Belgian Institute for Space Aeronomy (BIRA-IASB)

Institut d'Aéronomie Spatiale de Belgique (IASB)

Belgisch Instituut voor Ruimte-Aeronomie (BIRA)

Reactive gases in a changing atmosphere: global observations, data assimilation and services

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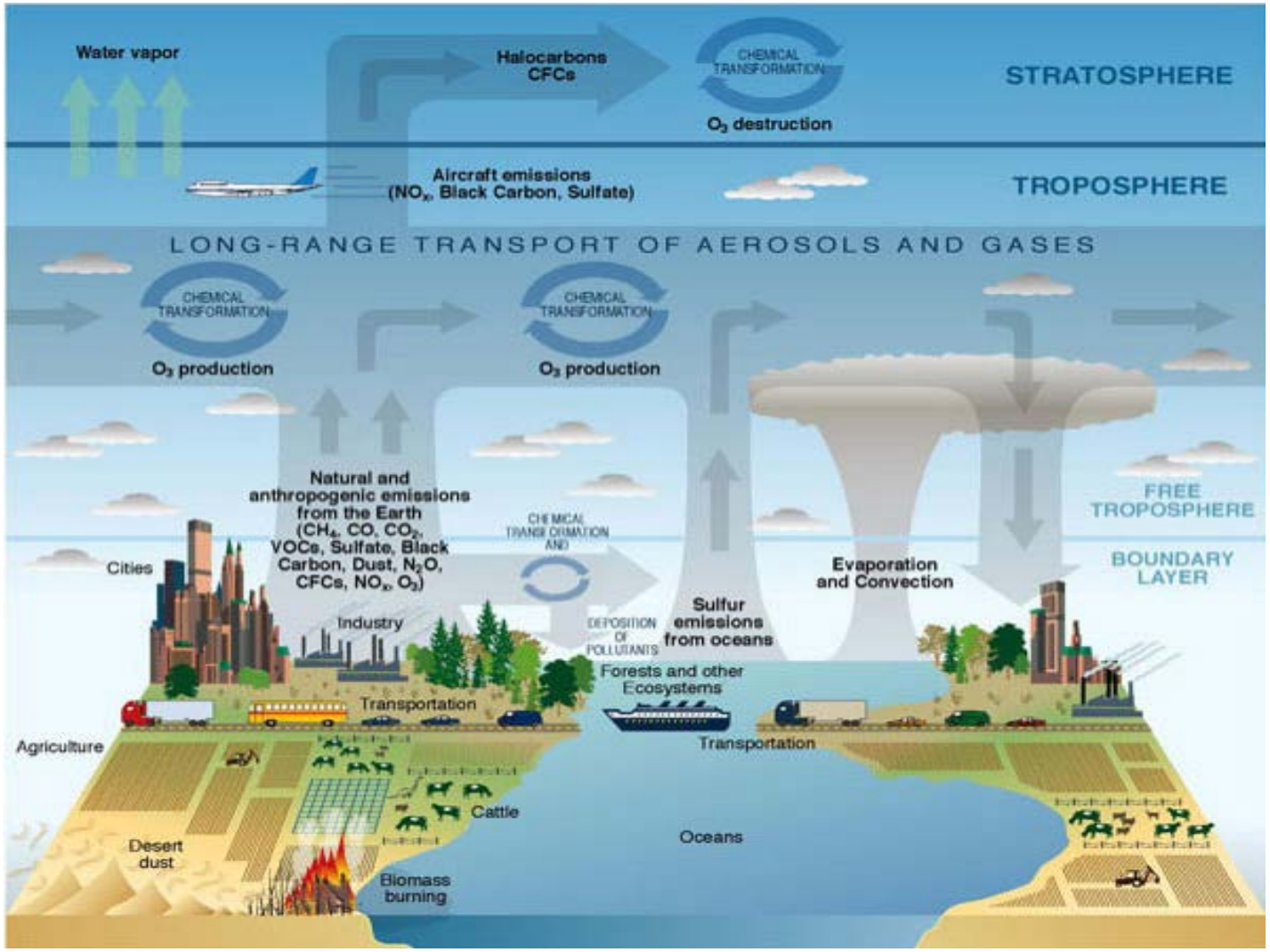
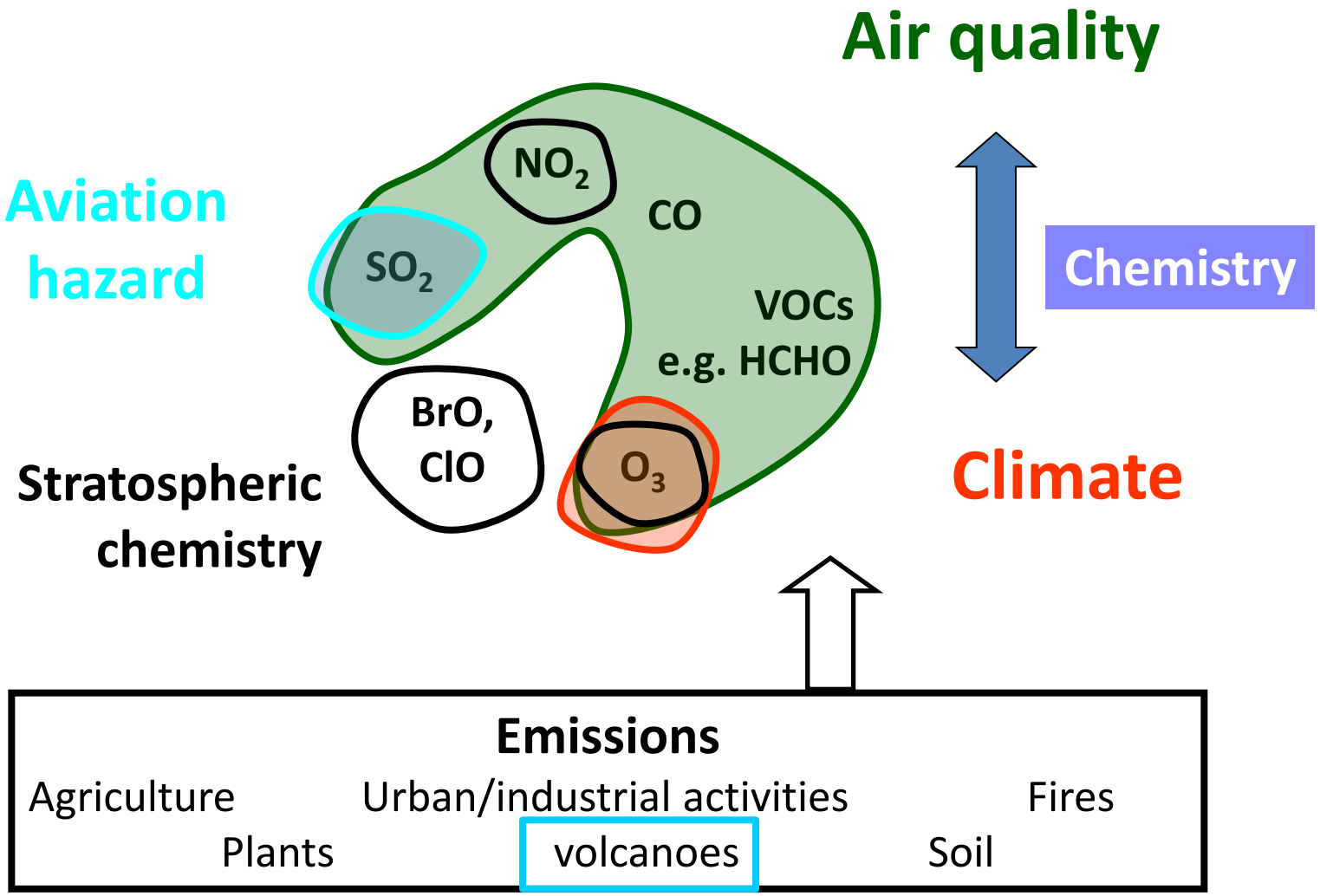
Outline

- Atmospheric reactive gases – introduction
- Stratospheric ozone research, data assimilation and services
- Global tropospheric gases monitoring from space
- The role of ground-based networks
- QA/ validation systems in support of global atmospheric composition observations

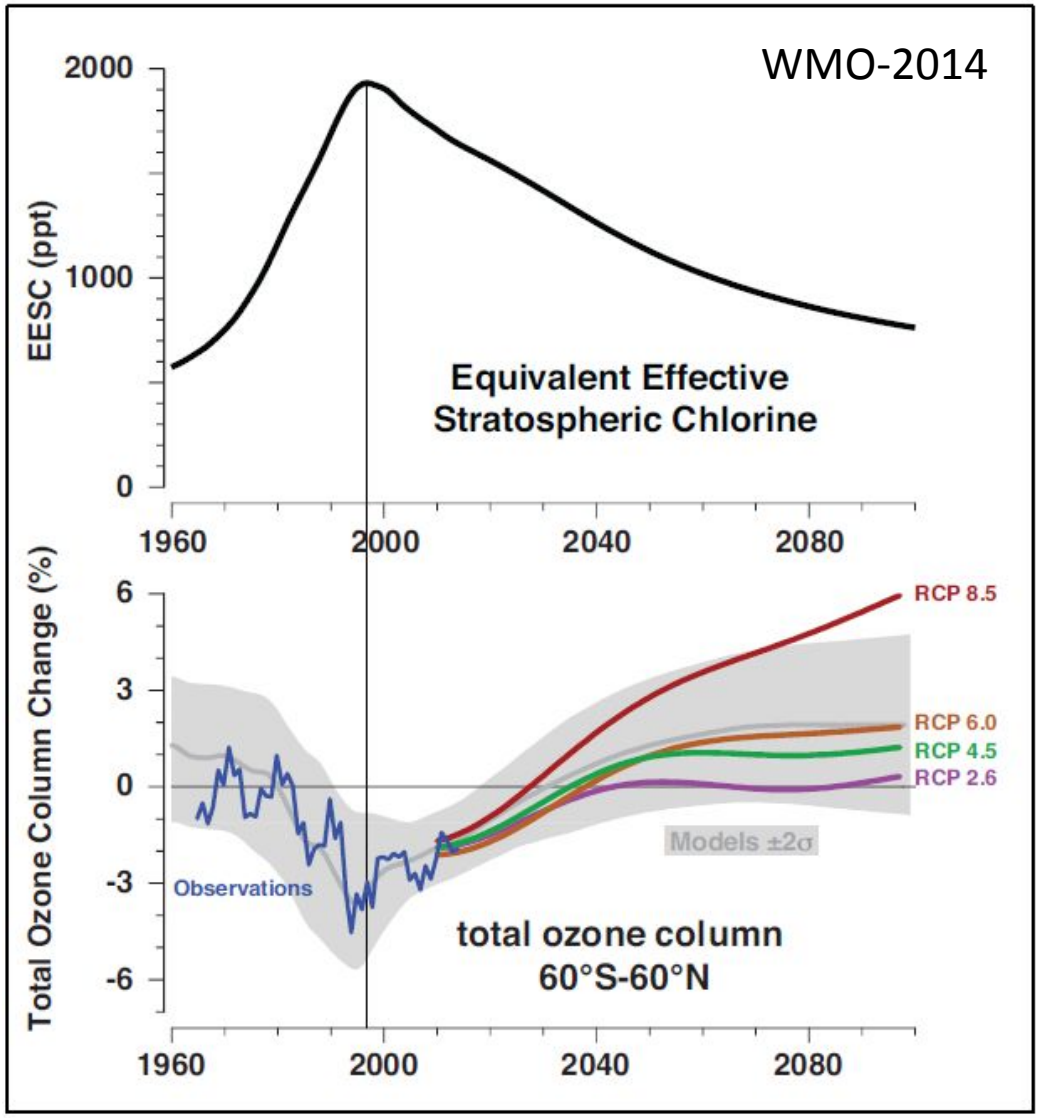
Atmospheric processes - overview



Reactive gases and their inter-relations



Ozone and chemistry-climate interactions



GCOS
GLOBAL CLIMATE OBSERVING SYSTEM

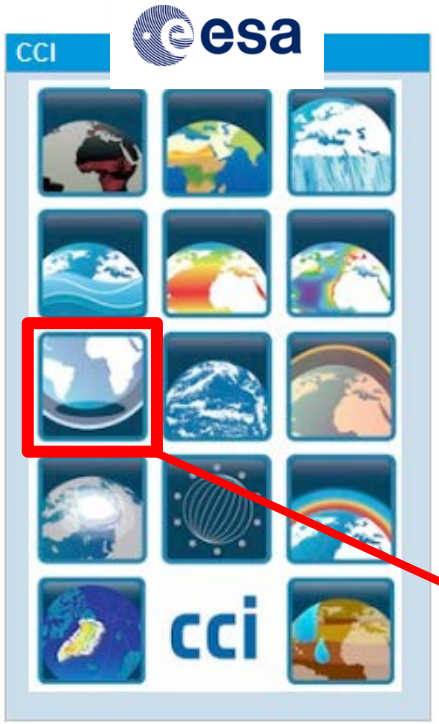
Essential Climate Variable (ECV)

Ozone is the most important radiatively active trace gas in the stratosphere

Ozone recovery is strongly linked to climate change.

Four possible greenhouse gas scenarios correspond to +2.6 (**purple**), +4.5 (**green**), +6.0 (**brown**), and +8.5 (**red**) W m^{-2} of global radiative forcing

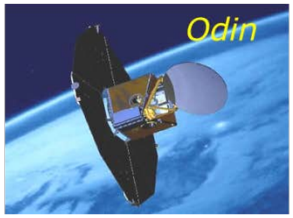
ESA Climate Change Initiative (CCI)



www.esa-cci.org

2010-2016

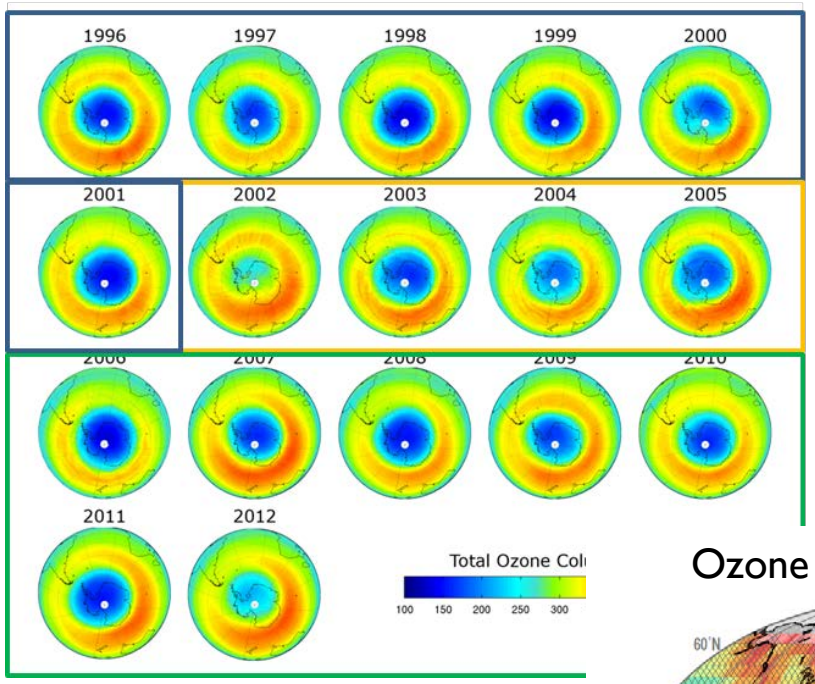
13 Essential Climate Variables (ECVs)



Ozone_cci (13 partners, BIRA lead)

- Development of state-of-the-art ozone Climate Data Records (CDRs) from all relevant European and ESA-associated sensors
- BIRA responsible for the development of the total ozone level-2 CDR + coordination of validation tasks

Total Ozone Climate Data Record



GOME

SCIAMACHY

GOME-2

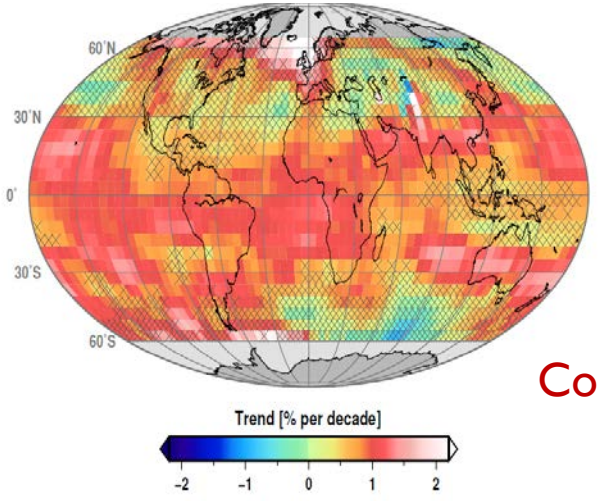
Lerot *et al.*, JGR, 2014

20 years of high-quality consistent data from 3 ozone sensors

Used for (e.g.):

- Level-3 data set generation
- Regional trends analysis
- Assimilation in atmospheric reanalysis (ECMWF)

Ozone trends (%/decade)

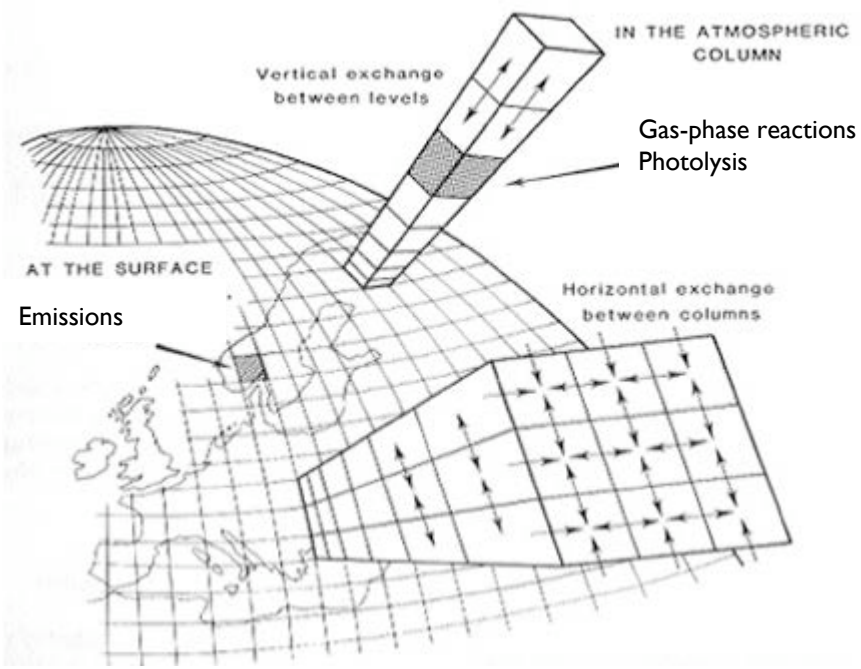


Coldewey *et al.*, GRL, 2014

The BASCOE Chemistry-Transport Model (CTM)

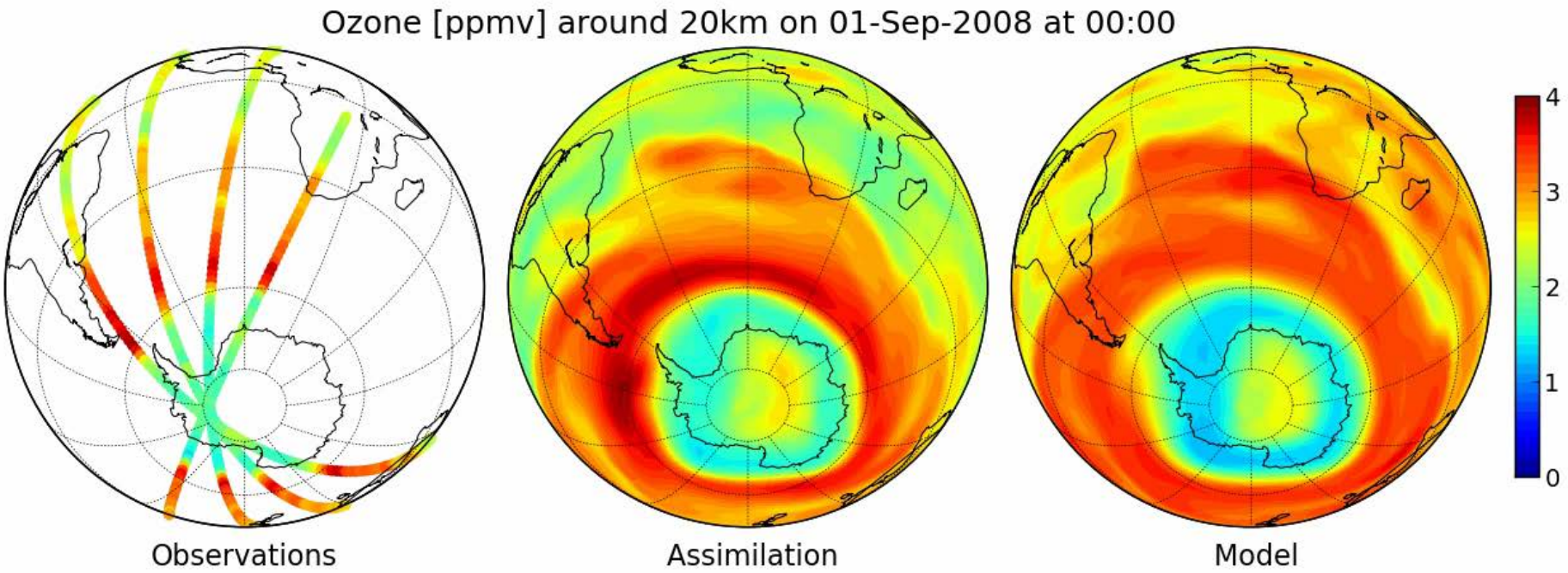
A 3D CTM of the stratosphere

- Chemistry:
  - 58 stratospheric species:
    O_3, NO_y, Cl_y, Br_y, CH_4, H_2O, CFCs, …
  - chemical solver for 200 reactions
  - Parameterization for
    Polar Stratospheric Clouds (PSC)
- Transport by winds
- Winds, T are <u>input</u> from meteo center



The BASCOE assimilation system

Principle of **Data Assimilation** (center): optimising a **model** state (right) in order to fit satellite **observations** (left)

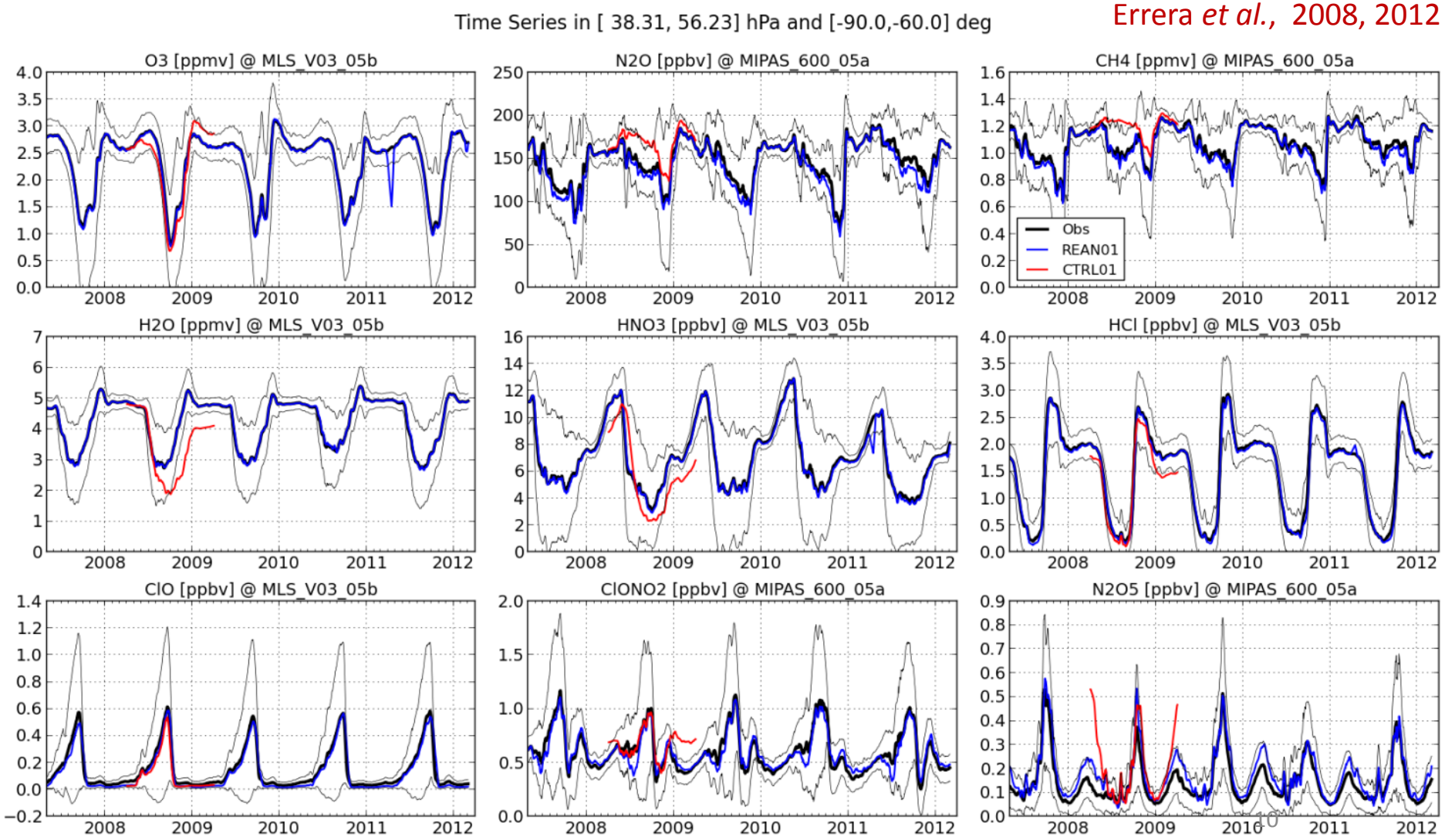


Methods: 4D-VAR and Ensemble Kalman Filter

Reanalyses of the Stratospheric Composition

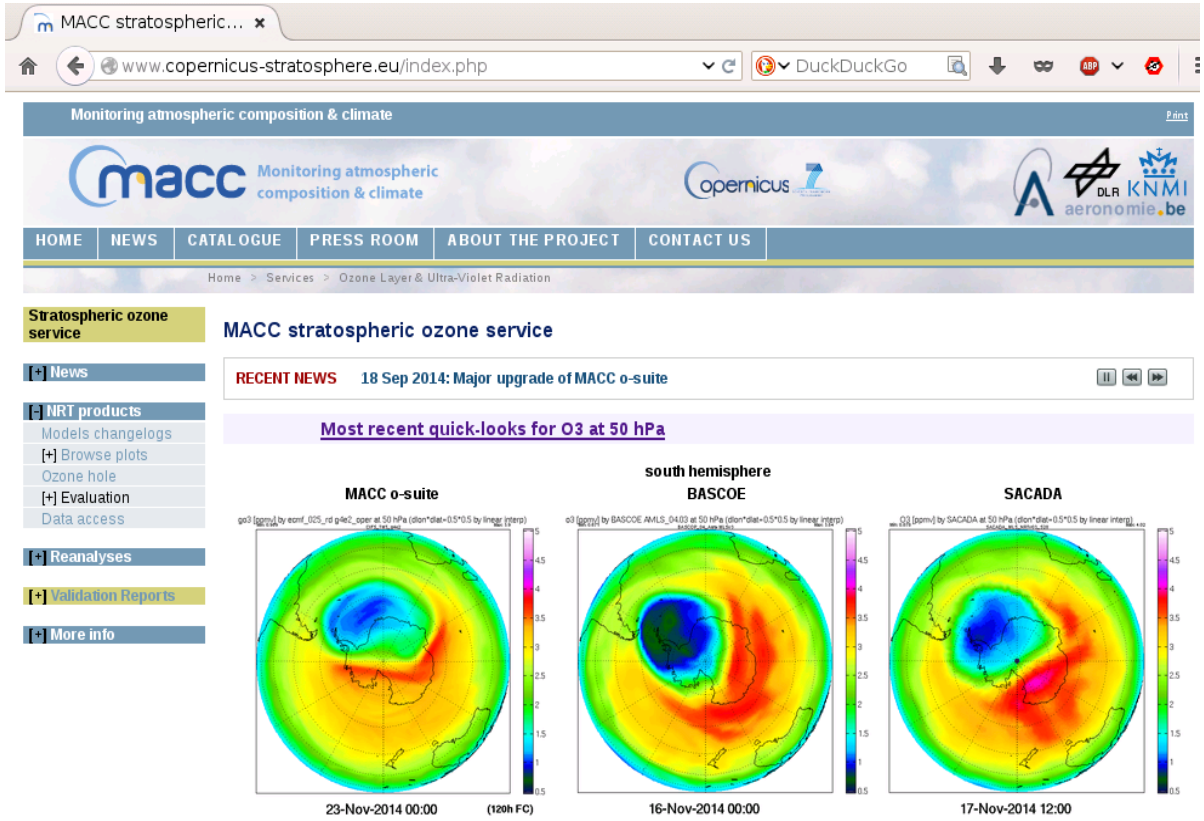
2007-2012, uses obs by Aura MLS (NASA) and MIPAS (ESA)

Errera *et al.*, 2008, 2012



MACC strato ozone **service for**

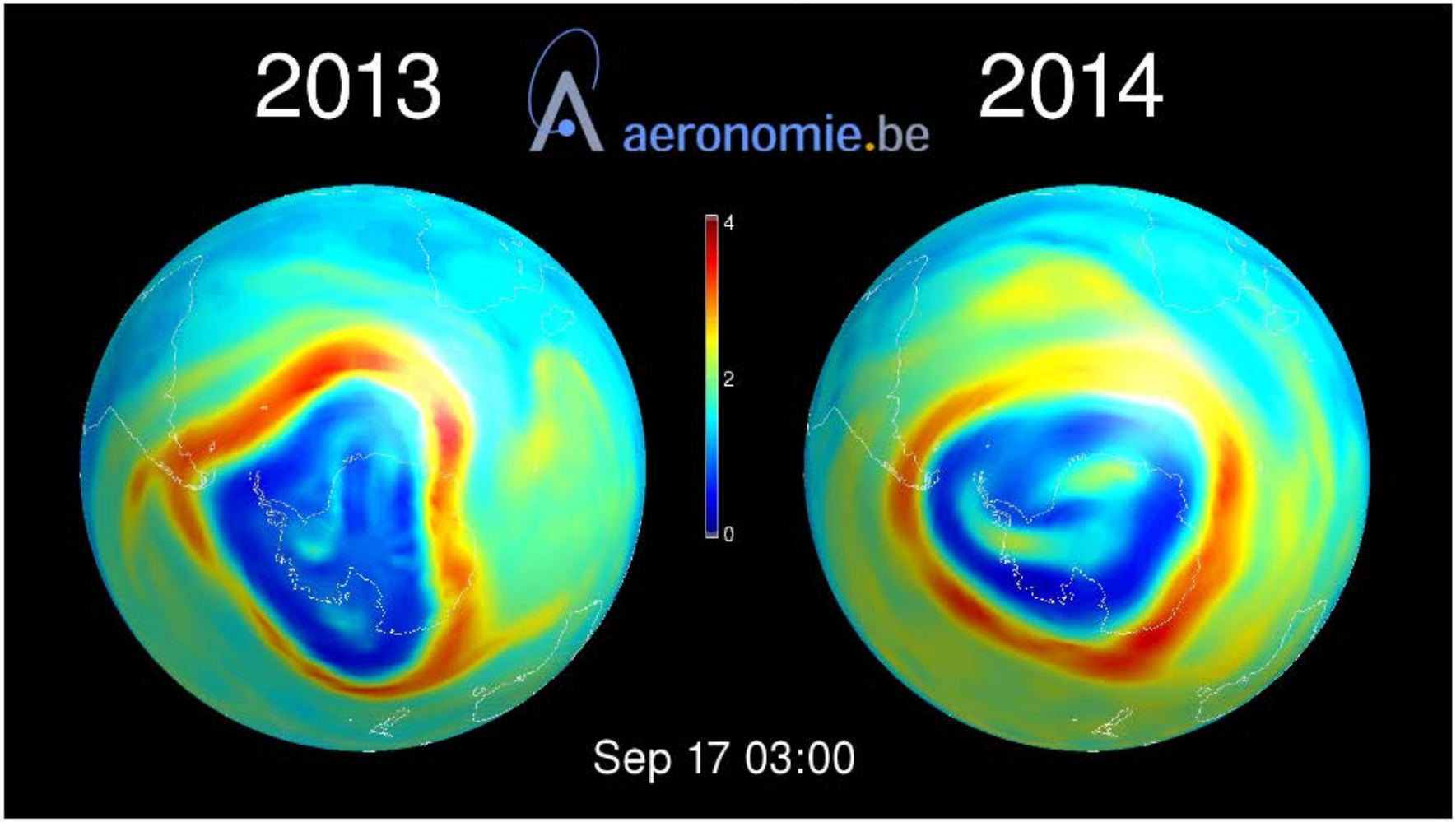
- Copernicus is a new <u>European system of Services for monitoring the Earth</u>
- Atmosphere component → preparatory projects MACC, soon CAMS



- BIRA contributions: validation, stratospheric ozone service
- compares main ECMWF model with BASCOE
- Delivers animations of current ozone holes

MACC strato ozone **service for**

Current ozone hole above Antarctic, compare with last year:

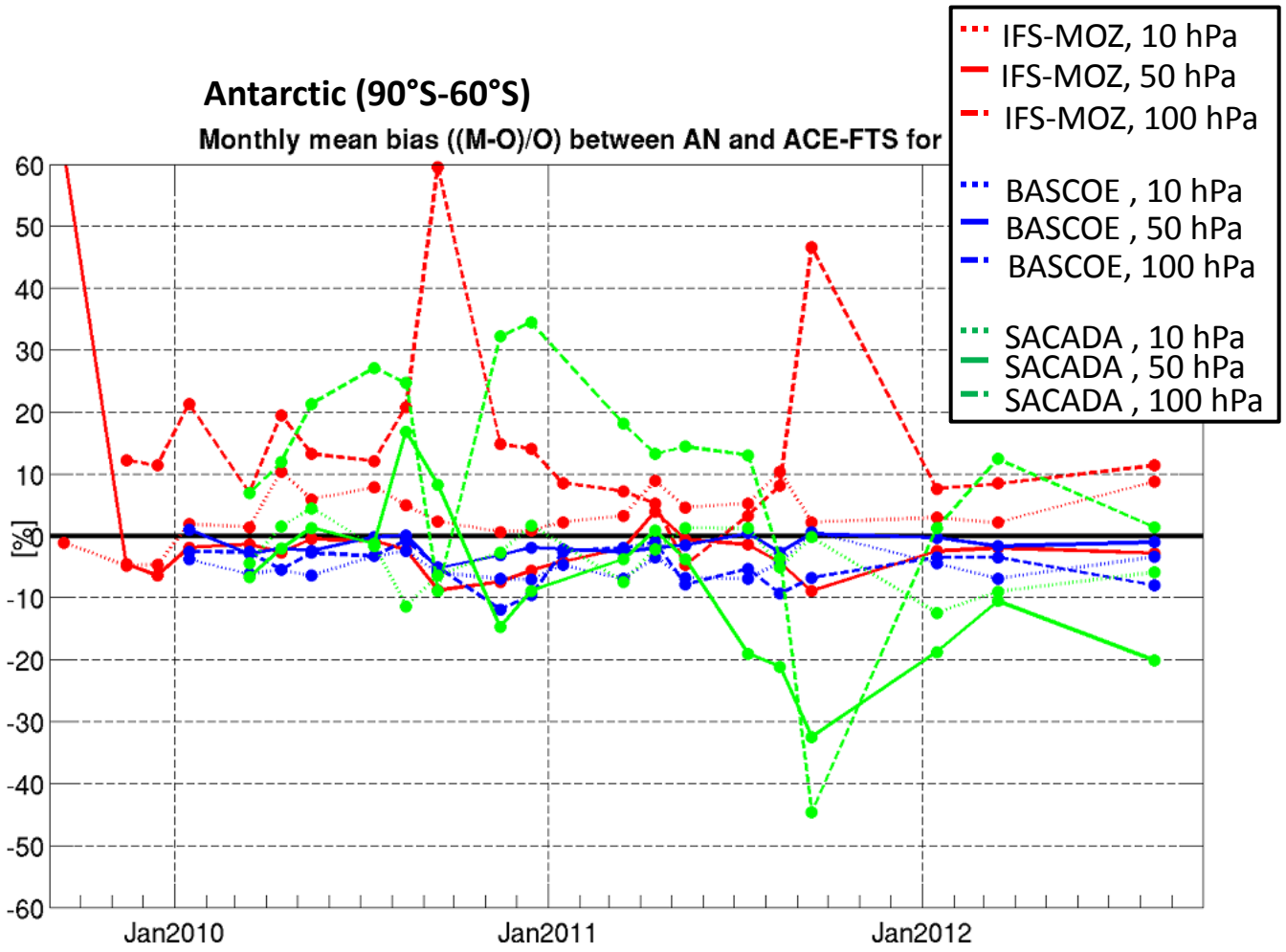


MACC stratospheric ozone **service**: Quality of ozone analyses by BASCOE NRT

During 2009-2012, ozone analyses by BASCOE NRT (blue) had better quality than those by main MACC model (red).

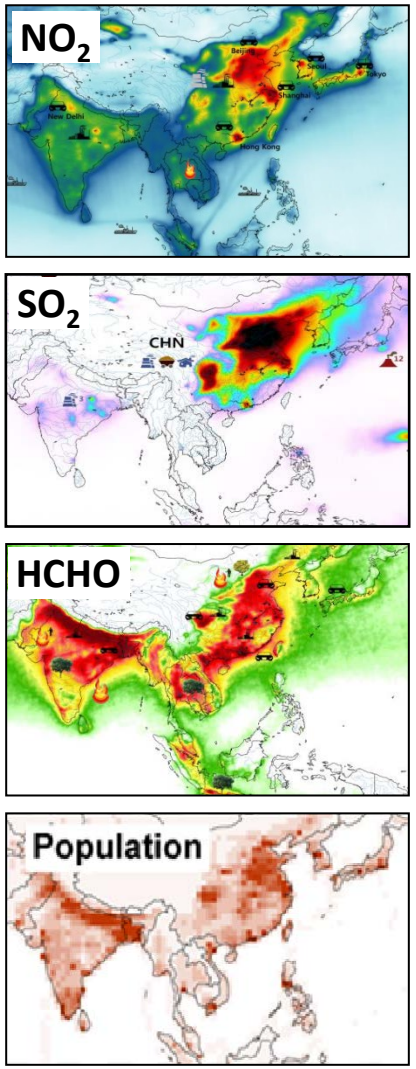
Causes: BASCOE focus on strato ozone
+ better usage of satellite data

Lefever *et al.*, ACPD, 2014



Tropospheric gases and air quality

- Tropospheric gases can be measured using UV-Vis satellite sensors (GOME, SCIAMACHY, OMI, GOME-2, …) and IR sensors (e.g. IASI)
- Allows for global monitoring of key air quality gases (NO_2, SO_2, HCHO, O_3, etc)
- BIRA has developed a strong expertise on such retrievals, through participation to successive missions since late nineties
- Intensive collaboration with international partners (e.g. KNMI, Bremen, Mainz, DLR)
- Focus on building long series of consistent data from multiple sensors, input for models, trend analysis, etc.



Satellite observations → Nadir UV sensors → LEO polar orbits

BIRA•IASB 1964•2014

1995 2002 2006 2012 2016

GOME / ERS2

10:30 am
320x40 km^2
3 days

10:00 am
60x30 km^2
6 days

SCIAMACHY / ENVISAT

OMI / AURA

01:30 pm
13x24 km^2
1 day

GOME-2 / METOP-A

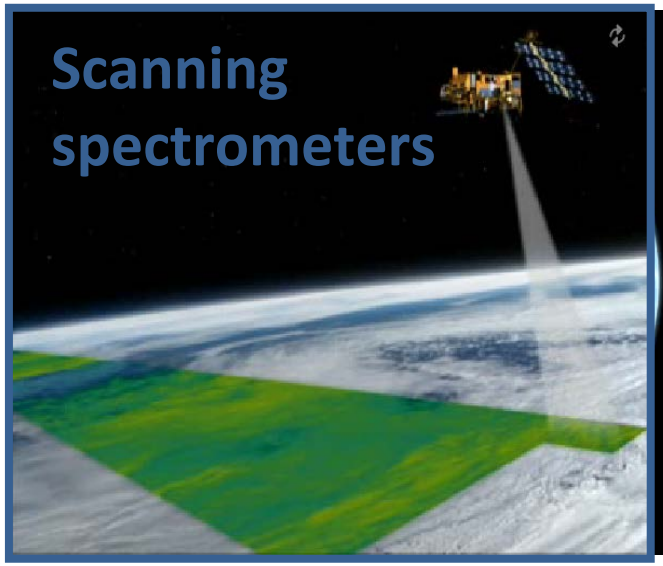
09:30 am
40x80 km^2
1,5 day

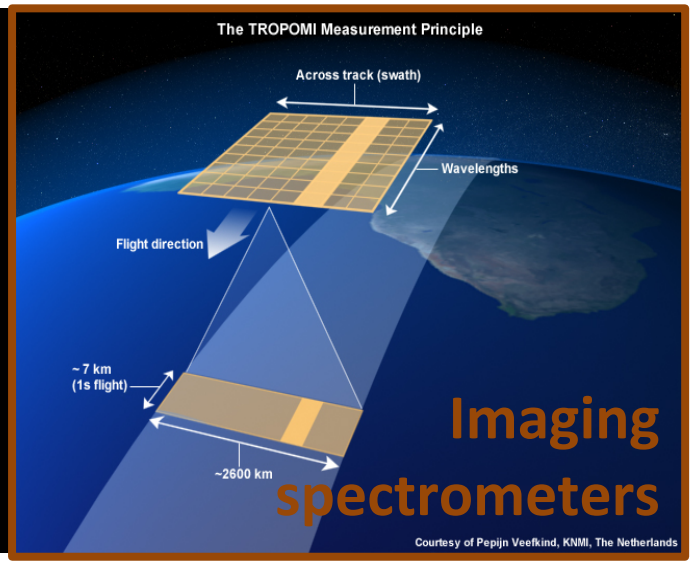
METOP-B

C

TROPOMI **S5P**

01:30 pm
7x7 km^2
1 day





opernicus

Royal Netherlands Meteorological Institute
Ministry of Infrastructure and the Environment

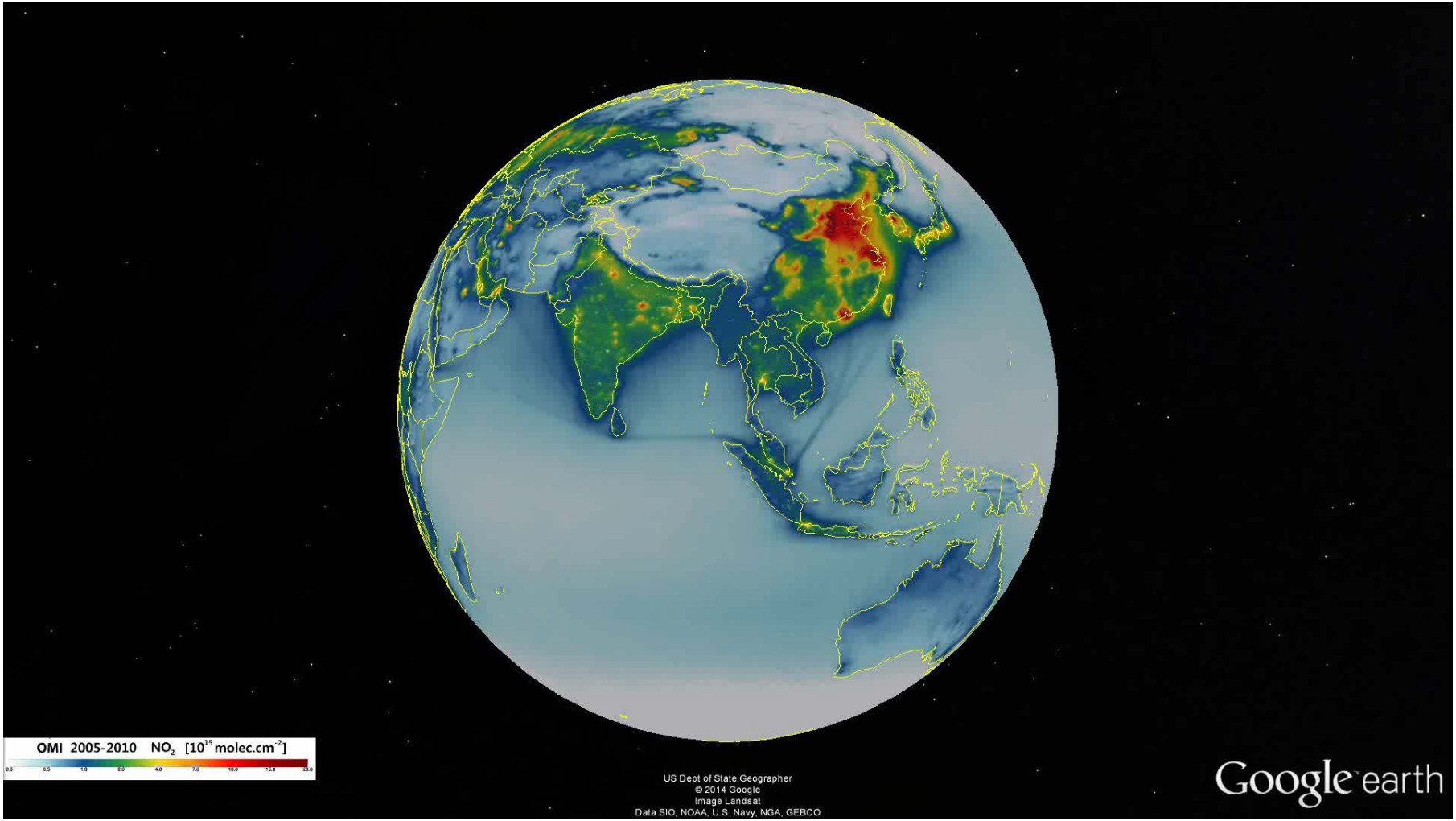
.be

Global tropospheric NO_2

Royal Netherlands Meteorological Institute
Ministry of Infrastructure and the Environment

TEMIS

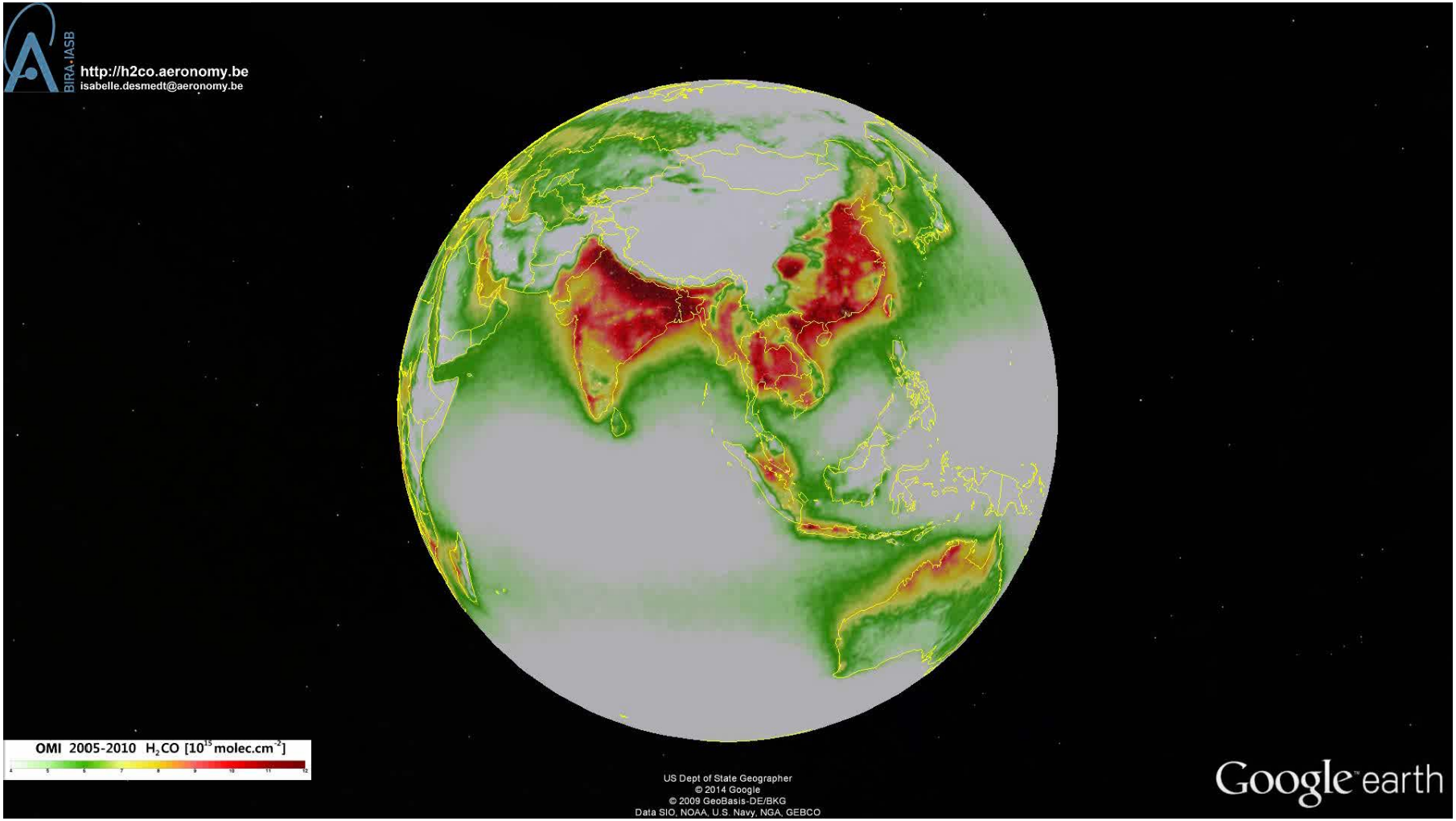
BIRA•IASB 1964•2014



Credit: I. De Smedt , Y. Huan and H. Brenot

belspo .be

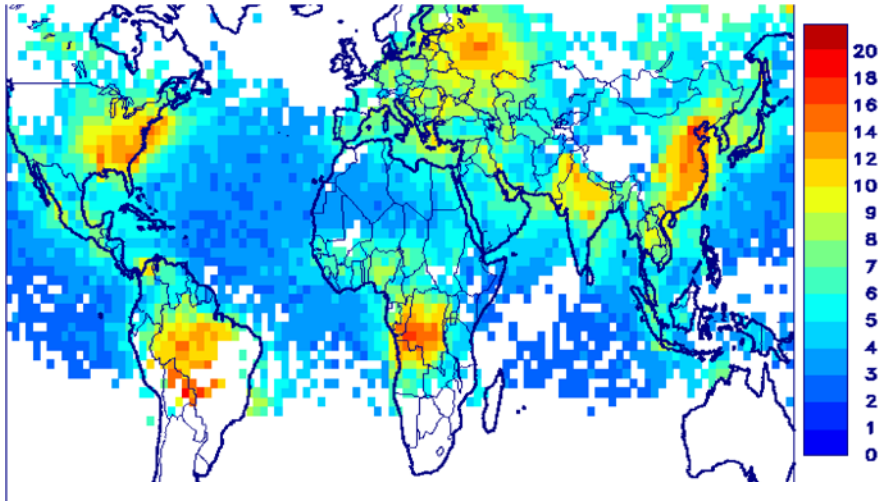
Global tropospheric HCHO

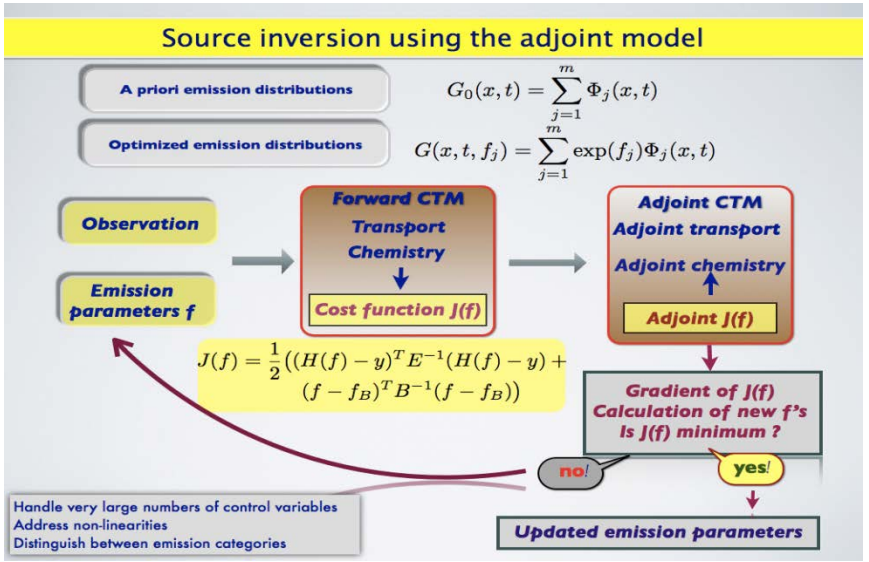


Credit: I. De Smedt and H. Brenot

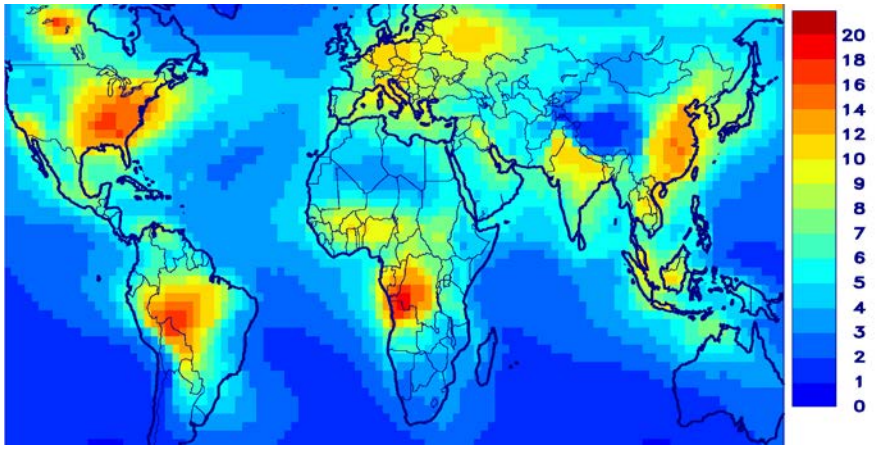
Inverse modeling of emissions using 3D-CTMs

GOME-2 H_2CO July 2010

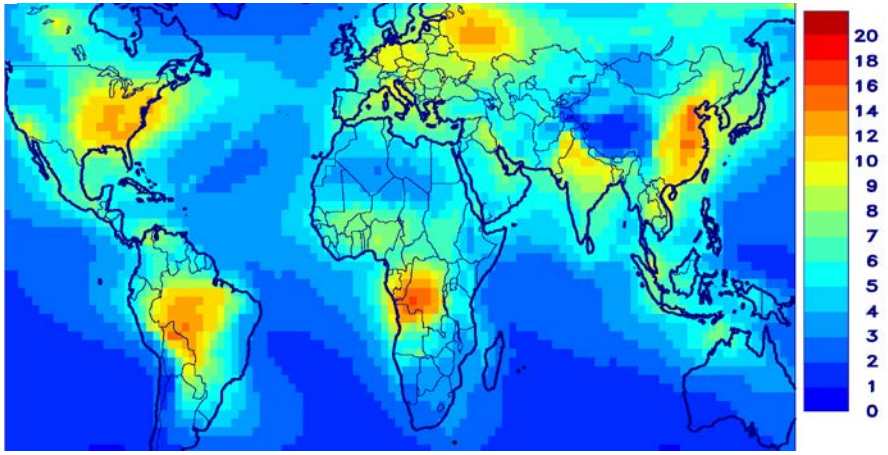




A priori IMAGESv2 H_2CO

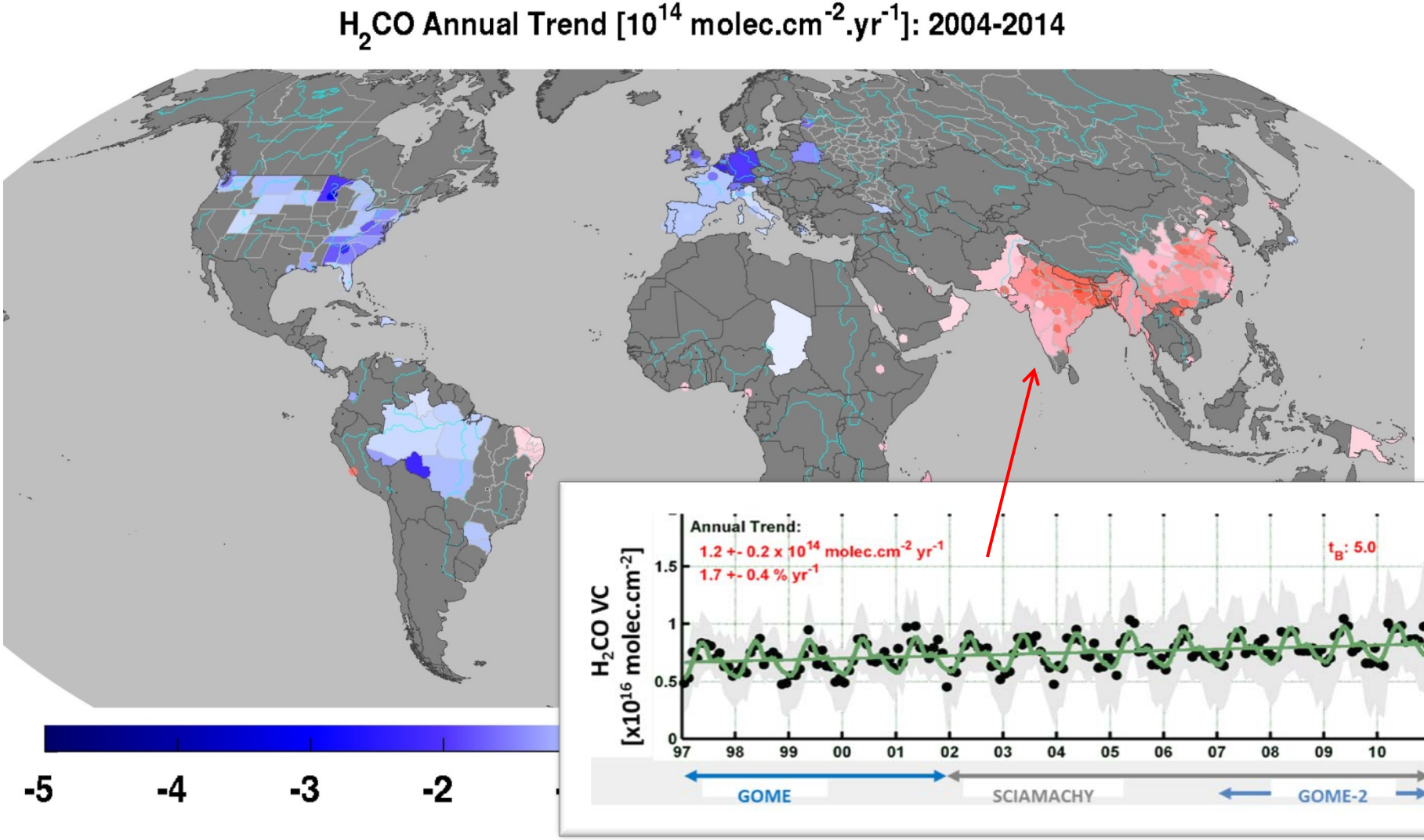


Optimized columns



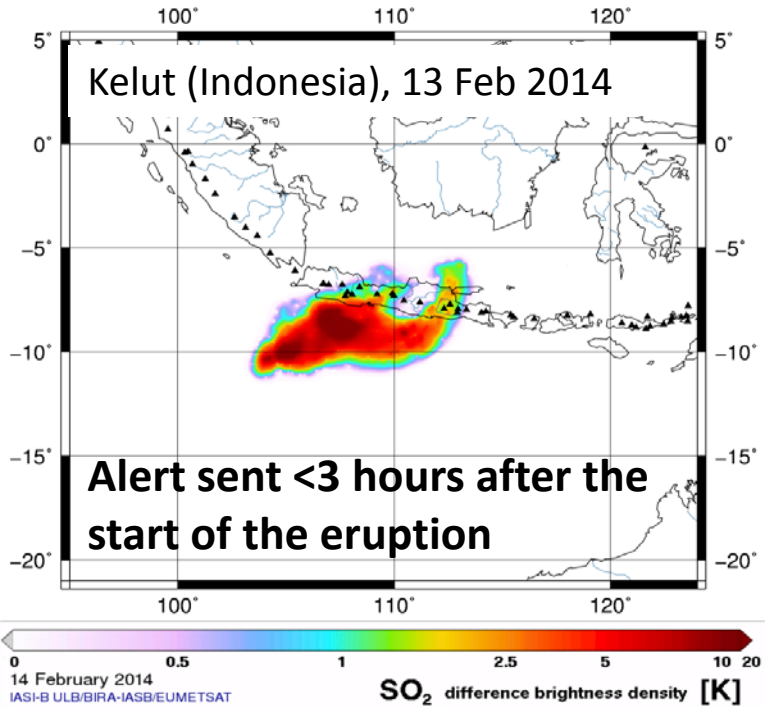
Courtesy of Stavrakou and Müller

Long-term trends in HCHO emissions



De Smedt *et al.*, 2010, 2011, 2012

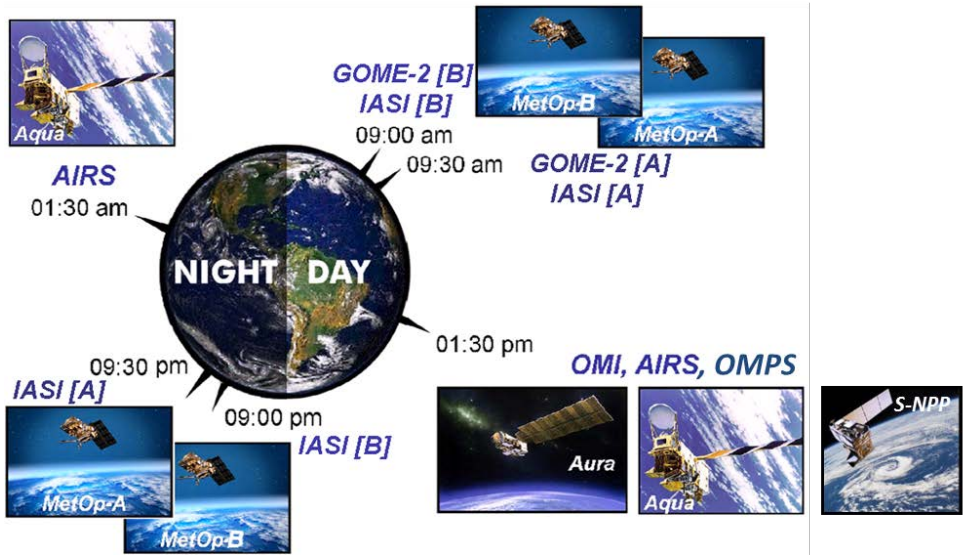
Support to Aviation Control Service



Alert and information service on volcanic eruption

- SO_2 and volcanic ash detection from UV and TIR hyperspectral satellite instruments
- 7 international partners
- 230 Users: volcanic ash advisory centers (VAACs), observatories, airlines, pilots, Met Offices.

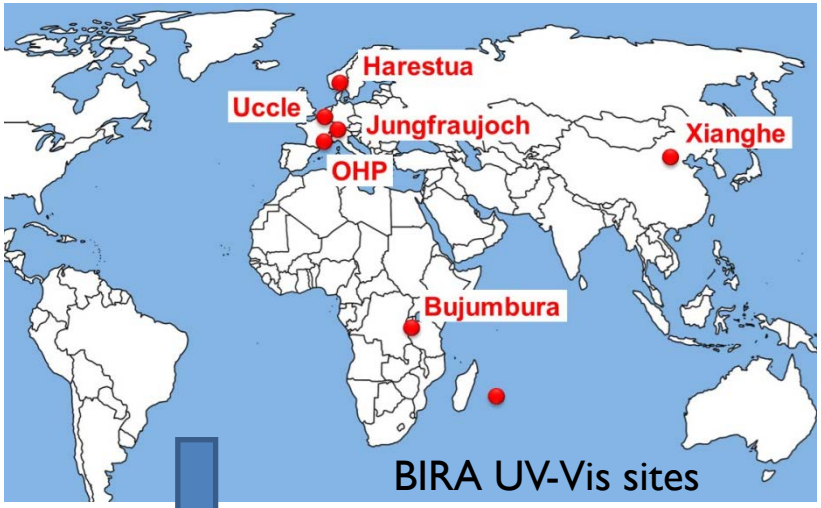
Constellation of satellite instruments



http://sacs.aeronomie.be

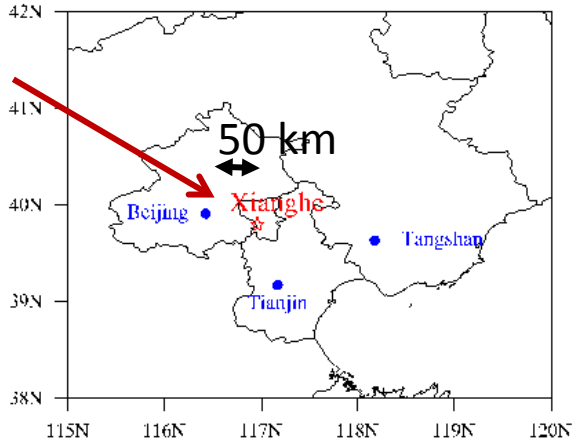
Ground-based reference network data

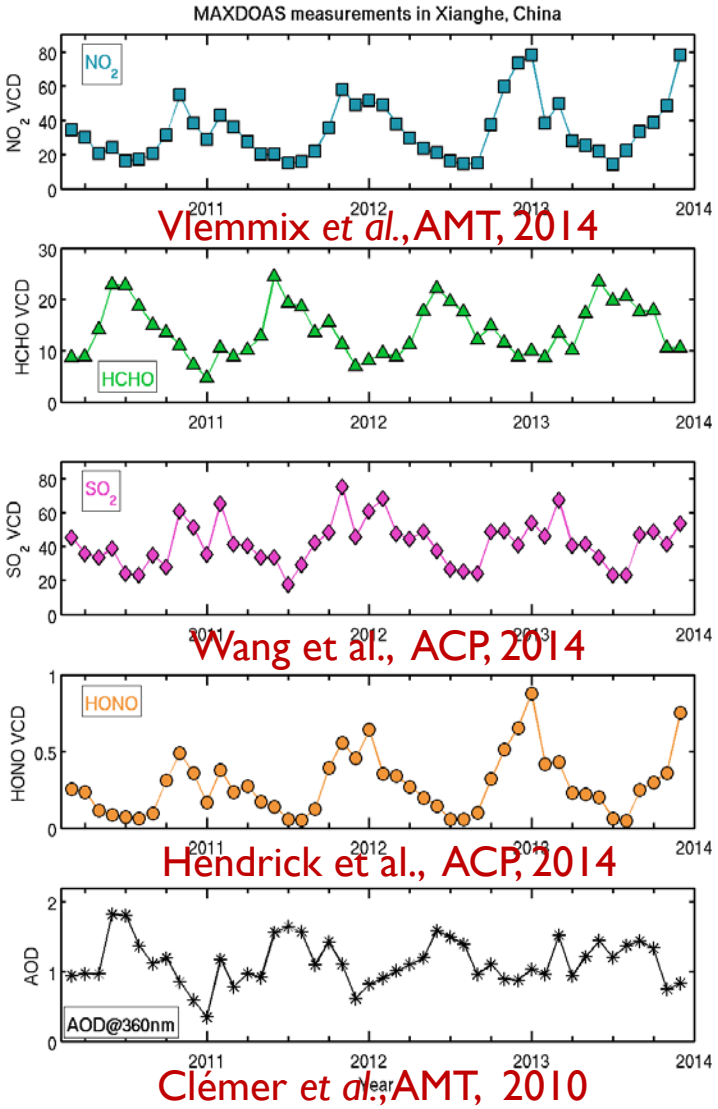
- High-quality ground-based reference data sets are essential for satellite validation
- Remote-sensing DOAS technique developed at BIRA since early nineties, as part of international NDACC network
- Reference sites currently operated at 6 (7) stations, providing column and profile measurements of all relevant UV-Vis species (NO_2, O_3, BrO, HCHO, SO_2, aerosol etc)
- BIRA is a major actor in developing the UV-Vis component of NDACC
- Essential contribution to preparation of Copernicus/Sentinels programme



Example: OMI validation in Xianghe

BIRA MAXDOAS



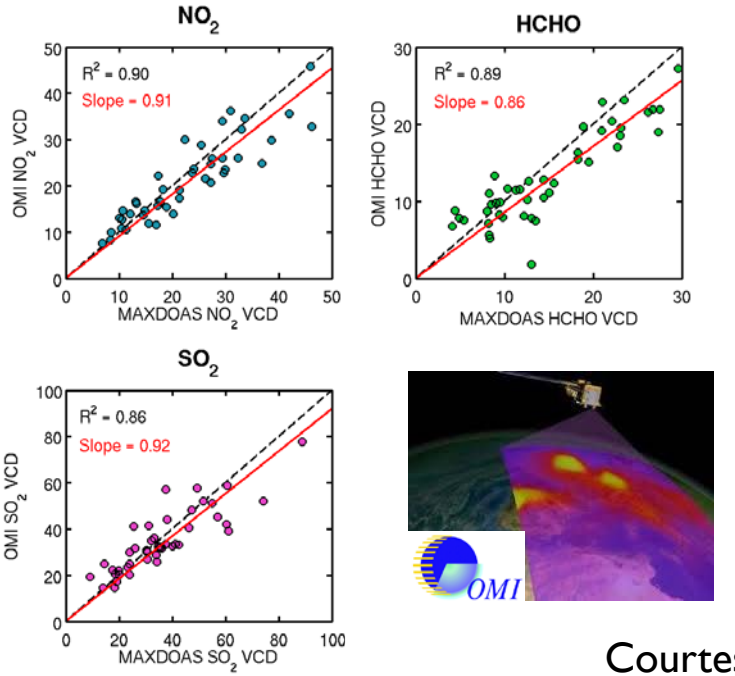


Vlemmix *et al.*, AMT, 2014

Wang et al., ACP, 2014

Hendrick et al., ACP, 2014

Clémer *et al.*, AMT, 2010



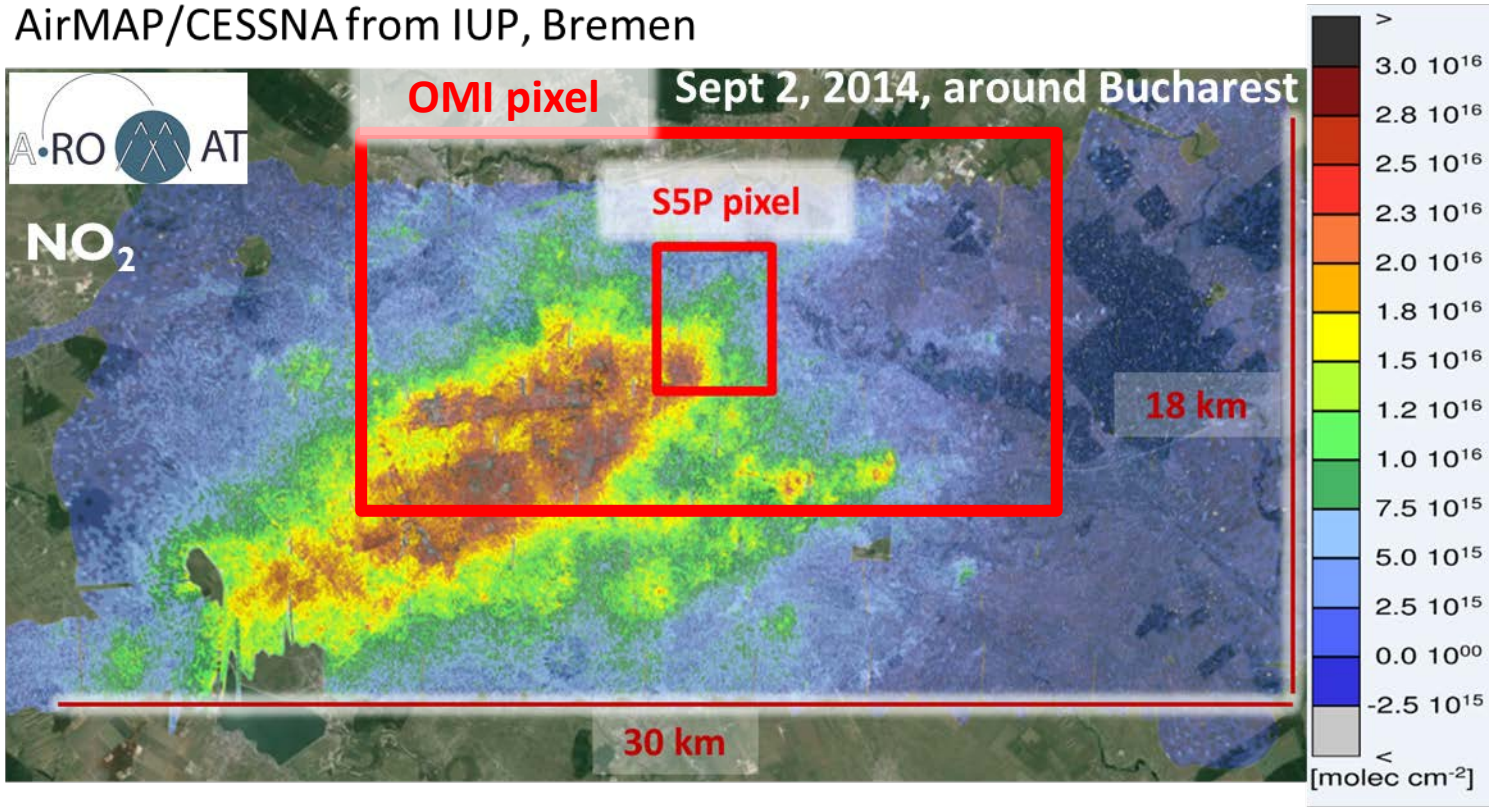
Courtesy F. Hendrick , C. Gielen

GOME-2 pixel

Airborne imaging systems

- Imaging DOAS systems on board of aircraft or UAVs
- Allow for high-resolution (satellite sub-pixel) mapping of pollutants
- Developments ongoing at BIRA and VITO on APEX and SWING experiments

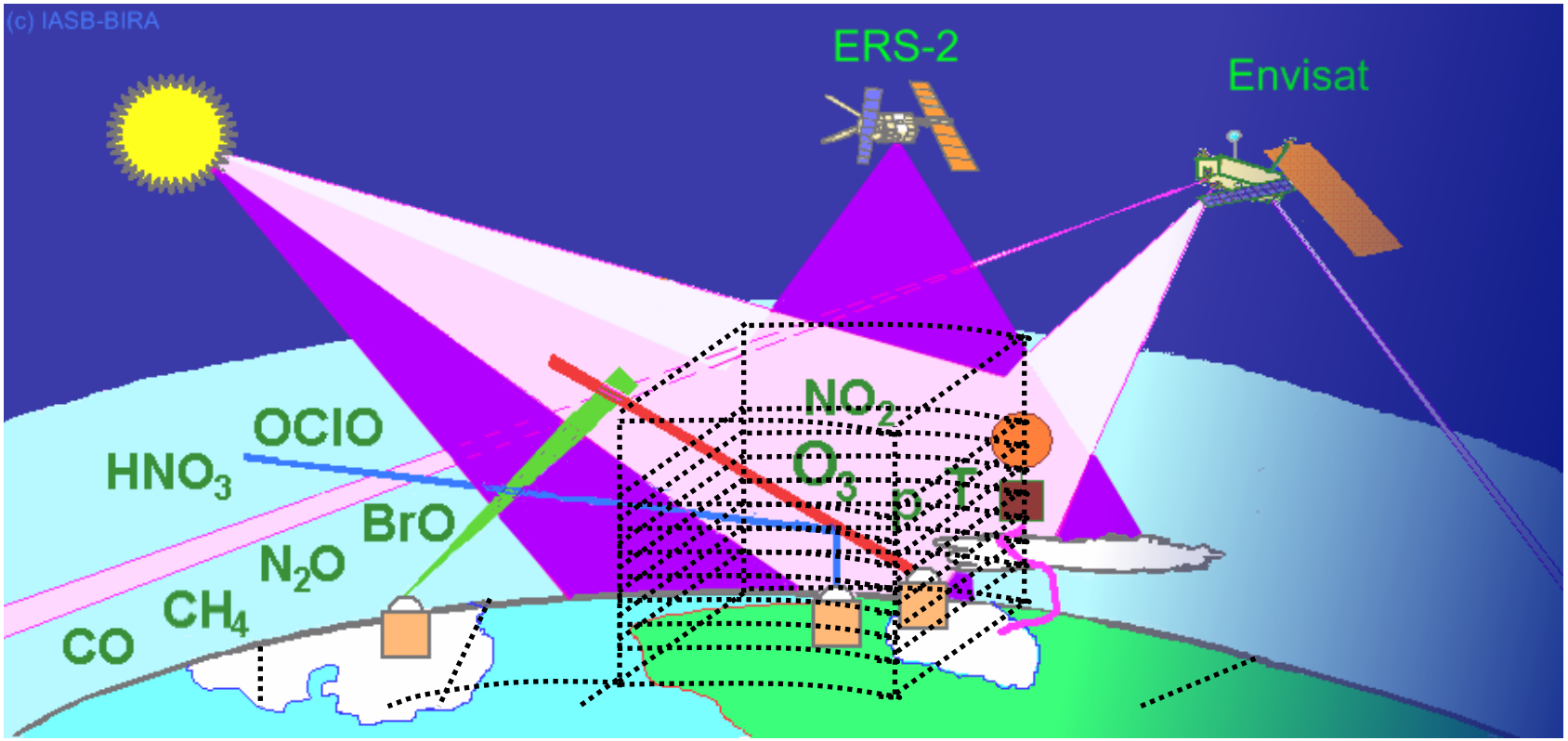
AirMAP/CESSNA from IUP, Bremen



Courtesy A. Richter, IUP Bremen

The Multi-TASTE validation system

Semi-automated, versatile system for the geophysical validation of atmospheric composition satellite data, using reference data from ground-based networks and balloons



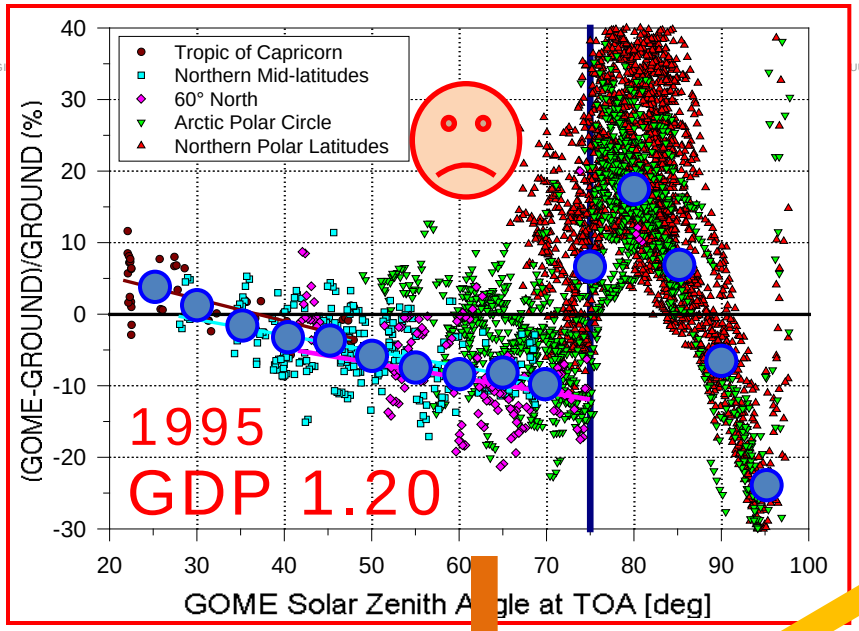
Credit: J.-C. Lambert

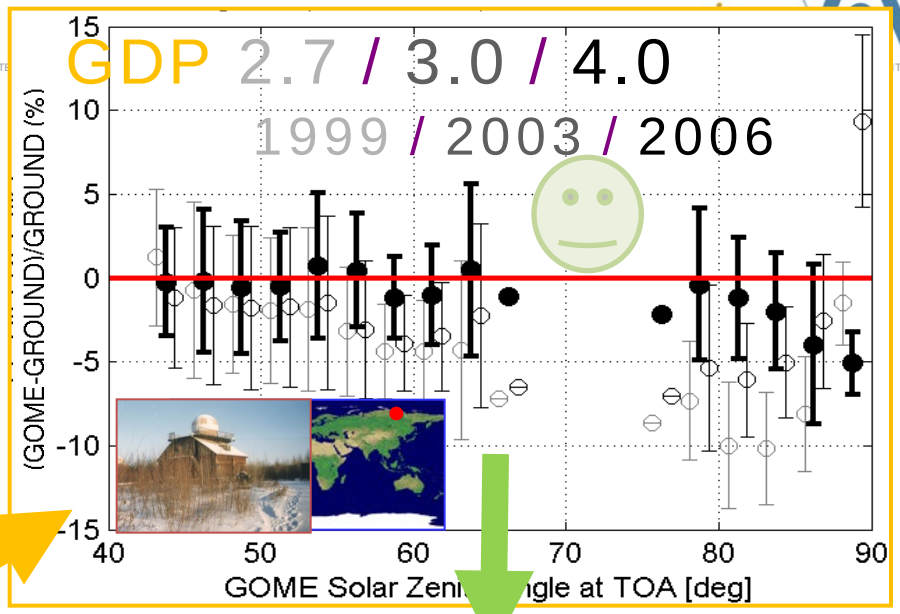
The Multi-TASTE validation system

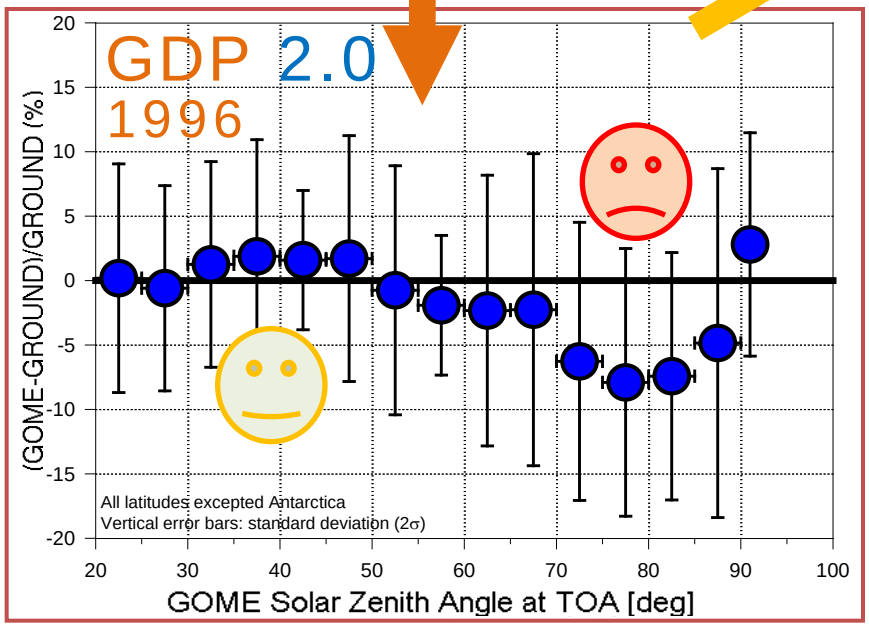
Chain of QA / Validation process

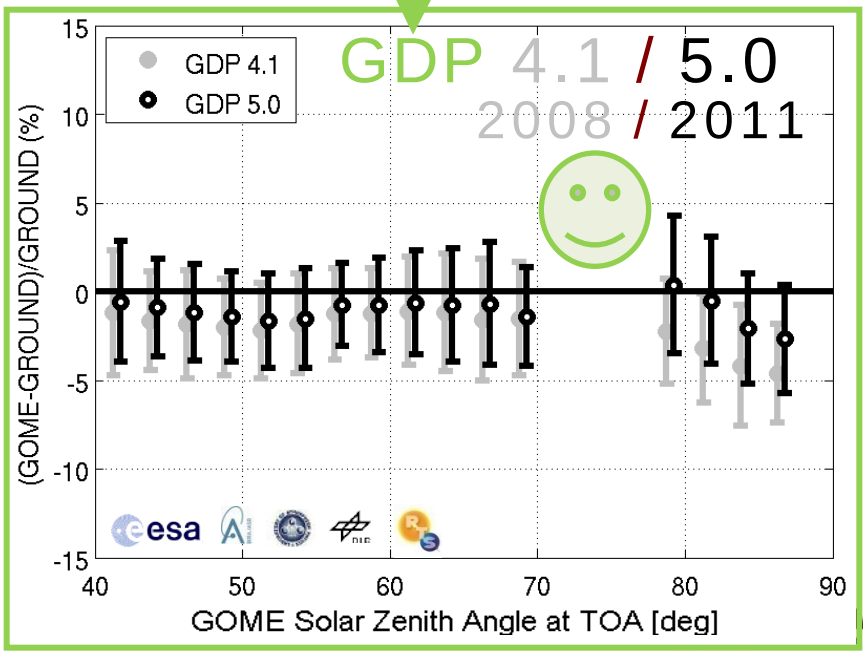
1. Translation of user requirements into validation requirements
2. Satellite data selection, filtering and post-processing
3. Data content study (DCS) of satellite dataset
4. Information content study (ICS) of satellite dataset
5. Selection and characterisation of correlative reference data
6. Identification and characterisation of co-located data pairs
7. Homogenization: Resampling, smoothing, and conversions of representation systems and units
8. Data comparisons: bias, spread, stability, dependences…
9. Derivation of appropriate Quality Indicators
10. Discussion of compliance with user requirements

Services: Support to data evolution



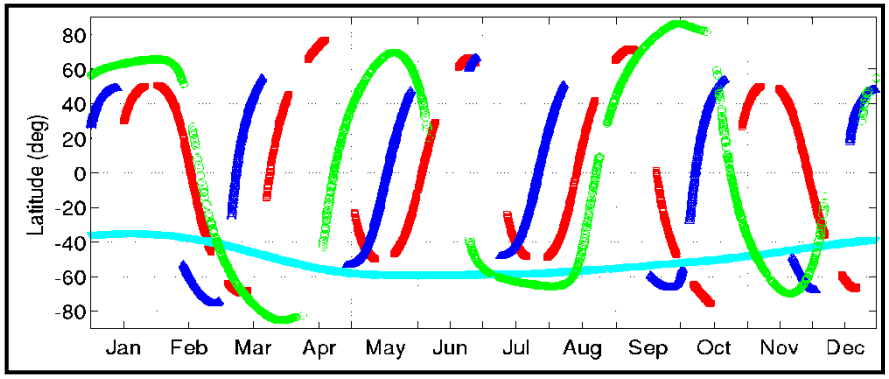




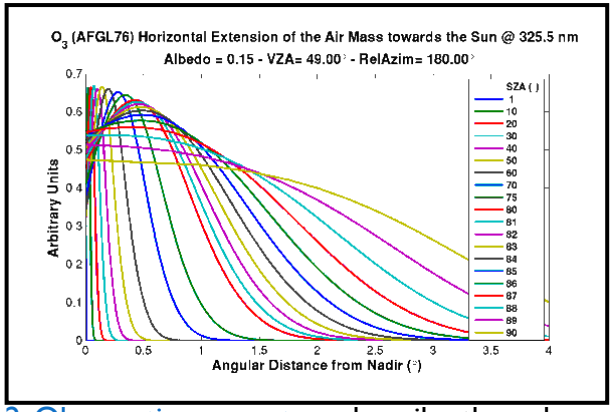


The OSSSMOSE metrology simulator

OSSE = Observing System Simulation Experiment

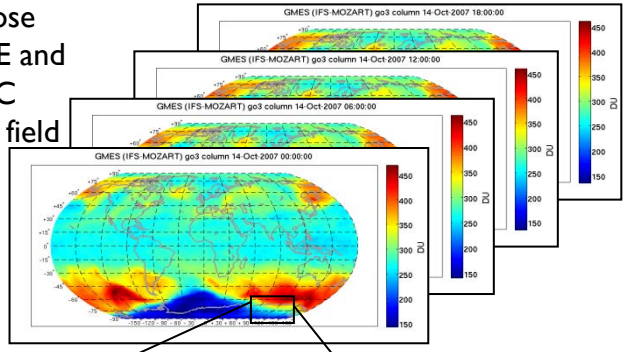


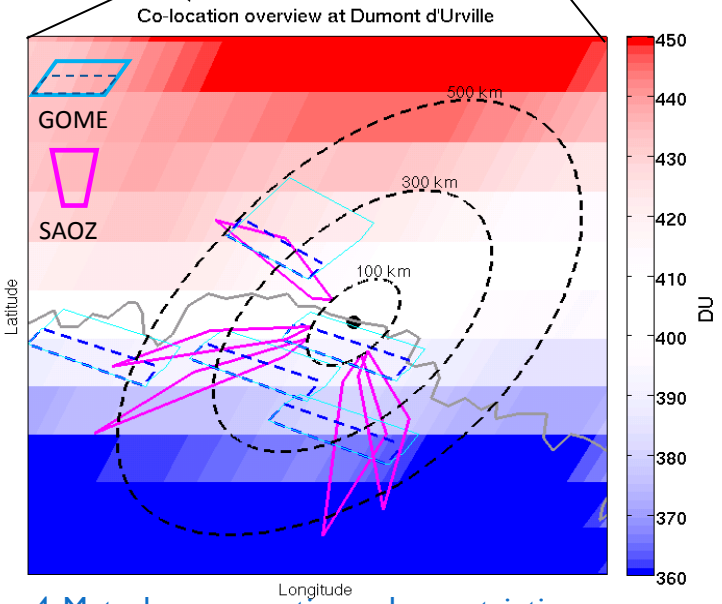
1. Observing system metadata describe the geolocalisation and time/date series of remotely sensed data acquired by the system (e.g., a network or satellite), including metrology driving parameters like solar elevation, swath width, cloud cover…



2. Observation operators describe the volume, weight and dependences of measurement sensitivity of the remotely sensed data.

3. Reanalysis such as those produced with BASCOE and IFS-MOZART for MACC provide the 4D gridded field of the target species.





4. Metrology properties and uncertainties (e.g., smoothing and sampling) are estimated by applying the metadata-driven observation operators on the modelled fields.

Services: Metrology

- Concepts, tools and methods for metrology type characterisation of remotely sensed data
  - Generic and specific studies using OSSSMOSE
  - Library of multi-dimensional observation operators
  - Library of methods for smoothing and sampling studies
- Data and Services Validation Protocols
  - ESA's GMES atmospheric service element
  - ESA's GECA Generic Environment for Cal/Val Analysis
  - Contribution to the establishment and implementation of the GEO-CEOS Quality Assurance framework for Earth Observation (QA4EO)
  - EC FP7 MACC-1/2 atmospheric core service
  - EC FP7 PASODOBLE air quality downstream services
  - ESA's CCI Ozone
  - EC FP7 QA4ECV QA/Validation system DPM
  - EC H2020 GAIA-CLIM climate observing system design

Conclusions

Current expertise and strengths:

- Stratospheric ozone observations and modelling --> BIRA is key player in Atmospheric Copernicus Service (CAMS) and ESA CCI
- Tropospheric gases observations --> BIRA is key player in algorithm developments, and strongly involved in the preparation of future missions (e.g. Sentinels)
- QA/validation --> BIRA strongly involved in establishment of reference ground-based systems (MAXDOAS) and advanced exploitation of them for assessment of existing and future missions (e.g. OSSSMOSE OSSE)

Focus for future activities:

- Reinforce BIRA role in Copernicus Atmosphere Service, incl. scientific developments for Sentinel atmospheric products
- Further develop ground-truthing methods and services necessary for future missions, including airborne (UAV) techniques
- Explore ways to better address study of chemistry-climate interactions

Acknowledgements

Atmospheric Composition – Reactive Gases

H. Brenot
T. Danckaert
I. De Smedt
C. Fayt
C. Gielen
F. Hendrick
C. Hermans
C. Lerot
A. Merlaud
G. Pinardi
F. Tack
N. Theys
J. van Gent
H. Yu

J.C. Lambert (D32 Lead)

A. De Rudder
J. Granville
D. Hubert
A. Keppens
T. Verhoelst

Q. Errera (D33 Lead)

S. Skachko

S. Chabrillat (D34 Lead)

E. Botek
Y. Christophe

Thank you for your attention!