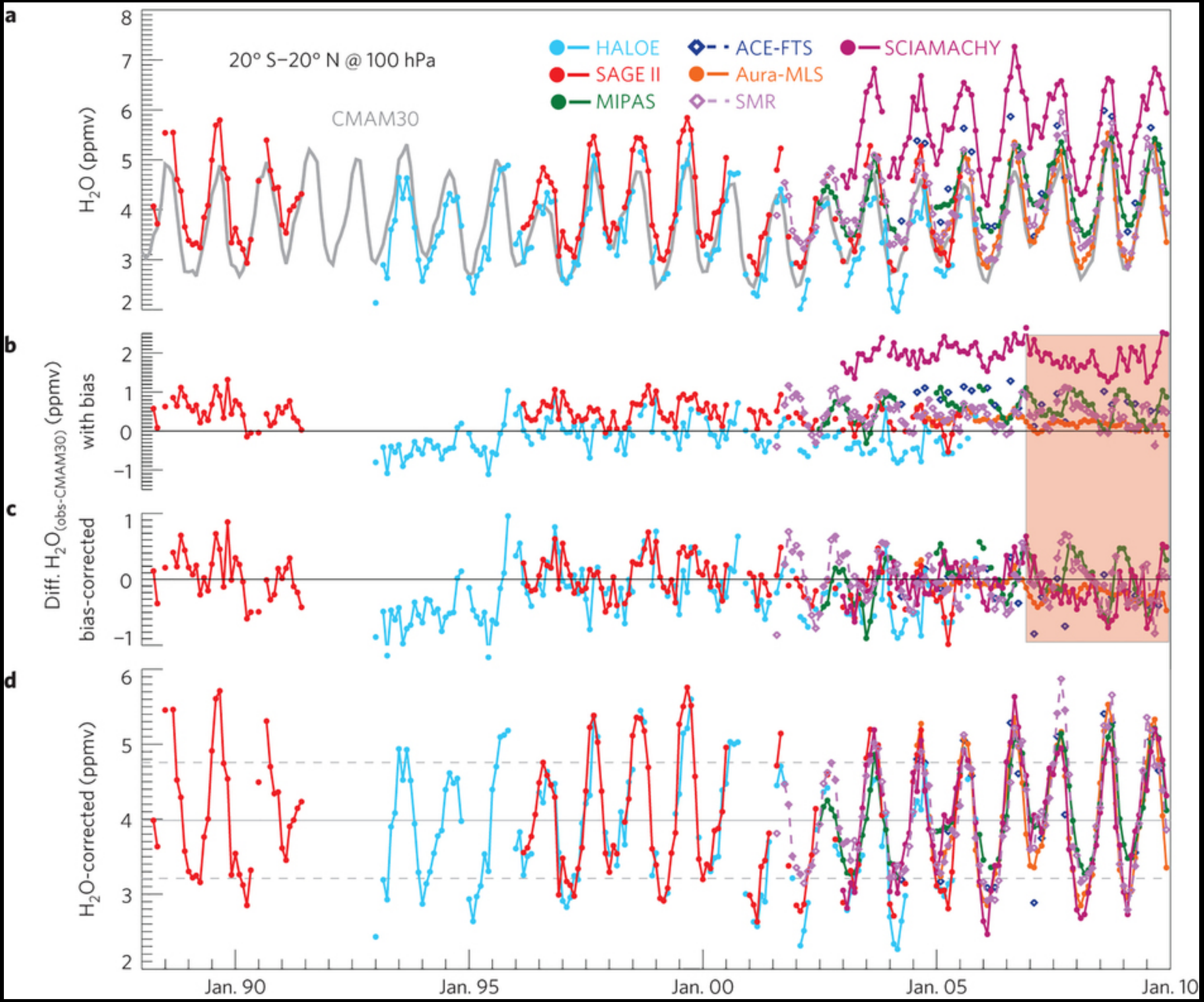


Capelle et al, JAMC, 2012

IASI climate variables: mean surface temperature



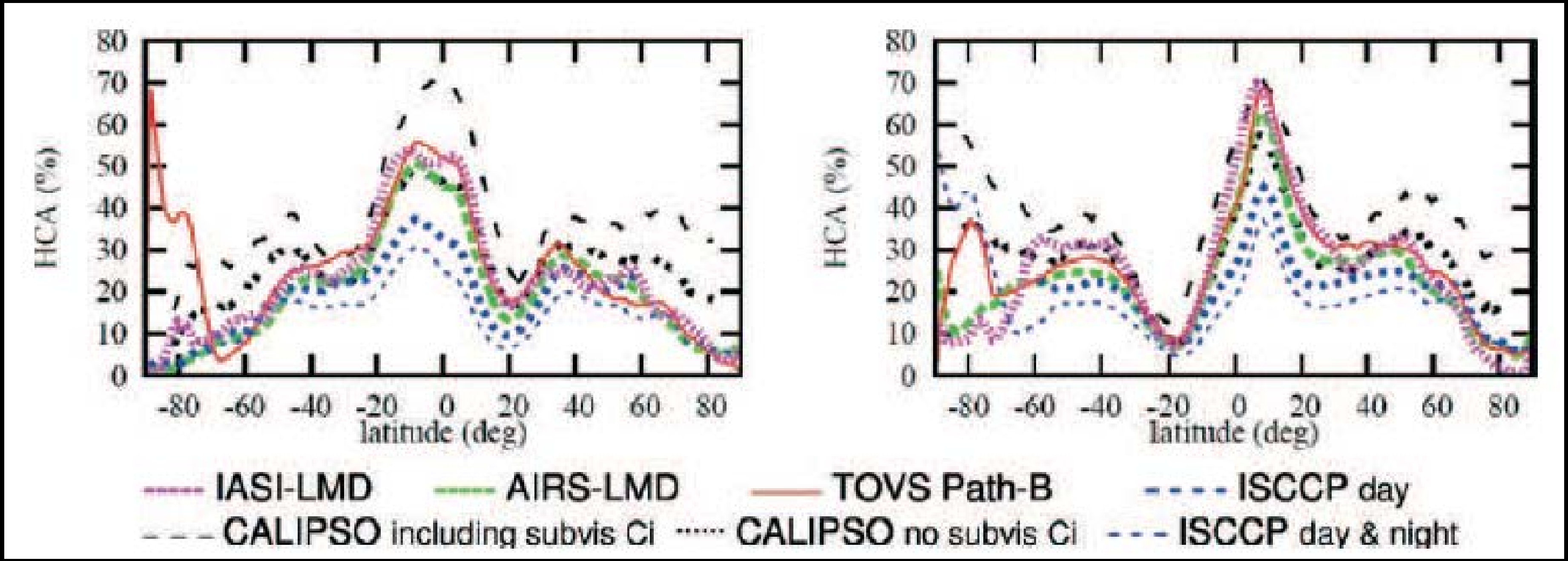
Capelle et al, JAMC, 2012



MIPAS + other limb sounders: Vertical structure of stratospheric water vapour trends derived from merged satellite data

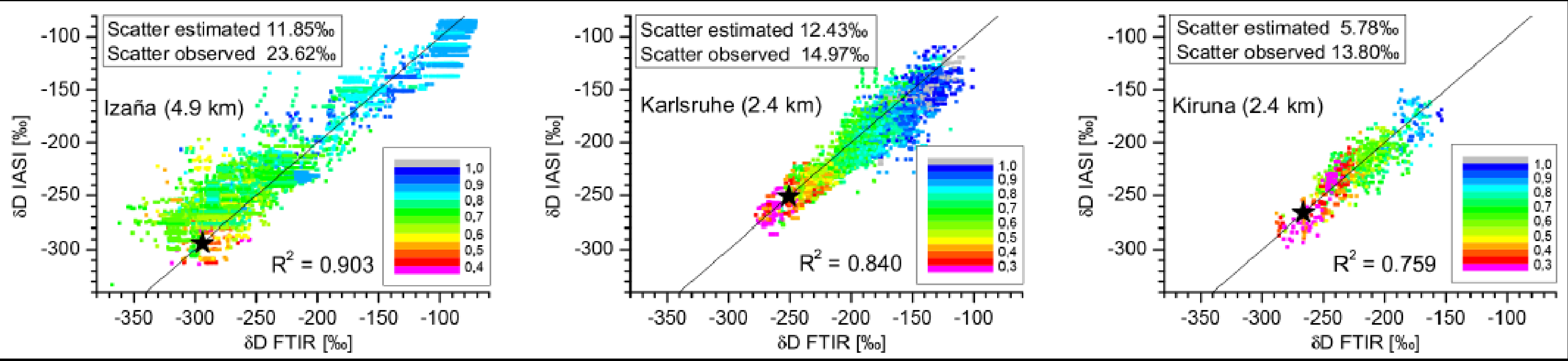
Hegglin et al., Ngeo, 2014

IASI climate variables: high cloud amount



Hilton et al., BAMS, 2012

IASI climate variables: hydrological cycle

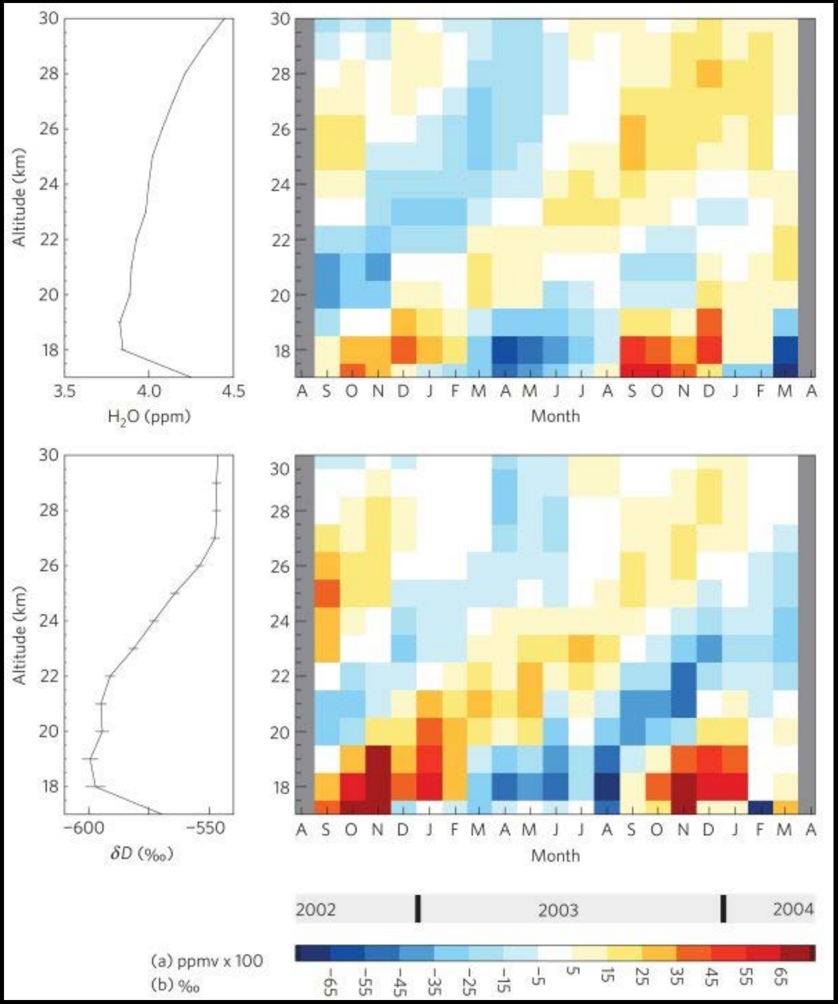


Correlation between the IASI and smoothed FTIR δD data.

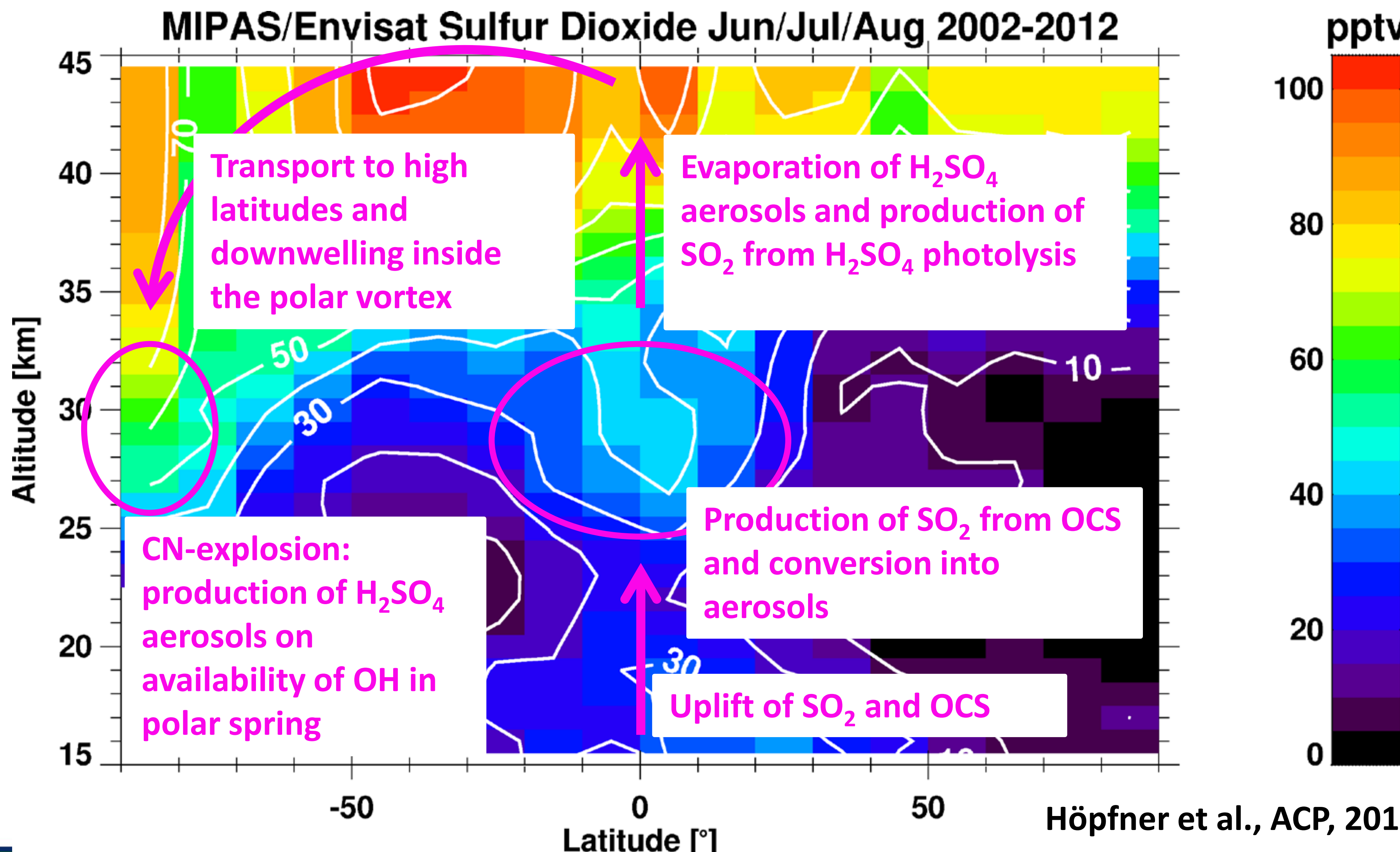
Colours: IASI degree-of-freedom; black star: a- priori; black line: 1-to-1 diagonal

Wiegele et al., AMT, 2014

MIPAS: δD tape recorder

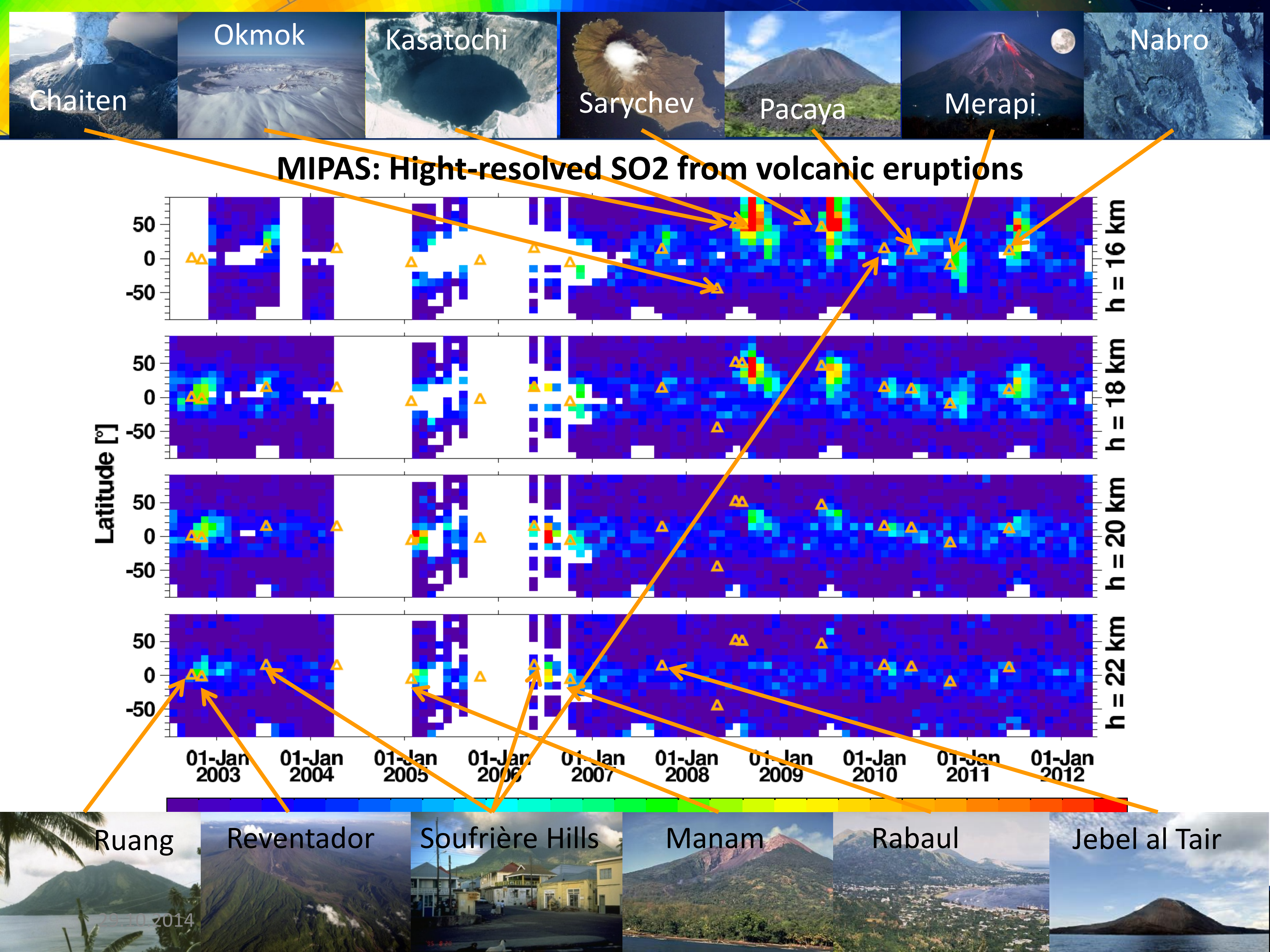


Steinwagner et al., Ngeo, 2010

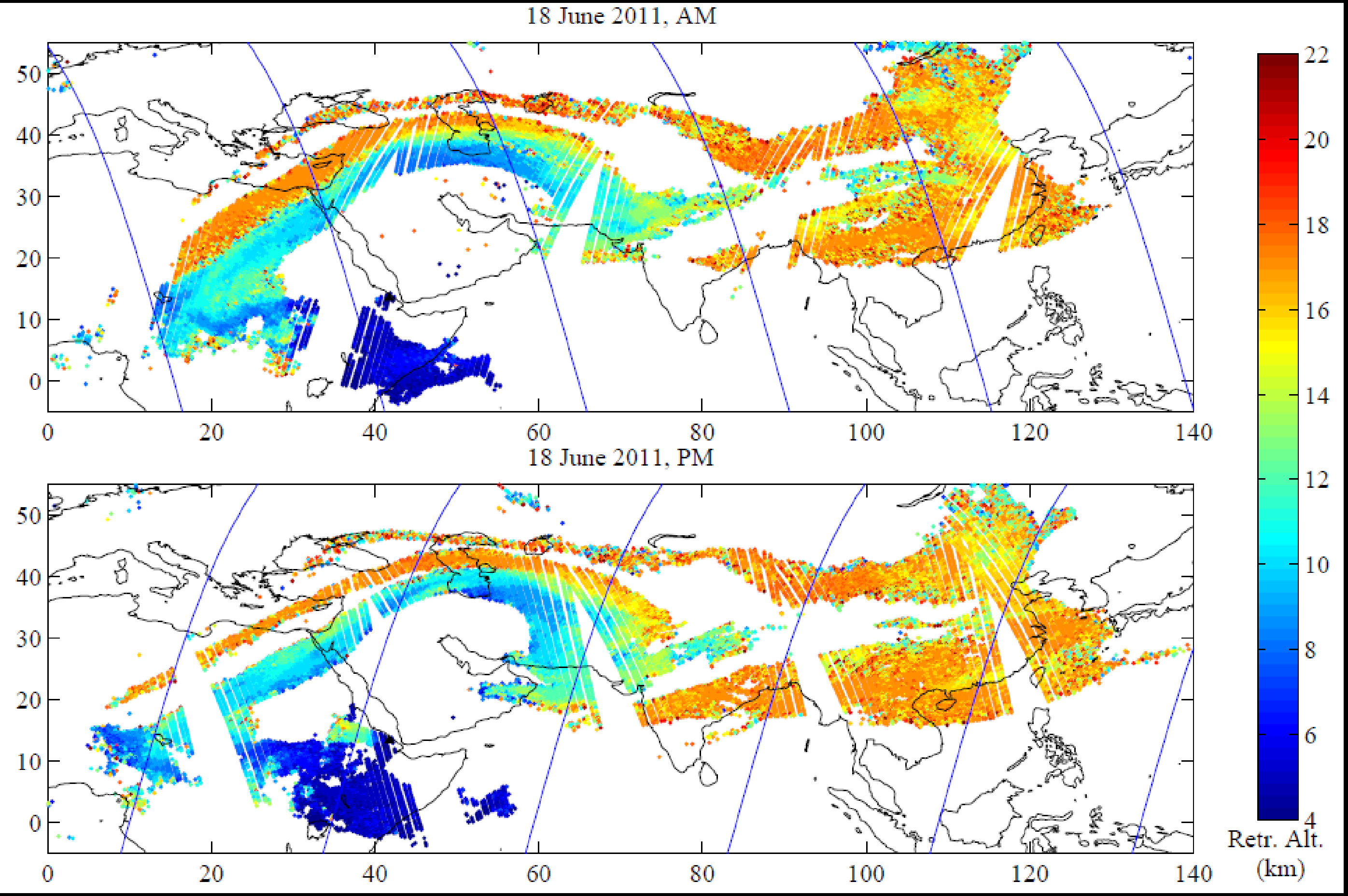


Höpfner et al., ACP, 2013

MIPAS: Hight-resolved SO2 from volcanic eruptions



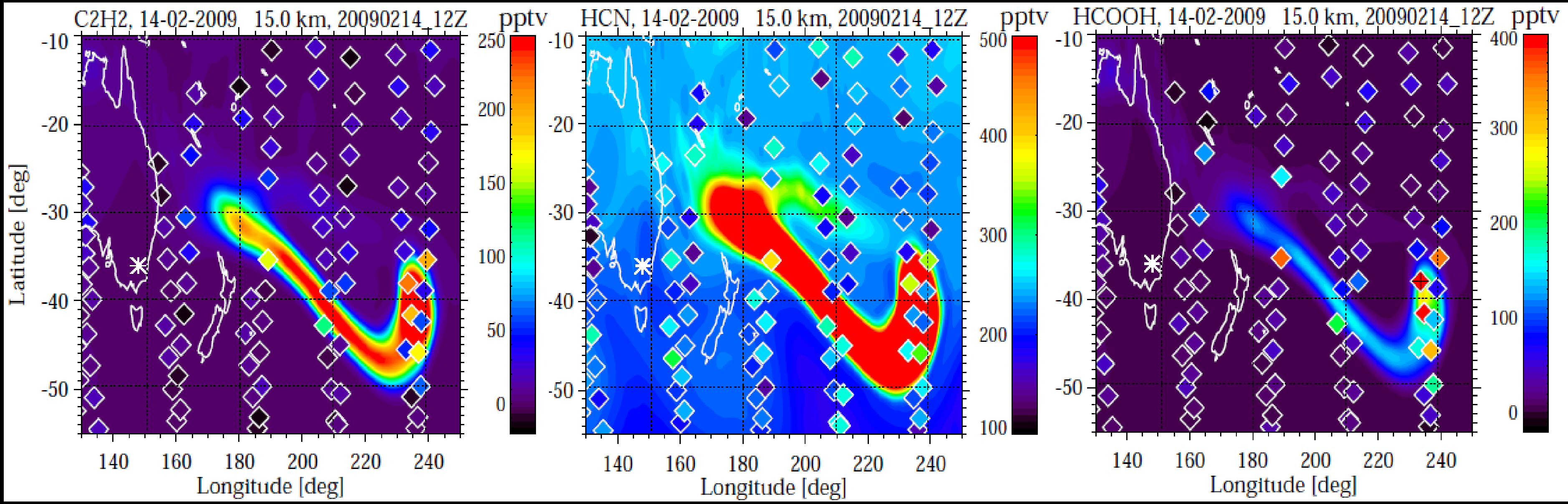
IASI SO2 plume tracking: Nabro eruption



Clarisse et al., ACP, 2014

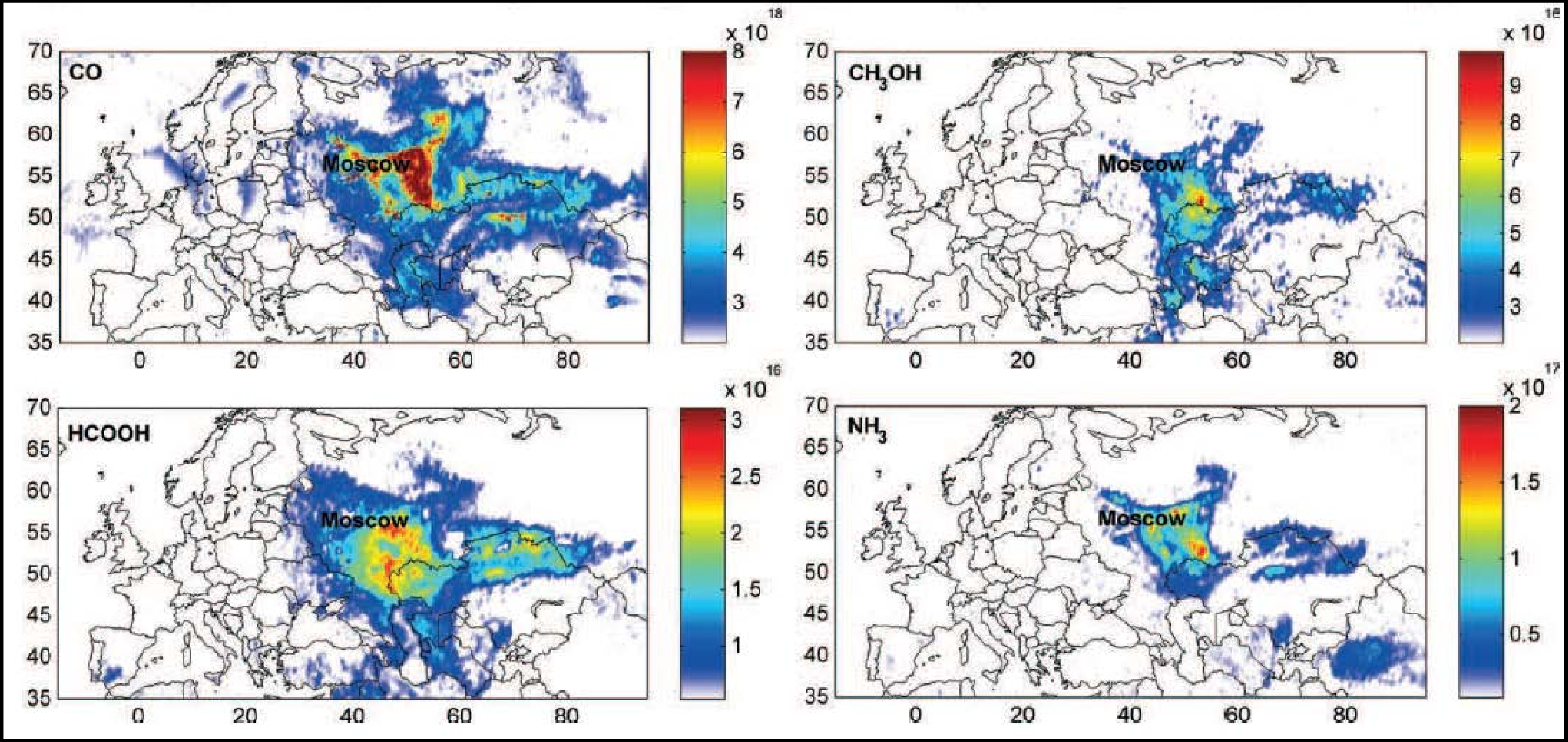
Air quality/pollution

MIPAS vs. GEM-AQ: Australian fires 2009
C2H2, HCN, HCOOH @15 km



Glatthor et al., ACP, 2013

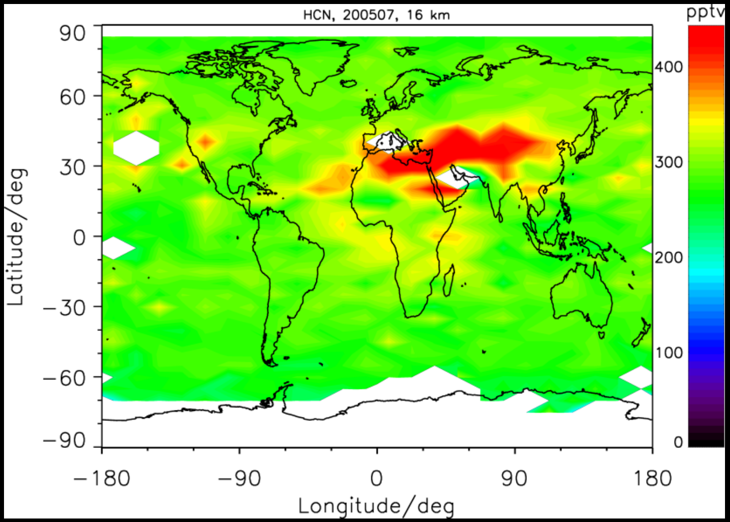
IASI pollution tracking: Russian fires summer 2010

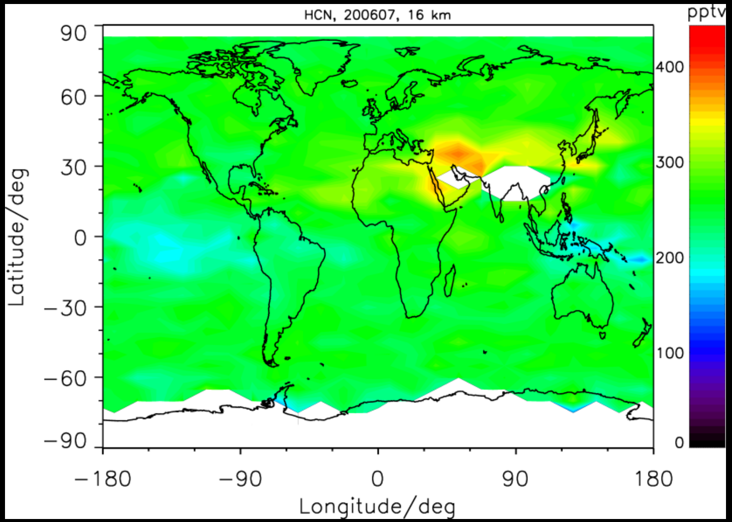


Hilton et al., BAMS, 2012

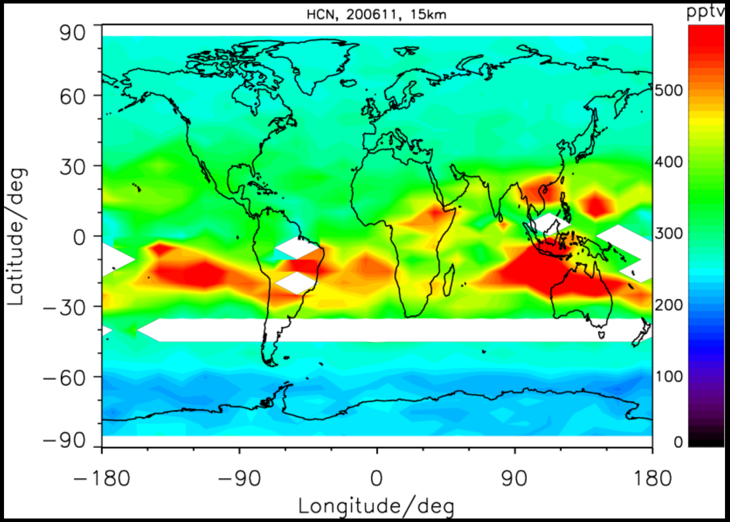
MIPAS: Global transport of pollution: HCN @15 km

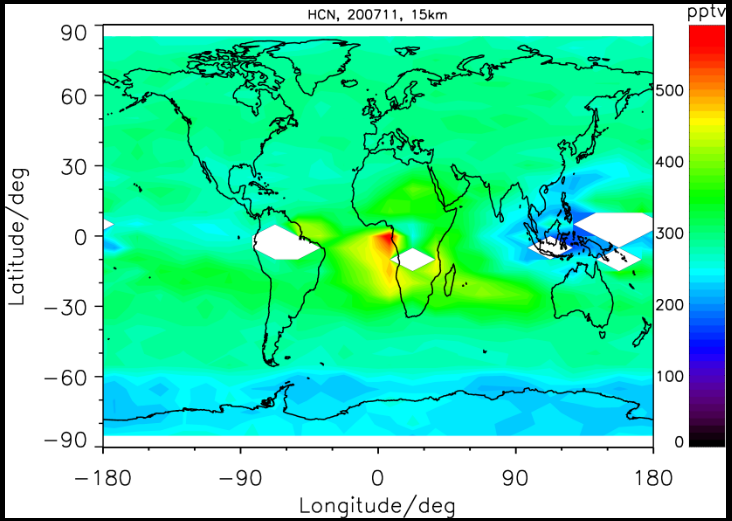
Jul



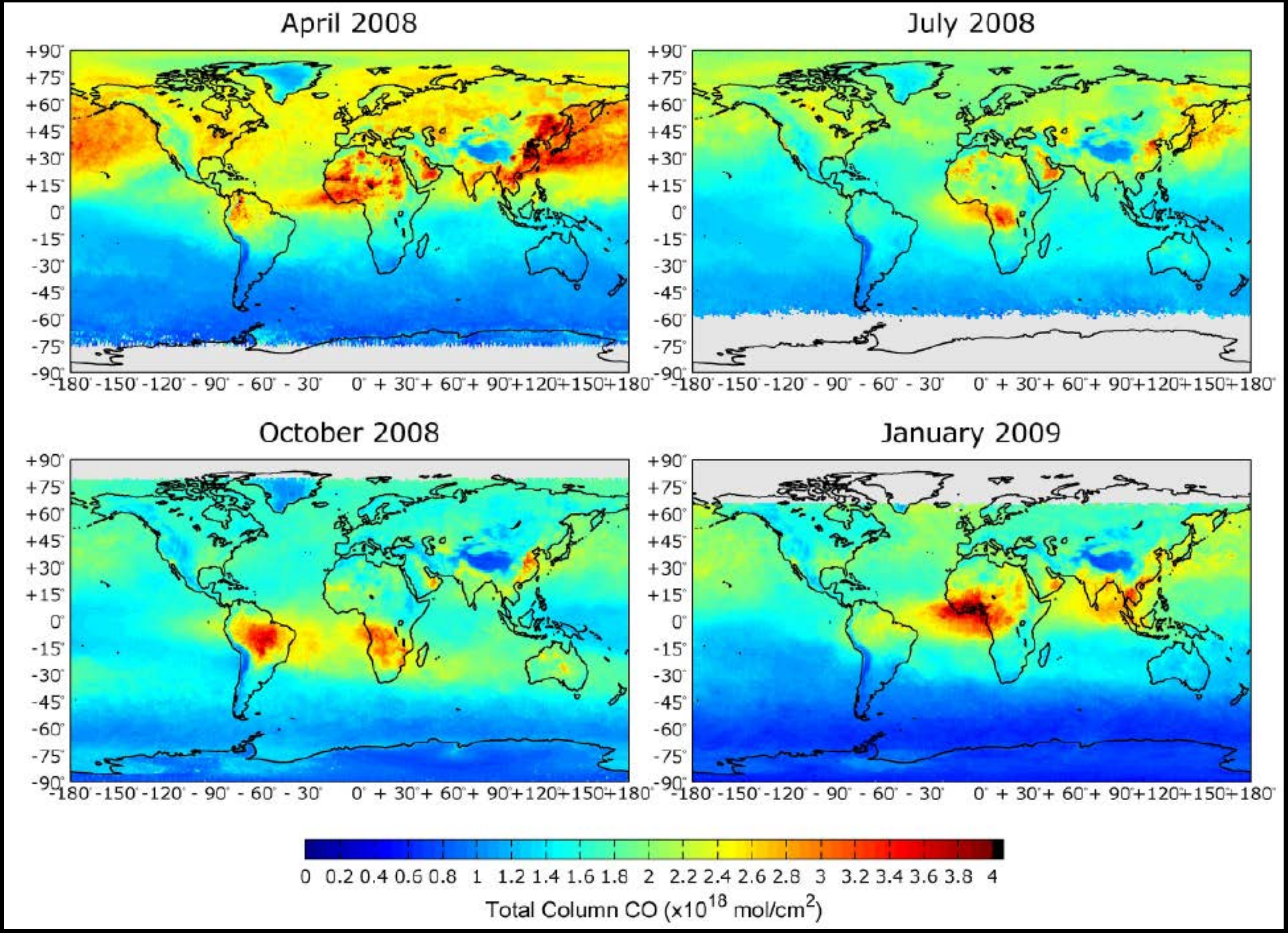


Nov



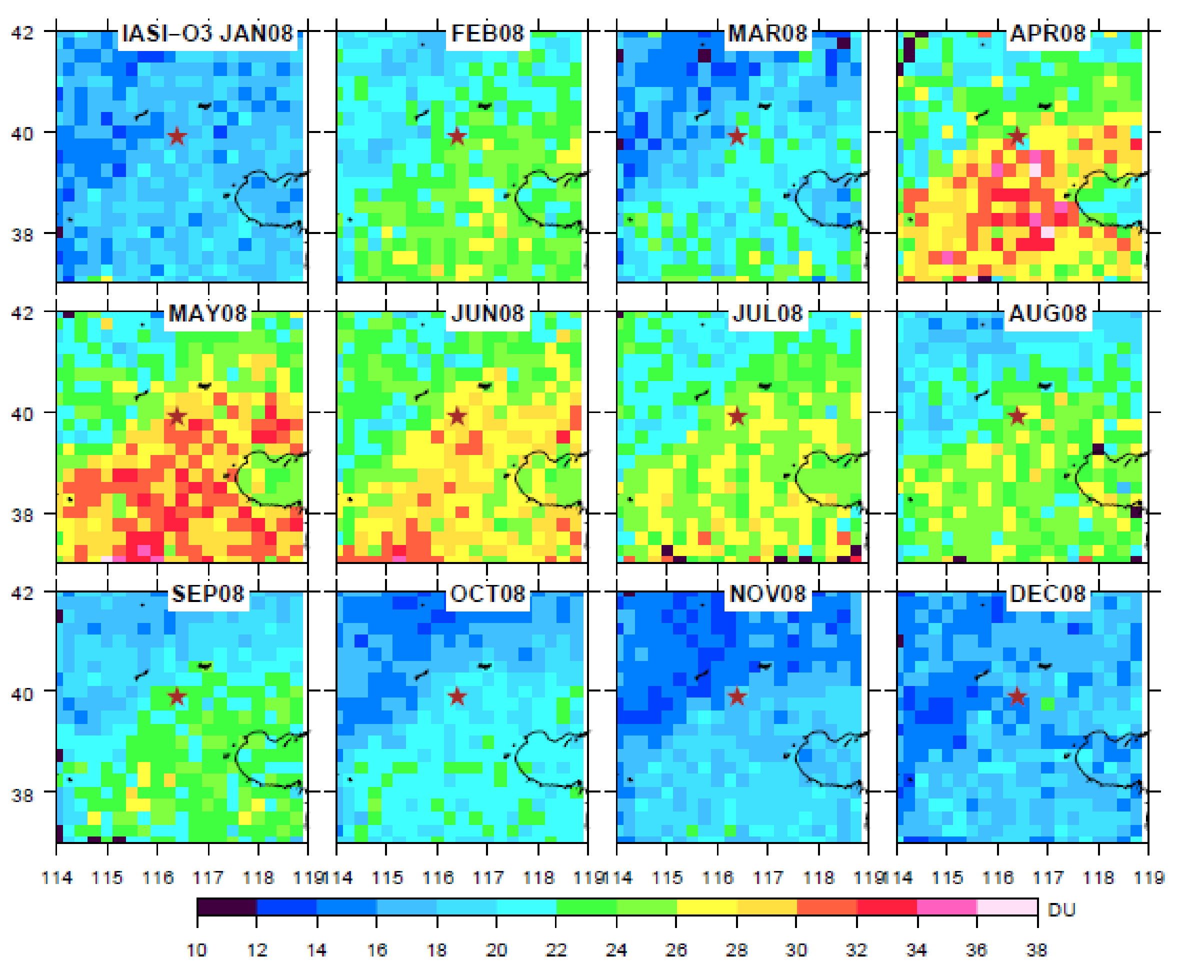


IASI tropospheric pollution: CO



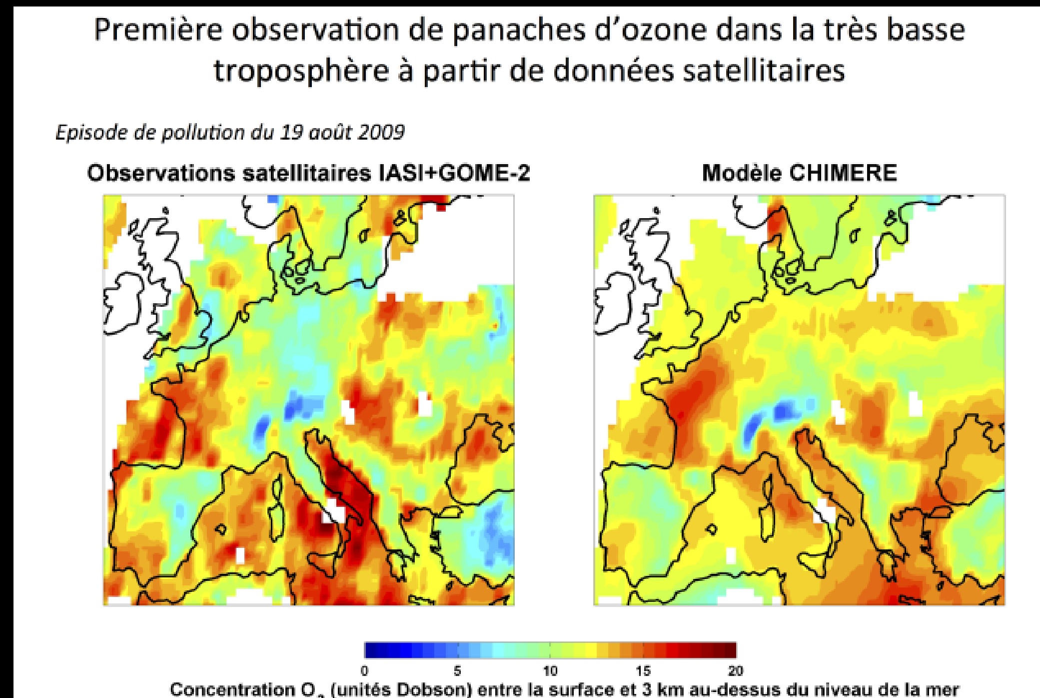
Clerbaux et al., ACP, 2009

IASI tropospheric pollution: ozone (0-6 km) @ Beijing

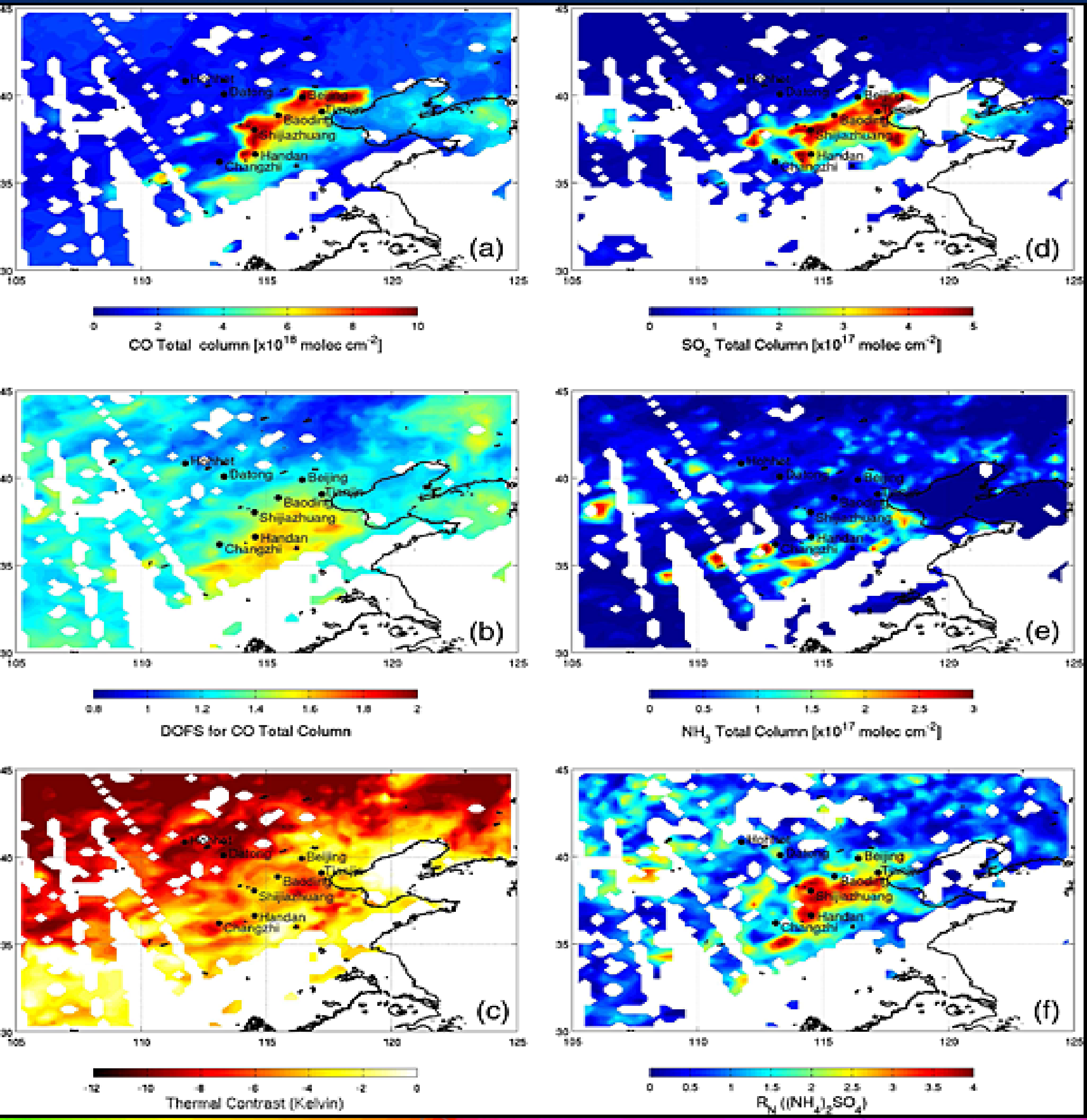


Dufour et al., ACP, 2010

IASI + GOME-2 tropospheric pollution: ozone at lowest levels



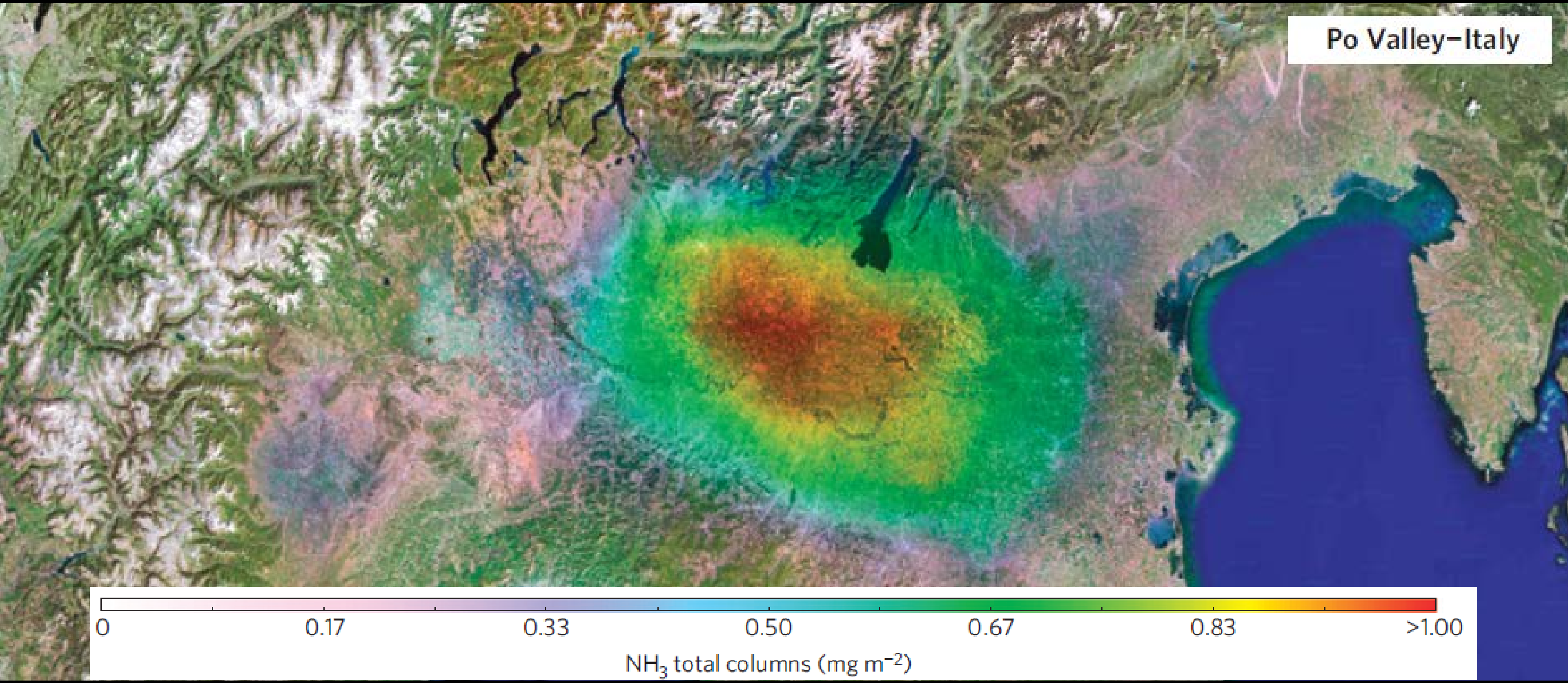
Cuesta et al., ACP, 2013



First simultaneous space measurements of atmospheric pollutants in the boundary layer from IASI: A case study in the North China Plain

Boynard et al., GRL, 2013

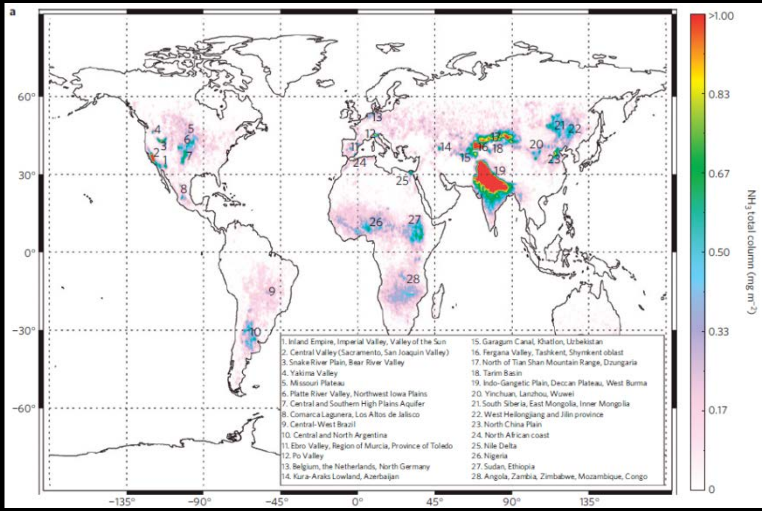
IASI NH3



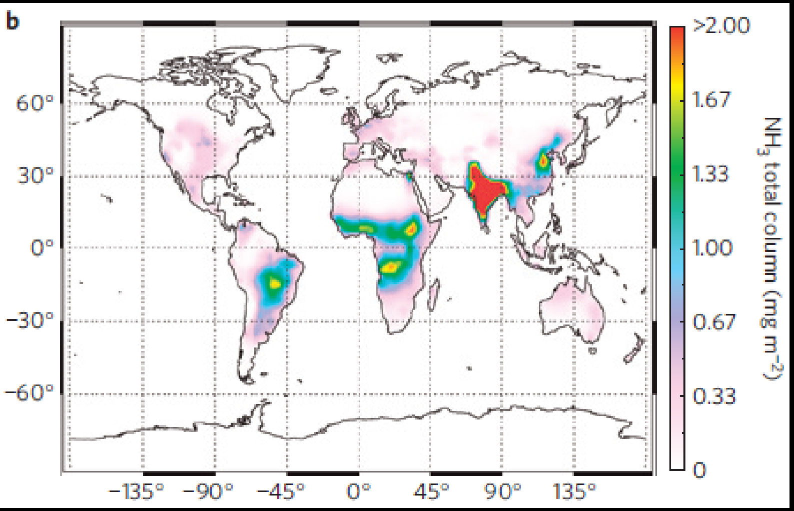
Clarisse et al., Ngeo, 2009

IASI NH3

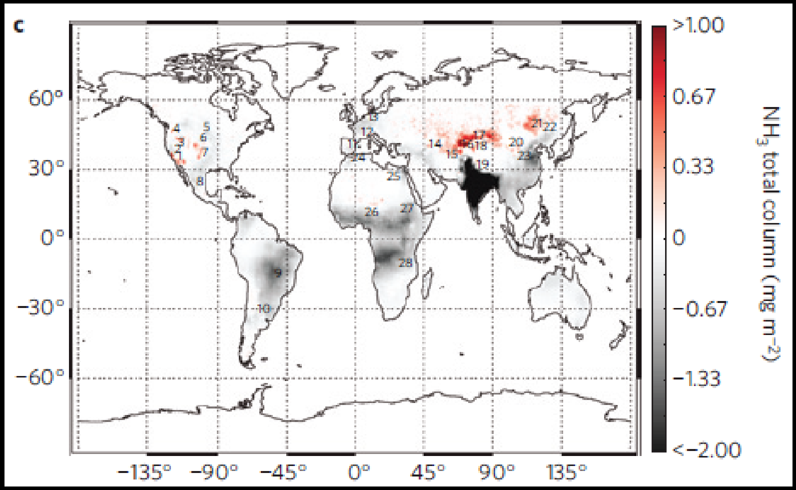
Measurement mean 2008



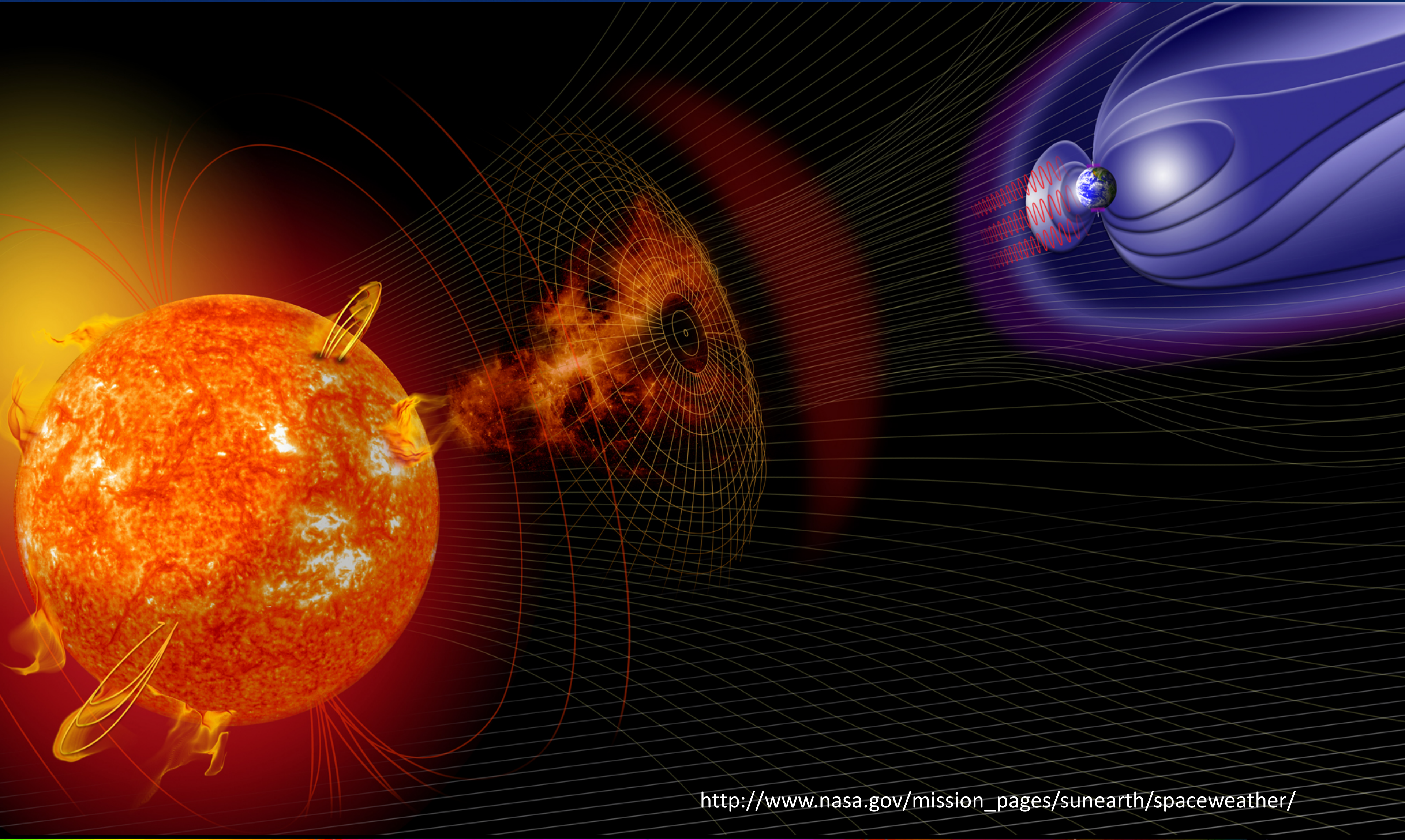
Model



Meas - Mod



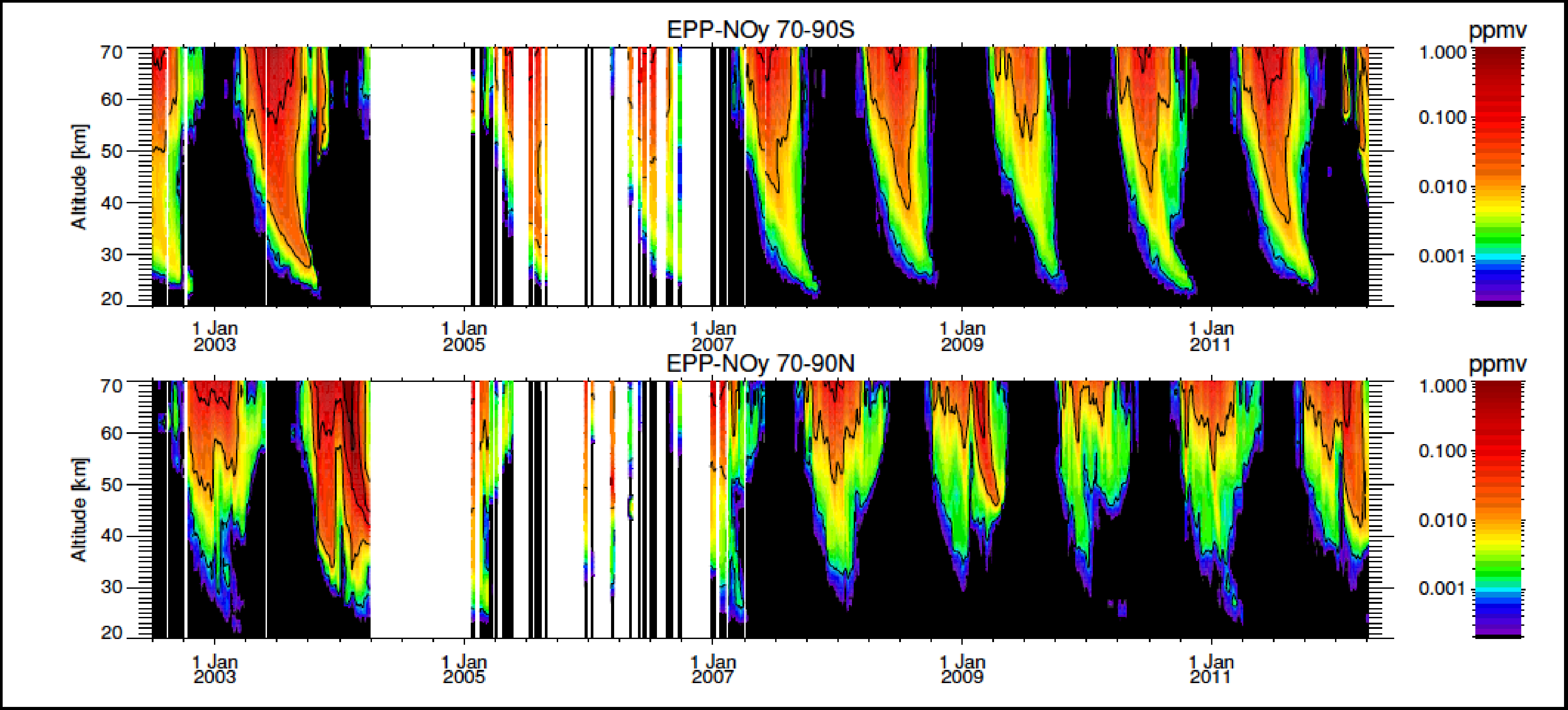
Clarisse et al., Ngeo, 2009



http://www.nasa.gov/mission_pages/sunearth/spaceweather/

Michael Höpfner

MIPAS: Mesospheric and stratospheric NO_y produced by energetic particle precipitation



Funke et al., JGR, 2014


The Future
NEXT EXIT

Future: hyperspectral IR nadir sounding

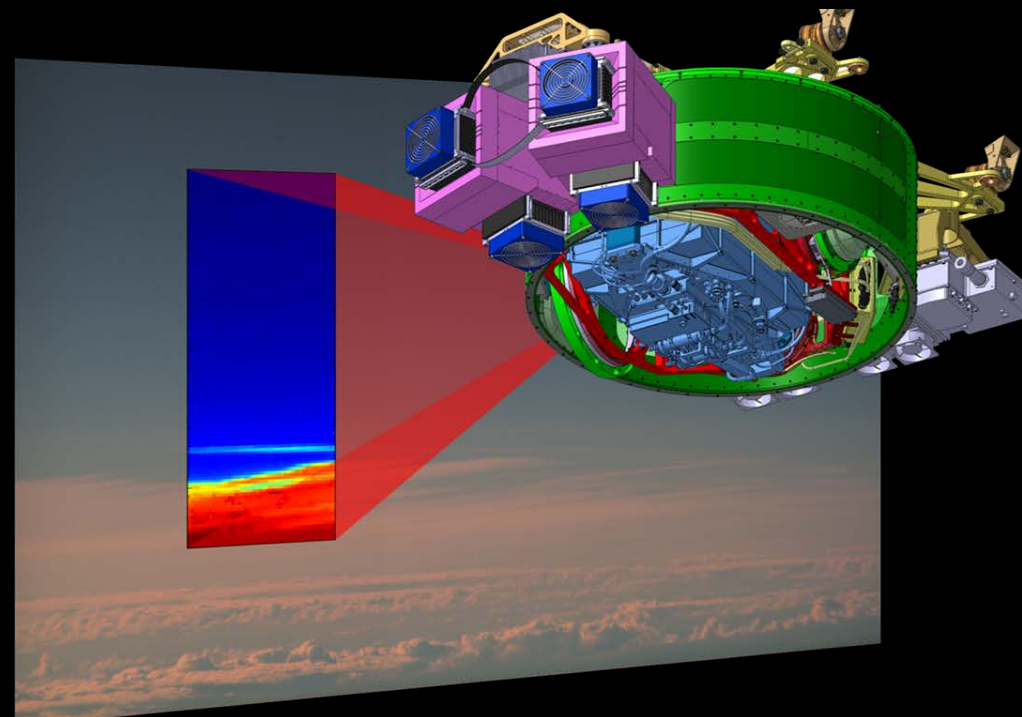
Polar orbit (LEO)

IASI

- 2017: Metop C
- After 2020: IAS on EPS-SG (like IASI but better spectral resolution)

Imaging FTS

2d IR detector combined with interferometer: 256x256 detector pixel (i.e. spectra) in one view instead of 1 in case of MIPAS or 2x2 in case of IASI



Riese et al., AMT, 2014
Friedl-Vallon et al., AMT, 2014

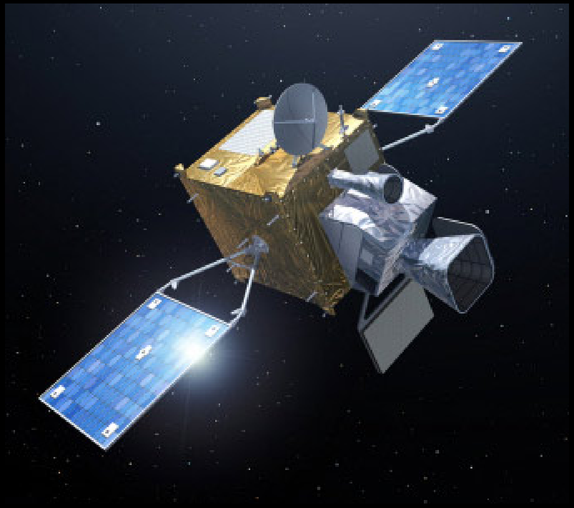
Future: hyperspectral IR nadir sounding

Polar orbit (LEO)

IASI

- Metop C: 2017 –
- IAS on EPS-SG (like IASI but better spectral resolution)

Geostationary orbit (GEO)



Infrared Sounder (IRS) on Meteosat Third Generation (MTG-S)

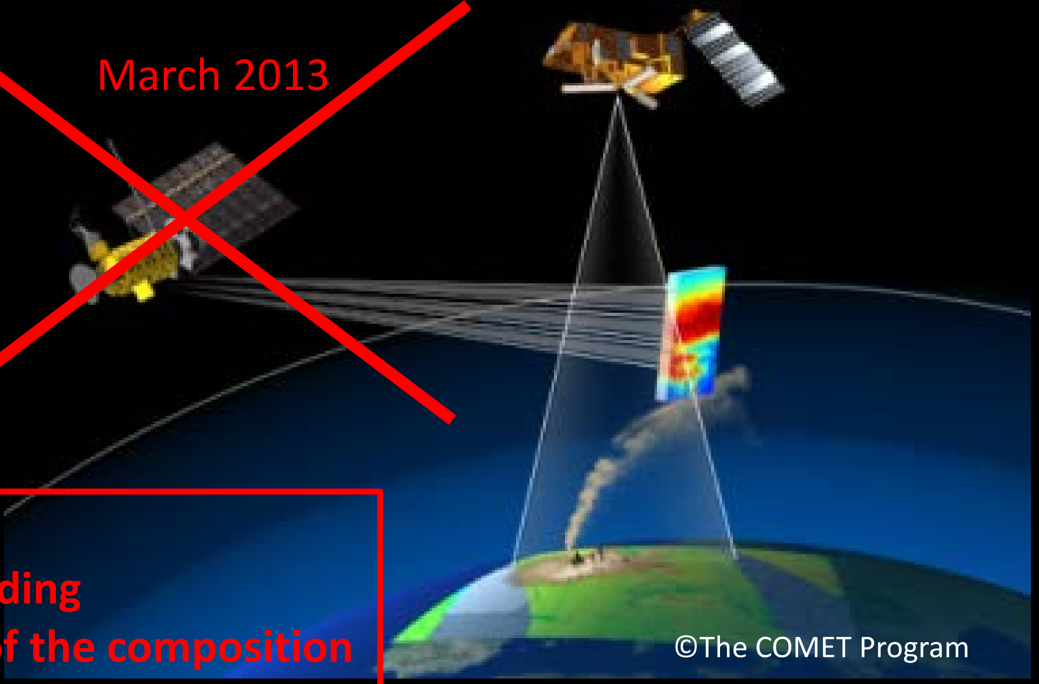
- 2020
- First operational imaging FTS
- 4 km horiz., 1h temp. resolution

Future: hyperspectral IR limb sounding

PREMIER: ESA Earth Explorer 7 Candidate

PREMIER and MetOP: observational geometry

March 2013



Two science instruments

- IRLS (imaging infrared limb-sounder)
- STEAM-R (microwave limb sounder)

Both instruments measure 2D fields

- Vertical and across-track
- Very high sampling and coverage

DANGER
Future: no space-borne limb sounding
→ We will loose the knowledge of the composition of the higher atmosphere in a changing climate