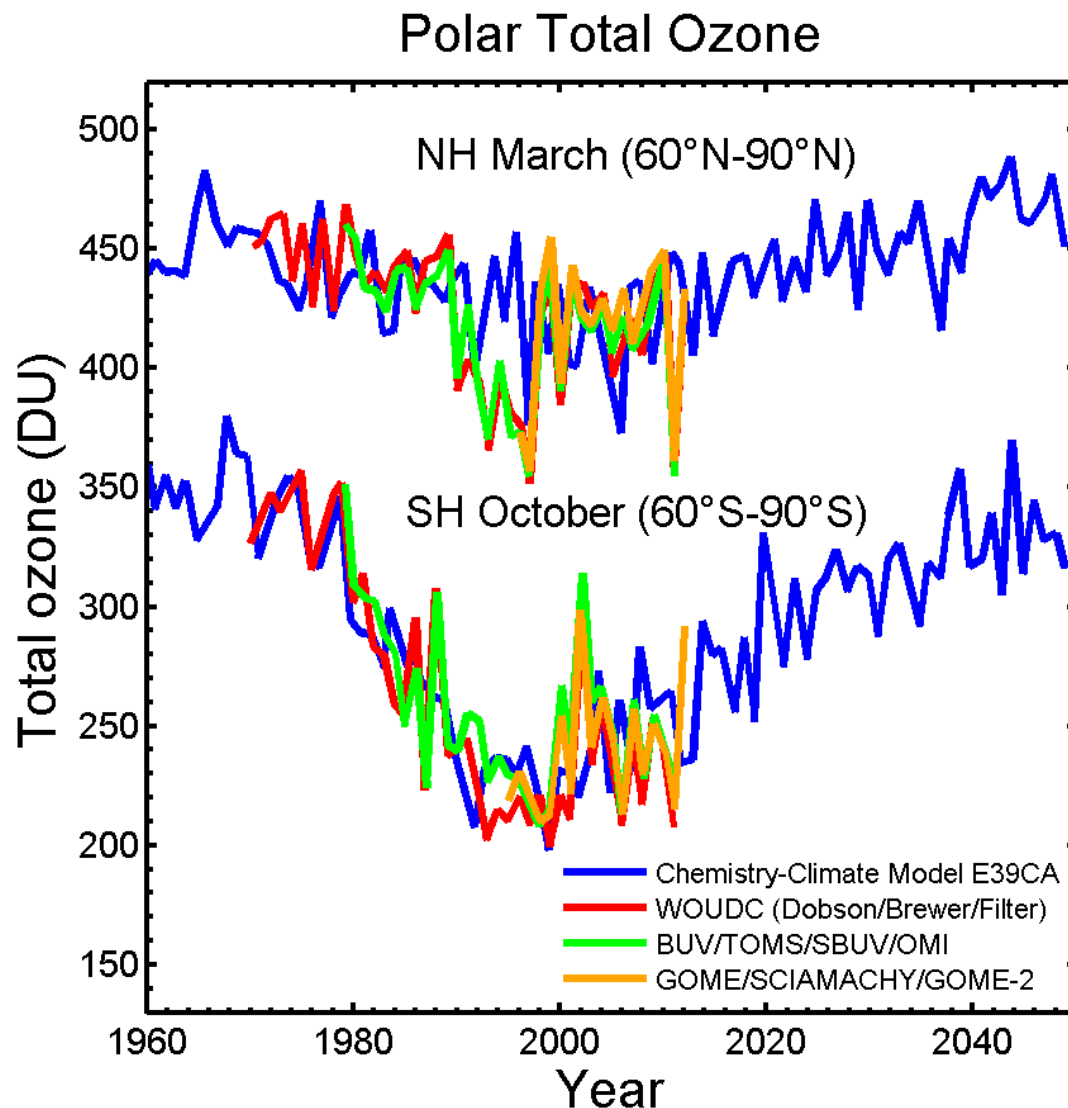
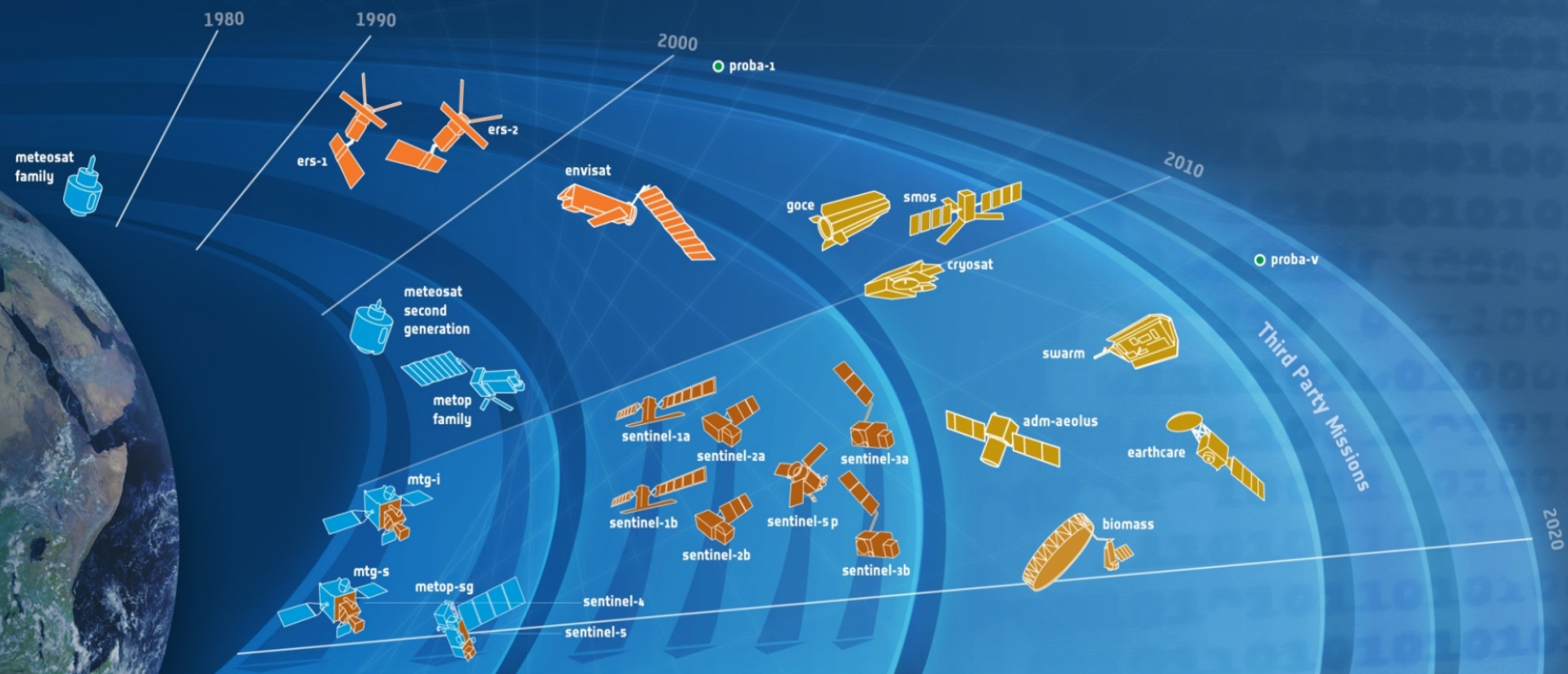


EUROPEAN SPACE AGENCY ACTIVITIES

Claus Zehner
ESA/ESRIN



European Earth Observation Satellites



Meteorological Missions

driven mainly by Weather forecasting and Climate monitoring needs. These missions developed in partnership with EUMETSAT include the Meteorological Operational satellite programme (MetOp), forming the space segment of EUMETSAT's Polar System (EPS), and the new generation of Geostationary Meteosat satellites (MSG & MTG satellites).

Copernicus Sentinel Missions

driven by Users needs to contribute to the European **Global Monitoring of Environment & Security** (GMES) initiative. These satellite missions developed in partnership with the EU include C-band imaging radar (Sentinel-1), high-resolution optical (Sentinel-2), optical and infrared radiometer (Sentinel-3) and atmospheric composition monitoring capability (Sentinel-4 & Sentinel-5 on board Met missions MTG and EPS-SG respectively).

Earth Explorer Missions

driven by Scientific needs to advance our understanding of how the ocean, atmosphere, hydrosphere, cryosphere and Earth's interior operate and interact as part of an interconnected system. These **Research** missions, exploiting Europe's excellence in technological innovation, pave the way towards new development of future EO applications.

Missions With Partners

ESA Operated Missions

Copernicus Missions & Ozone



Copernicus: an Earth Observation Programme for Global Monitoring for the Environment and Security.

Led by the **European Commission** in partnership with **ESA** and the **European Environment Agency**.

ESA is responsible for implementing the space component, including developing the Sentinel satellite series.

Sentinel 1A: launched on April 3 2014.

Sentinel-5 Precursor (2016), Sentinel- 4 (2018), and Sentinel-5 (2020) missions target atmospheric composition products, which include **Ozone** column measurements.



PAST: ERS-2 - GOME, Envisat - GOMOS, MIPAS
SCIAMACHY

CURRENT: Metop A/B - GOME2/IASI, Odin – OSIRIS,
SMR, SciSat – ACE, MAESTRO

FUTURE: Atmospheric Sentinels, Metop C, MTG-IRS,
Metop-NG

Continuous nadir viewing Ozone measurements on
polar and geostationary satellites are guaranteed for
the next ~20 years.

**Limb/Occultation Ozone measurements are missing
right now and are currently not planned in Europe!**

ERS/Envisat Phase F Activities:

- **Improve Level 1 data (e.g. GOME, SCIAMACHY)**
- **Improve Level 2 data (e.g. GOMOS)**

EO Long Term Data Preservation Programme:

- **EO data are a 'corporate asset' (including raw data)**
- **Data Transcription from tapes**
- **Enable Fast Reprocessing**

ESA Climate Change Initiative (CCI)

Objectives of the CCI



Realise the full potential of the long-term global EO archives that ESA, together with its Member states, has established over the last thirty years ...

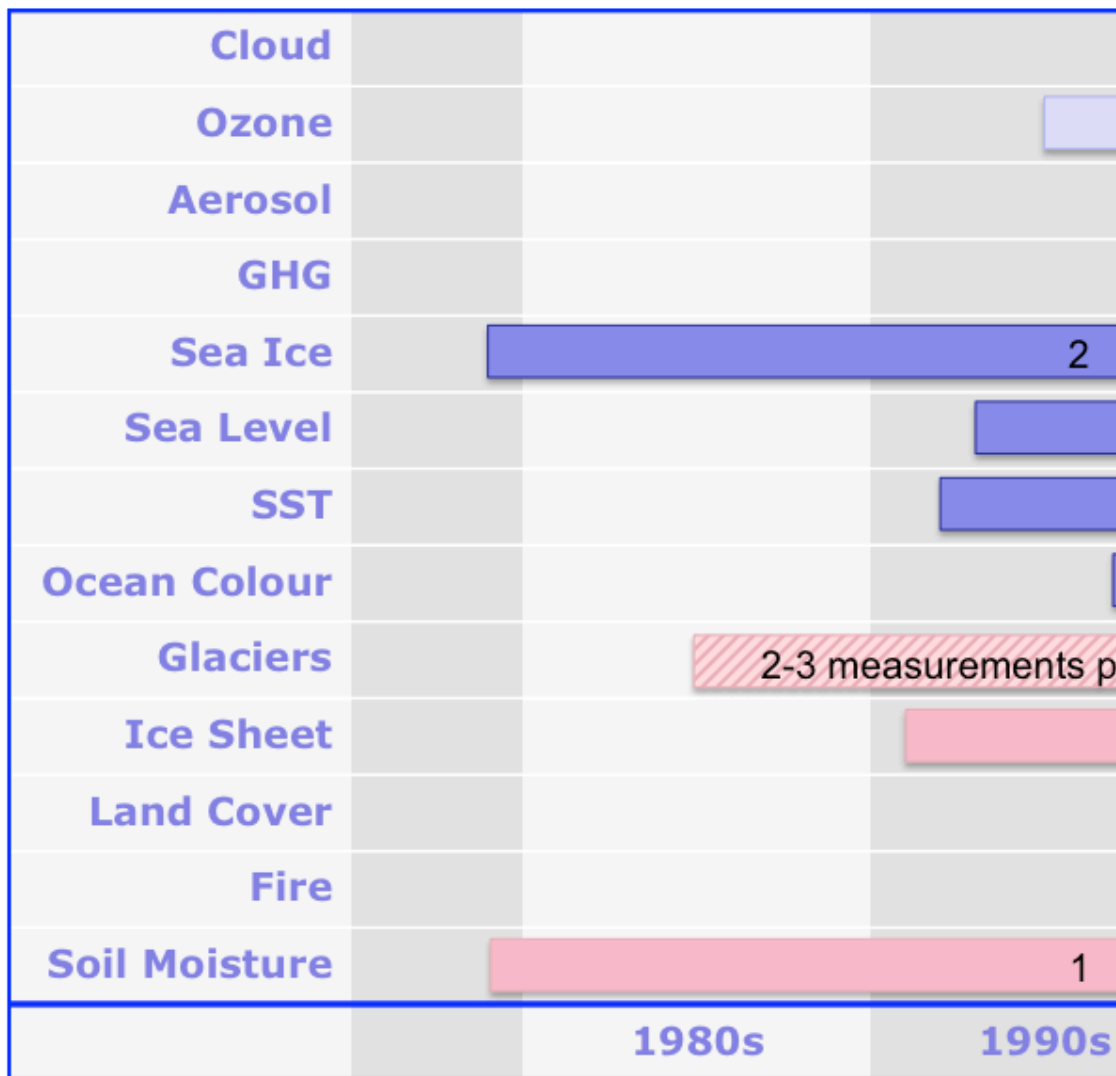
... as a significant and timely contribution to the [Essential Climate Variables \(ECV\)](#) databases required by the United Nations Framework Convention on Climate Change.

START: 2010 with a 6 years duration, budget of 88 Meuro, 2 project phases each of 3 years

[13 ECV Projects](#), 1 Project on ECV [Assessment by Climate Modellers](#) (CMUG)

6 Years   88 Meuro

CCI Products Time Coverage



Objectives of the CCI



Starting from GCOS Requirements for satellite ECVs



Key European Experts involved (including climate modellers)



Algorithm Selection (Round Robin exercise)



Validation/Error characterisation



Long Term Data Generation (easy access)



ECV Evaluation by Climate Modellers



**Ozone: <http://www.esa-ozone-cci.org> - logos:
institutions involved in O3_cci - lead by BIRA/IASB**

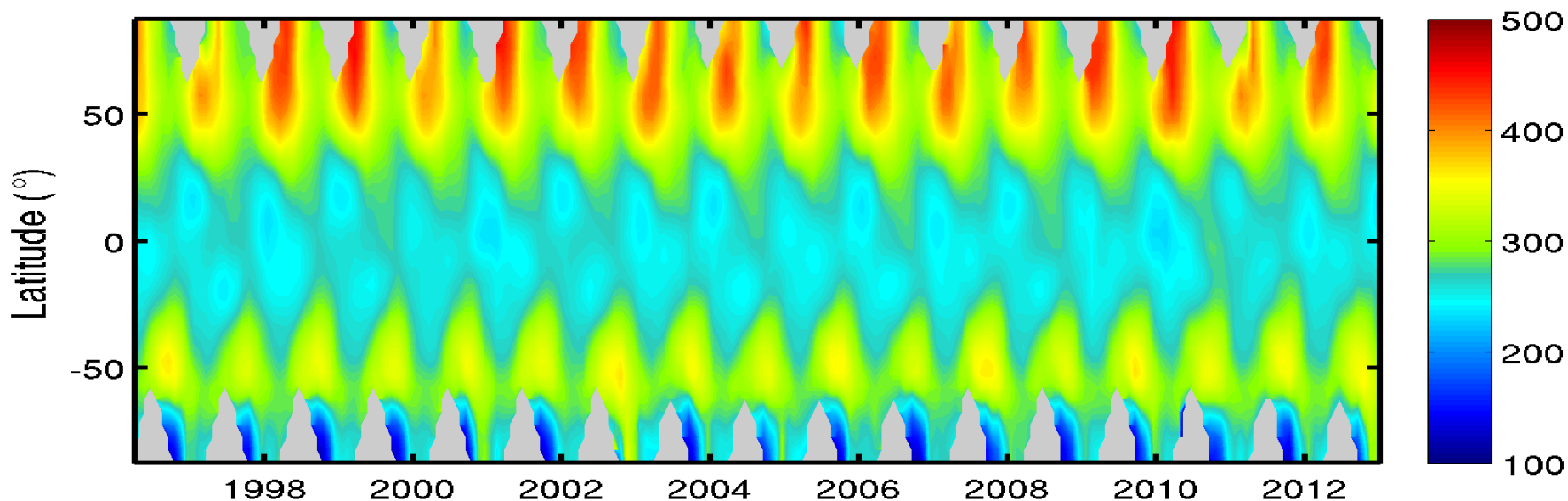


Total Ozone

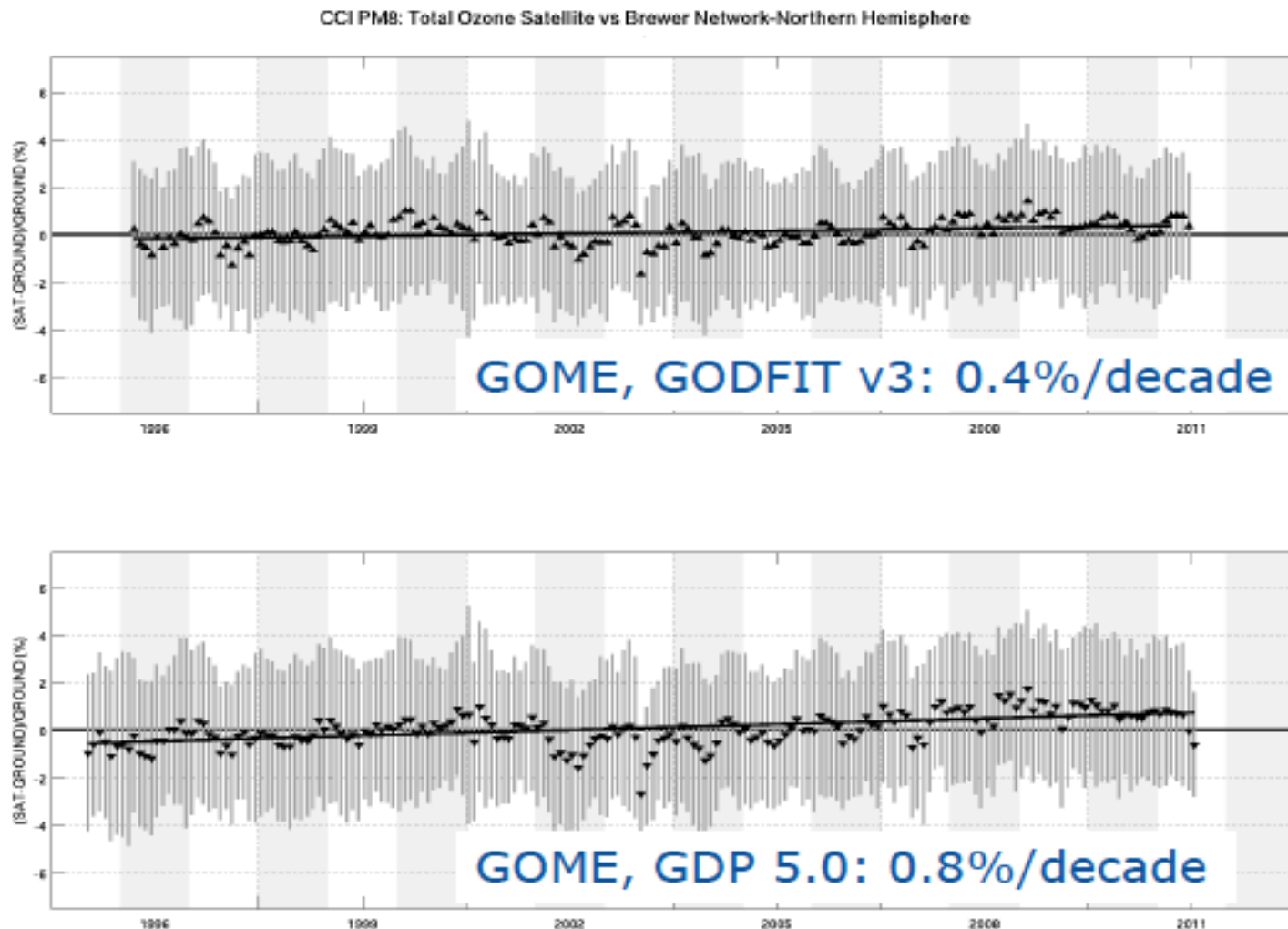


Total ozone

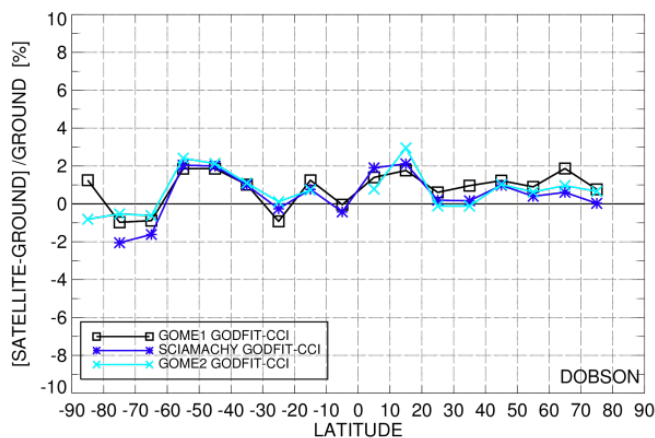
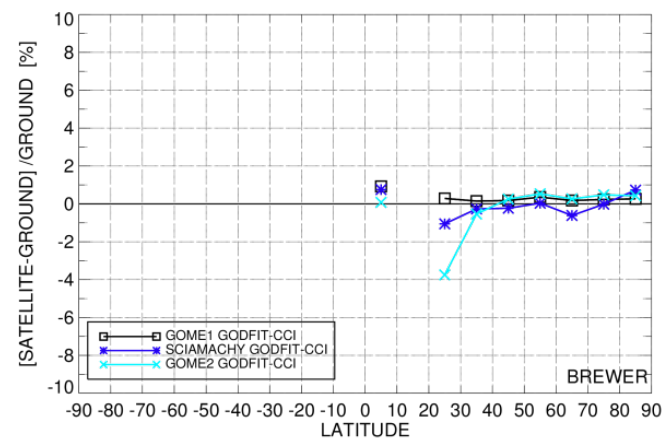
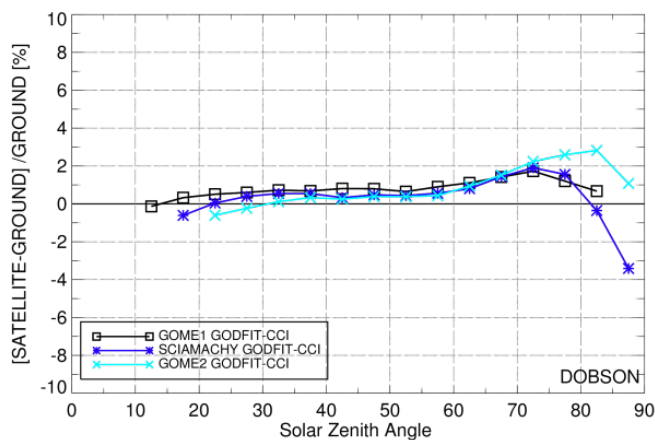
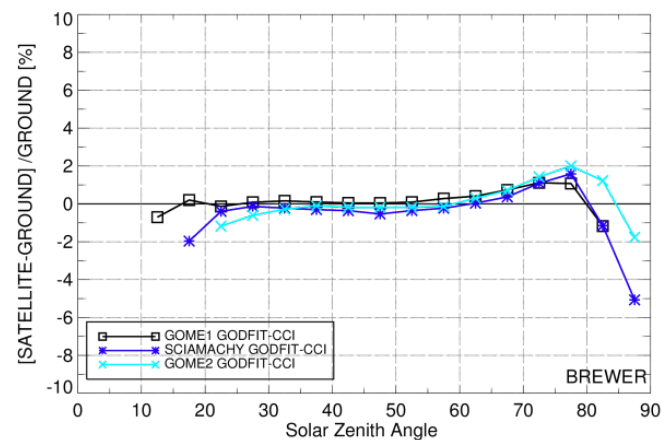
Level-2	Full reprocessing using GODFIT multi-sensor prototype algorithm	GOME (1996-2011) SCIAMACHY (2002-2012) GOME-2 (2007-2012)
Level-3	Monthly-averaged data set, residual inter-sensor bias corrected using GOME as a reference	GOME, SCIAMACHY, GOME-2 (1996-2011)



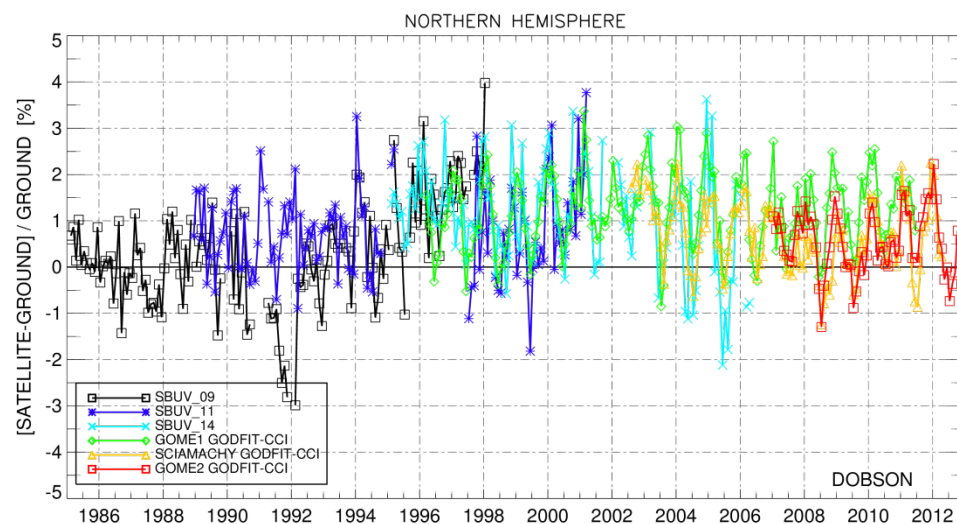
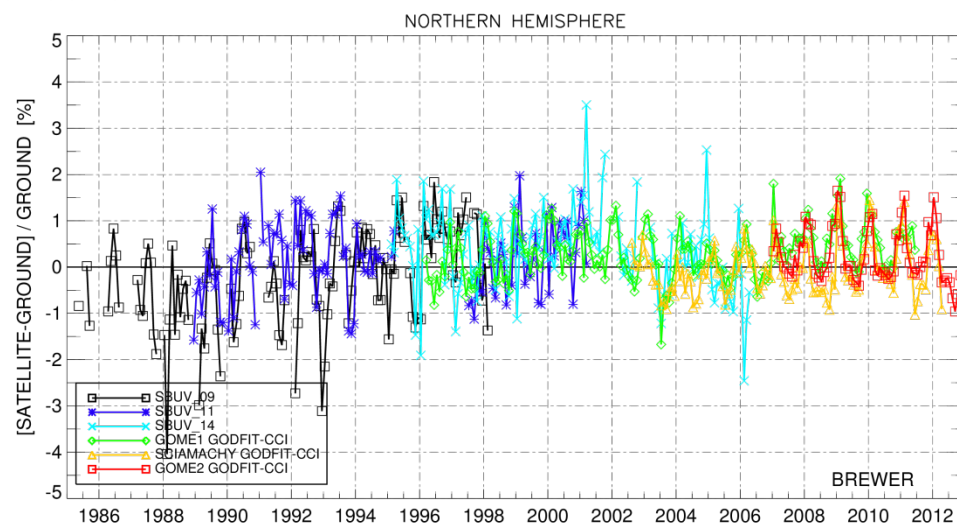
GODFITV3/GDP5 – stability wrt. GB network



Validation: Latitudinal [upper] and SZA [lower] dependencies

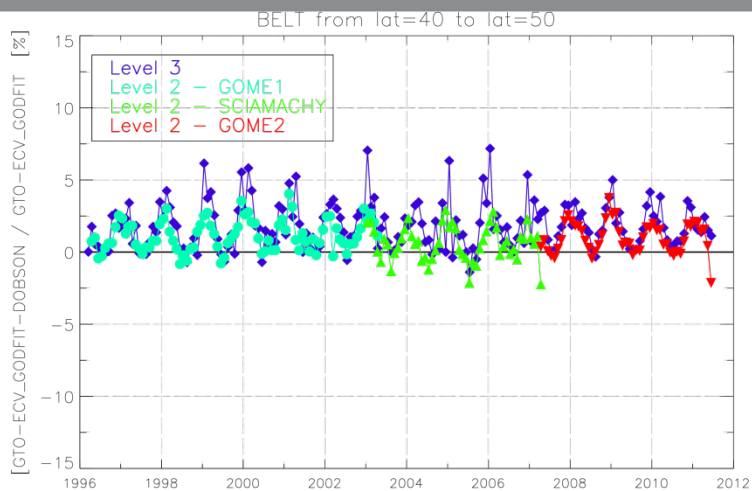


Comparison with the SBUV v8.5 long term TOC dataset



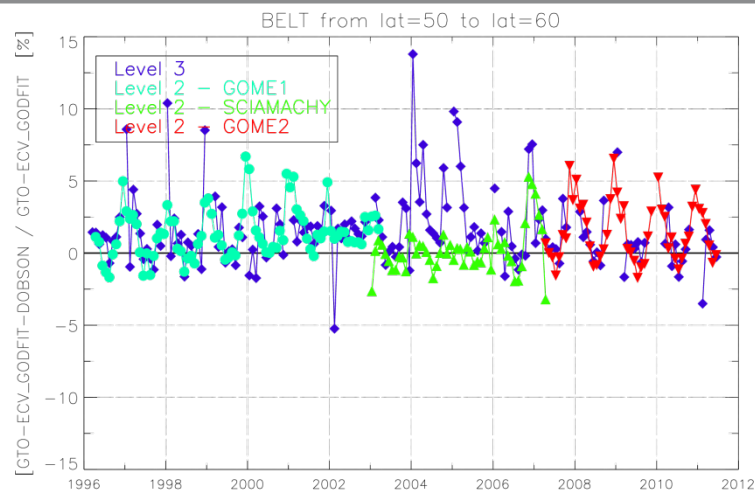
European Space Agency

NH Belt Statistics



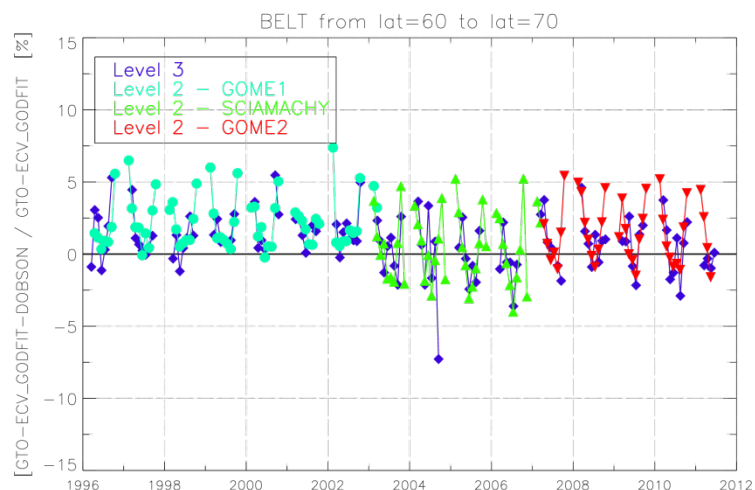
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Aristotle University of Thessaloniki



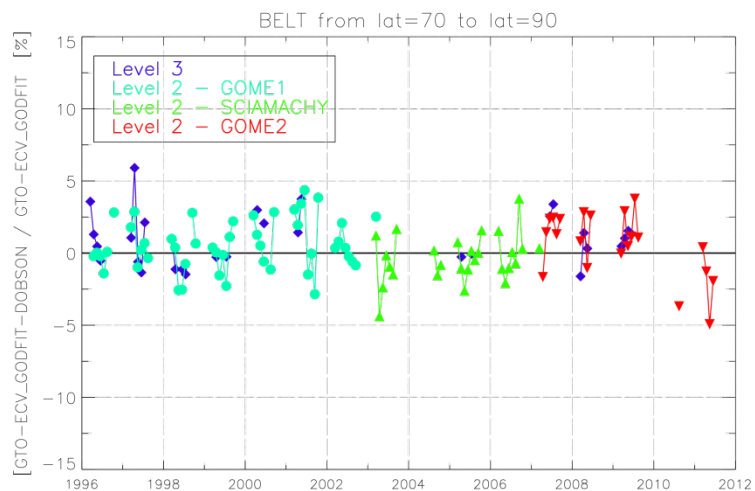
Created on Tue Oct 29 12:18:46 2013

Aristotle University of Thessaloniki



Created on Tue Oct 29 12:18:51 2013

Aristotle University of Thessaloniki



Created on Tue Oct 29 12:18:53 2013

Aristotle University of Thessaloniki

European Space Agency

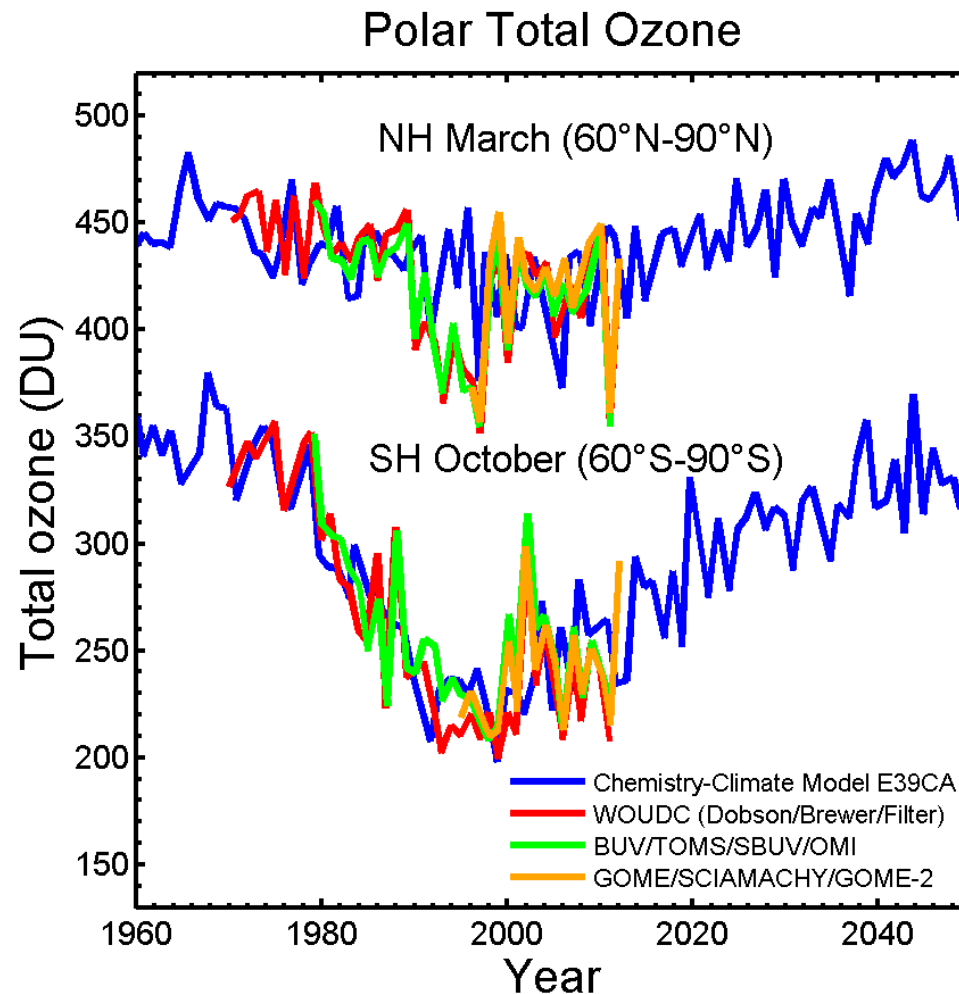
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Validation Results



	GOME GODFIT v3	SCIA GODFIT v3	GOME-2A GODFIT v3	TC_L3_MRG
NH drift [/decade]	B: 0.4% D: 0.2%	B: 0.3% D: -0.8%	B: -0.8% D: 0.4%	B: 0.0% (ML) D: 0.0% (ML)
Mean bias	+0.1%	-0.2%	-1%	B: 0 %
Seasonality	<1.5%	<1%	<1%	<1.5% (D)
Scatter	±2/2.5%	±2/2.5%	±2/2.5%	±3-4%
Latitude	Reflects rather station-to-station inhomogeneities			
SZA	-1% SZA>80°	-1% SZA>80°	-1% SZA>84°	NA
Clouds	-1% if cloudy	-1% if cloudy	-1% if cloudy	NA
Teff	Flat	Flat	Flat	NA

“free running” atmospheric models (CCMs)



European Space Agency

ECV Assessment/Evaluation



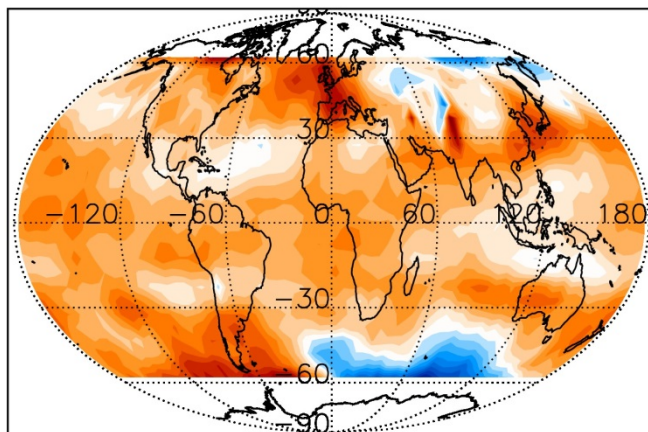
Comparison with other data sets and CCMs

O3-CCI period:

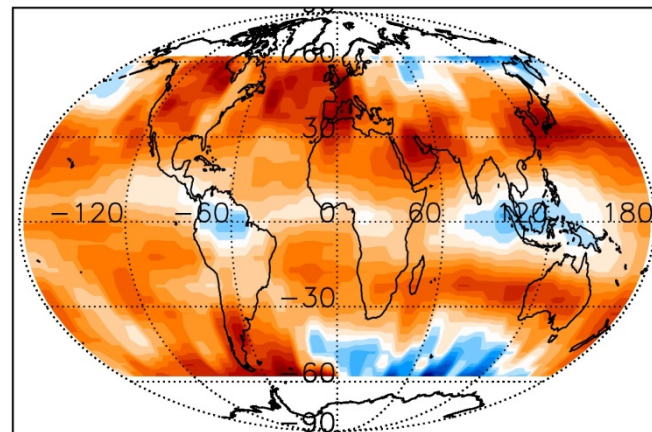
03/1996 - 06/2011

(Coldewey-Egbers,
Loyola, et al.)

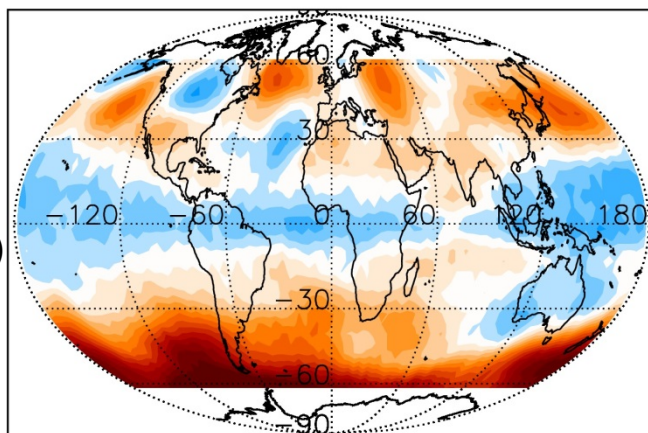
GTO-ECV



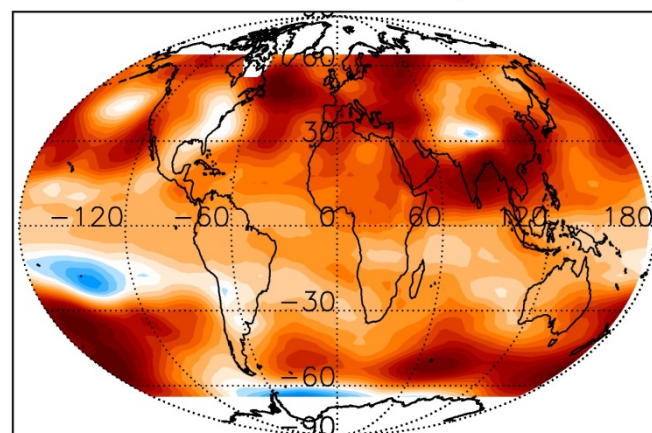
NASA-MOD



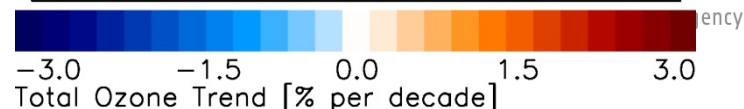
E39C-A



UMUKCA-UCAM

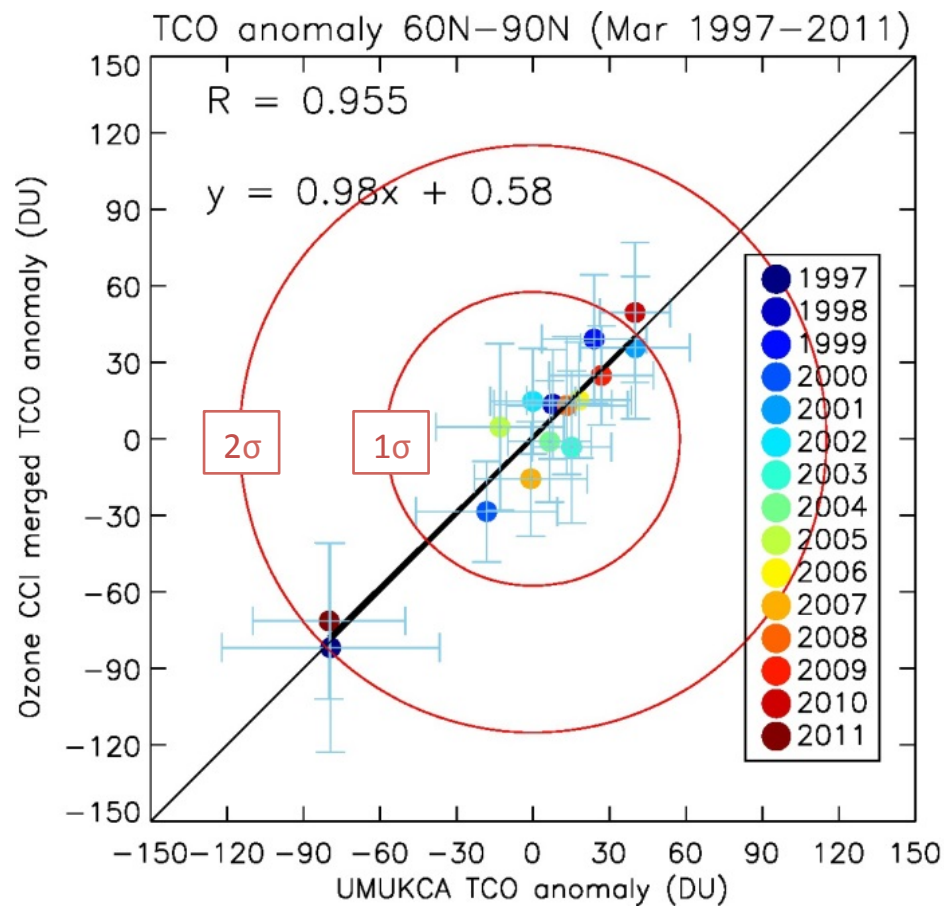


Free running CCMs
(Braesicke, Dameris)

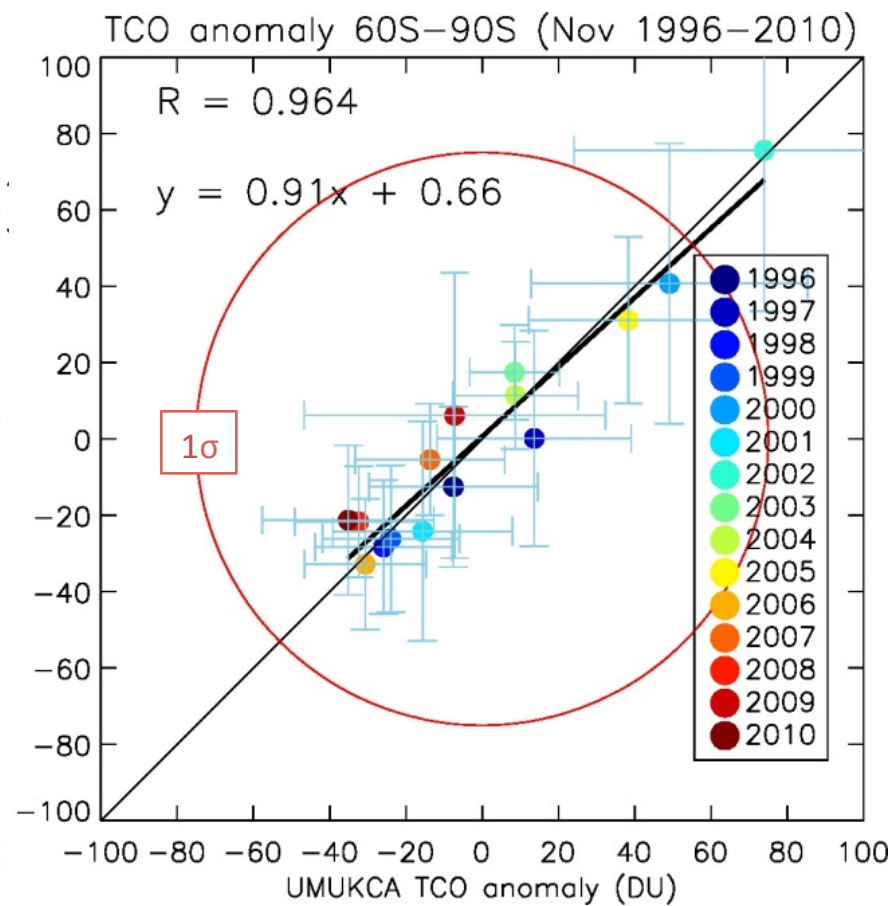


Ozone Anomalies Scatter Plots

MARCH



November



The **biases** (model/observations) do not necessarily kill:

- Spring ozone anomalies for cold years in the NH can be modelled.
- Spring ozone anomalies for the SH vortex split in 2002 are captured.

Interannual ozone variability:

- The chemistry is doing well, when the meteorological biases are small (nudging with ERA-Interim).
- Variability in the free running model is realistic with a small overestimate in the SH (underlying dynamical model).

New data provides excellent benchmark for model performance (including standard deviations)!

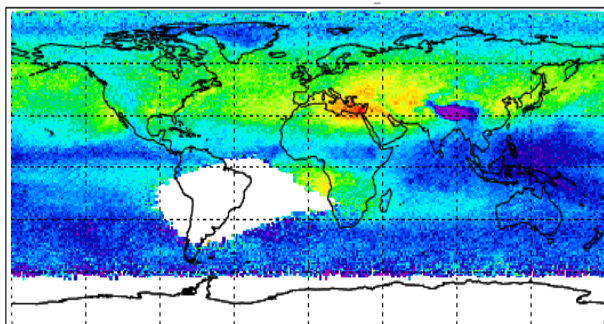
Nadir Ozone Profiles



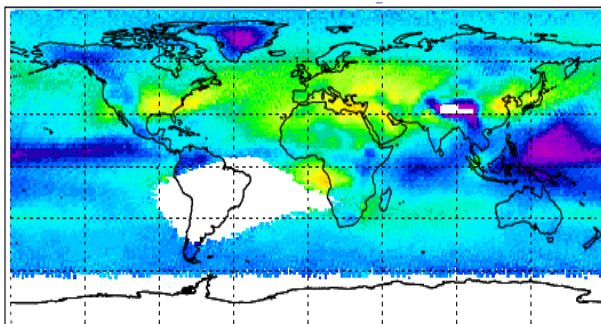
Nadir Ozone Profiles

Level-2	Demonstration CCI algorithm, with profiles on fixed pressure levels common to limb products – RAL algorithm selected (best performance in troposphere)	GOME (1997) GOME-2 (2007-2008)
Level-3	Monthly mean gridded data	GOME (1997) GOME-2 (2007-2008)
Level-4	Assimilated ozone profiles on 6 hourly global fields	GOME (1997) GOME-2 (2007-2008)

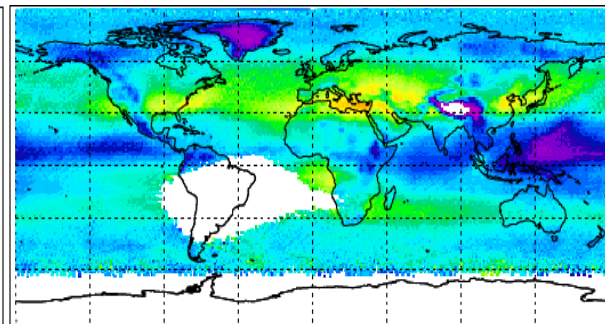
GOME2



TOMCAT

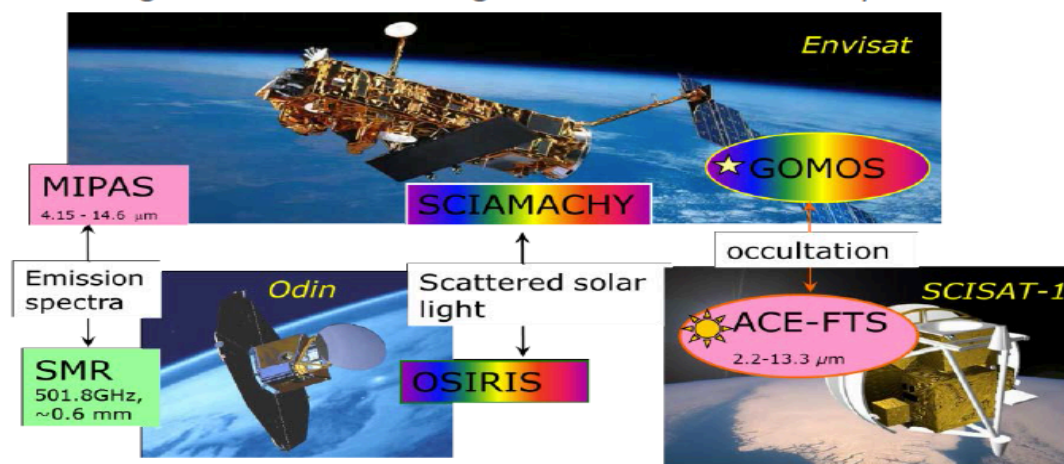


TOMCAT (GOME2 AKs)

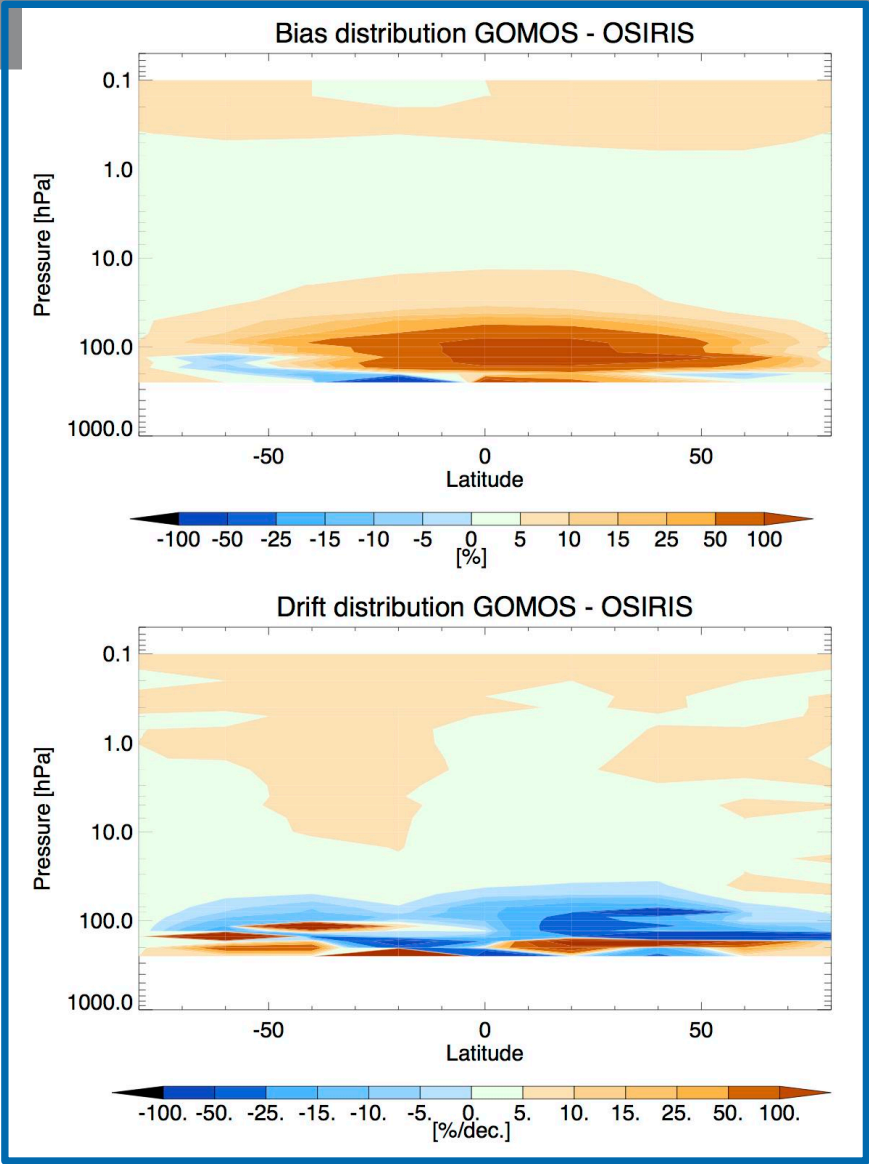
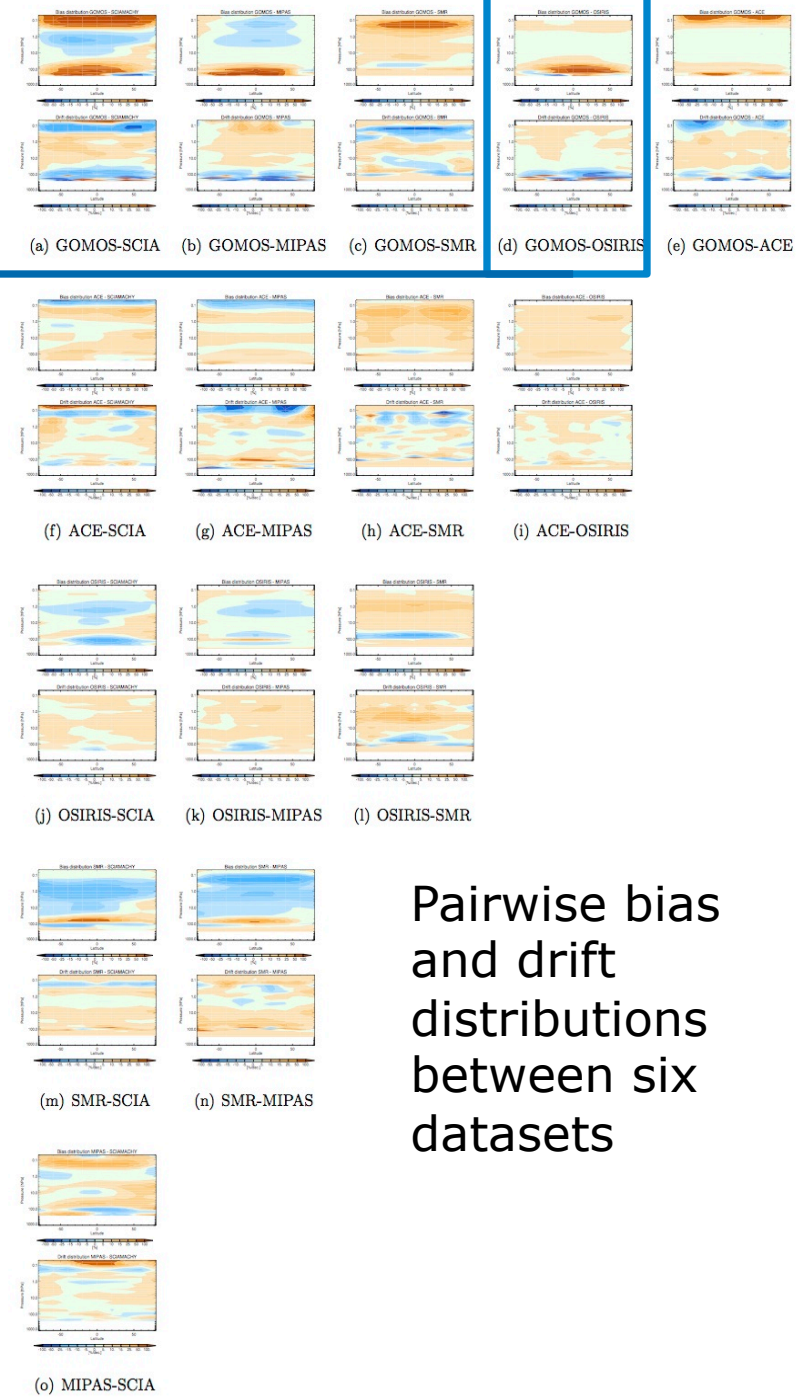


Limb Ozone Profiles

Level-2	Harmonized Single Instrument (HARMOZ): individual profiles with a common pressure grid and concentration unit, MIPAS Round Robin: selection of KIT algorithm	SCIAMACHY, GOMOS, MIPAS, OSIRIS, SMR, ACE (all lifetime)
Level-3	Single Instrument Monthly Mean Zonal Mean (MZM) – 10° latitude bin	SCIAMACHY, GOMOS, MIPAS, OSIRIS, SMR, ACE (all lifetime)
	Merged Mean (MMZM) – including monthly zonal mean and bi-weekly mean (20° long. 10° lat.)	SCIAMACHY, GOMOS, MIPAS, OSIRIS, SMR, ACE (2007-2008 demonstration),



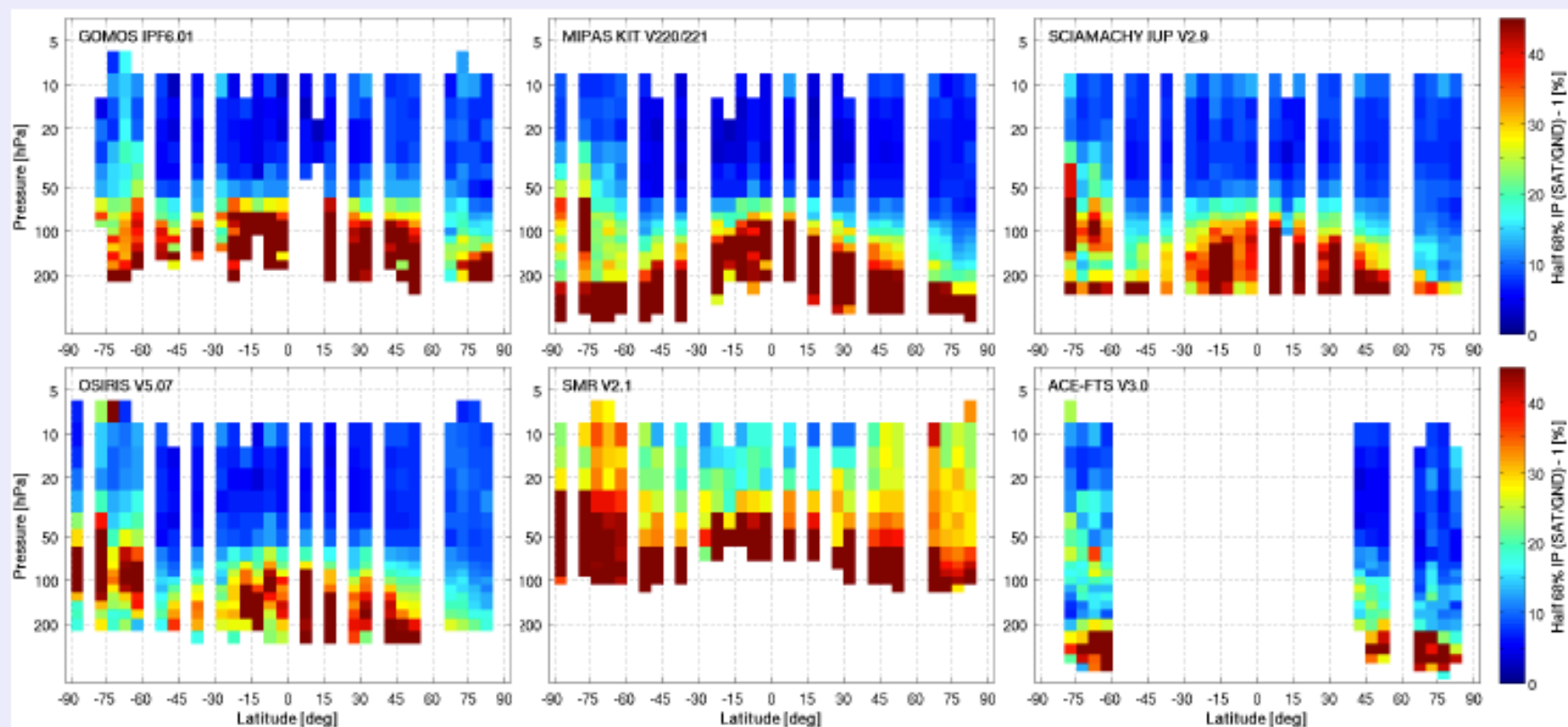
Bias and Drift analysis



Pairwise bias and drift distributions between six datasets

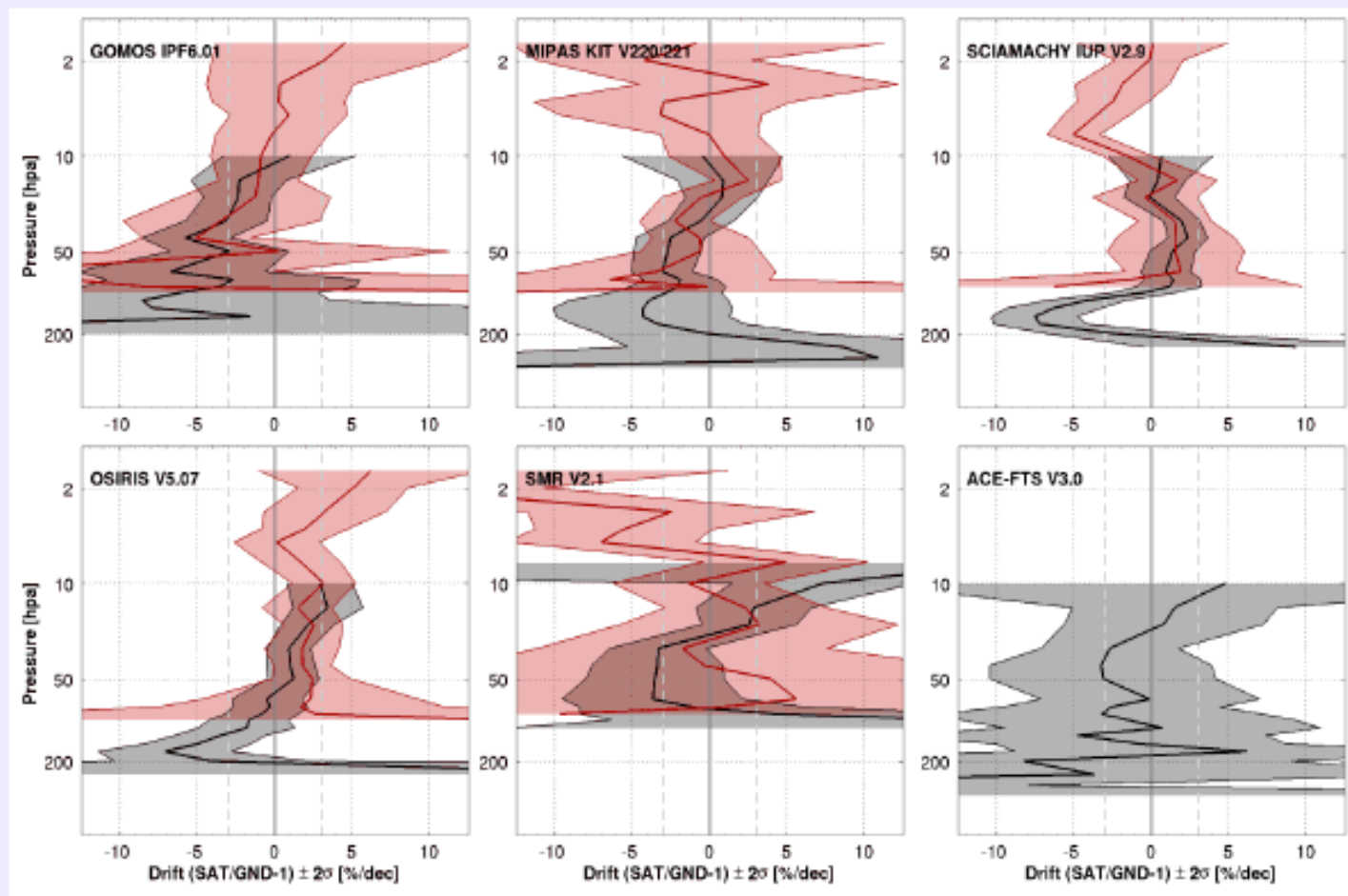
Comparison spread: meridian structure

- Typical distinction UTLS and middle atmosphere, increase in variability during Antarctic O3 hole conditions
- Comparison spread above 50hPa similar for most instruments: 5-10%
- Except **SMR**: 20-30%, due to (much) lower single profile precision



Stability: network average

- Lower stratosphere: all instruments drift less than $\pm 3\%$ / decade relative to ground networks
- Significant drifts in UTLS or MA for GOMOS ($\searrow < 50\text{hPa}$), SCIAMACHY ($\searrow \sim 5\text{hPa}$), OSIRIS ($\nearrow > 5\text{hPa}$) and possibly SMR ($\searrow > 5\text{hPa}$)



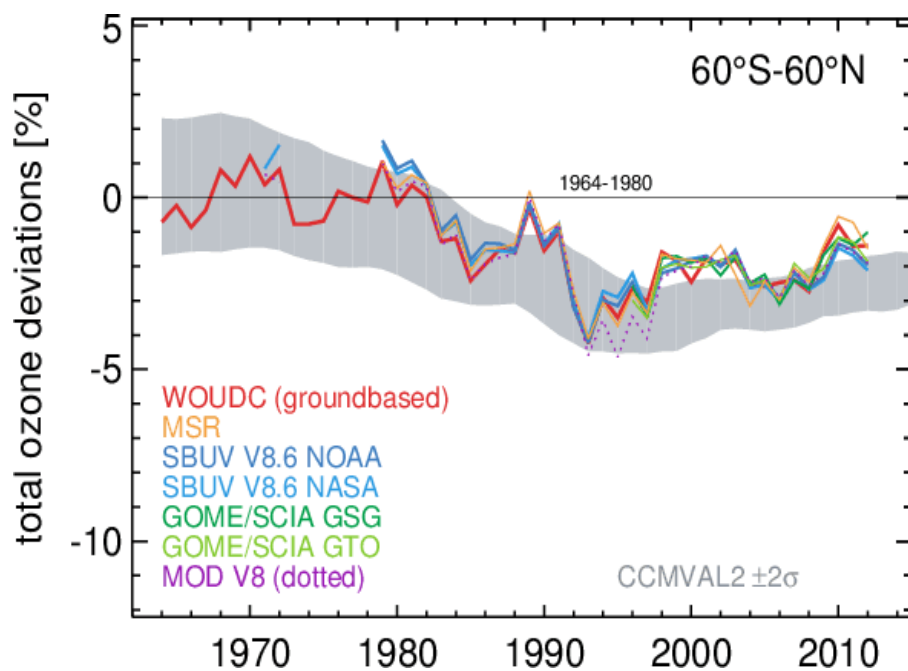
SONDE
LIDAR

freely available at: <http://www.esa-ozone-cci.org/?q=node/160>

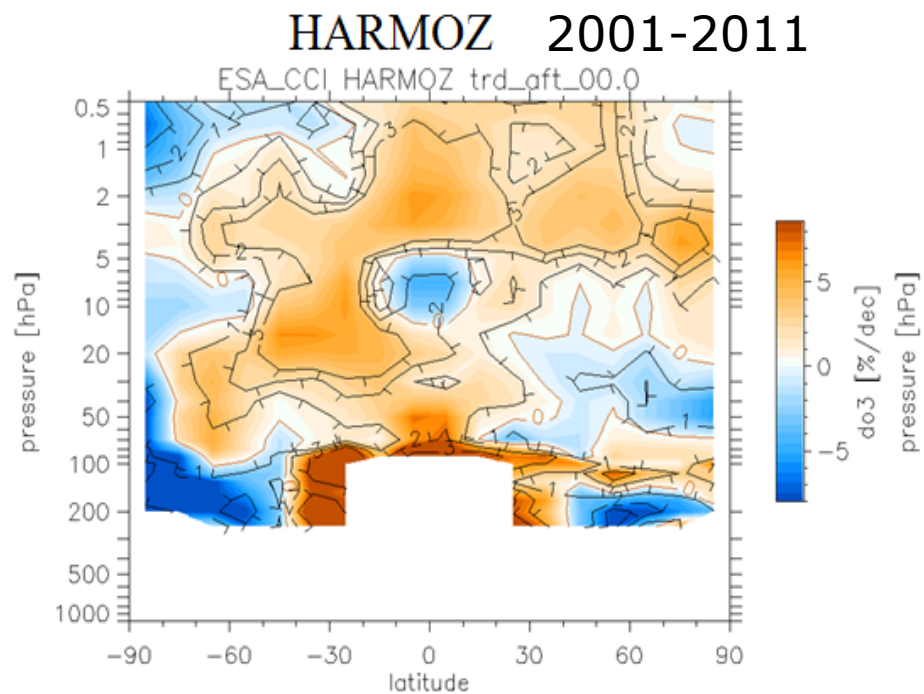
[illegible]

Profile trends in WMO Ozone Assessment 2014

- Chapter 2: Global Ozone (Co-authors: **M. Weber, J. Urban**; contributing authors: **R. van der A, M. Coldewey-Egbers, D. Loyola**)
- Chapter 3: Polar Ozone (Lead author: **M. Dameris**; contributing authors: **R. van der A, M. Weber**)



9th ORM Meeting | WMO, Geneva | 15/05/2014 | Slide 25



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GCOS Requirements for ozone



Target Requirements					
Variable/ Parameter	Horizontal Resolution	Vertical Resolution	Temporal Resolution	Accuracy	Stability
Ozone profile in upper stratosphere and mesosphere	100-200km	3km	daily	5-20%	<1%
Ozone profile in upper troposphere and lower stratosphere	100-200km	1-2km	4h	10%	1%
Total ozone	20-50km	N/A	4h	Max (2%; 5 DU)	<1%
Tropospheric ozone	20-50km	5km	4h	10-15%	1%

Qualitative assessment of compliance w.r.t. requirements



1. General: GCOS requirements for ozone can only be *partially met* using current and near-future satellite instruments.
2. Reprocessed GOME, SCIAMACHY and GOME-2 total ozone data sets match GCOS requirements on *spatial resolution, accuracy and stability*. Requirements on time resolution cannot be met with current sensors, but likely for Europe with Sentinel-4. Additional requirements on length of data series are not fulfilled with European data sets, but will after merging with US data series.
3. Demonstration nadir profile data products (GOME, GOME-2) match requirements on *horizontal resolution, temporal resolution and accuracy in the stratosphere* (and they are close to match the same requirements in the troposphere). Vertical resolution requirements cannot be met with nadir sensors. Accuracy and temporal resolution requirements are not met in the UTLS region with UV sensors, however the addition of the IASI instrument in Phase-II will improve on this situation.
4. Limb and occultation instruments match all requirements in the *stratosphere*. In the UTLS, the requirements on vertical resolution, temporal resolution and accuracy are not met.

Main Achievements of O3_cci first phase



User Requirements Analysis, linked to GCOS, IGACO, CMUG

Consistent error analysis for all sensors

Ensure traceability (e.g. algorithm/validation documentation)

Independent validation of all Level-2 and level-3 data sets (round-robins, algorithm development, final assessment) was essential

System specification → a fully distributed processing system is efficient

Simple data access via Webpage/ftp server

Climate research assessment by Climate Modellers, comprehensive use of CCI data sets

Ozone_cci related peer-reviewed publications > 35 (so far)

Interaction with the [User Community](#)

- Planning of datasets should be in close participation with climate modelers and researcher/data user
- Data can provide feedback to climate modelers for diagnosing climate models and to data users for data interpretation (e.g. when to use and when not to use data)

[Common data formats](#) and definition of terms facilitates the use of data is important

- See for instance: WMO Report 2014, SI2N activity, SPARC DI

Data Merging

- There [is not a "universal recipe"](#) for data merging as different applications need different data sets
- [Sampling errors](#) are significant for instruments with coarse sampling

Lessons learned:



Validation:

- stringent user requirements (1%/decade) level) $\Rightarrow$ need for dedicated selection of ground-based (and satellite) “reference” data
- there is unequal/unstable quality of GB data in the tropics
- 10%-level validation of tropospheric/UTLS data requires improved treatment of smoothing differences and further inspection of reference data
- representativeness of ozone monitoring networks not suitable for the validation of L3 zonal means
- basic principle: show that L3 generation does not degrade L2 quality $\Rightarrow$ L2-type validation of L3 & L3 data inspection
- L3/L4: How to proceed further? Adopt evaluation techniques used for DA systems?
- importance of the cross-sections being used (systematic errors)

Improvements targeted in O3_cci Phase-II (next 3 years)



- Consolidation of ozone products portfolio → longer time-series
- Continued improvement of retrieval algorithms for nadir UV sensors → soft calibrations, cloud correction scheme, add OMI (and OMPS), harmonise columns and profiles.
- Include the IASI instrument (improved information content in UTLS).
- New focus on tropospheric data products, using different approaches → nadir profiles (UV and TIR), CCD, limb-nadir matching
- Extend altitude range of limb products → UTLS and mesosphere
- Link/merge European data sets to historical US data series (ongoing co-operation within CEOS-Atmospheric Composition Constellation)

[illegible]