JÜLICH FORSCHUNGSZENTRUM

esa

→ ADVANCED ATMOSPHERIC TRAINING COURSE 2014

Ground based observations and their use for satellite data validation

Dr. Oksana Tarasova

World Meteorological Organization

Presentation outline

1) The concept of the Global Atmosphere Watch (GAW) Programme
2) Observations in GAW
3) GAW Quality Assurance
4) Examples of the ground based observations use for the satellite products validation
5) Lessons learned

Ground based vs. Satellite observations

- Long-term consistency
- Smaller uncertainty/ better precision
- Direct measurements

BUT

- Limited spatial coverage
- Diverse measurement techniques

- Limited life time
- Larger uncertainties
- Retrieval from radiation measurements

BUT

- Global coverage
- One instrument

Two approaches are complementary and can be used for cross-verification

Ground based networks and GAW

Foundation of Global Atmosphere Watch Programme:

"Collecting adequate information on the chemical composition of the atmosphere and on the consequences of the anthropogenic impact on a global scale is **valuable and possible** only IF all the relevant measurements are expressed in the same units or on the same scale and IF data from the countries and at differrent sites are comparable"

Note: GAW foundation has some implications for satellite validation

What is the GAW Programme?

- WMO/GAW was established 1989 by merging GO_3OS and BAPMoN.
- GAW is a partnership involving contributors from about 100 countries.

Surface-based *in situ* and remote sensing observations are the backbone of the GAW network, which consists of Global and Regional stations and stations working within contributing networks.

Currently GAW coordinates activities and data from 30 Global stations, 400 Regional stations, and 100 Contributing stations (http://gaw.empa.ch/gawsis/)

GAW requires that the stations are not **directly impacted** by pollution sources (other requirements are at www.wmo.int/gaw)

GAW focal areas

- Stratospheric Ozone and vertical ozone distribution
- Greenhouse Gases (CO_2 and its isotopes , CH_4 and its isotopes, N_2/O_2 ratio, N_2O, SF_6, CFCs and substitutes)
- Reactive Gases (O_3, CO, VOCs, NOx, SO_2)
- Precipitation Chemistry
- Aerosols (chemical and physical properties, AOD)
- UV Radiation
- GAW Urban Meteorology (GURME) project

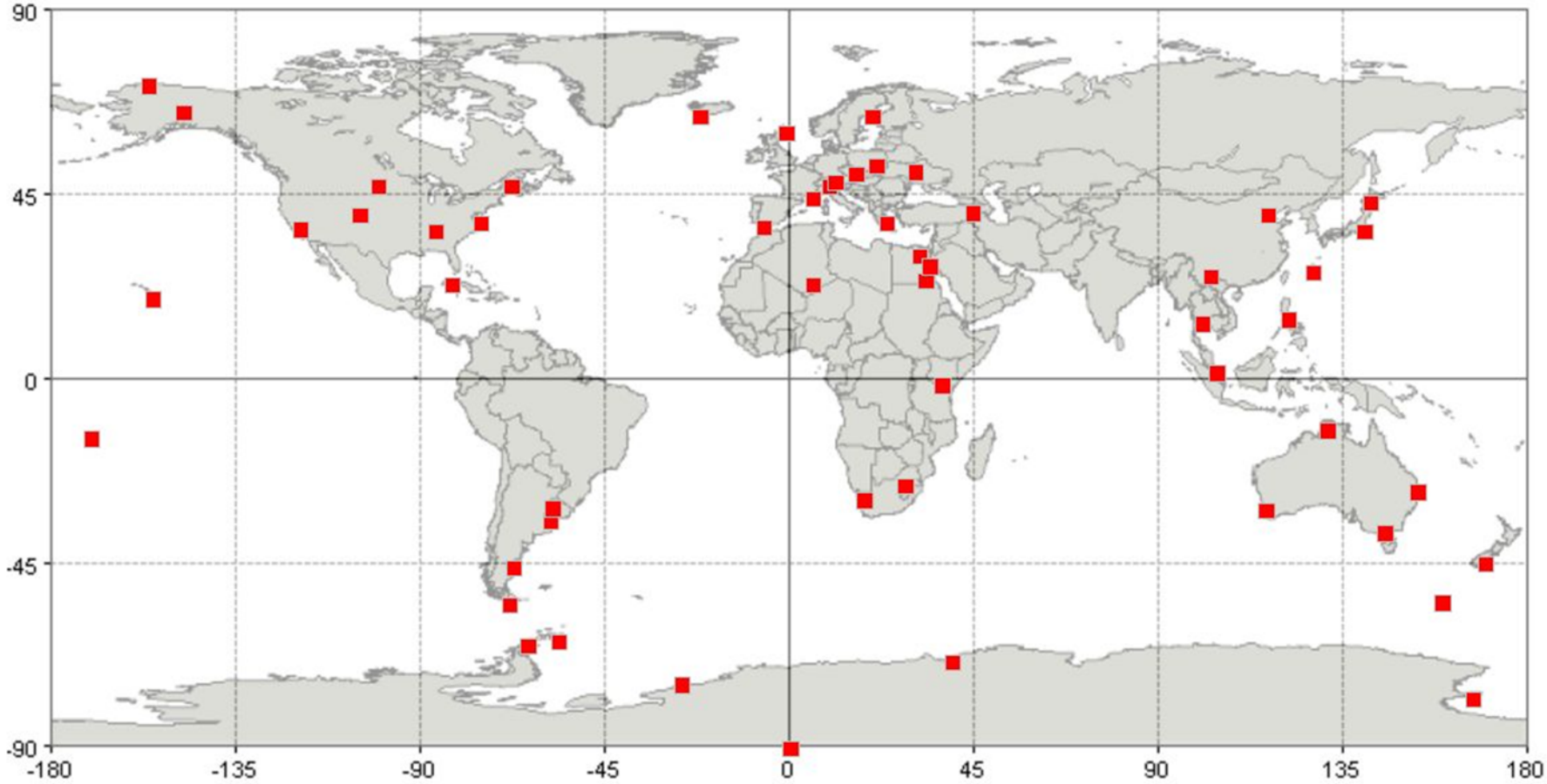
Types of observations in GAW

- Stratospheric ozone and vertical ozone distribution*:
  - Ground based remote sensing for total ozone column measurements and vertical distribution (Brewer and Dobson spectrophotometers, Lidar (e.g. in NDACC))
  - Ozone sounding (in situ vertical profile measurements)

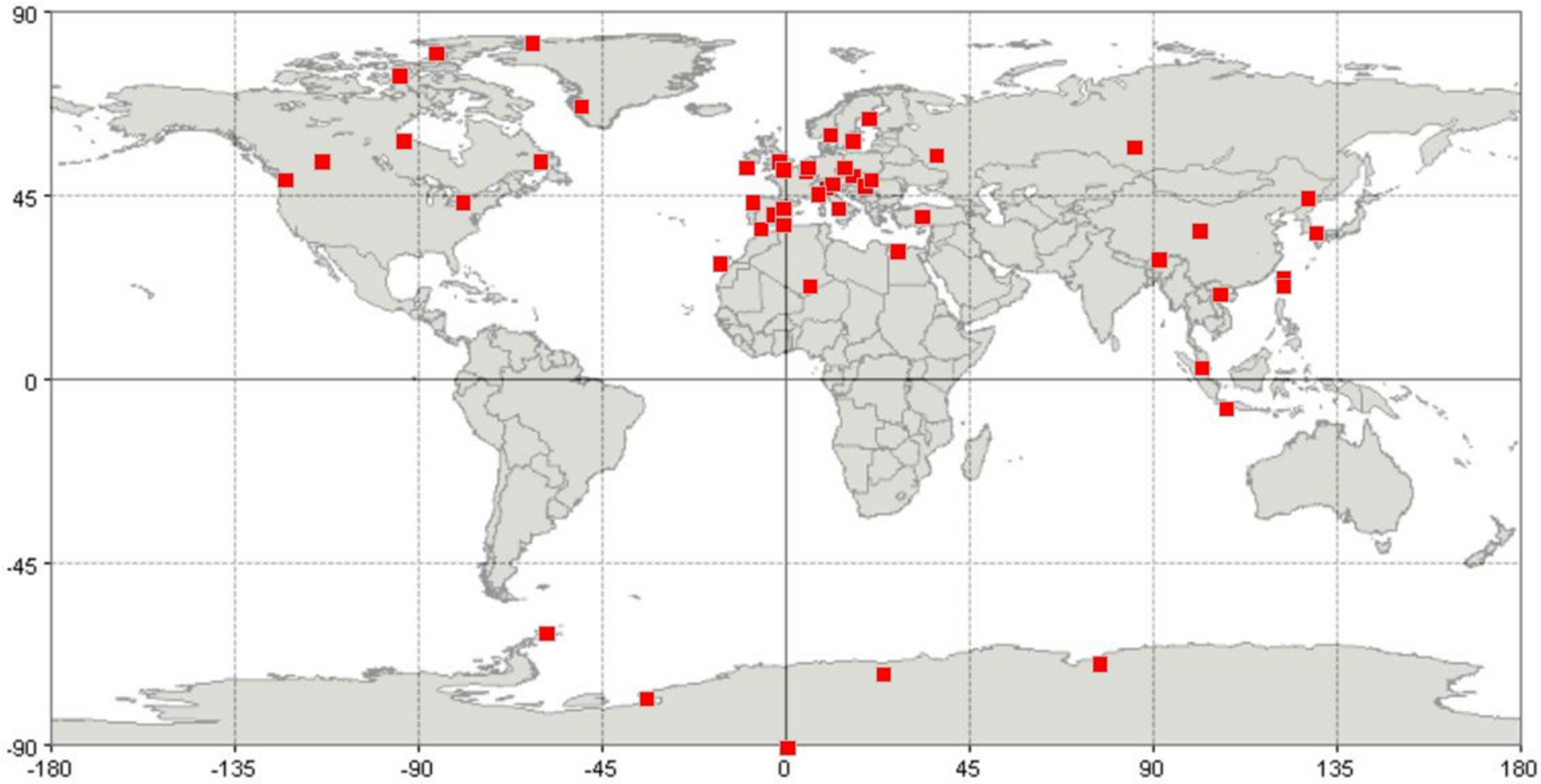
Observational data are archived in the World Ozone and UV Radiation Data Centre (WOUDC) at www.woudc.org

* appropriate for satellite data validation

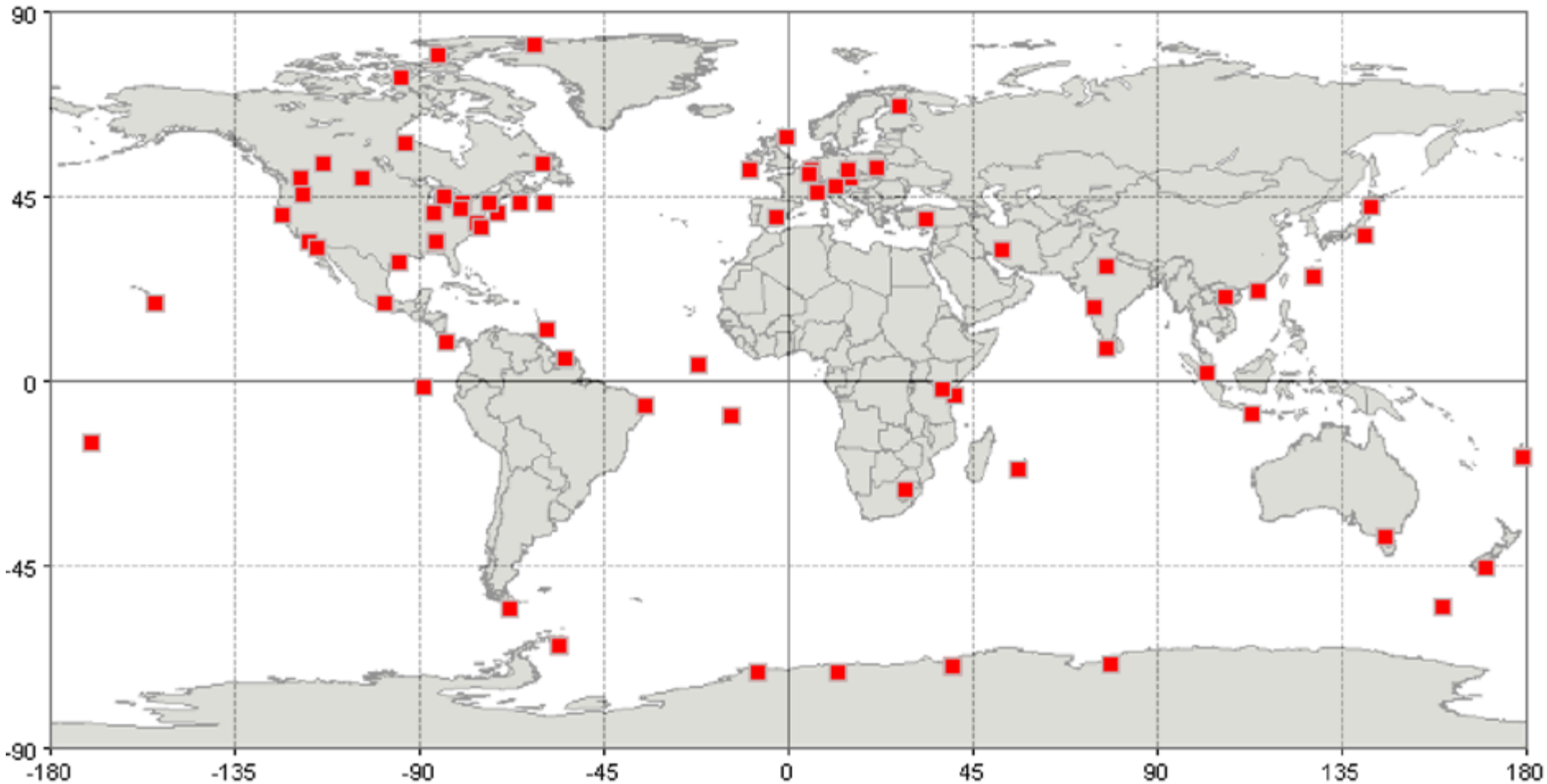
Dobson Total Ozone Network: Data 2012-2013



Brewer Total Ozone Network: Data 2012-2013



Ozonesonde Network: Data after 1-1-2008



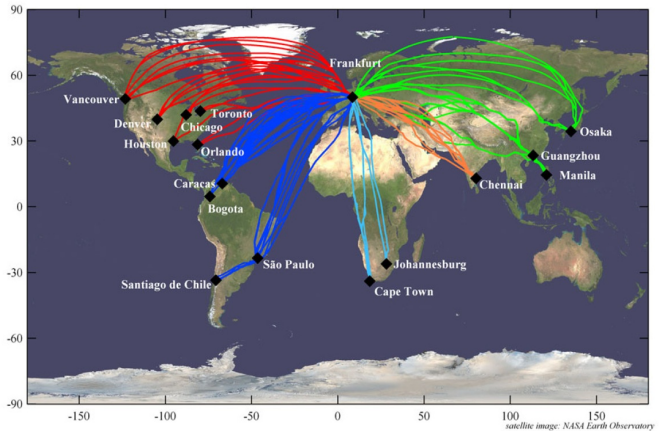
Types of observations in GAW

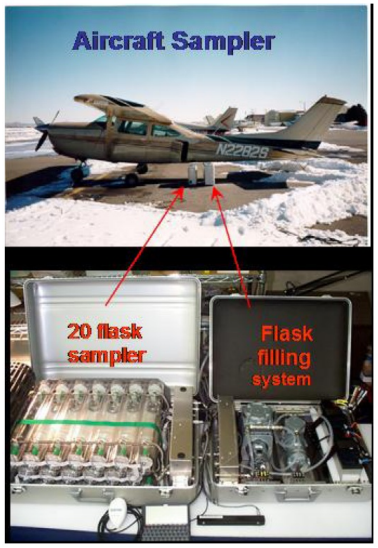
- Greenhouse gas observations:
  - In situ continuous measurements (including ship borne) with GC, NDIR, spectroscopic methods **
  - Flask sampling (including ship borne) **
  - Aircraft based flask sampling and continuous measurements
  - Ground based remote sensing for total column and vertical distribution (TCCON and NDACC contributions)

Observational data are archived in the World Data Centre for Greenhouse Gases (WDCGG) at http://ds.data.jma.go.jp/gmd/wdcgg/

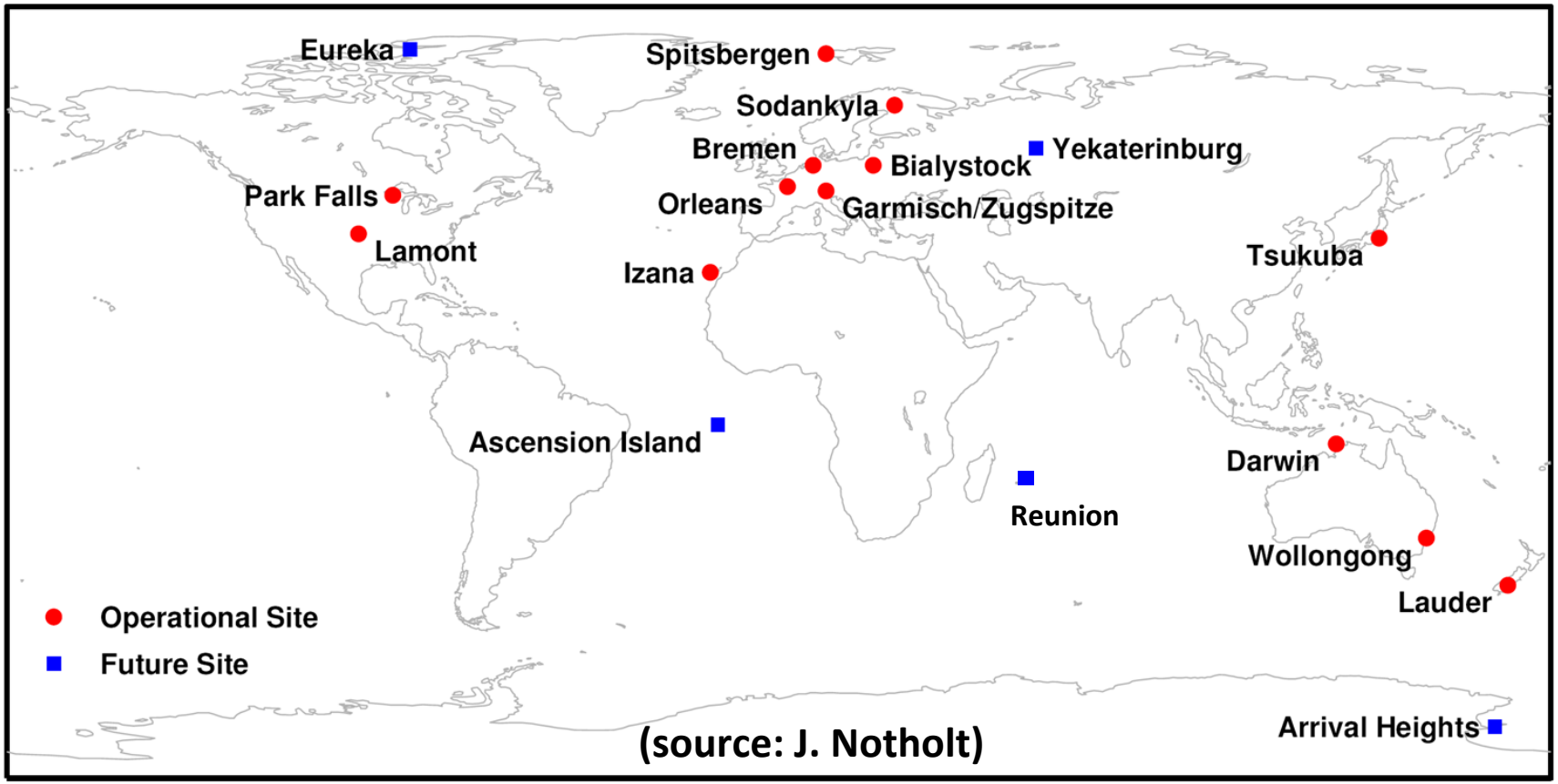
Aircraft observations of CO_2 , CH_4 and N_2O mixing ratios

- Regular commercial aircraft observations in the CONTRAIL project
- Commercial flights on a monthly basis in the CARIBIC project
- NOAA currently obtains twice-monthly vertical profiles of several greenhouse gases at 17 sites (mostly over North America)
- Japan Meteorological Agency (JMA) continues monthly aircraft observations of tropospheric greenhouse gases (including CO_2, CH_4 and N_2O) in the western North Pacific region





TCCON (Total Carbon Column Observing Network) , https://tccon-wiki.caltech.edu/



(source: J. Notholt)

Types of observations in GAW

- Reactive gases - Tropospheric ozone:
  - The same as for total ozone (tropospheric part)
  - In situ observations from aircraft (IAGOS, CARIBIC)
- In situ continuos observations** (UV absorption, Chemiluminescence , Electrochemical techniques, CRDS, DOAS, MaxDOAS)

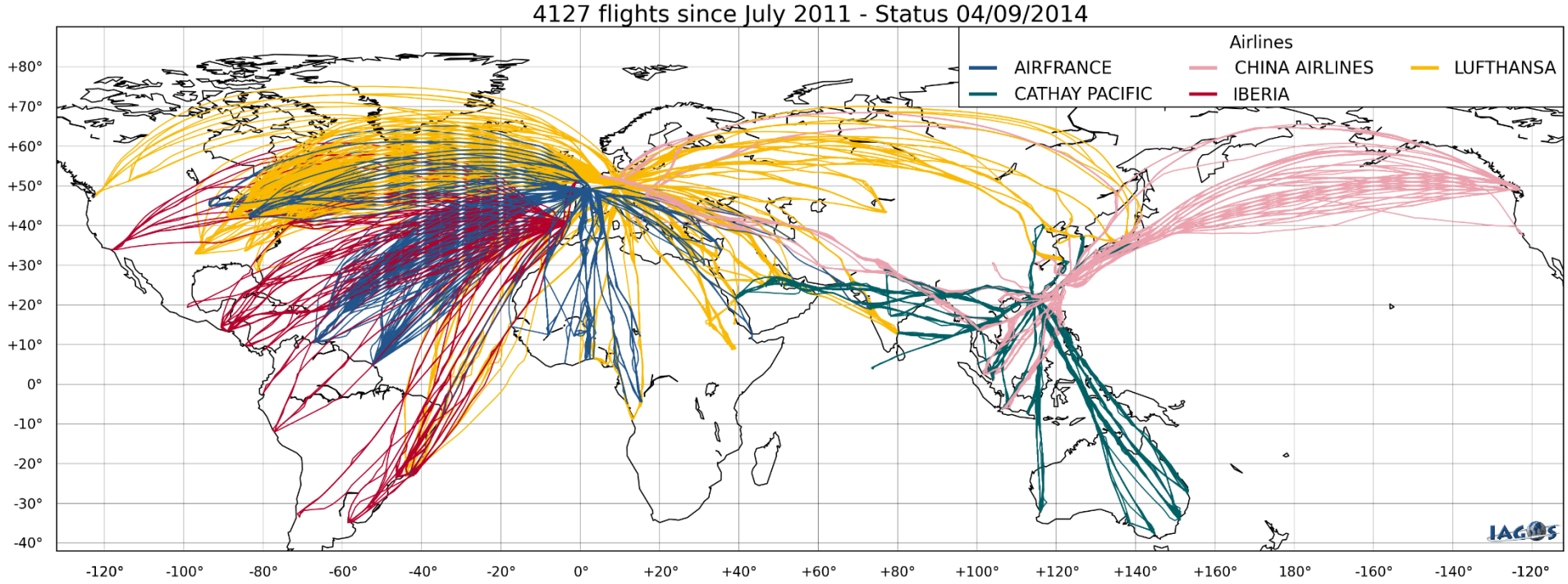
Observational data** are archived in the World Data Centre for Greenhouse Gases (WDCGG) at http://ds.data.jma.go.jp/gmd/wdcgg/

Types of observations in GAW

- Reactive gases – Carbon monoxide:
  - In situ continuous observations** (NDIR, GC/FID, GC/HgO, spectroscopic methods)
  - Flask sampling** (at the ground station)
  - Aircraft flask sampling (same as for GHG)
  - In situ observations from aircraft (IAGOS, CARIBIC)
  - Ground based total column observations (FTIR in TCCON and NDACC)

Observational data** are archived in the World Data Centre for Greenhouse Gases (WDCGG) at http://ds.data.jma.go.jp/gmd/wdcgg/

In-service Aircraft for a Global Observing System (IAGOS)



IAGOS uses GAW Quality Assurance concept

(source: V. Thouret)

Types of observations in GAW

- Reactive gases – Nitrogen Oxides (NO, NO_2) :
  - In situ continuous observations** (chemiluminencent methods and spectroscopy(TDLAS, DOAS, CRDS, FTIR))
  - Ground based remote sensing (Brewer, MaxDOAS, FTIR)
  - In situ observations from aircraft (IAGOS, CARIBIC)

Observational data** are archived in the World Data Centre for Greenhouse Gases (WDCGG) at http://ds.data.jma.go.jp/gmd/wdcgg/

Types of observations in GAW

- Reactive gases – Sulphur dioxide (SO_2) :
  - In situ continuous observations** (ion chromatography, photometry)

Observational data** are archived in the World Data Centre for Greenhouse Gases (WDCGG) at http://ds.data.jma.go.jp/gmd/wdcgg/

Types of observations in GAW

- Reactive gases – Volatile Organic Compounds (VOCs) :
  - In situ continuous observations and flask sampling** (GC/FID, GS/MS, PTR-MS, DOAS)
  - FTIR column measurements (IR group NDACC)

Observational data** are archived in the World Data Centre for Greenhouse Gases (WDCGG) at http://ds.data.jma.go.jp/gmd/wdcgg/

List of priority VOCs in GAW

Molecule	Lifetime ($OH=10^6$ cm^{-3})	Steel flask	Glass flask	Analysis Method
1. Ethane	1.5 months	√	√	GC/FID
2. Propane	11 days	√	√	GC/FID
3. Acetylene	15 days	√	√	GC/FID
4. Isoprene	3 hours	?	?	GC/FID, PTR-MS
5. Formaldehyde	1 day	-	-	DOAS
6 Terpenes	1-5 hours	-	-	GC/MS, PTR-MS
7. Acetonitrile	0.5-1 year	-	?	GC/MS,PTR-MS
8. Methanol	12 days	-	?	GC/FID, PTR-MS
9. Ethanol	4 days	-	?	GC/FID, PTR-MS
10. Acetone	1.7 months	?	?	GC/FID, PTR-MS
11. DMS	2 days	?	?	GC/FID, PTR-MS
12. Benzene	10 days	√	?	GC/FID, GC/MS
13. Toluene	2 days	-	?	GC/FID, GC/MS
14. Iso and normal Butane	5 days	√	√	GC/FID, GC/MS
15. Iso/normal Pentane	3 days	√	√	GC/FID, GC/MS

Types of observations in GAW

- Atmospheric wet deposition:
  - Rain water samples analysis in the laboratory

Analyte	Status	Preferred Methods
pH	Required	Glass electrode
Conductivity	Required	Conductivity cell
Alkalinity	Optional	Titration
Cl^-, NO_3^-, SO_4^{2-}	Required	IC
NH_4^+	Required	IC, AC
Na^+, K^+, Ca^{2+}, Mg^{2+}	Required	IC, ICP, AAS/AES
Organic Acids[2]	Optional	IEC, IC
NO_2^-, F^-	Optional	IC
PO_4^{3-}	Optional	IC, AC

IC = ion chromatography; AC = automated colorimetry; ICP = inductively coupled plasma spectrometry, IEC = ion exclusion chromatography; AAS = atomic absorption spectrometry; AES = atomic emission spectrometry

Types of observations in GAW

- Aerosol characteristic observations
- Physical Properties (in situ instruments):
  - particle number concentration (size integrated)
  - particle number size distribution
  - particle mass concentration (two size fractions)
  - cloud condensation nuclei number concentration (at various super-saturations)

- Chemical Properties (in situ instruments):
  - mass concentration of major chemical components (two size fractions)

Observational data are available in the World Data Centre for Aerosols (WDCA) at www.gaw-wdca.org

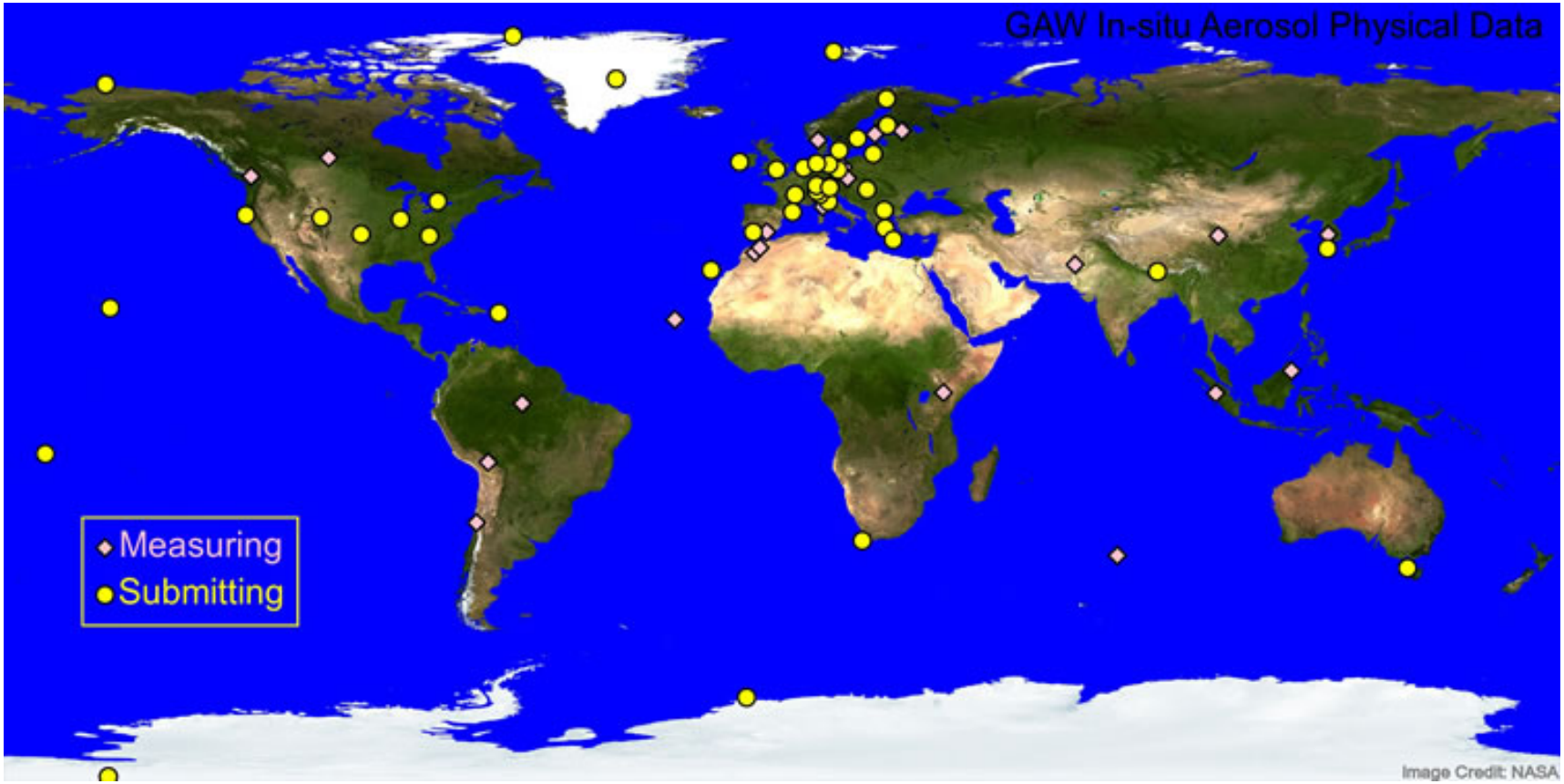
Types of observations in GAW

- Aerosol characteristics observations
- Optical Properties:
  - light scattering coefficient (various wavelengths)
  - light hemispheric backscattering coefficient (various wavelengths)
  - light absorption coefficient (various wavelengths)

- Column and Profile:
  - aerosol optical depth (various wavelengths)
  - vertical profile of aerosol backscattering coefficient
  - vertical profile of aerosol extinction coefficient

Observational data are available in the World Data Centre for Aerosols (WDCA) at www.gaw-wdca.org

GAW in-situ aerosol monitoring network (physical and chemical properties of aerosol)

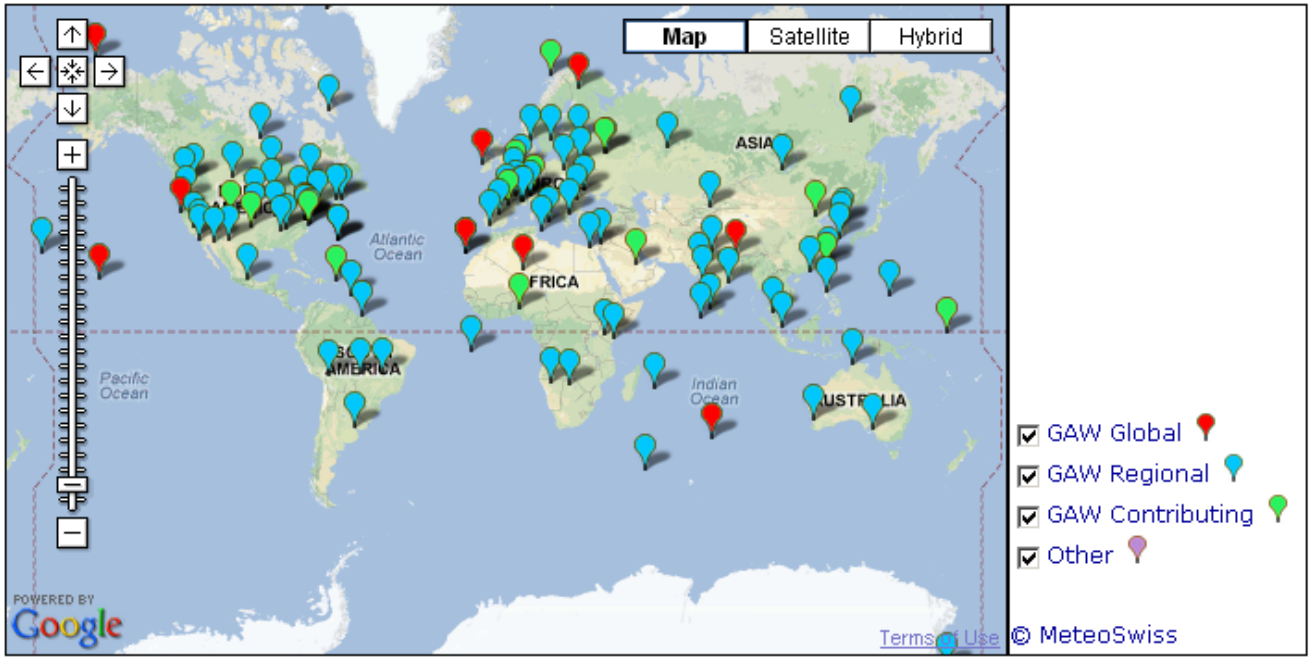


The Ground-based Global AOD Network

The global AOD observational network is co-sponsered by a number of agencies and programmes, in particular

- AEROCAN, federated to AERONET
- AERONET,
- PHOTONS, federated to AERONET
- GAW (PFR),
- PolarAOD,
- German AOD network,
- SibRad, and
- SKYNET

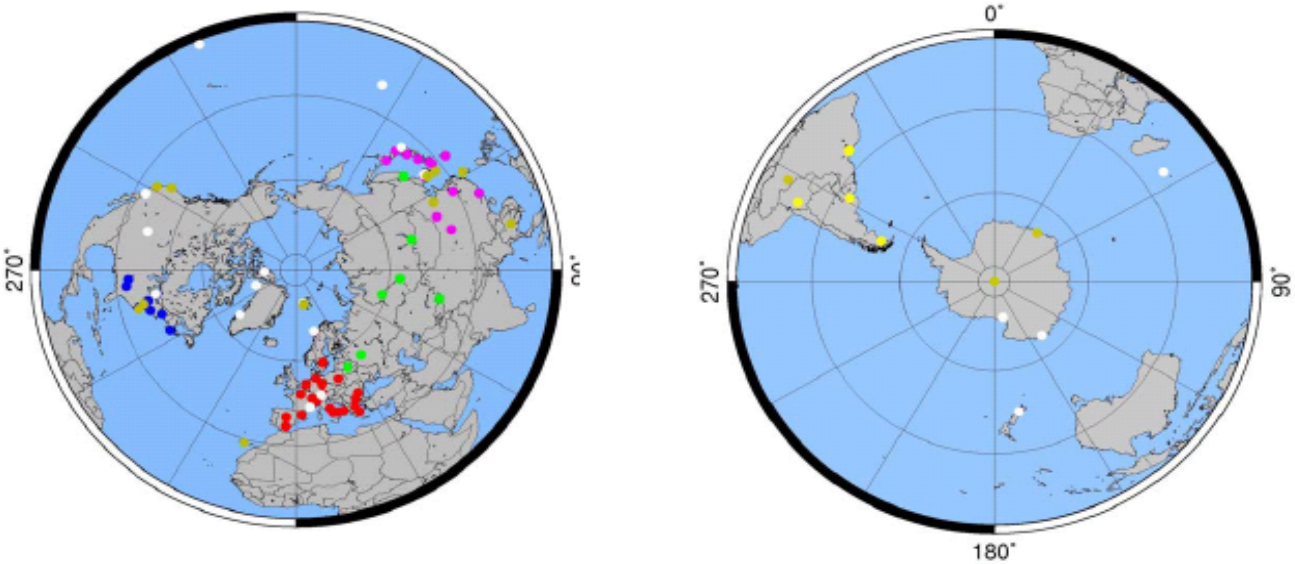
total: 122 sites



Global AOD Reference Network GAW-PFR

GAW-PFR network, manufactured and coordinated by World Optical Depth Research and Calibration Center, Davos (Switzerland) is operated by GAW stations. Consists of 29 stations and 23 submit data in NRT on hourly basis

GAW Aerosol LIDAR Observing Network-GALION



Letters of agreement were signed between GAW and the following lidar networks as GAW contribution networks:

- the Latin America Lidar Network (ALINE)
- the European Aerosol Research Lidar Network (EARLINET)
- the Asian Dust and Aerosol Lidar Observation Network (AD-Net)

Types of observations in GAW

- UV Radiation:
  - Ground based UV radiation measurements (Three general types of instruments are used: **broadband filters** (integrate over either the UV-B or UV-A spectrum or the entire broadband UV region responsible for affecting human health), **narrowband filters** (use one or more interference filters to integrate over discrete portions of the UV-A and/or UV-B spectrum) and **spectroradiometers** (measure across a pre-defined portion of the spectrum sequentially using a fixed passband)).

Observational data are archived in the World Ozone and UV Radiation Data Centre (WOUDC) at www.woudc.org

UV Radiation measurement network

Stations matching criteria (total: 163)

Observations summary

- There are many other than GAW ground based observational networks out there
- GAW covers limited number of chemical species
- Not all networks collaborate with GAW, hence they adhere to the network specific harmonization principles, including measurement techniques and traceability principles
- Some examples will be given using GAW network itself as well as contributing networks (TCCON) and collaborating project (NORS)

Quality Management Framework principles

- ✓ Network-wide use of only one reference standard or scale (primary standard). In consequence, there is only one institution that is responsible for this standard.
- ✓ Full traceability to the primary standard of all measurements made by Global, Regional and Contributing GAW stations.
- ✓ The definition of data quality objectives (DQOs).
- ✓ Establishment of guidelines on how to meet these quality targets, i.e., harmonized measurement techniques based on Measurement Guidelines (MGs) and Standard Operating Procedures (SOPs).
- ✓ Establishment of MGs or SOPs for these measurements.
- ✓ Use of detailed log books for each parameter containing comprehensive meta information related to the measurements, maintenance, and 'internal' calibrations.
- ✓ Regular independent assessments (system and performance audits).
- ✓ Timely submission of data and associated metadata to the responsible World Data Centre as a means of permitting independent review of data by a wider community.

Why does GAW have its QA principles

For GAW **network compatibility** is MORE important than absolute calibration (or traceability):

-We need to define small spatial gradients (including gradients between the countries)

-We need to have trend estimates by different countries relative to the same reference

-Long-term stability of the network primary reference, hence the whole network has the same reference independent of the point when new stations join the Programme. GAW has an experience with multiple scales which created unnecessary complexity in QA system.

-Only harmonized data sets can be used to calculation of global averaged mole fraction and be used for inverse modelling and comparison with model simulations

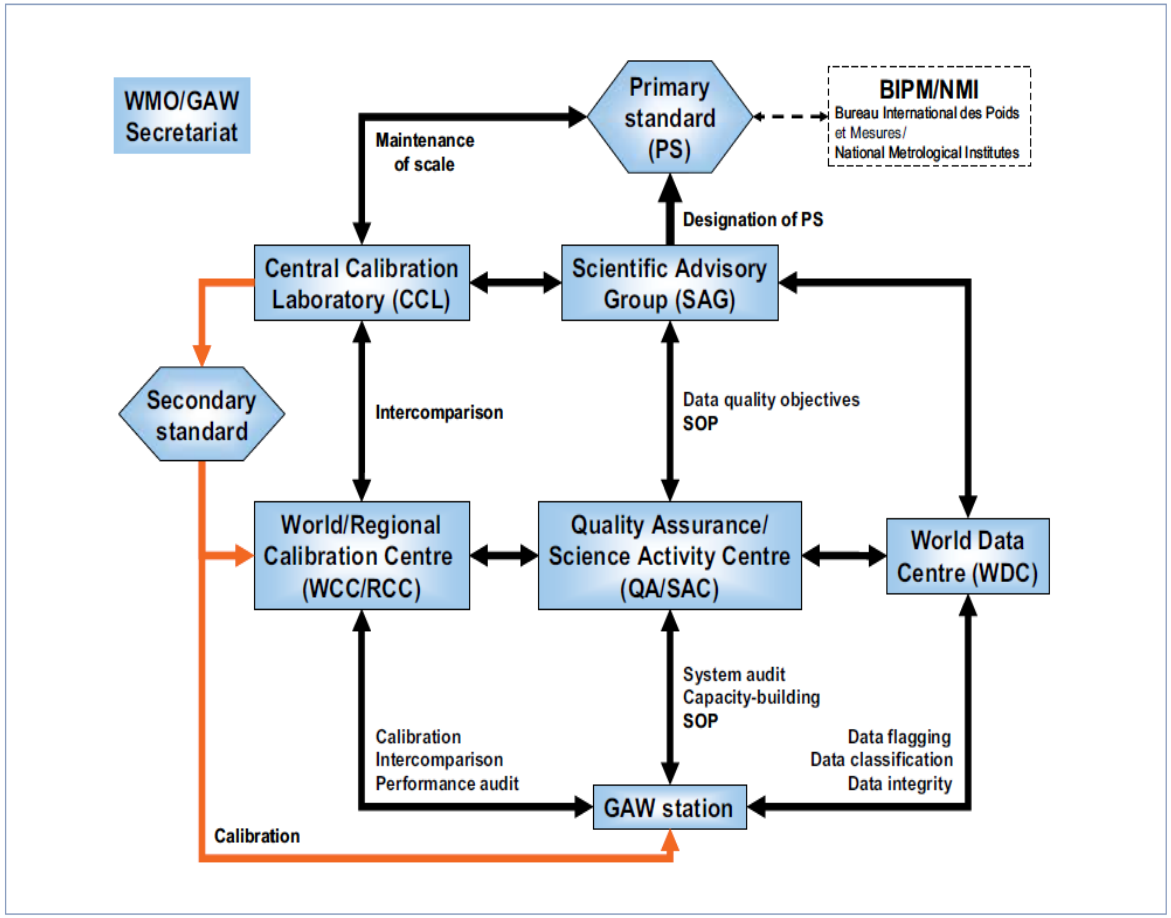
Network compatibility is different from measurement uncertainty and absolute traceability

Complexity of the GAW approach

- GAW has six groups of variables with completely different properties (long-lived gases, short-lived gases, total column, physical properties of aerosols, chemical composition of aerosols and rain water)
- Different variables allow for different traceability chain
- Different groups express requirements in a different way

- Within GAW Central Calibration Laboratories are responsible for support of the network reference (standard or scale)
- Network reference can be**: gas standards, reference instrument or reference method**
- Some CCL are taking part in BIPM key comparison to check the absolute traceability of the reference

GAW Quality Assurance system



GAW World Central Facilities

Variable	QA/SAC	Central Calibration Laboratory (CCL) (Host of Primary Standard)	World Calibration Centre (WCC)	Regional Calibration Centre (RCC)	World Data Centre (WDC)
CO_2	JMA (A/O)	ESRL	ESRL (round robin) Empa (audits)		JMA
carbon isotopes		MPI-BGC			JMA
CH_4	Empa (Am, E/A) JMA (A/O)	ESRL	Empa (Am, E/A) JMA (A/O)		JMA
N_2O	UBA	ESRL	IMK-IFU		JMA
CFCs, HCFCs, HFCs					JMA
SF_6		ESRL			JMA
H_2		MPI-BGC			JMA
Total Ozone	JMA (A/O)	ESRL[1], EC[2]	ESRL[1], EC[2]	BoM[1], ESRL[1], IZO[2] JMA[1], MOHp[1], MGO[3], OCBA[1], SAWS[1], SOO-HK[1]	EC[5], DLR[6]
Ozone Sondes	IEK-8	IEK-8	IEK-8		EC
Surface Ozone	Empa	NIST	Empa	OCBA	JMA
Precipitation Chemistry	NOAA-ARL	ISWS	ISWS		NOAA-ARL
CO	Empa	ESRL	Empa		JMA
VOC	UBA	NPL	IMK-IFU		JMA
SO_2					JMA
NO_x	UBA		IEK-8 (NO)		JMA
Aerosol	UBA (physical properties)		IfT (physical properties)		NILU[5], DLR[6]
Optical Depth		PMOD/WRC[4]	PMOD/WRC		NILU
UV Radiation				ESRL (Am), EUVC/PMOD (E)	EC
Solar Radiation		PMOD/WRC	PMOD/WRC		MGO

[1]Dobson, [2]Brewer, [3]Filter instruments, [4]Precision Filter Radiometers (PFR), [5]ground-based, [6]satellite-based

Central Calibration Laboratories

Host of WMO World Reference Standards for long-lived GHG

- CO_2, CH_4, N_2O, SF_6

NOAA ESRL USA

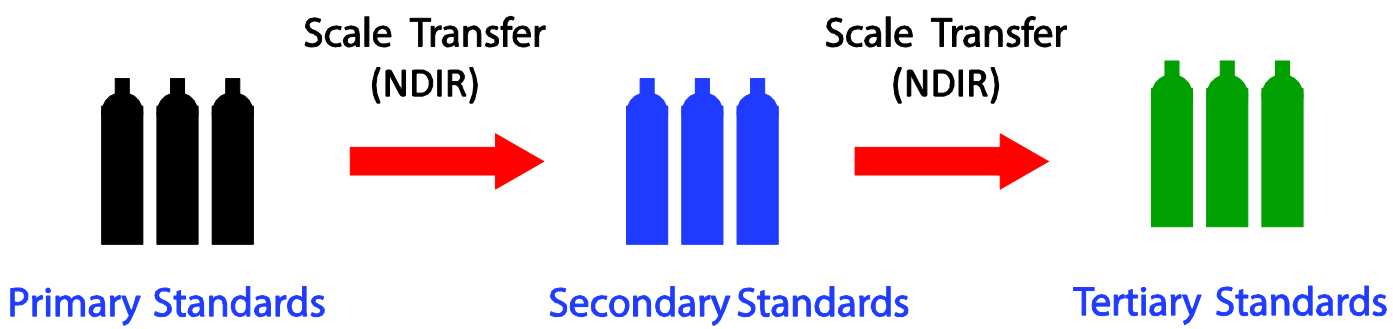
Collaboration under the CIPM MRA includes collaboration with the Consultative Committee for Amount of Substance (CCQM), Gas Analysis Working Group (GAWG) MRA allows NOAA to represent WMO in the following recent key comparisons:

- CCQM-K82 (Methane in air at ambient level)
- CCQM-K83 (Halocarbons in air at ambient levels)
- CCQM-K84 (Ambient CO)

Propagation of WMO Mole Fraction Scale for CO_2

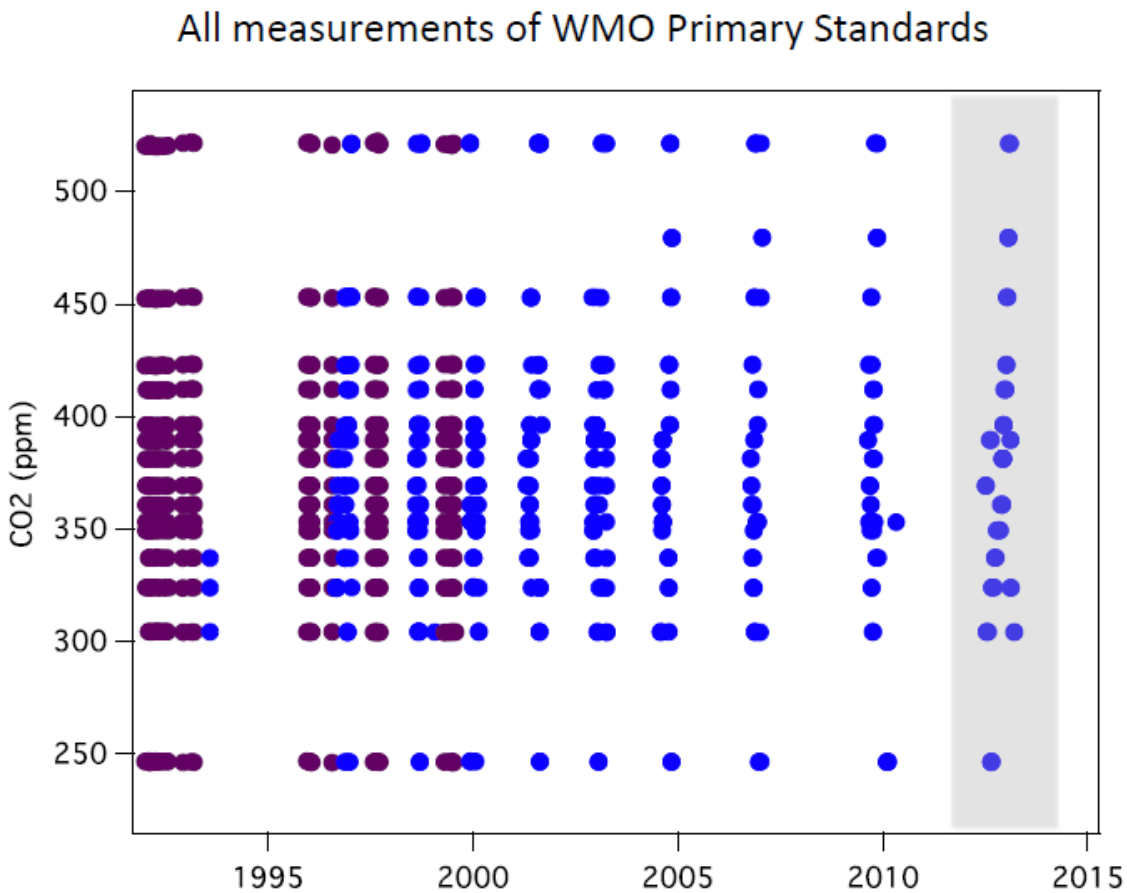
WMO CO_2 scale

- Reference scale for CO_2 in dry air, maintained by NOAA/GMD
- Defined by 15 primary standards (~ 250 – 520 ppm)



Courtesy of B.Hall

Stability of WMO Mole Fraction Scale for CO_2



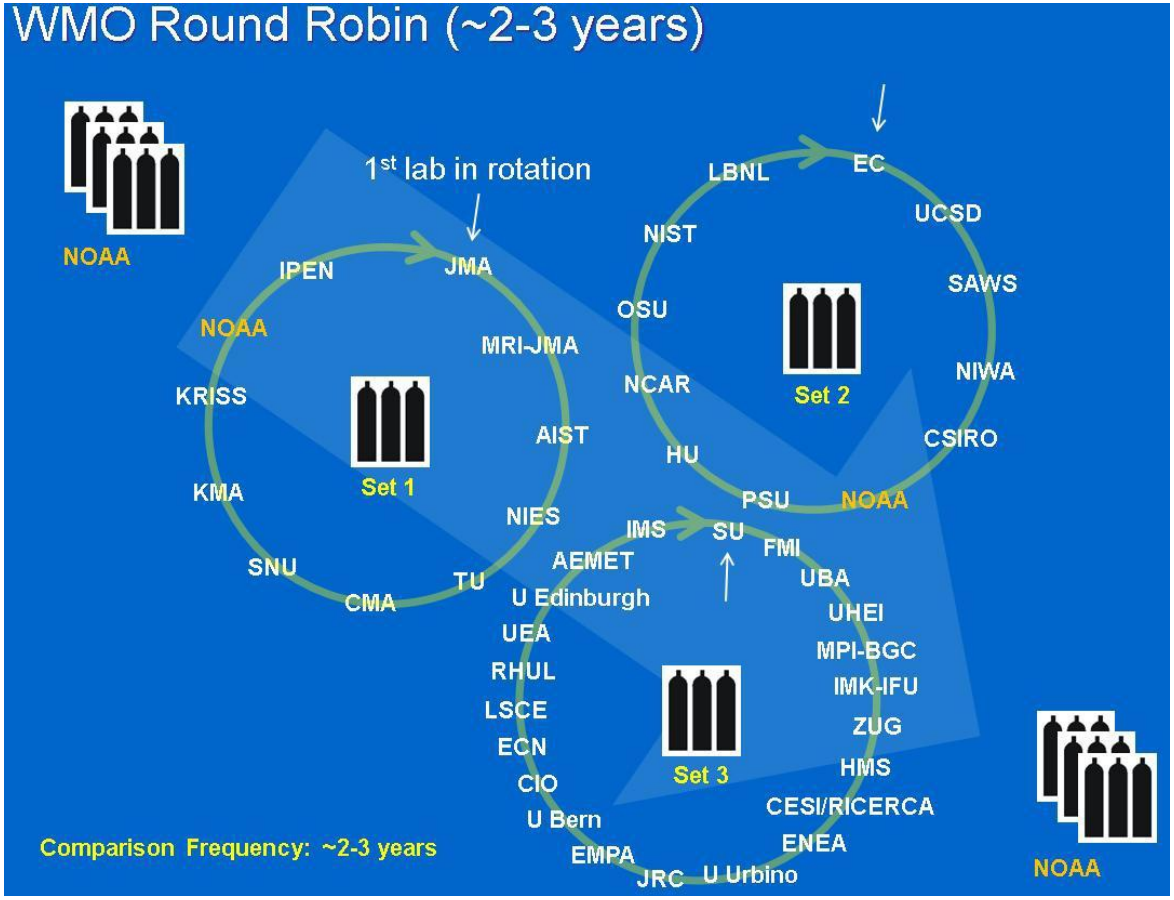
Courtesy of B.Hall

World Calibration Centres

Linking Observations to World Reference Standards and Ensuring Network Comparability through comparison campaigns and regular audit

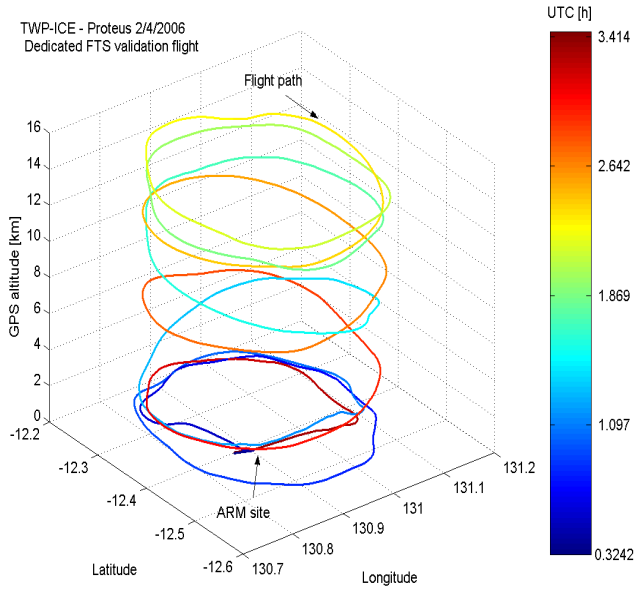
CO_2	- NOAA ESRL USA - EMPA, Switzerland (audits)
CH_4	- EMPA, Switzerland (Am,E/A) - JMA, Japan (A/O)
N_2O	Karlsruhe Institute of Technology (KIT), Institute for Meteorology and Climate Research, IMK-IFU, Garmisch-Partenkirchen, Germany
SF_6	Korea Meteorological Administration

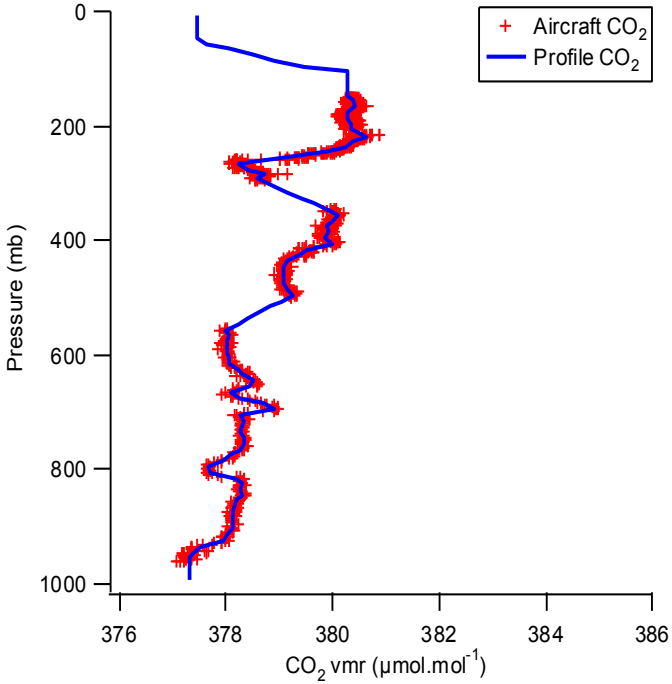
Comparison campaigns



- Regional and global comparisons (round-robin or instrumental)
- Stations audit
- Stations twinning

TCCON Validation – relation to WMO scales



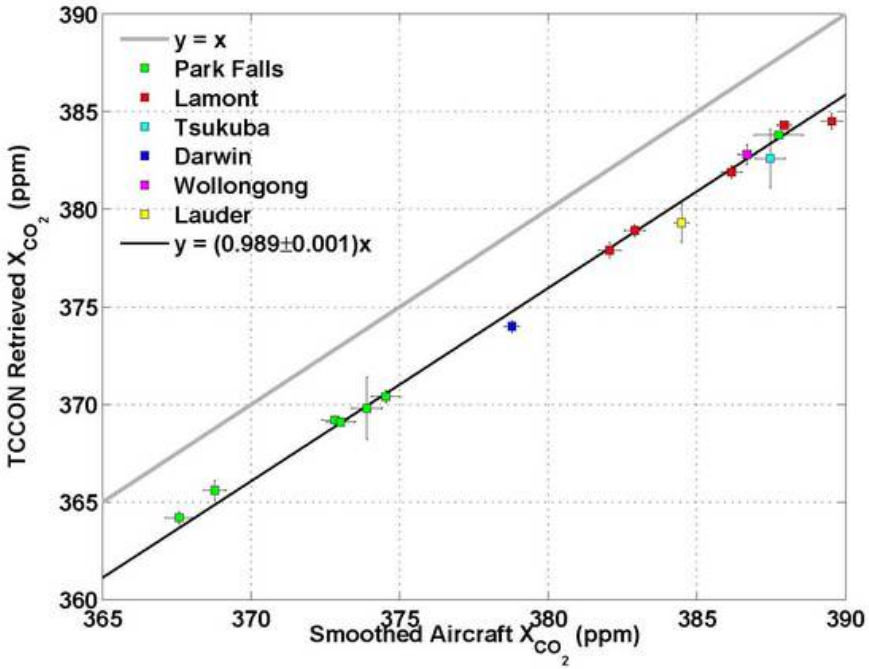


- eg TWP-ICE Darwin 2006
- CO_2 analyser on board
- Integrate vertical profile

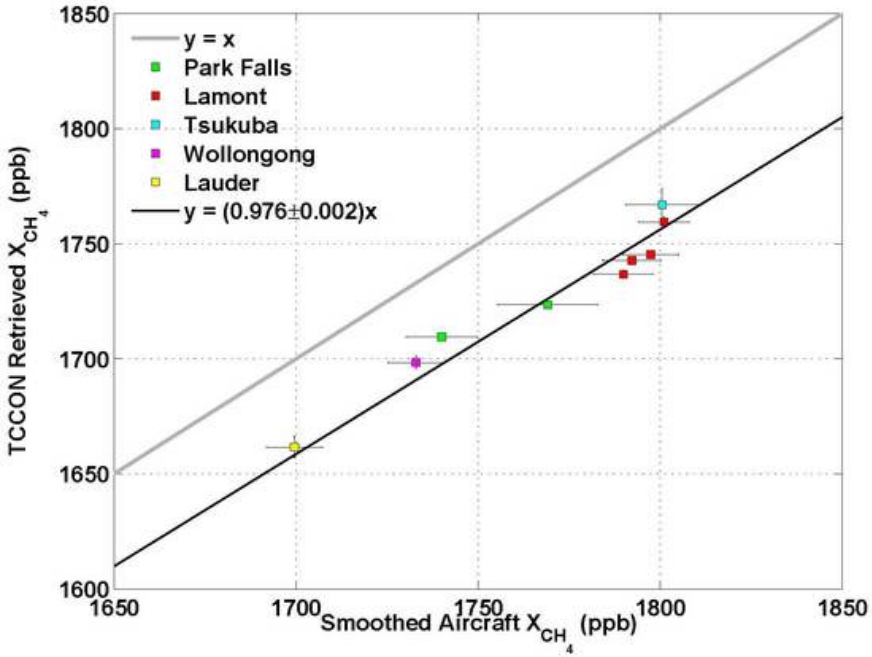
(Courtesy: D. Griffith)

TCCON validation against aircraft profiles CO_2 and CH_4

CO_2 (1σ 0.1%)



CH_4 (1σ 0.2%)

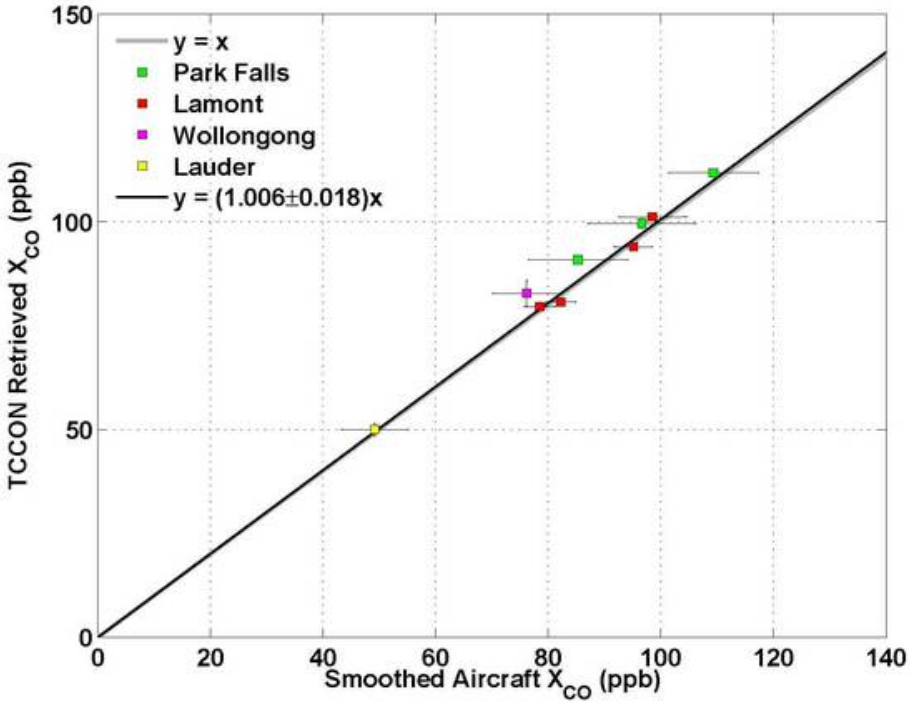


- Further detail:
  Wunch, D., et al. (2010), Calibration of the Total Carbon Column Observing Network using Aircraft Profile Data, *Atmos. Meas. Techn., 3, 1351-1362.*

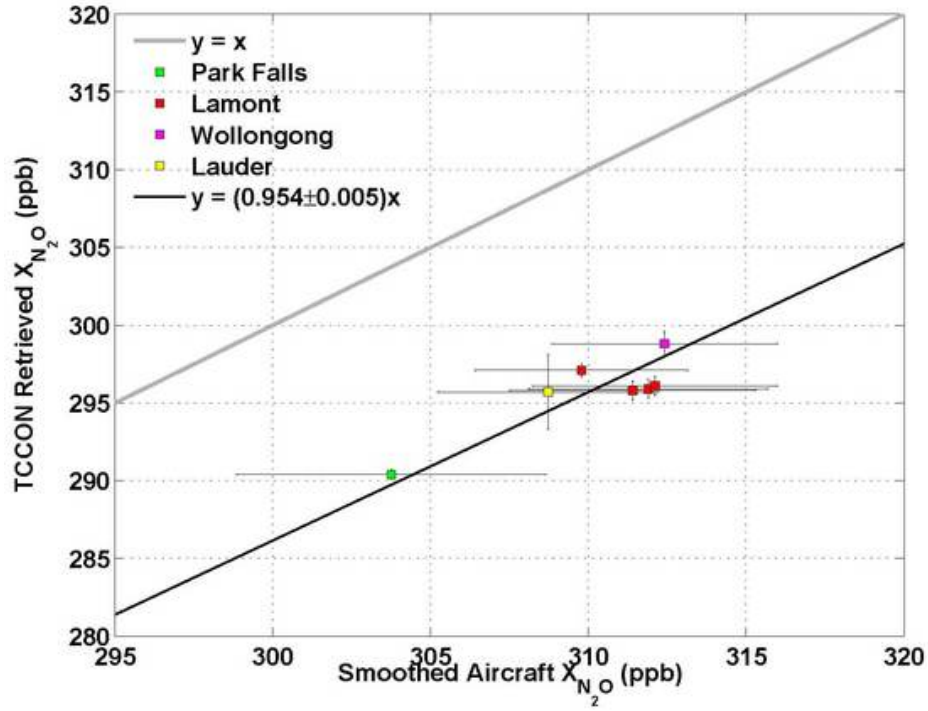
(Courtesy: D. Griffith)

TCCON validation against aircraft profiles
CO and N_2O

CO (1σ 2%)



N_2O (1σ 0.5%)



- Further detail:
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(Courtesy: D. Griffith)

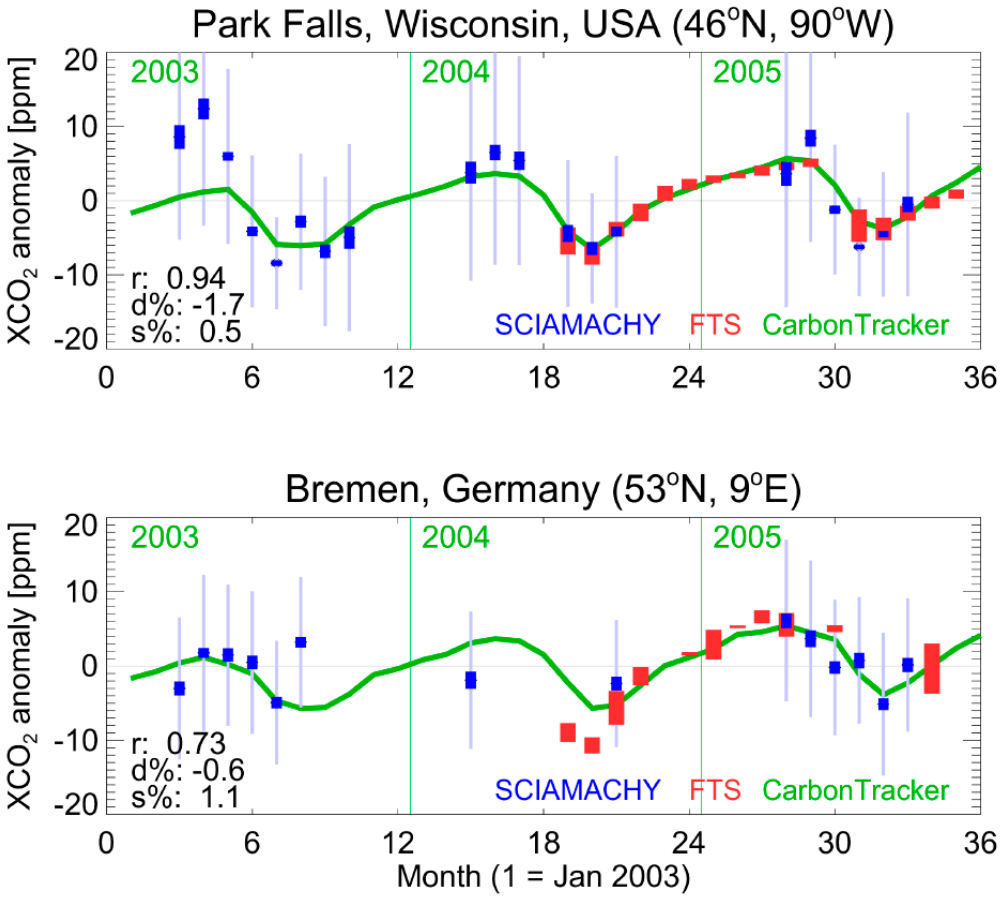
Comparison satellite – TCCON

Total column (NIR)

- ~~OCO: 2009 – 2010~~
- OCO-2: 2012 – 2014 ?
- Sciamachy: 2003 – 2013
- GOSAT: 2009 – 2013

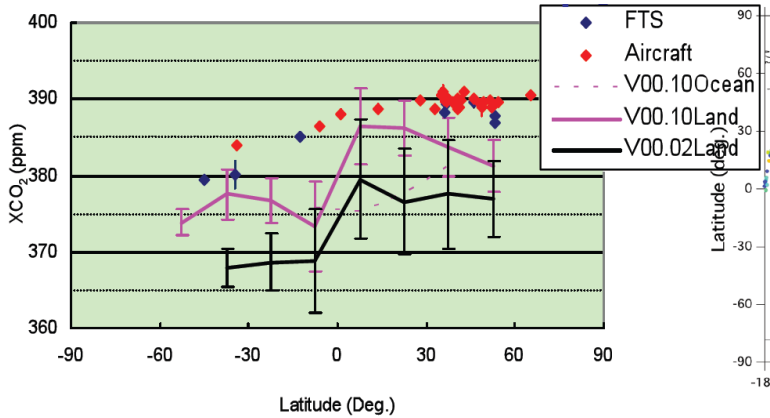
Upper troposphere (TIR)

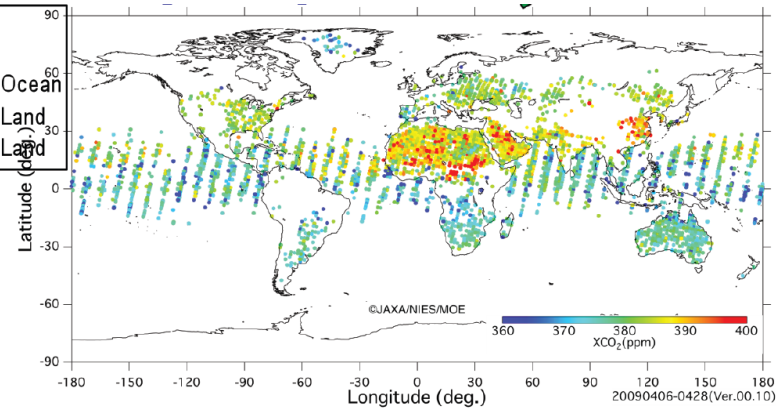
- TOVS
- AIRS
- IASI



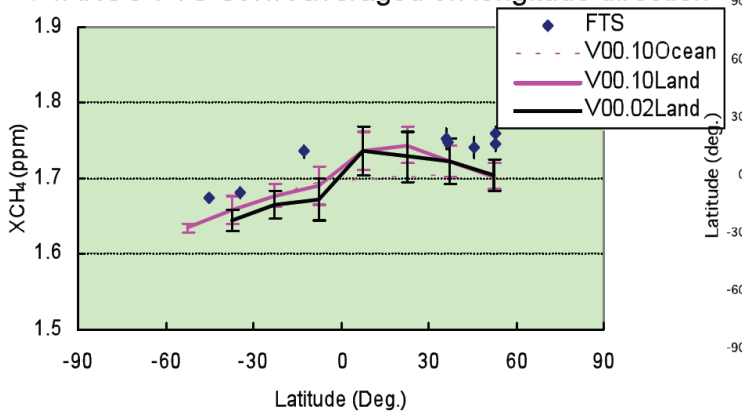
(Buchwitz et al., ACP 2007)

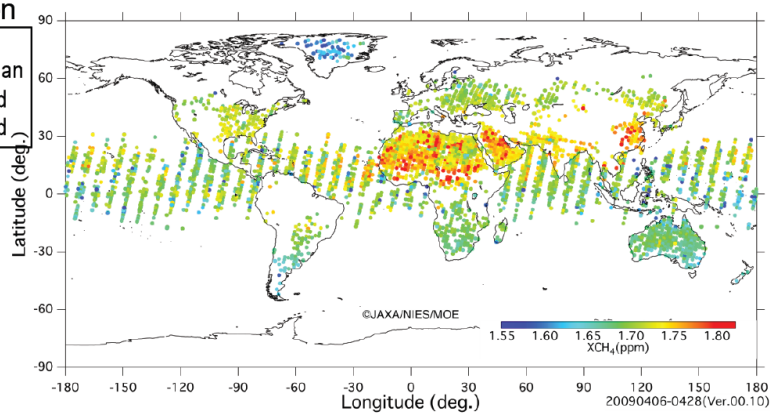
GOSAT validation (preliminary results)





◆ : ground-based FTS(GOSAT overpass ± 30 min)
◆ : aircraft (CONTARIL +NOAA)
— : TANSO FTS SWIR averaged on longitude direction





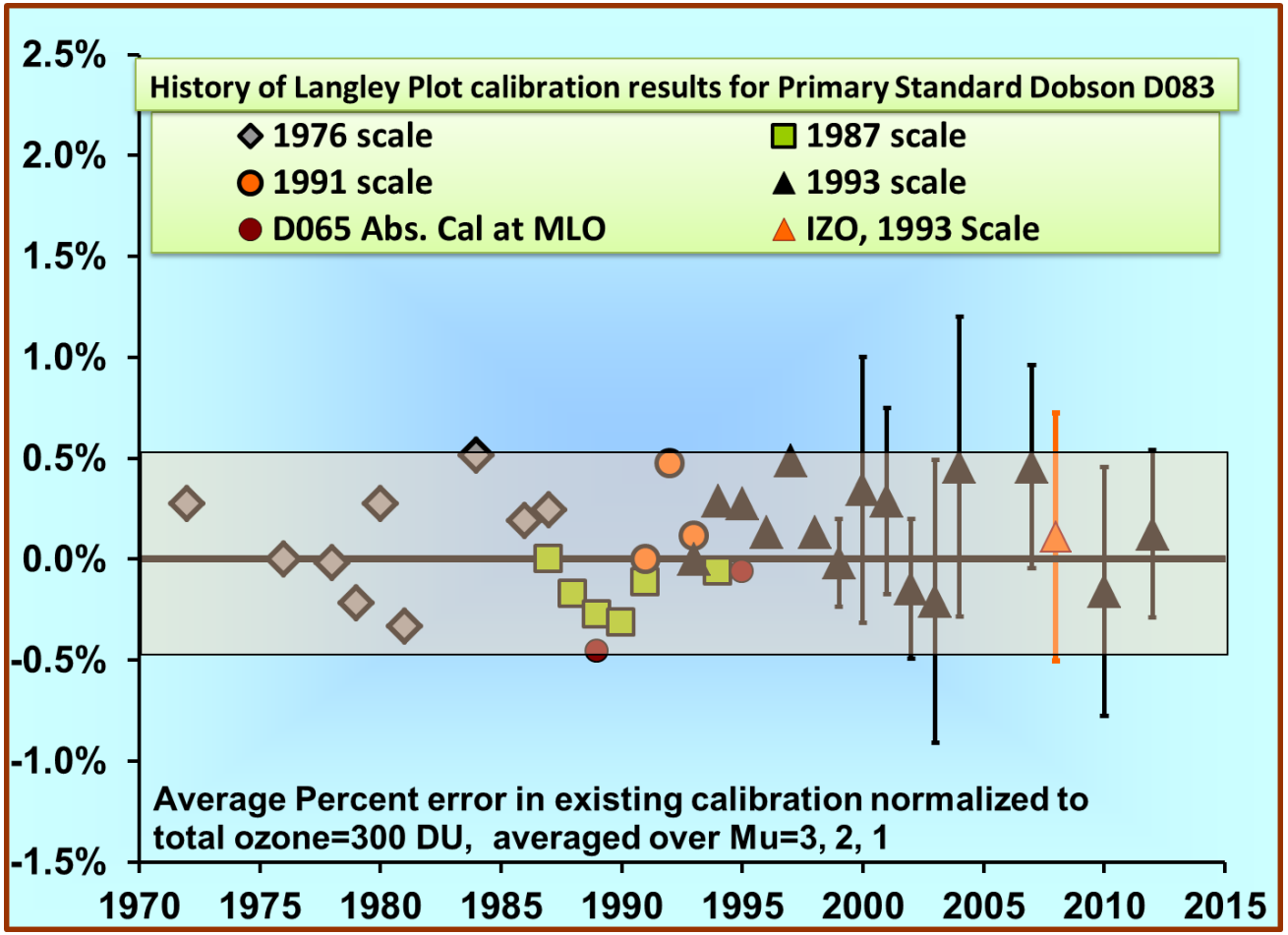
(courtesy of Isamu Morino and Osamu Uchino, NIES)

Quality Assurance for Ozone measurements

	Central Calibration Laboratory	World Calibration Center
Total Ozone	- NOAA ESRL (Dobson instrument) - Environment Canada (Brewer instrument)	- NOAA ESRL (Dobson instrument) - Environment Canada (Brewer instrument)
Ozone Sondes	Institute of Energy and Climate Research: Troposphere (IEK-8), Juelich	Institute of Energy and Climate Research: Troposphere (IEK-8), Juelich

- CCLs are keeping the primary instruments that are calibrated at Mauna Loa using Langley plot method
- Secondary standards calibrated by CCLs are used for regional comparisons to ensure traceability to the primary instrument

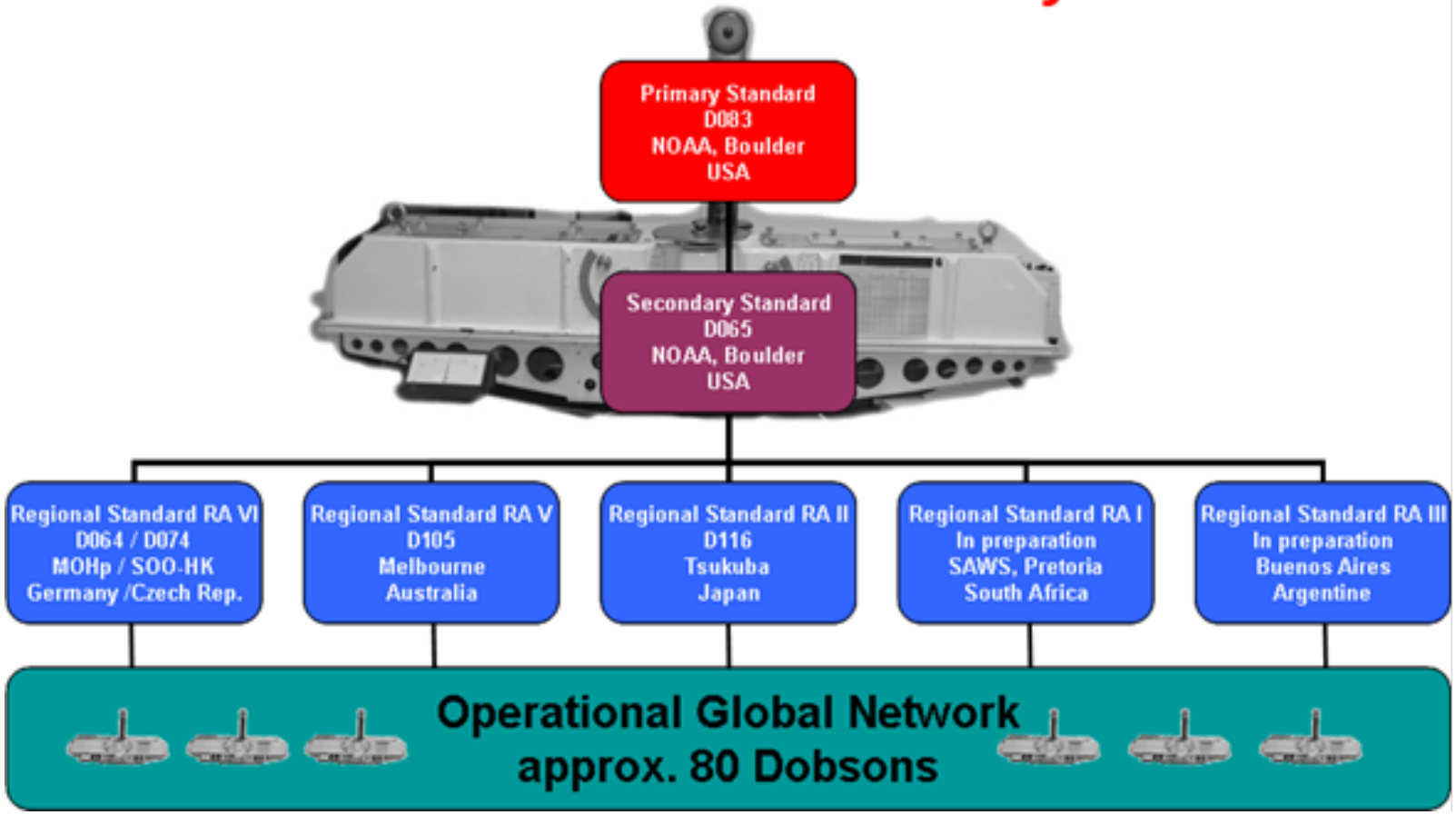
Stability of the Dobson primary instruments



Ozone sondes traceability

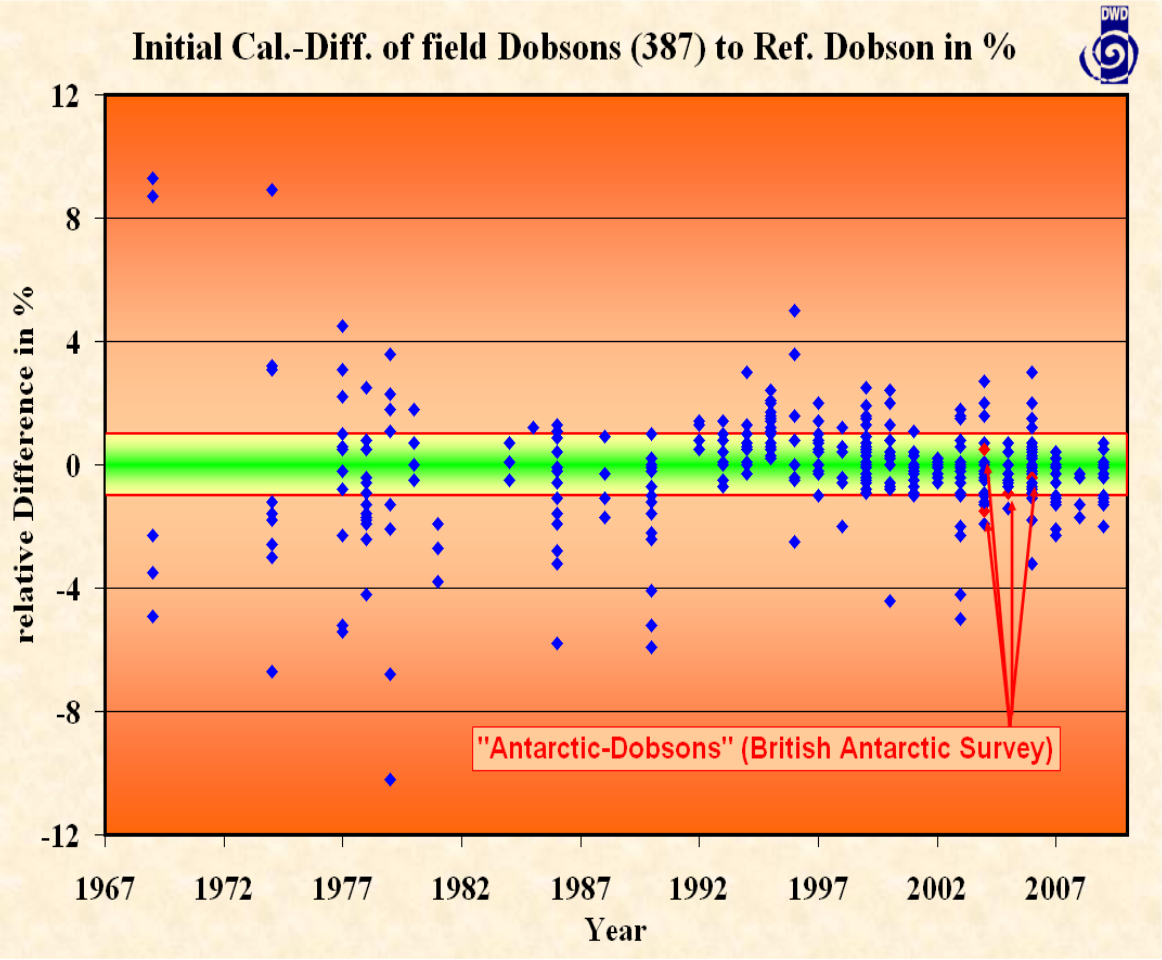
- Ozone sondes are operated according to ASOPOS (Assessment of Standard Operating Procedures for Ozone Sondes) report: Quality Assurance and Quality Control for Ozone Sonde Measurements in GAW (GAW Report Nr.201)
- Performance (precision, bias, and accuracy/uncertainty) of O_3-sondes are related to UV-photometer at WCCOS, Jülich, Germany. At surface conditions this instrument is related to the secondary standard UV-photometer instrument. For tropospheric conditions the agreement is better than ± 1 ppb
- However, for lower pressures (i.e. higher altitudes) there is no primary standard available

Global Dobson Calibration System



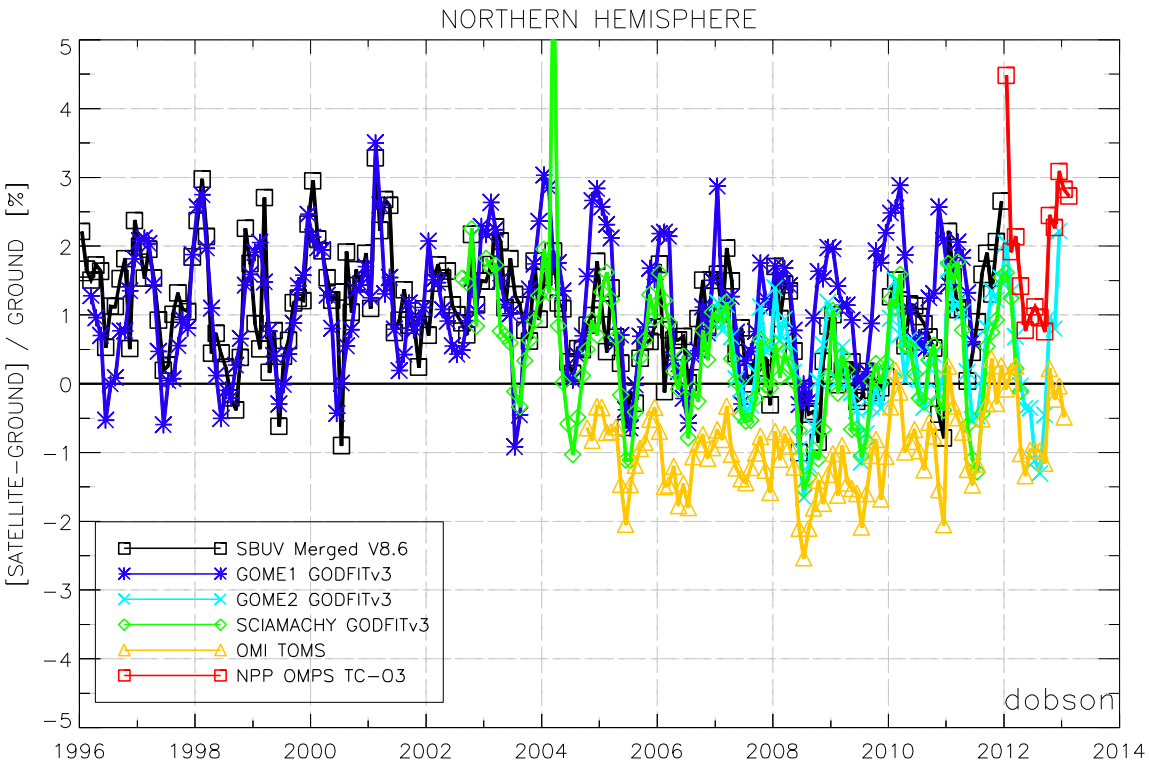
Courtesy: J. Staehelin

Dobson network consistency



Courtesy: J. Staehelin

Northern Hemisphere time series



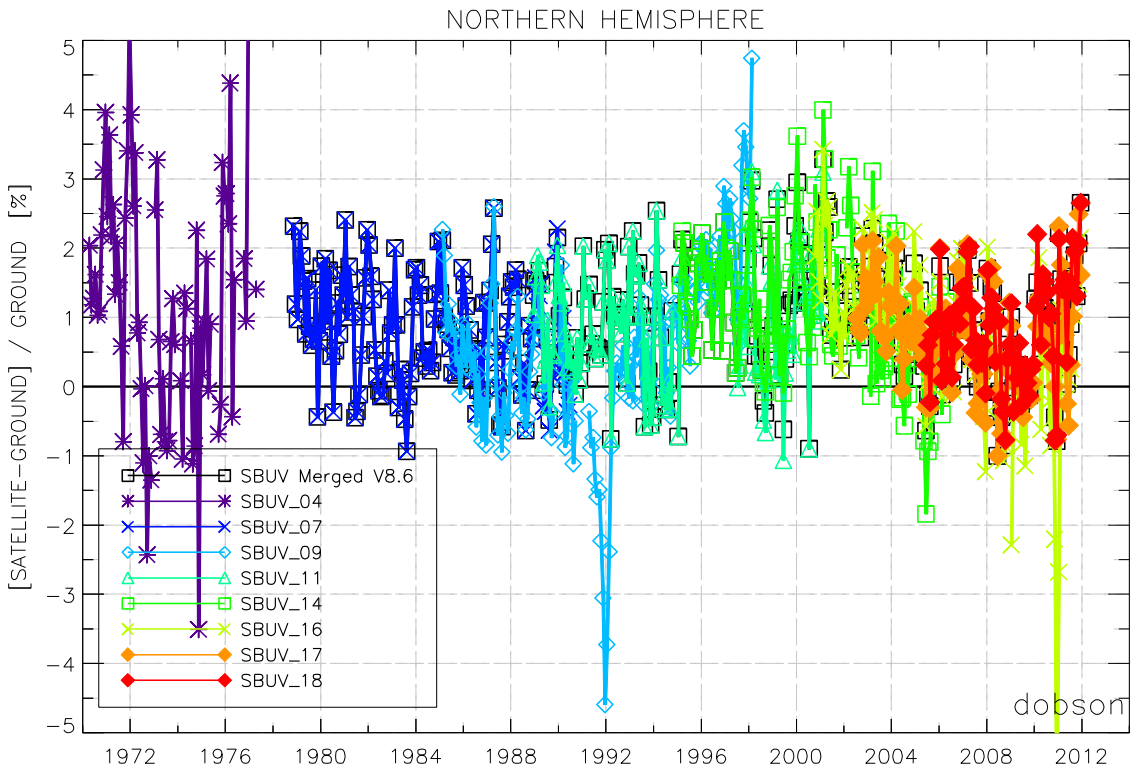
INSTRUMENT	MEAN ± SDEV %
SBUV	1.00±0.82%
GOME1	1.15±0.88%
GOME2	0.32±0.81%
SCIAMACHY	0.41±1.00%
OMI	-0.96±0.60%
OMPS	1.99±1.08%

Created on Mon Apr 08 08:58:51 2013

Aristotle University of Thessaloniki

Courtesy: MariLiza Koukouli

Northern Hemisphere time series



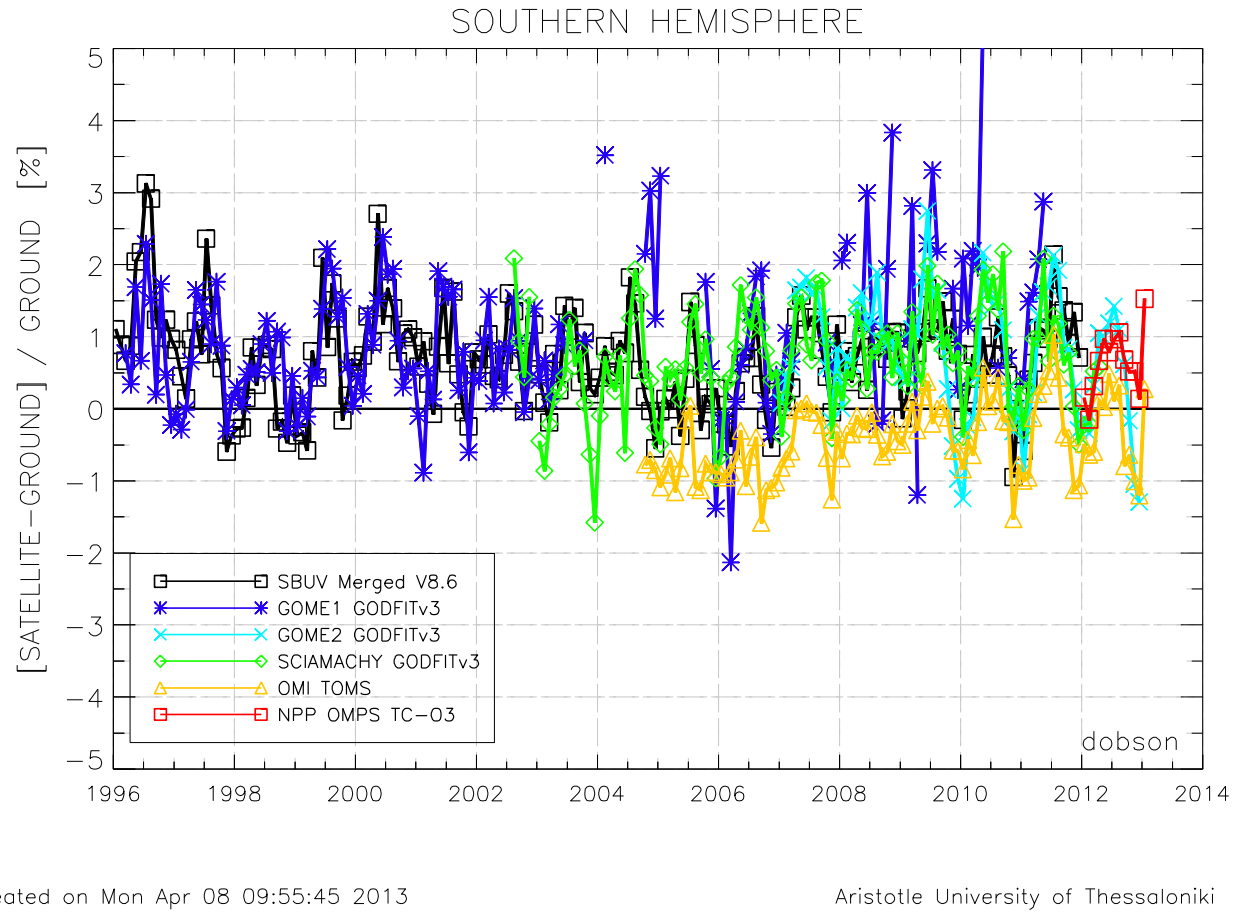
INSTRUMENT	MEAN ± SDEV %
SBUV	1.06±1.03%
SBUV_04	2.17±1.47%
SBUV_07	1.32±1.15%
SBUV_09	0.61±0.78%
SBUV_11	0.97±0.98%
SBUV_14	0.98±0.99%
SBUV_16	0.71±0.85%
SBUV_17	0.51±0.71%
SBUV_18	0.88±0.93%

Created on Fri Apr 05 14:39:16 2013

Aristotle University of Thessaloniki

Courtesy: MariLiza Koukouli

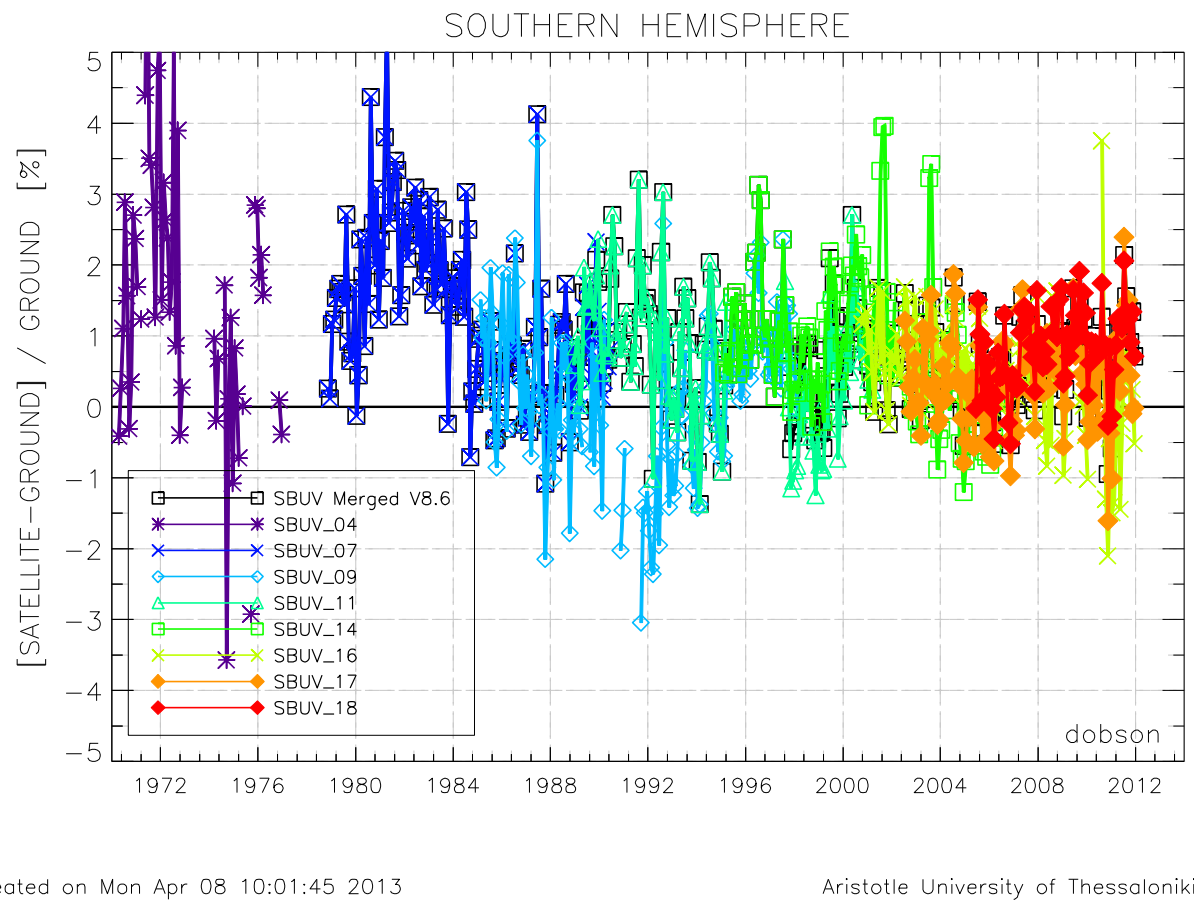
Southern Hemisphere time series



INSTRUMENT	MEAN ± SDEV %
SBUV	0.70± 0.67%
GOME1	0.97±1.04%
GOME2	0.75±0.87%
SCIAMACHY	0.65±0.72%
OMI	-0.43±0.51%
OMPS	0.63±0.45%

Courtesy: MariLiza Koukouli

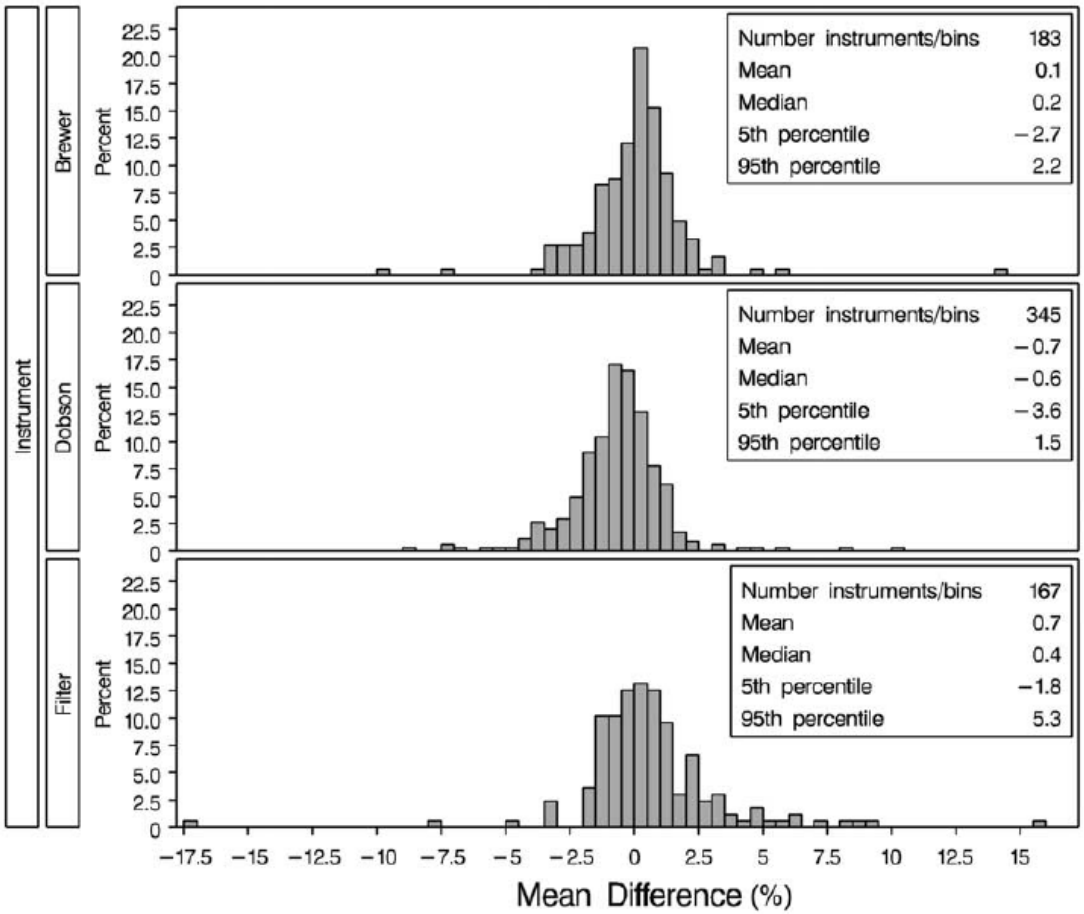
Southern Hemisphere time series



INSTRUMENT	MEAN ± SDEV %
SBUV	0.92±0.96%
SBUV_04	1.19±1.09%
SBUV_07	0.79±0.89%
SBUV_09	0.55±0.74%
SBUV_11	0.93±0.96%
SBUV_14	1.18±1.08%
SBUV_16	0.76±0.87%
SBUV_17	0.70±0.83%
SBUV_18	0.83±0.91%

Courtesy: MariLiza Koukouli

Consistency of the ground based networks for total ozone

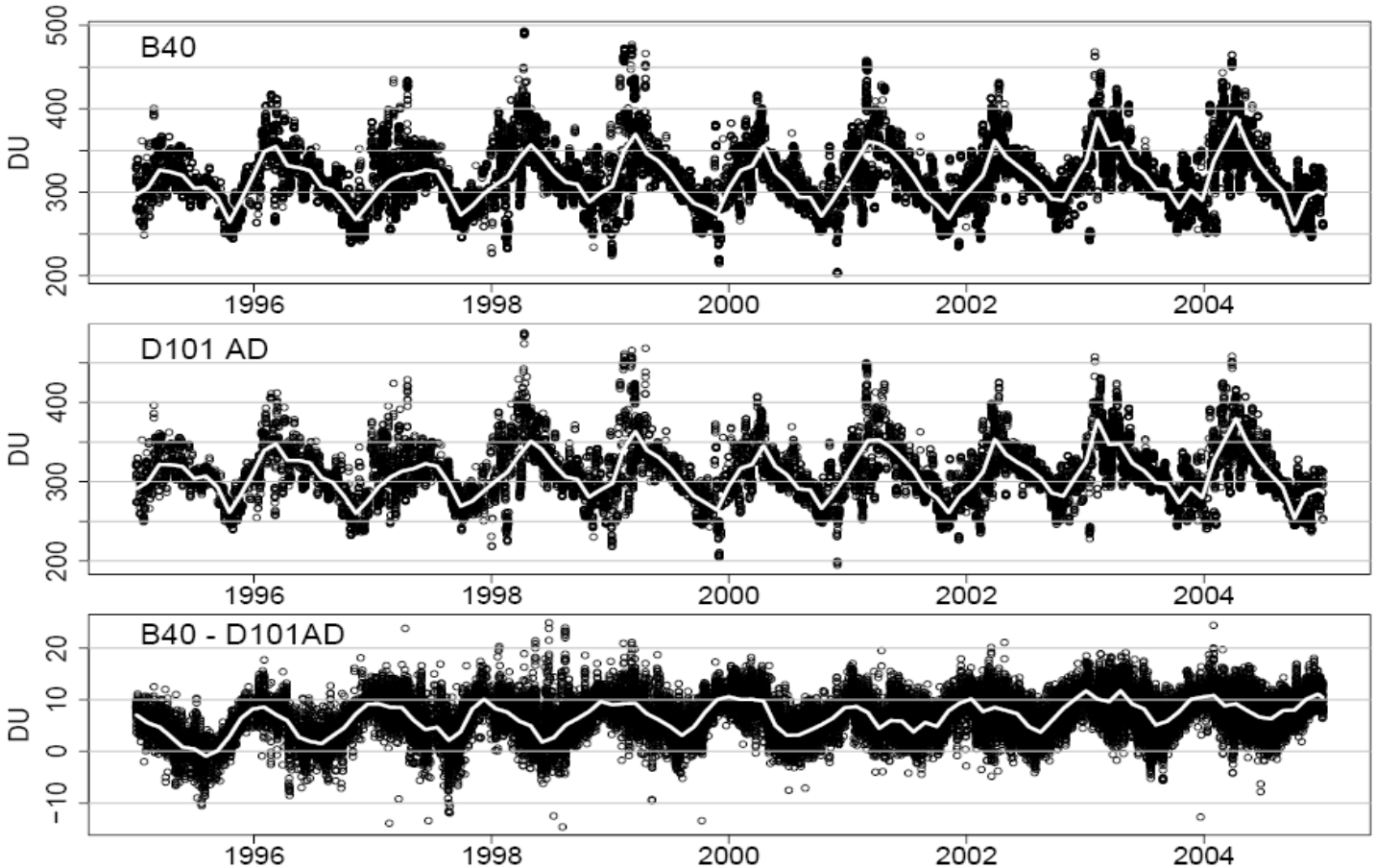


Histogram of distribution for the mean difference between ground-based DS observations and matched satellite overpasses for Dobson, Brewer, and filter instrument sites.

From Violetov V., JGR, 2008

Difference Brewer/Dobson Arosa in Huggins band: $\alpha(O_3)\ f(\lambda, t)$

(Scarnato et al., 2009)



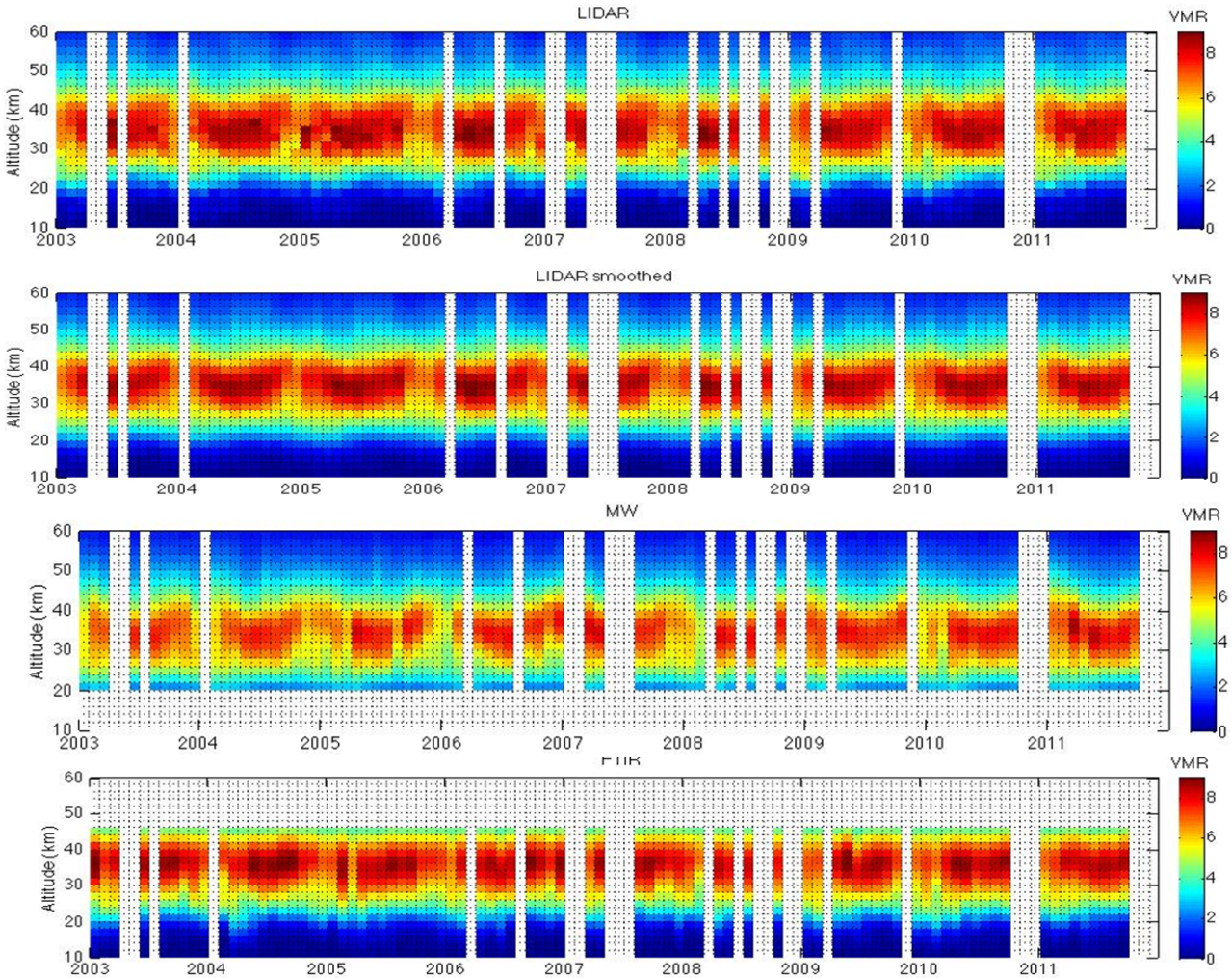
O_3 monthly mean times series of LIDAR, MW and FTIR profiles (Coincident date)

LIDAR

LIDAR smoot

MW

FTIR



Quality Assurance system for aerosol measurements

parameter	Central Calibration Laboratory	World Calibration Center
aerosol physical properties	missing	Institute for Tropospheric Research, Leipzig, Germany
aerosol chemical composition	missing	missing
aerosol optical depth (AOD)	Physikalisch-Meteorologisches Observatorium Davos/ World Radiation Centre, Davos, Switzerland	Physikalisch-Meteorologisches Observatorium Davos/ World Radiation Centre, Davos, Switzerland

AOD standards is Precision Filter Radiometers (PFR)

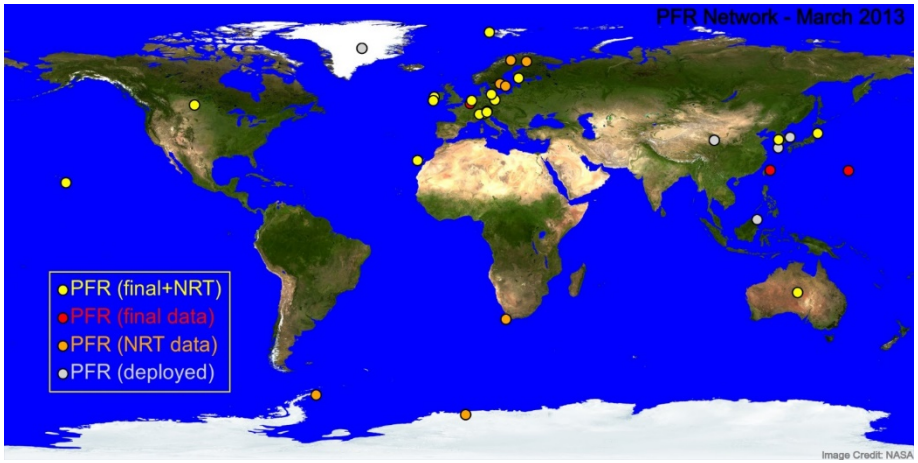
World Calibration Centre for Physical Aerosol Properties

To ensure network compatibility, WCCAP:

- Performs site audits of WMO-GAW and EMEP stations
- Organizes calibration and intercomparison workshops for physical aerosol instrumentation at the WCCPAP facilities for the following parameters:
    - light scattering coefficient
    - light absorption coefficient
    - particle number concentration
    - particle number size distribution
- Advices in the implementation of new sampling sites, inlet configuration, aerosol instrumentation
- Cooperates with a scientific community on evaluation of aerosol measurements

GAW-PFR Aerosol Optical Depth Network

- Precision Filter Radiometer
  - Manufactured and coordinated by World Optical Depth Research and Calibration Center
  - Operated by GAW stations and national networks
  - Many stations submit both NRT and final data
  - Some stations not yet submitting any data

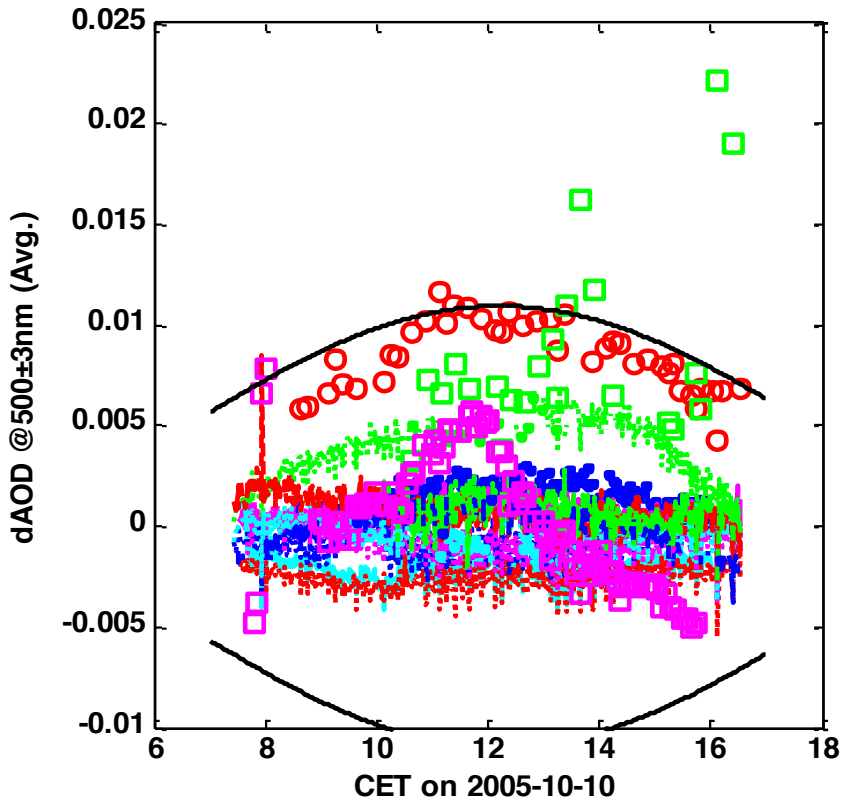


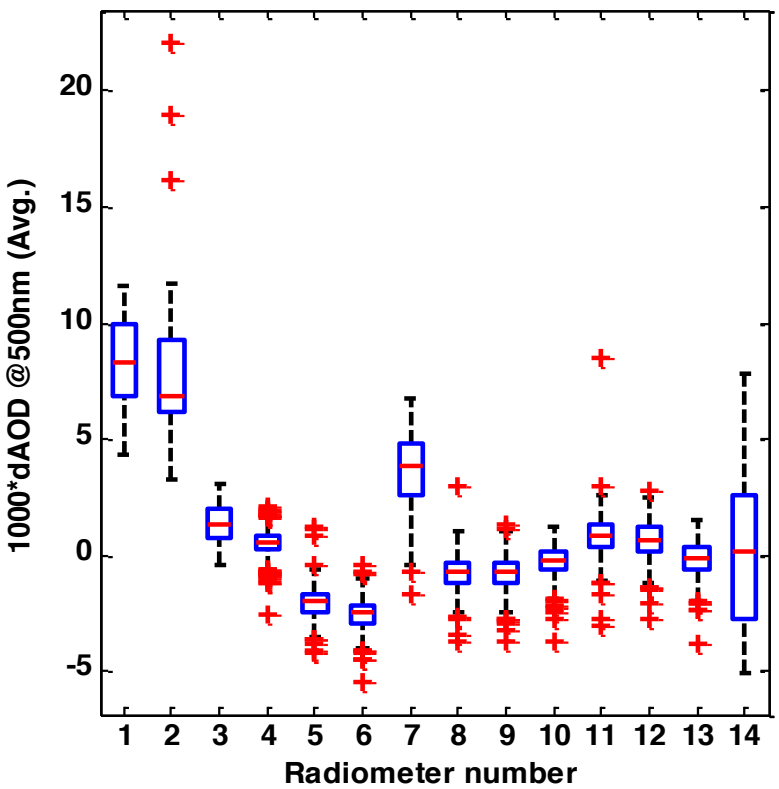
Can be used as a reference network for global AOD measurements

Traceability of AOD network

- FRC-II intercomparison in Davos (2005), 14 instruments
- AERONET – GAW comparison at 3 co-location (2006)
- PolarAOD campaign @Ny Ålesund (2006)
- EUSAAR intercomparison, 6 instruments, September 2007
- EUSAAR site audits at 3 stations in 2008
- PolarAOD @Izaña, October 2008
- EUSAAR site audits at 2 stations in 2009
- FRC-III intercomparison in Davos in 2010
- PolarAOD comparison in Davos in 2012

FRC-II AOD Intercomparison 2005

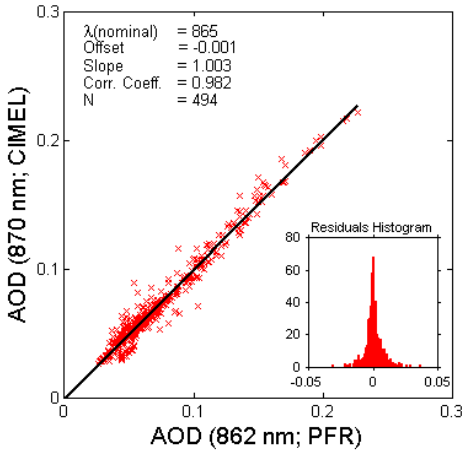


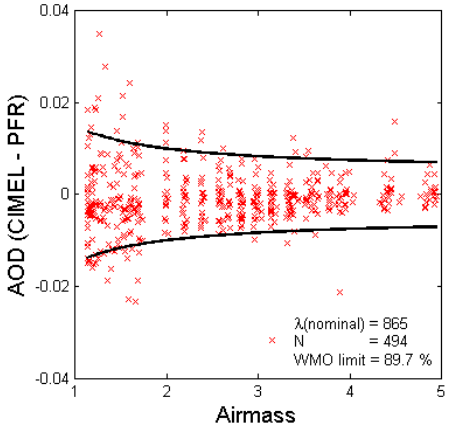


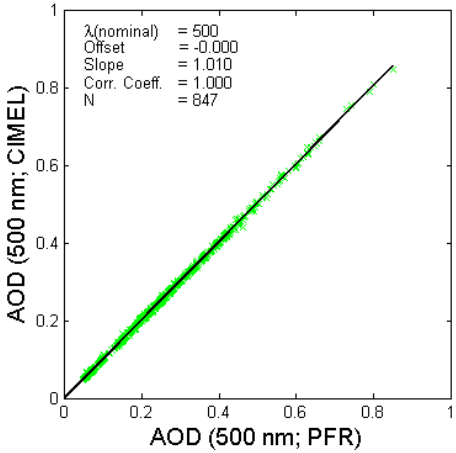
(Courtesy: Christoph Wehrli)

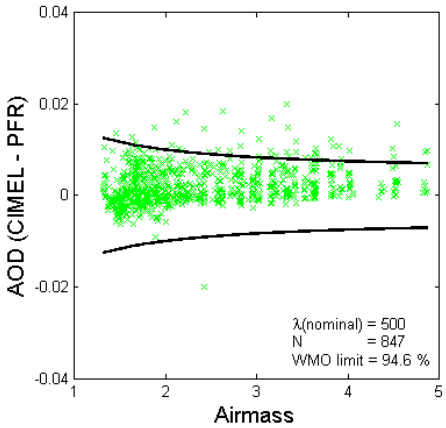
EUSAAR Audits 2008 (PFR vs. Aeronet)

Cabauw







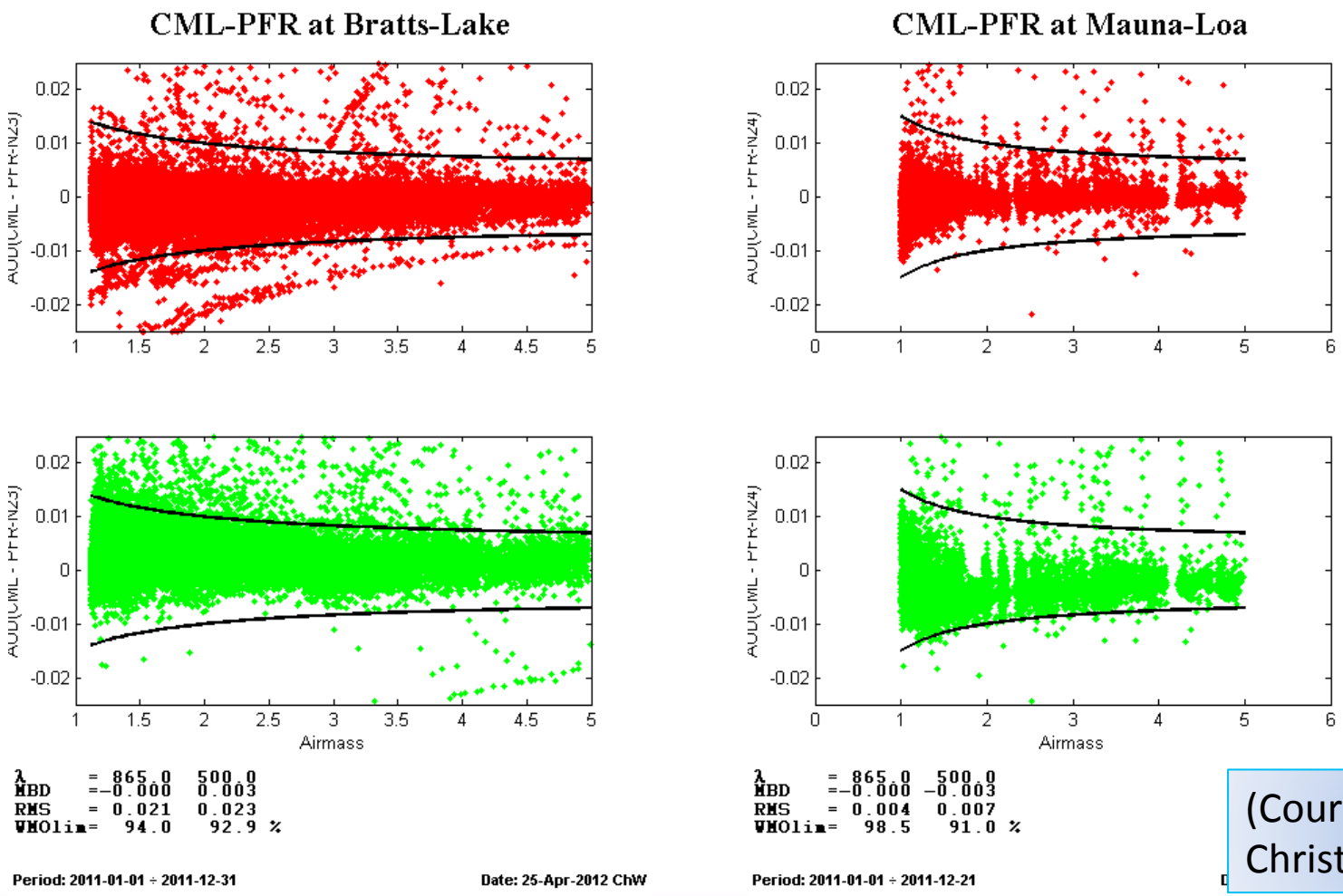


Ispra

(Courtesy: Christoph Wehrli)

Difference depends on the wavelength

Annual Comparison Aeronet - GAWPFR



Difference depends on location

(Courtesy: Christoph Wehrli)

Lessons learned

- «Ground truth» for satellite data validation can be different depending on the kind of the ground based network is selected
- Harmonization of the ground based network is essential to avoid biases between individual stations
- The representatives of the observations should be taken into account (GAW network due to gaps can introduce spatial biases in the data)
- GAW traceability concept (to the network standard rather than absolute traceability) should be taken in consideration when using GAW data for satellite validation