30 YEARS 1986-2016

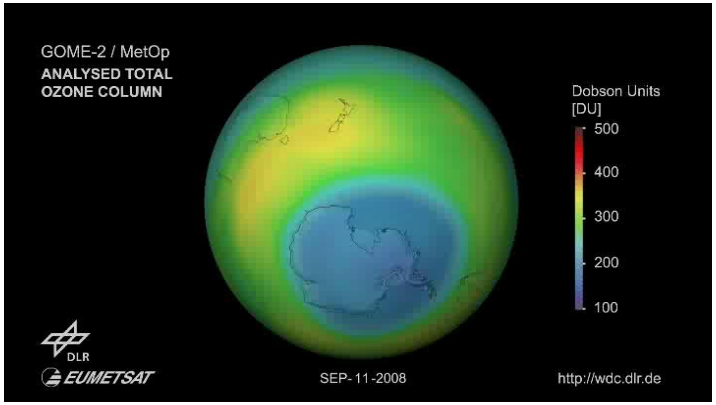
EUMETSAT

Monitoring of trace-gases, pollution and aerosols with EUMETSAT satellite instruments

Ruediger Lang

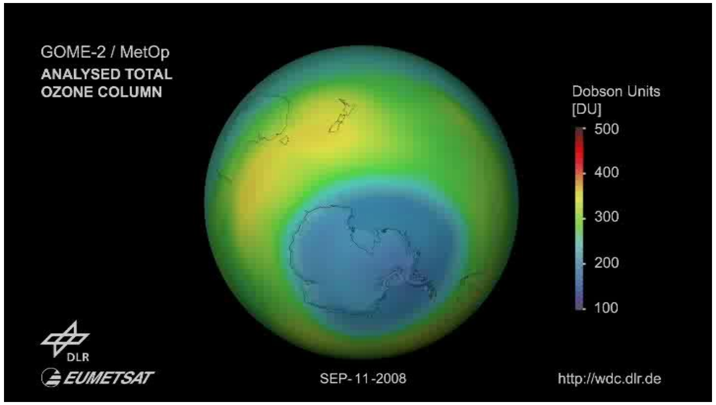
Rosemary Munro, Christian Retscher, Gabriele Poli, Andriy Holdak, Michael Grzegorski, Roger Huckle, Rasmus Lindstrot, Alexander Kokhanovsky

Atmospheric composition

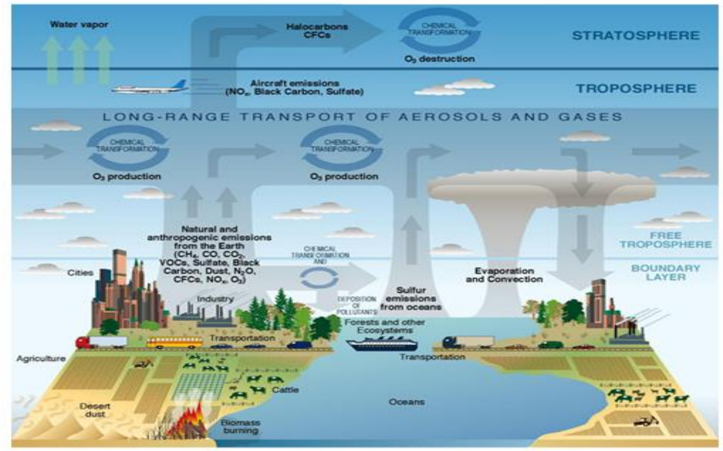


Stratospheric Ozone & Ozone Depletion Monitoring

Atmospheric composition



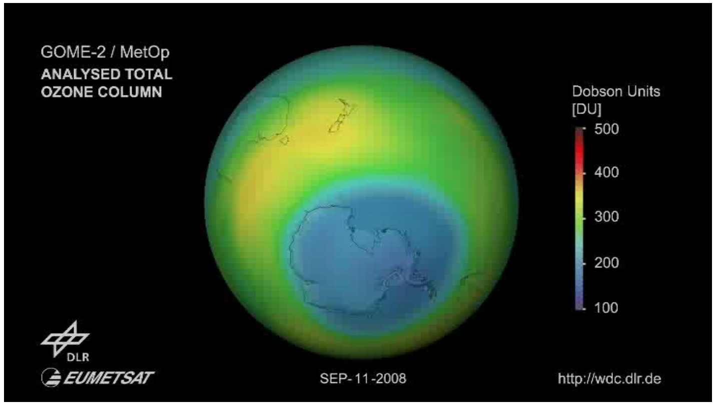
Stratospheric Ozone & Ozone Depletion Monitoring



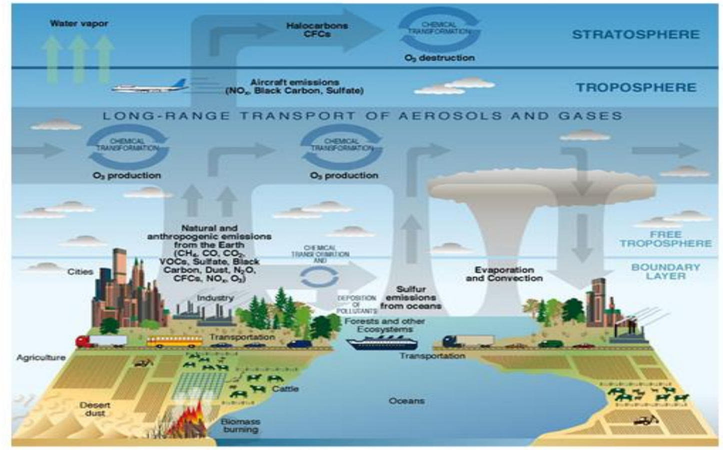
U.S. Global Change Research Program (www.globalchange.gov) / NCU

Air Quality Monitoring & Forecasting

Atmospheric composition



Stratospheric Ozone & Ozone Depletion Monitoring

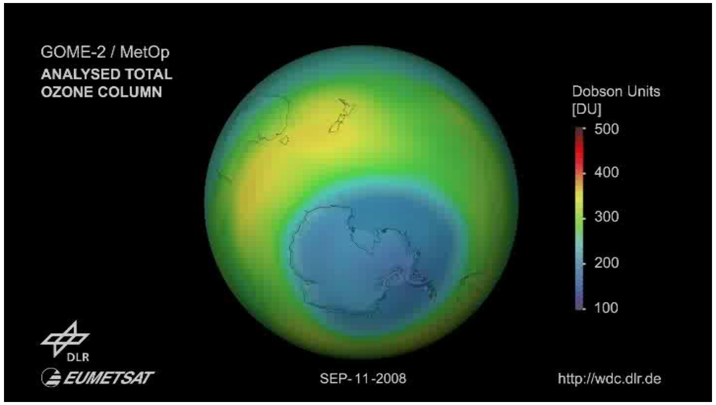


U.S. Global Change Research Program (www.globalchange.gov) / NCU

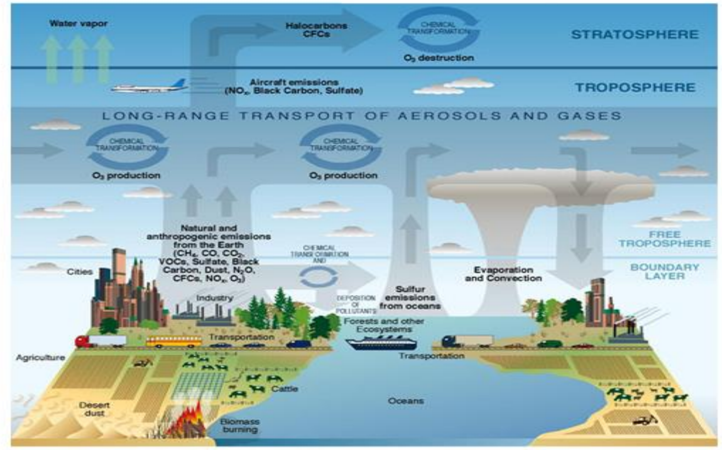
Air Quality Monitoring & Forecasting

Biomass Burning

Atmospheric composition



Stratospheric Ozone & Ozone Depletion Monitoring



U.S. Global Change Research Program (www.globalchange.gov) / NCU

Air Quality Monitoring & Forecasting

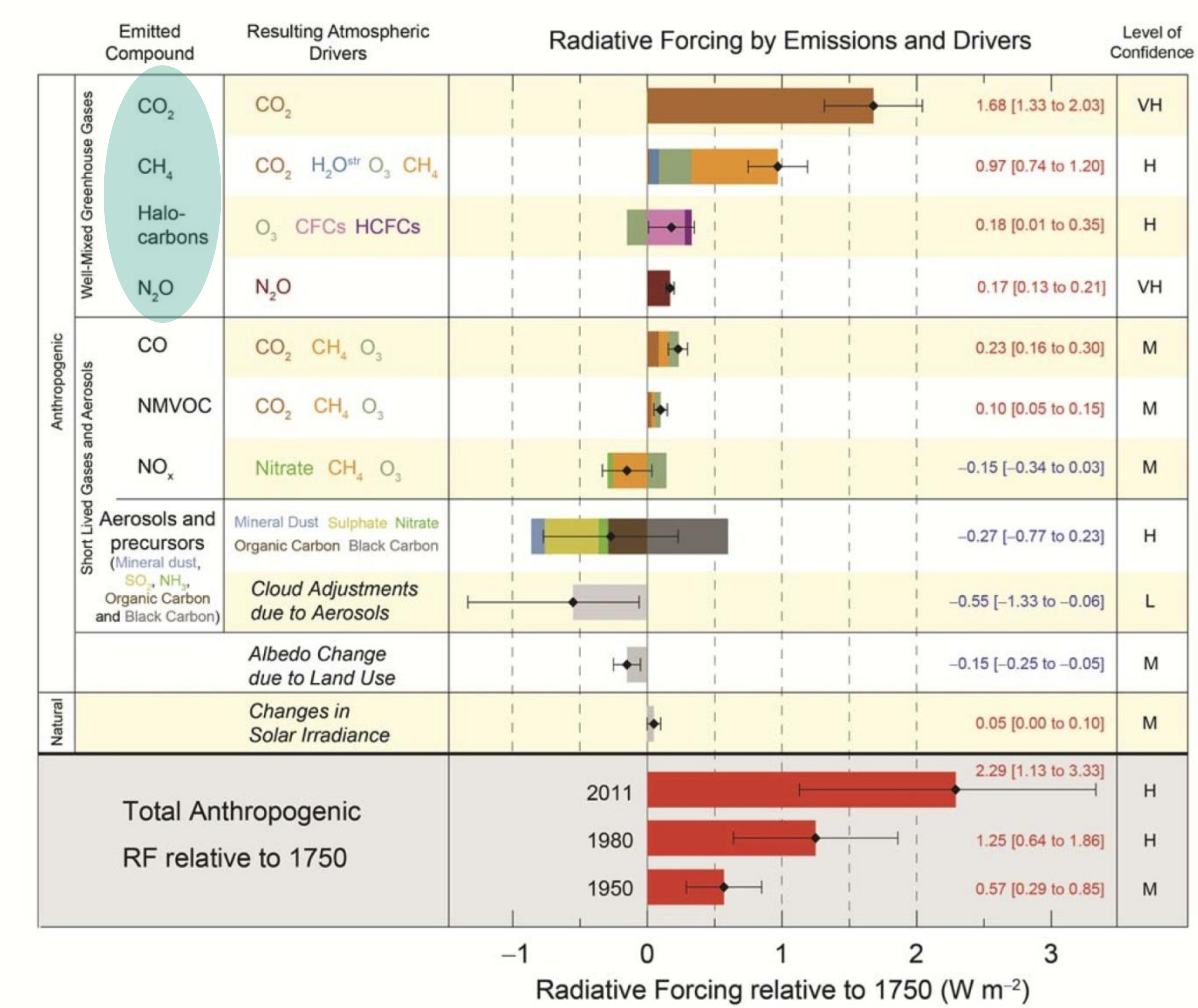
Biomass Burning

Aerosols and Volcanic Emissions

Atmospheric Composition-Climate Interaction

Primary emissions that are responsible for anthropogenic climate change are:

- **Greenhouse Gases (CO2, CH4, Halocarbons, N2O)**

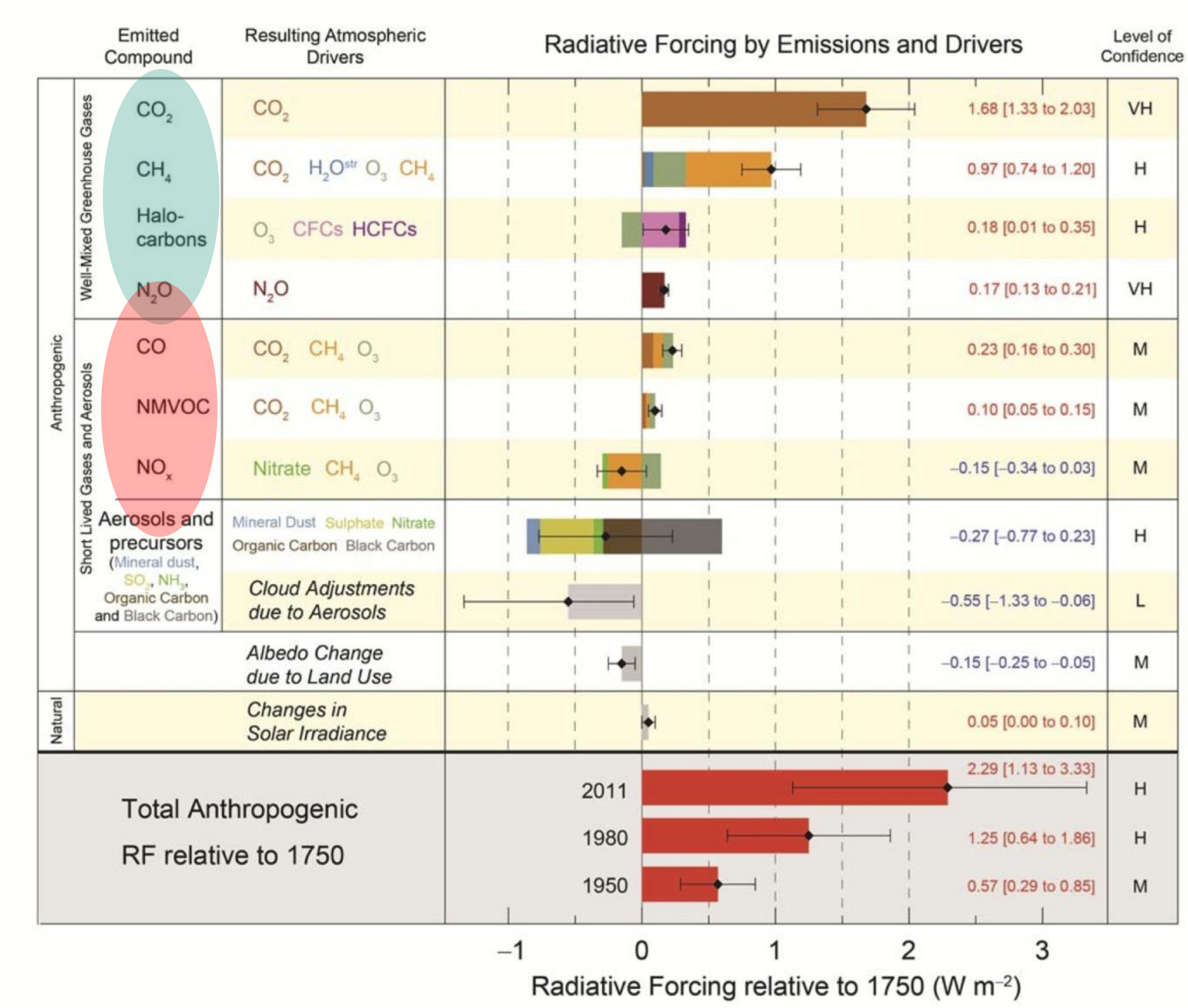


IPCC 2013

Atmospheric Composition-Climate Interaction

Primary emissions that are responsible for anthropogenic climate change are:

- **Greenhouse Gases (CO2, CH4, Halocarbons, N2O)**
- **Short lived reactive gases (CO NMVOC, NOx)**

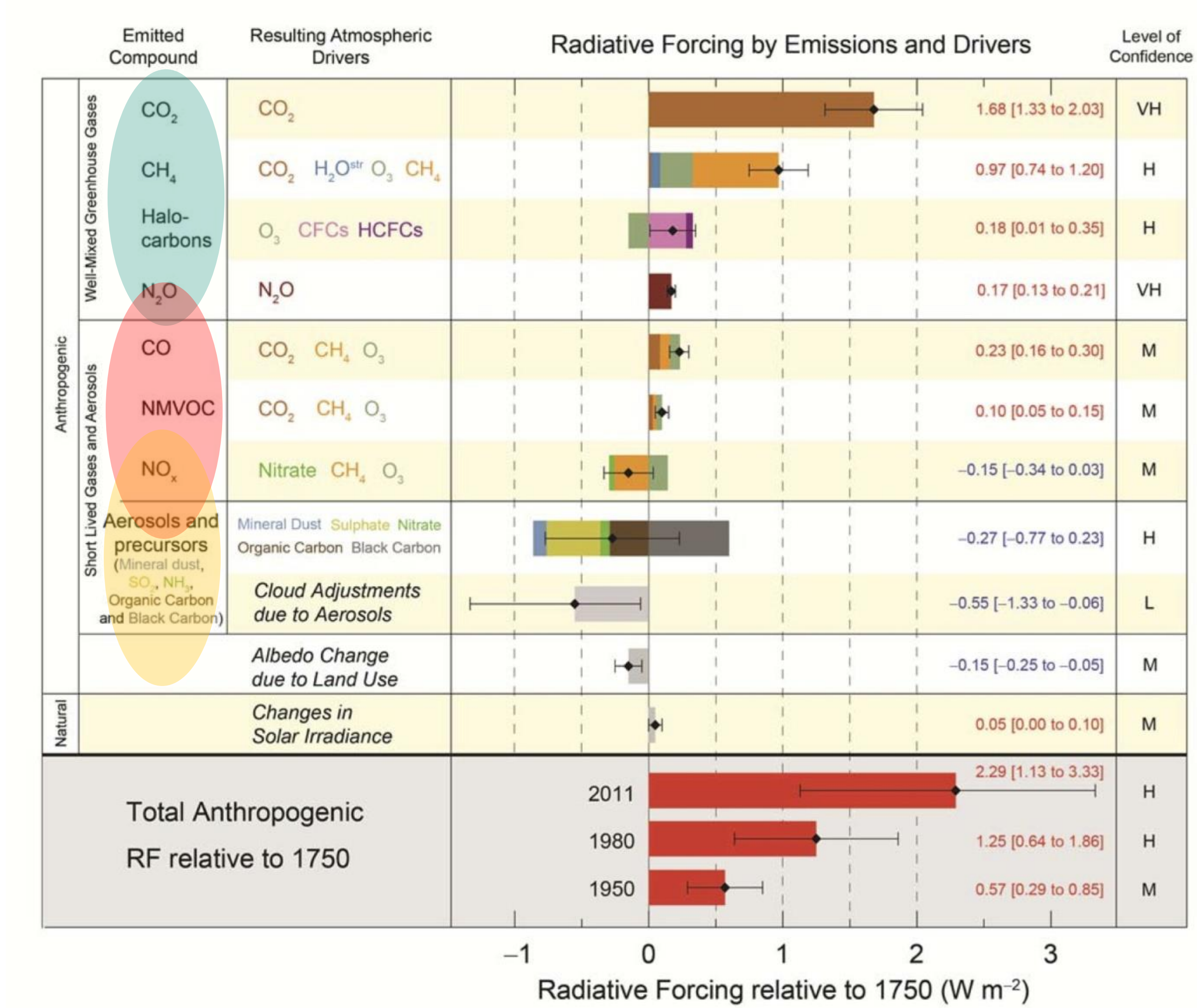


IPCC 2013

Atmospheric Composition-Climate Interaction

Primary emissions that are responsible for anthropogenic climate change are:

- **Greenhouse Gases (CO_2, CH_4, Halocarbons, N_2O)**
- **Short lived reactive gases (CO NMVOC, NOx)**
- **Aerosols**

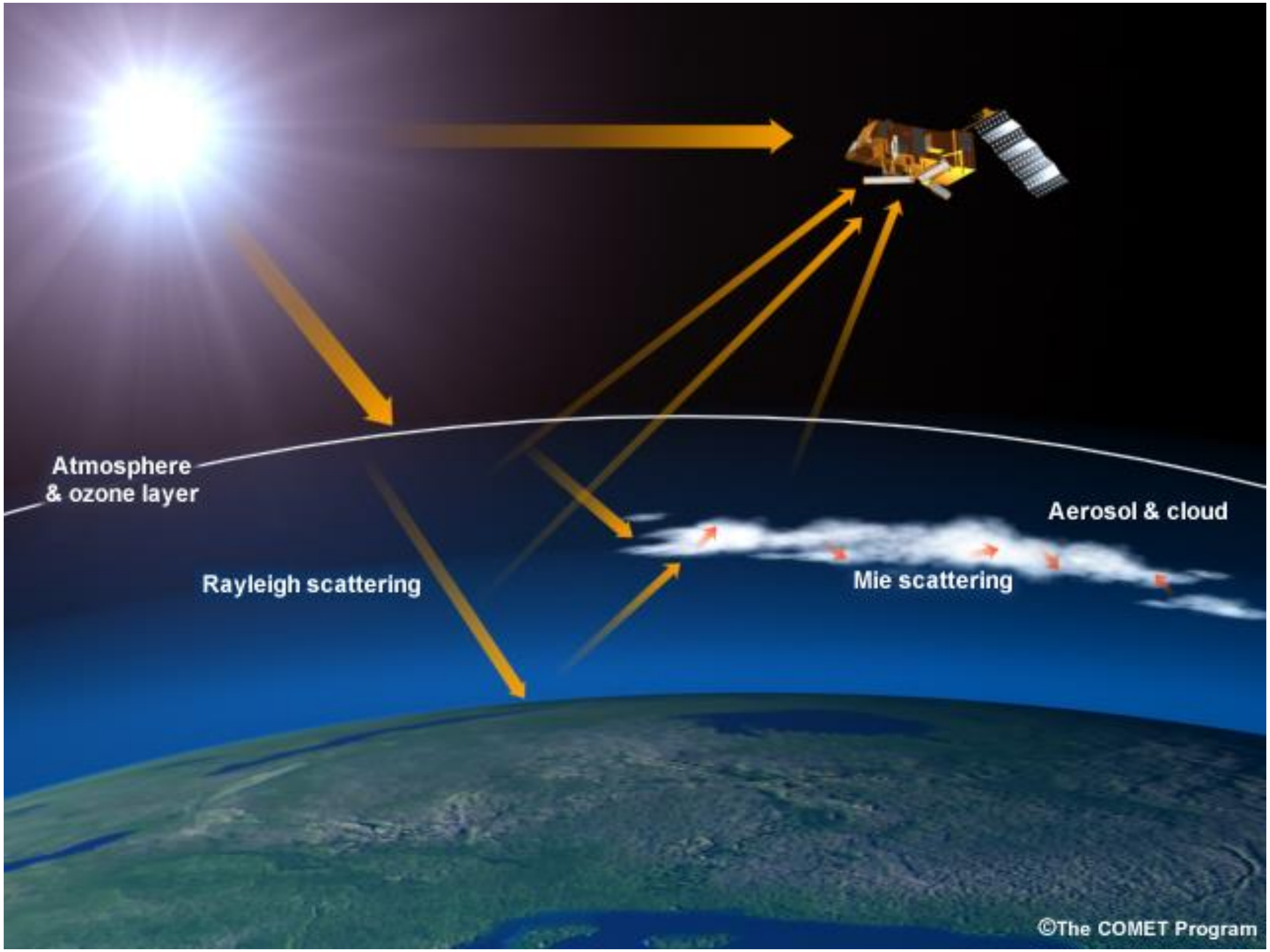


IPCC 2013

Atmospheric composition measurement Techniques UV/Visible/NIR/SWIR (UVNS) Solar Backscatter

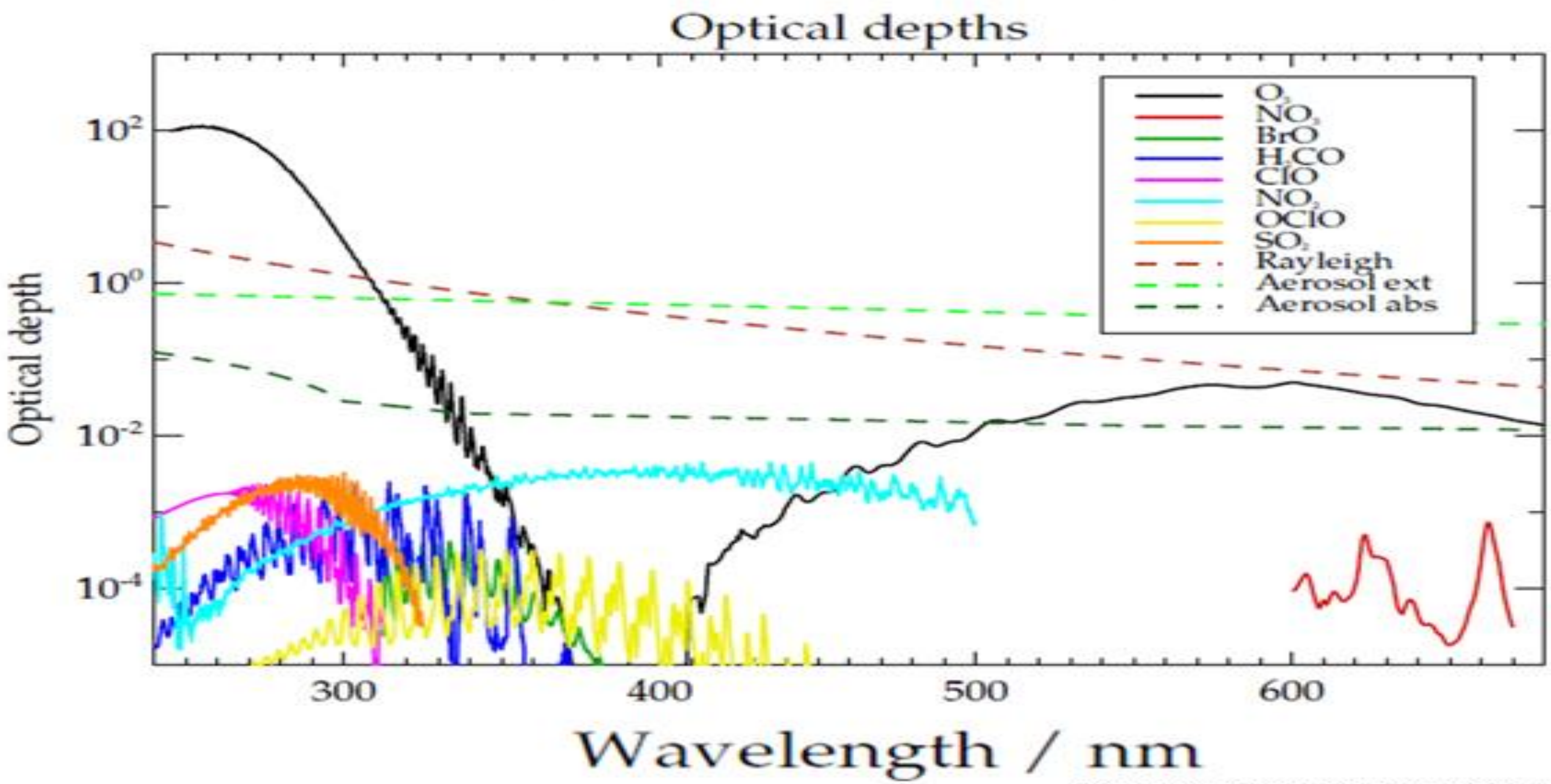
Radiative transfer calculations must take account of scattering by molecules (Rayleigh scattering) and (multiple) scattering by particles and clouds (Mie scattering).

The polarization state of the light after each scatter event also influences the observed total top-of-atmosphere (TOA) radiance especially in the UV-vis.



Atmospheric composition measurement Techniques:
UV/Visible Solar Backscatter

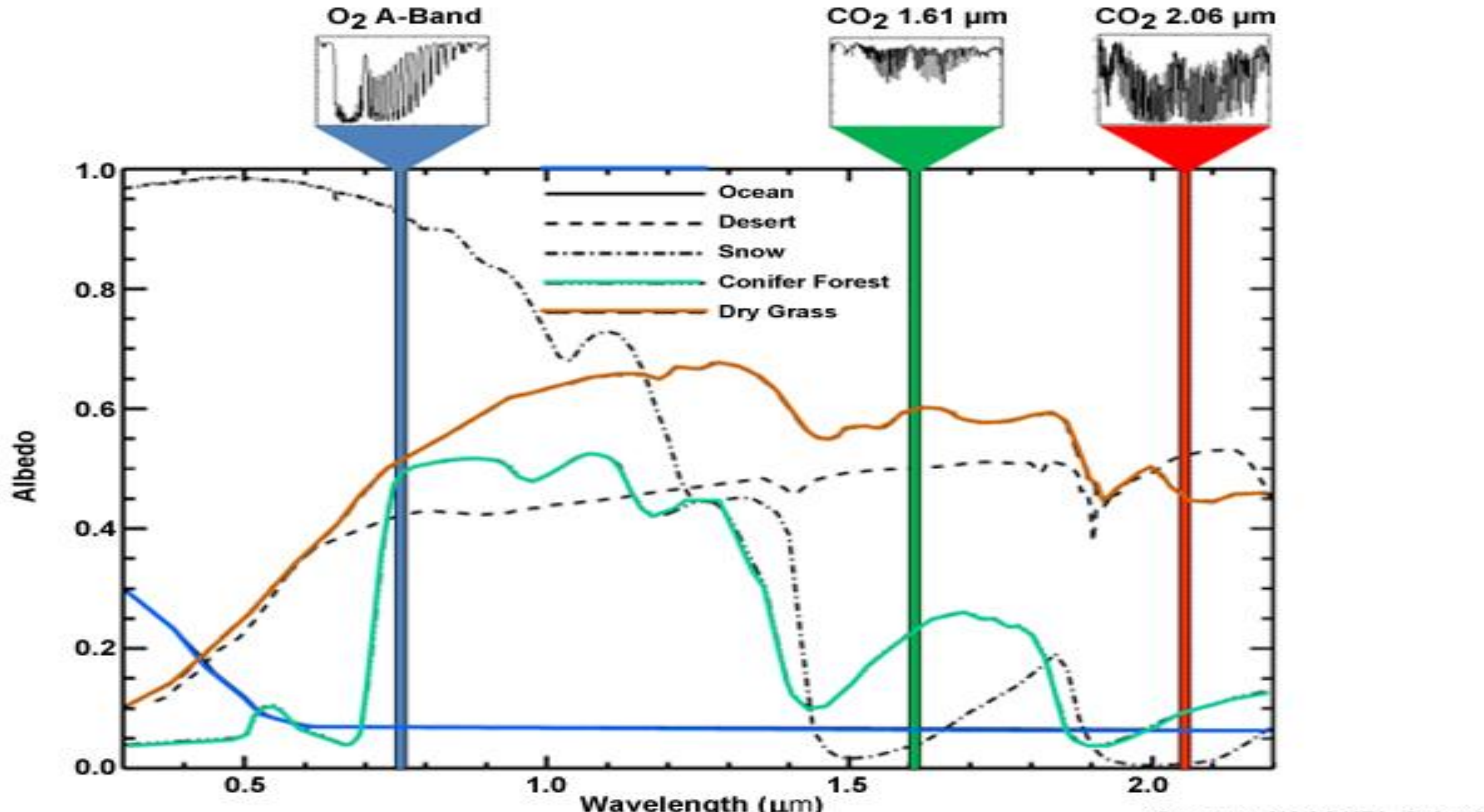
Trace gas signatures in UV/visible region



Courtesy of Brian Kerridge, STFC/RAL, UK / NCU

Many trace gases are measured in the UV/Visible spectral range.

Atmospheric composition measurement techniques
Visible/NIR to SWIR Solar Backscatter

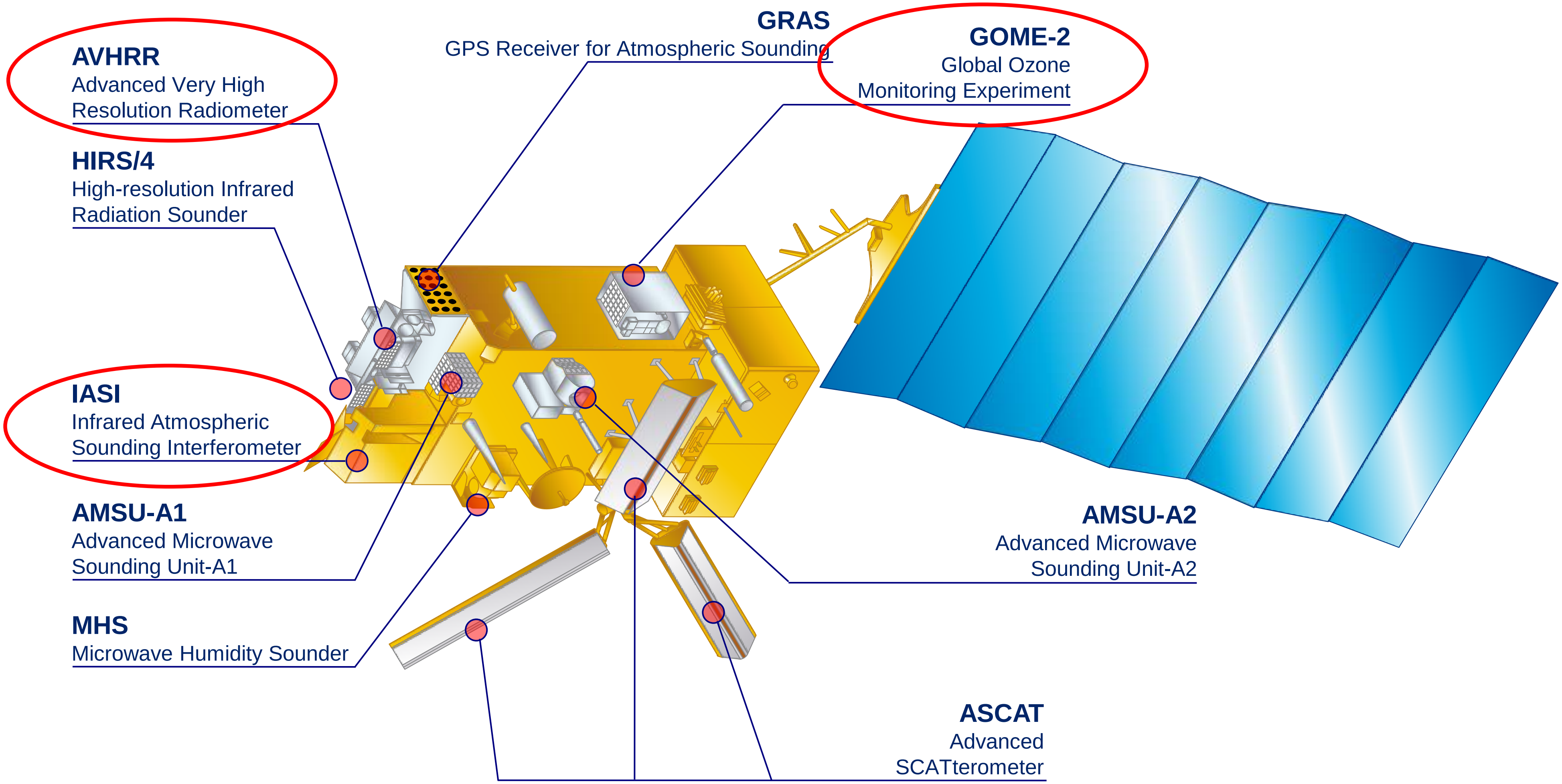


Courtesy NASA/JPL-Caltech

- Measurements made in the shortwave infrared can be used to measure CO, CH_4, and CO_2
- In the SWIR there is still a contribution to the signal measured from solar radiation back-scattered at the surface.
- Signal levels (particularly over the ocean) are very low, and over the land an accurate knowledge of the land cover type and wavelength-dependent surface albedo is required.

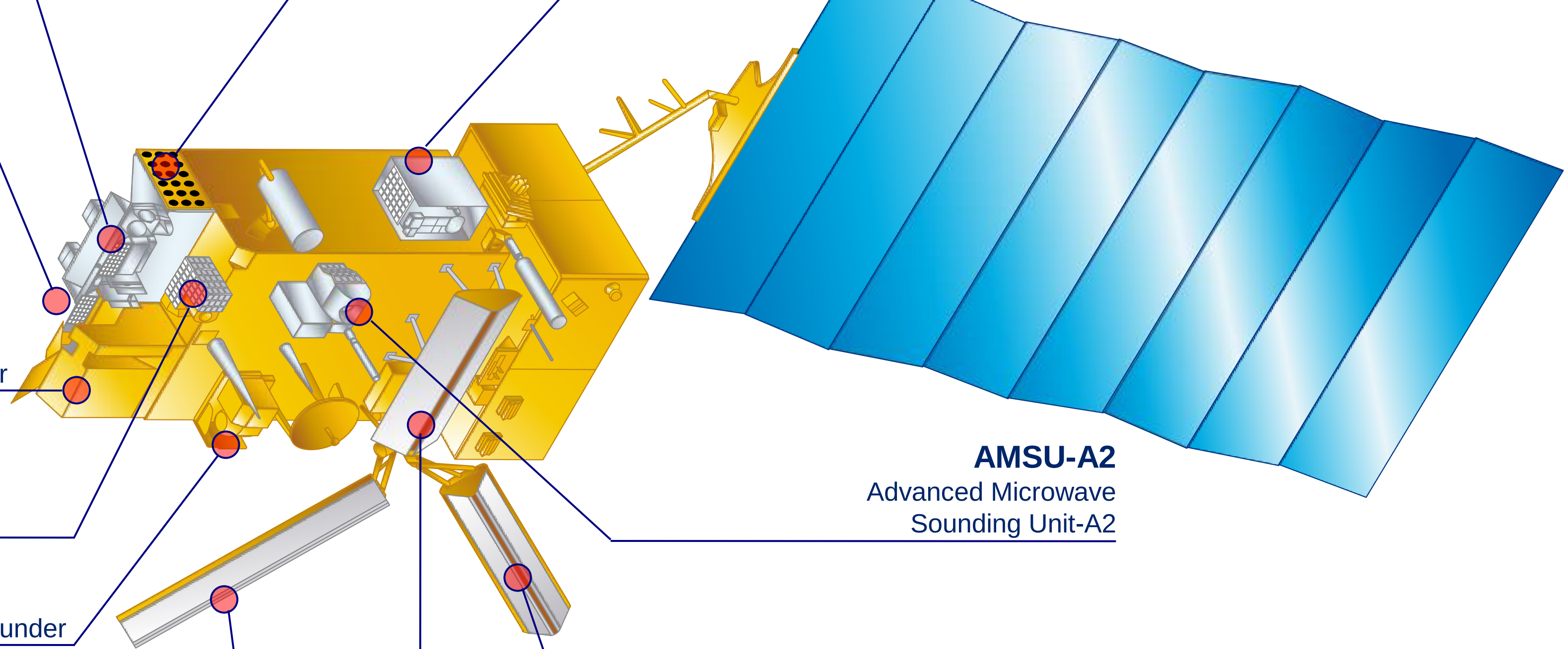
EUMETSAT Current and Future Missions for atmospheric composition

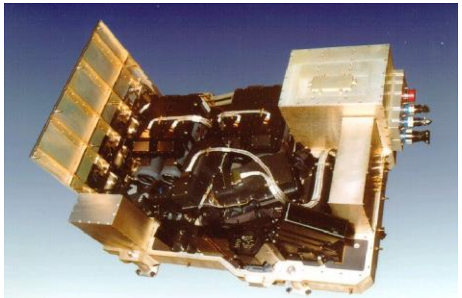
Metop (2006 – present)



EUMETSAT Current and Future Missions for atmospheric composition

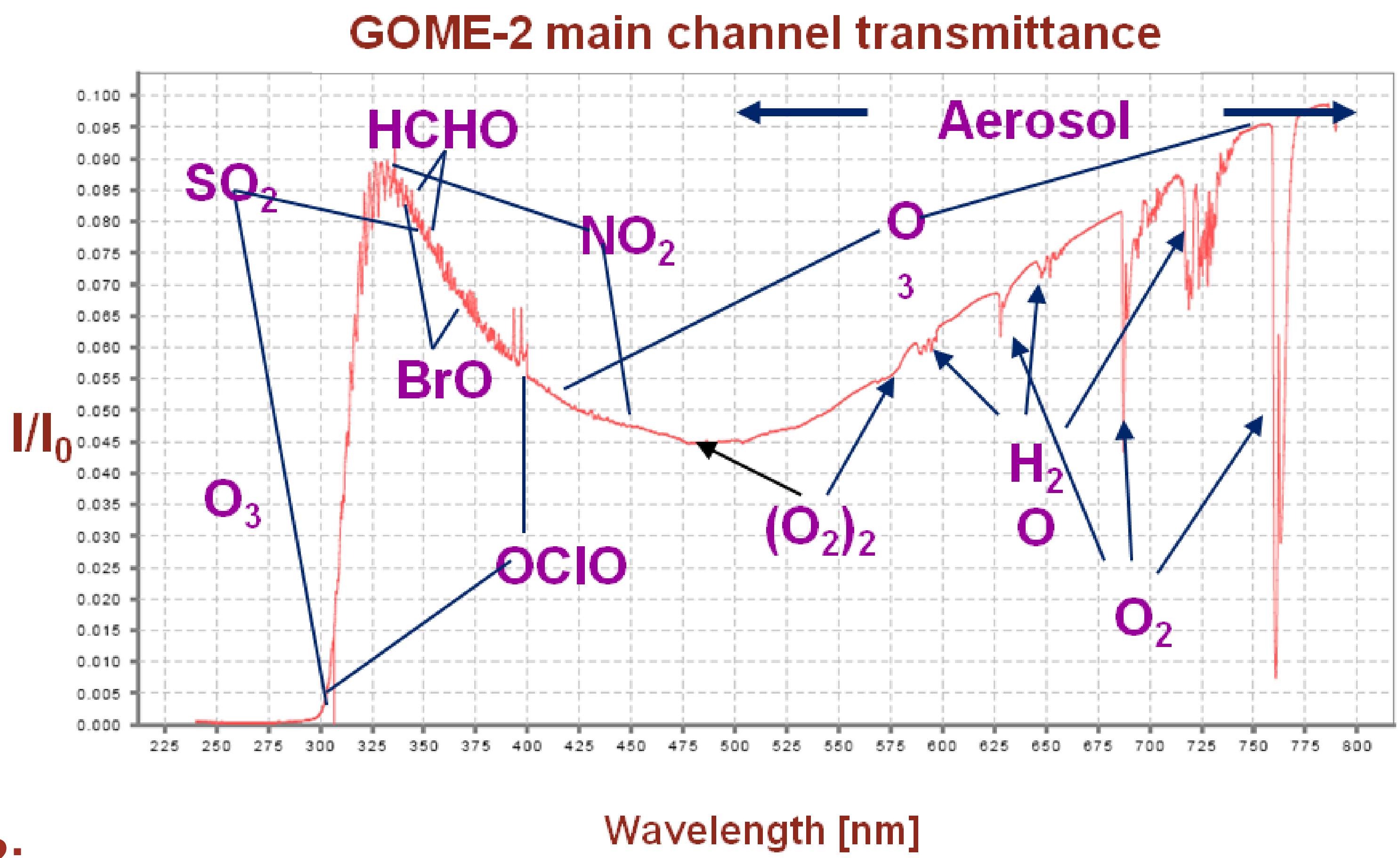
Metop (2006 – present)





The GOME-2 instrument on Metop

Measuring atmospheric composition from space



GOME-2:

- 4 channels with 4098 energy measurements of polarisation corrected radiances (40 x 80 km^2)
- 2 channels with 512 energy measurements of linear polarised light in perpendicular direction (S/P) (40 x 10 km^2)

EUMETSAT Current and Future Missions for atmospheric composition

30 YEARS 1986-2016

AVHRR
Advanced Very High Resolution Radiometer

HIRS/4
High-resolution Infrared Radiation Sounder

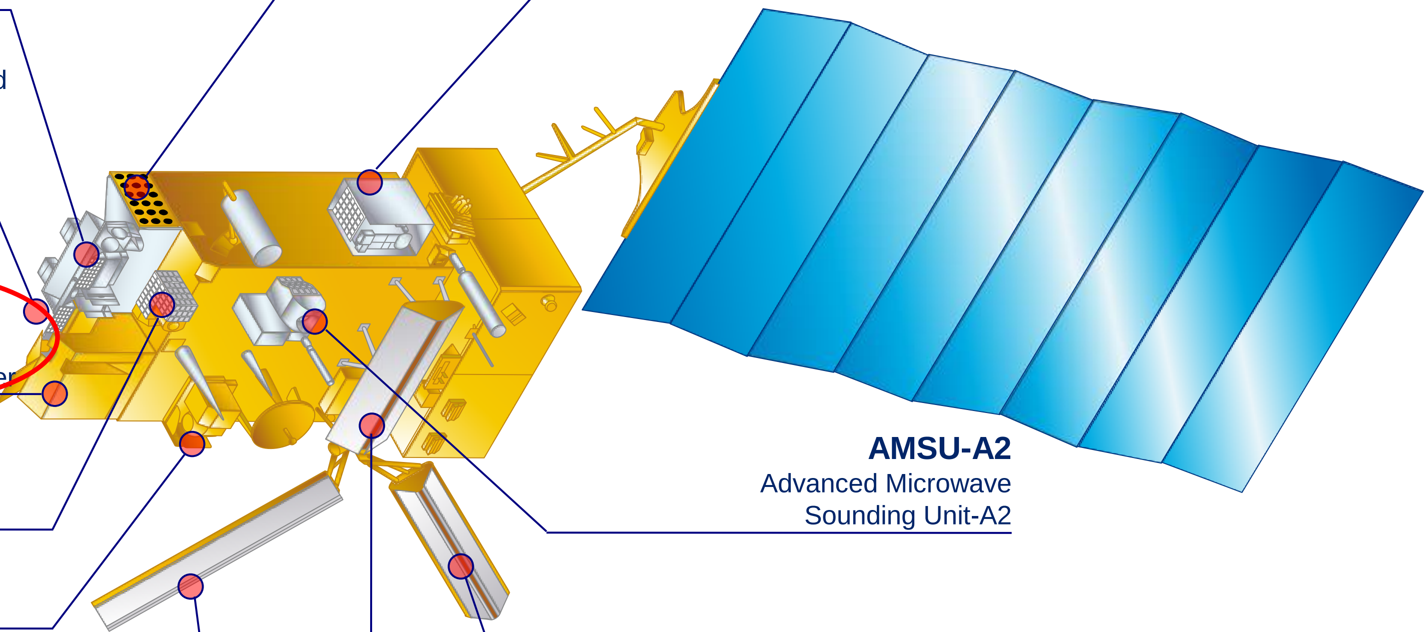
IASI
Infrared Atmospheric Sounding Interferometer

AMSU-A1
Advanced Microwave Sounding Unit-A1

MHS
Microwave Humidity Sounder

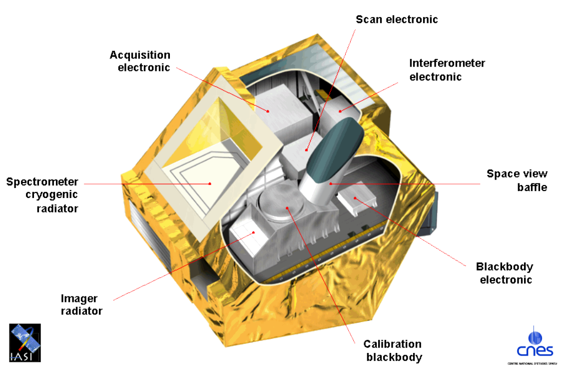
GRAS
GPS Receiver for Atmospheric Sounding

GOME-2
Global Ozone Monitoring Experiment



AMSU-A2
Advanced Microwave Sounding Unit-A2

ASCAT
Advanced SCATterometer

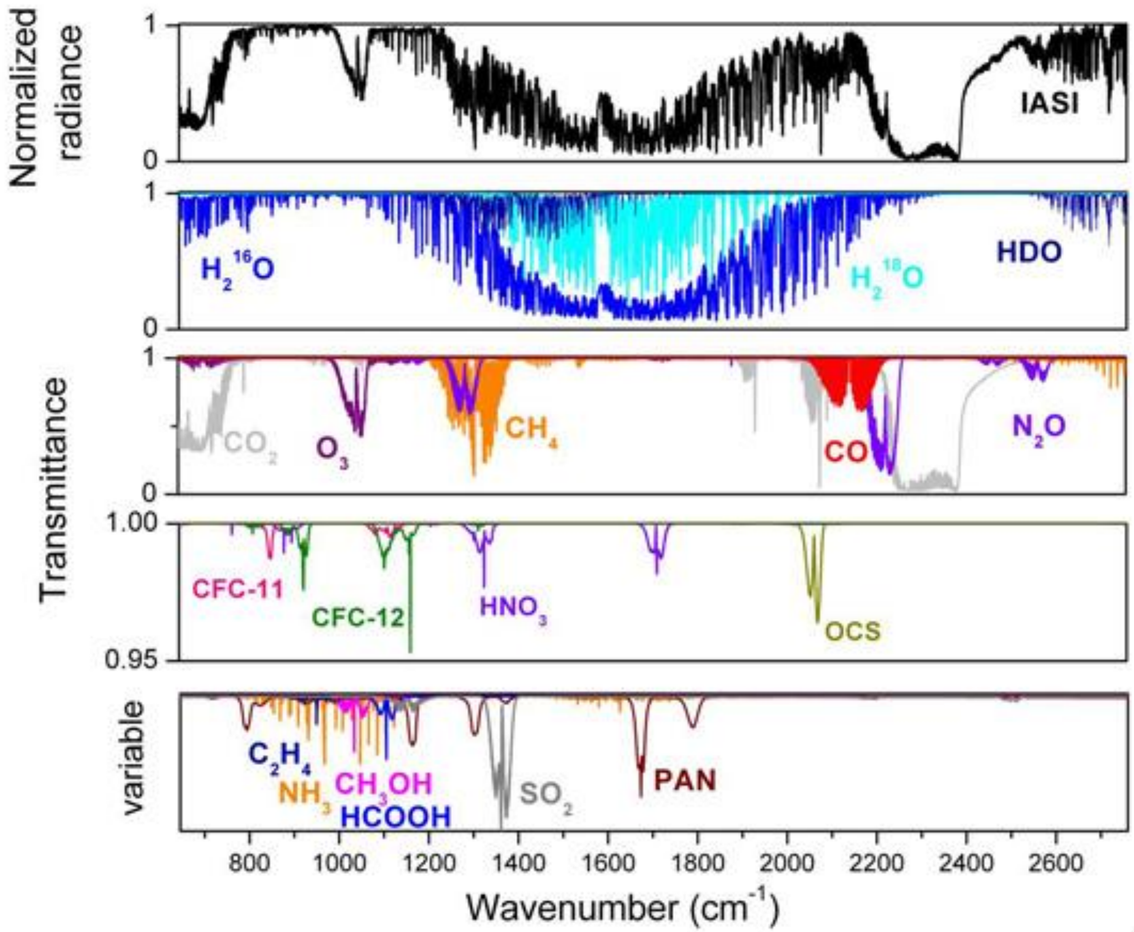


Metop (2006 – present)

EUMETSAT

Atmospheric composition measurement Techniques Thermal Infrared

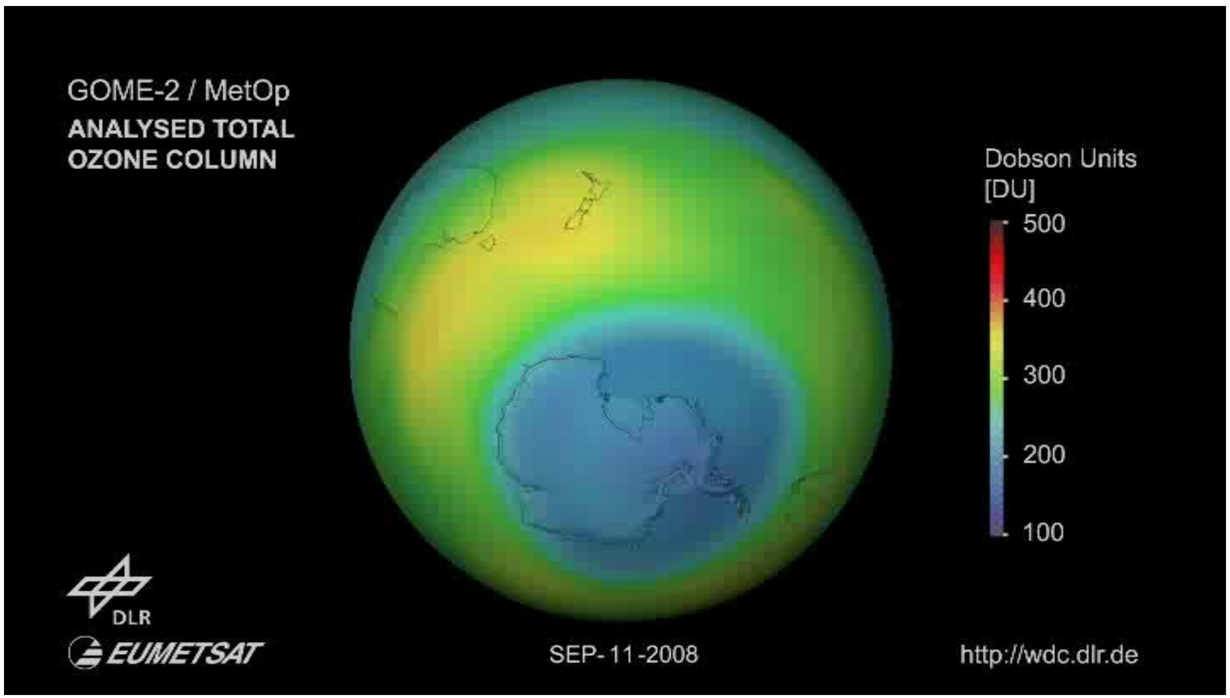
Instruments measuring in the thermal infrared part of the spectrum also collect data on a large array of atmospheric trace gases.



Stratospheric Ozone Monitoring & Ozone Depletion

Stratospheric ozone has been monitored from space since the 1970's when the ozone hole over the South Pole was first observed by ground-based systems.

Stratospheric ozone depletion is driven by ozone-depleting substances (ODS's)



Large losses of total ozone in Antarctica reveal seasonal ClO_x/NO_x interaction

J. C. Farman, B. G. Gardiner & J. D. Shanklin

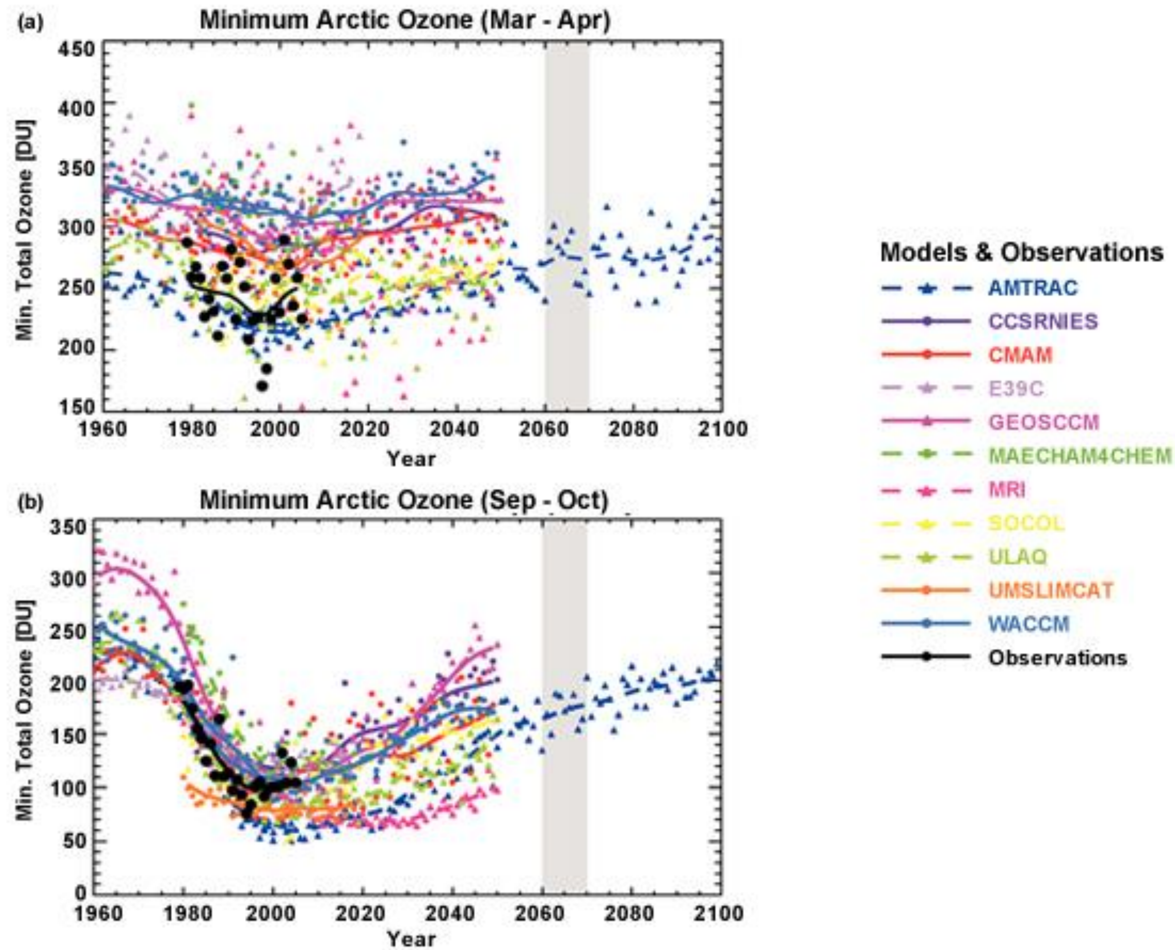
British Antarctic Survey, Natural Environment Research Council, High Cross, Madingley Road, Cambridge CB3 0ET, UK

Recent attempts[1,2] to consolidate assessments of the effect of human activities on stratospheric ozone (O_3) using one-dimensional models for 30° N have suggested that perturbations of total O_3 will remain small for at least the next decade. Results from such models are often accepted by default as global estimates[3]. The inadequacy of this approach is here made evident by observations that the spring values of total O_3 in Antarctica have now fallen considerably. The circulation in the lower stratosphere is apparently unchanged, and possible chemical causes must be considered. We suggest that the very low temperatures which prevail from midwinter until several weeks after the spring equinox make the Antarctic stratosphere uniquely sensitive to growth of inorganic chlorine, ClX, primarily by the effect of this growth on the NO_2/NO ratio. This, with the height distribution of UV irradiation peculiar to the polar stratosphere, could account for the O_3 losses observed.

Total O_3 has been measured at the British Antarctic Survey stations, Argentine Islands 65° S 64° W and Halley Bay 76° S 27° W, since 1957. Figure 1*a* shows data from Halley Bay.

Stratospheric Ozone Monitoring & Ozone Depletion

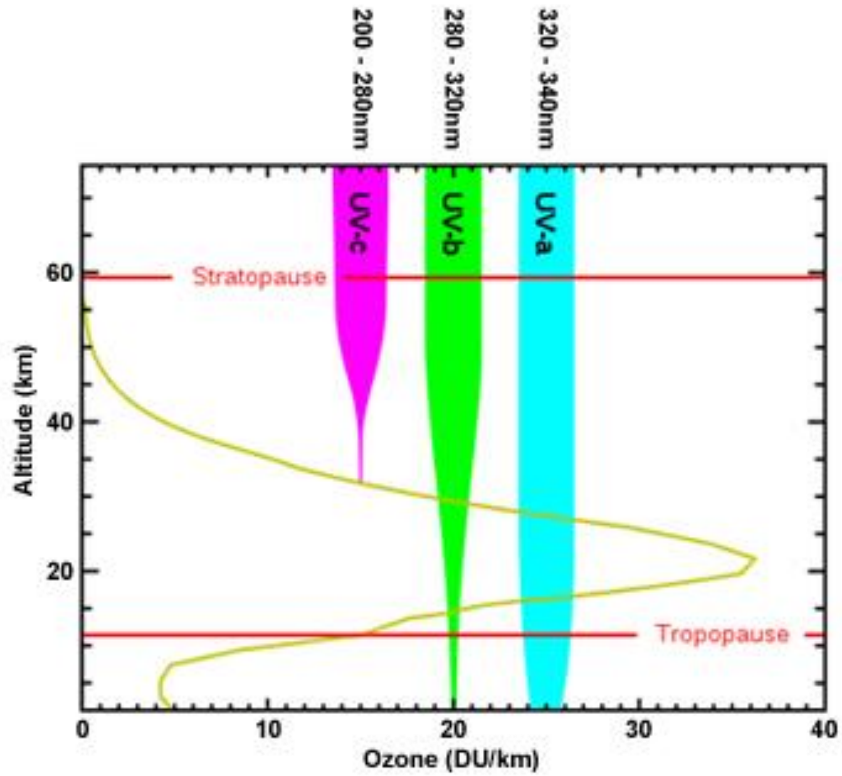
- Climate change could alter atmospheric circulation and temperature, which could affect stratospheric ozone recovery.
- Model predictions of future ozone including climate change effects do not yet give a fully consistent picture.
- Continued monitoring of the stratospheric ozone layer remains essential.



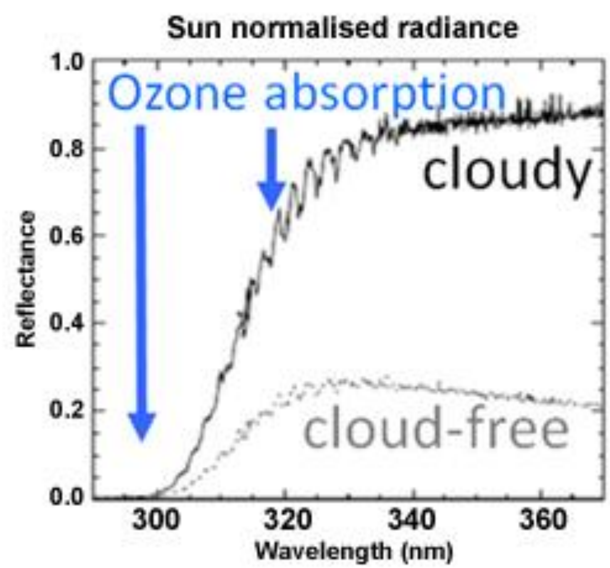
Climate Change 2007: The Physical Science Basis. Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Figure 7-18. Cambridge University Press.

Stratospheric Ozone Monitoring & Ozone Depletion

Ozone Absorption in the Atmosphere



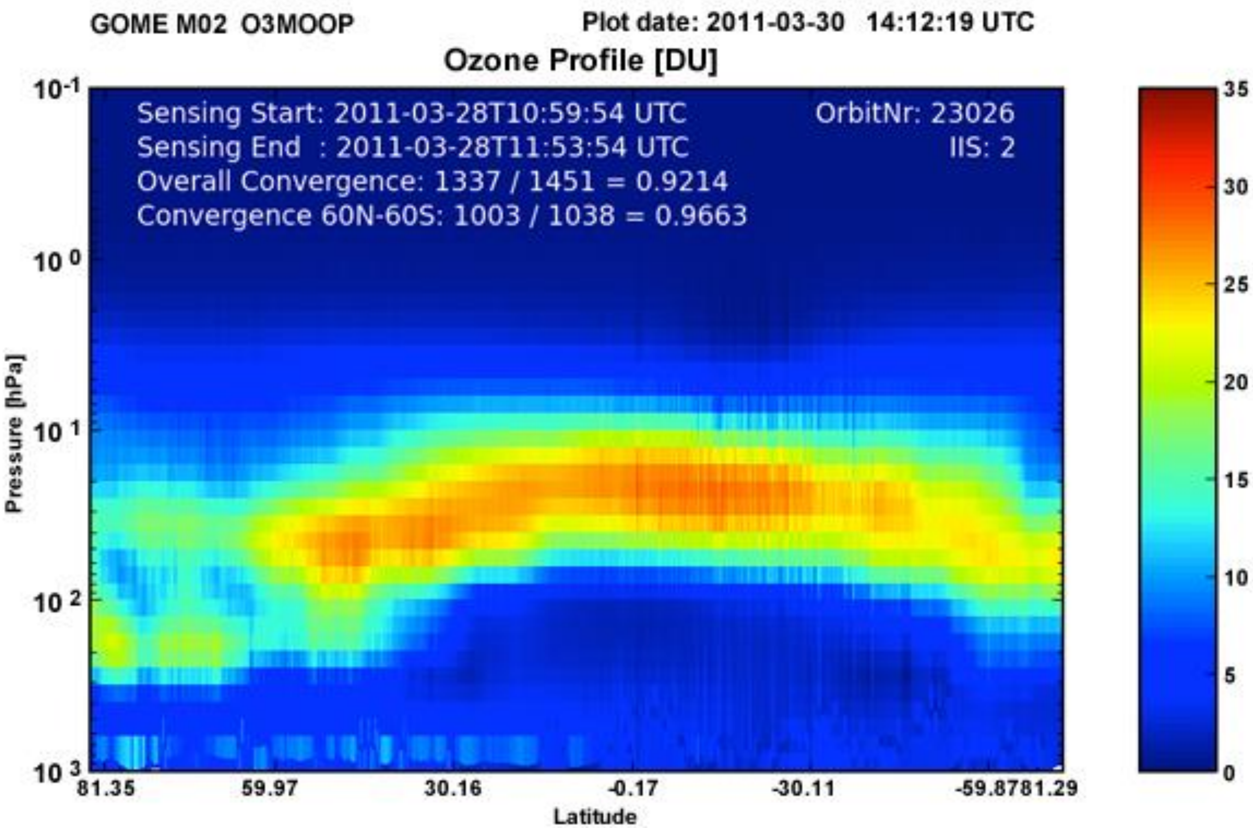
Ozone profiles retrievals from nadir looking sensors like GOME-2/Metop

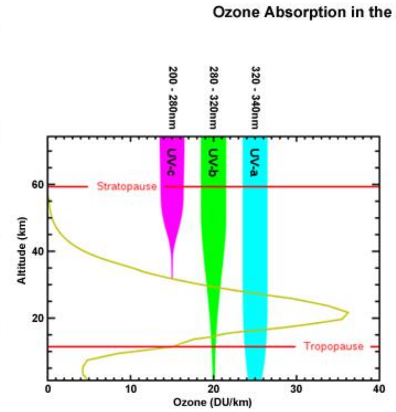


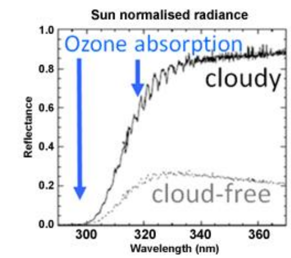
NASA/Courtesy of Brian Kerridge, STFC/RAL, UK / NCU

Stratospheric Ozone Monitoring & Ozone Depletion

Ozone profiles
from GOME-2 Metop
for ozone hole conditions





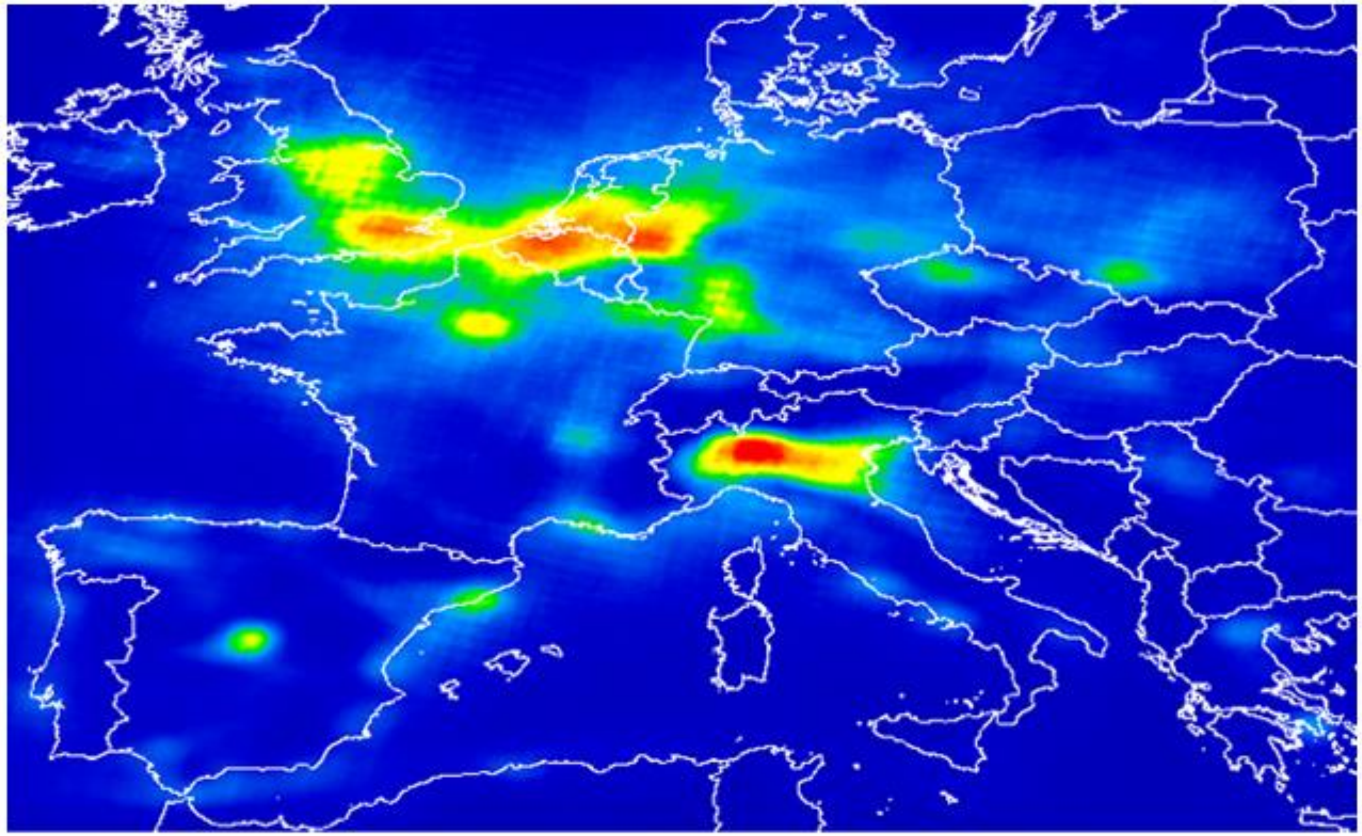


NASA/Courtesy of Brian Kerridge, STFC/RAL, UK / NCU

O. Tuinder, KNMI, O3MSAF/EUMETSAT

Air Quality Monitoring
NO_2

GOME-2 and Sentinel 4/5 are measuring trace gas information in the troposphere, particularly for tropospheric ozone and NO_2.

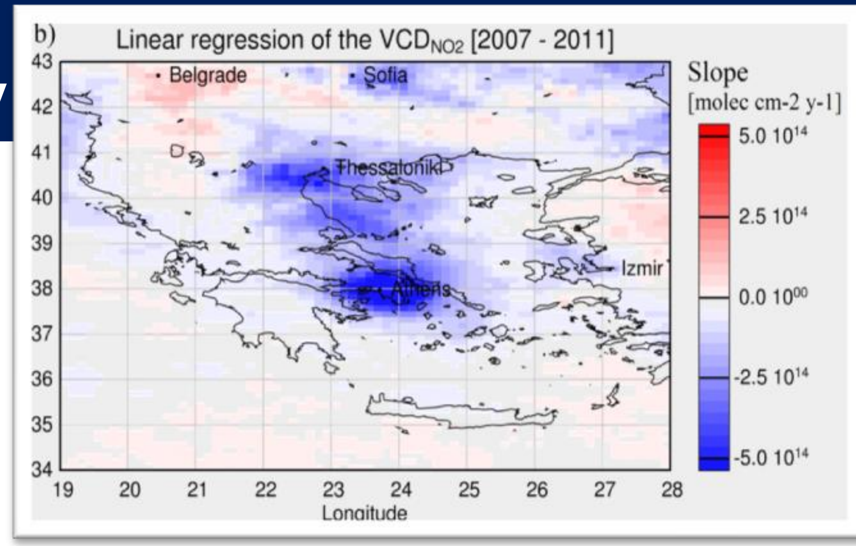


The ICSU World Data Center for Remote Sensing of the Atmosphere

Total amount of nitrogen dioxide (NO_2) in the atmosphere above Europe derived from one year of data from the GOME-2 instrument on Metop-A (March 2007 - February 2008)

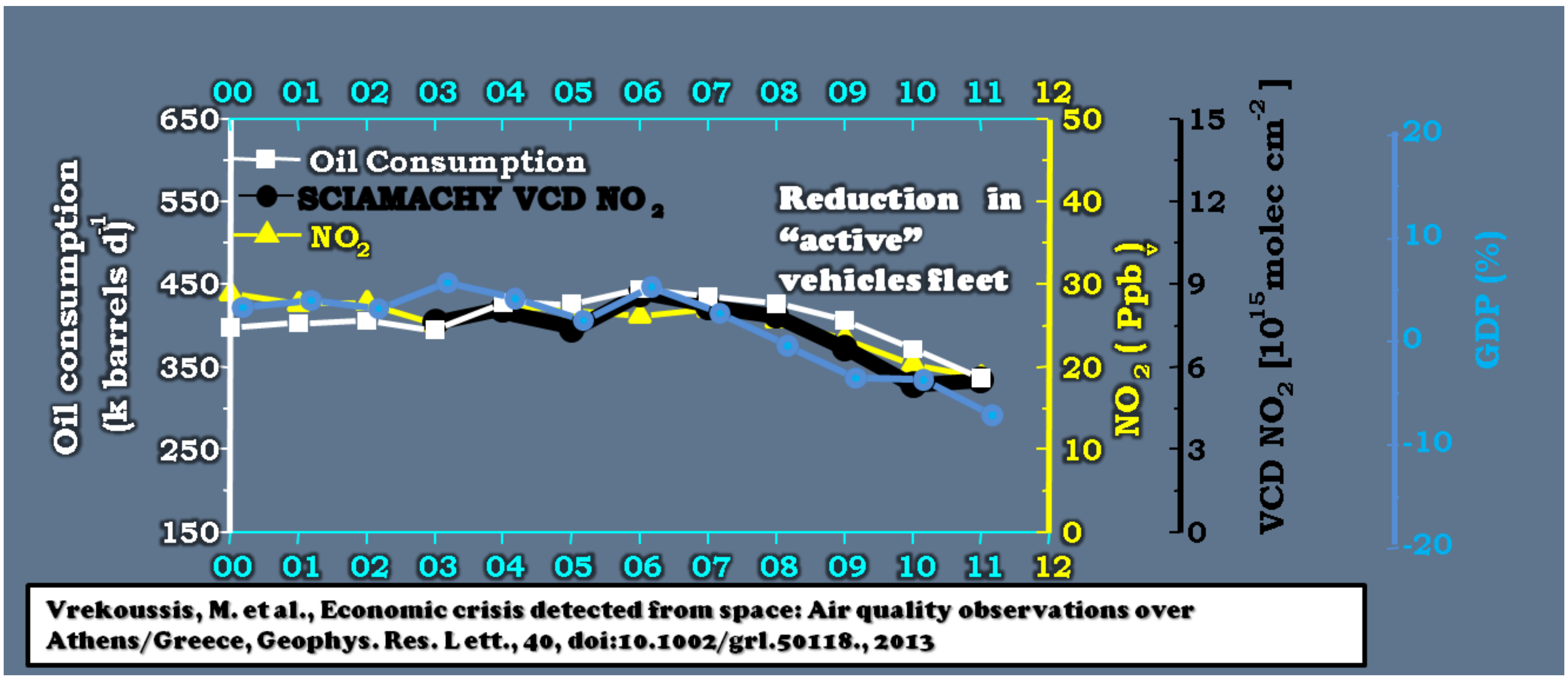
Air Quality Monitoring

NO_2 monitoring of the impact of the economy



The Impact of changes in the economy are very well observed NOx emissions

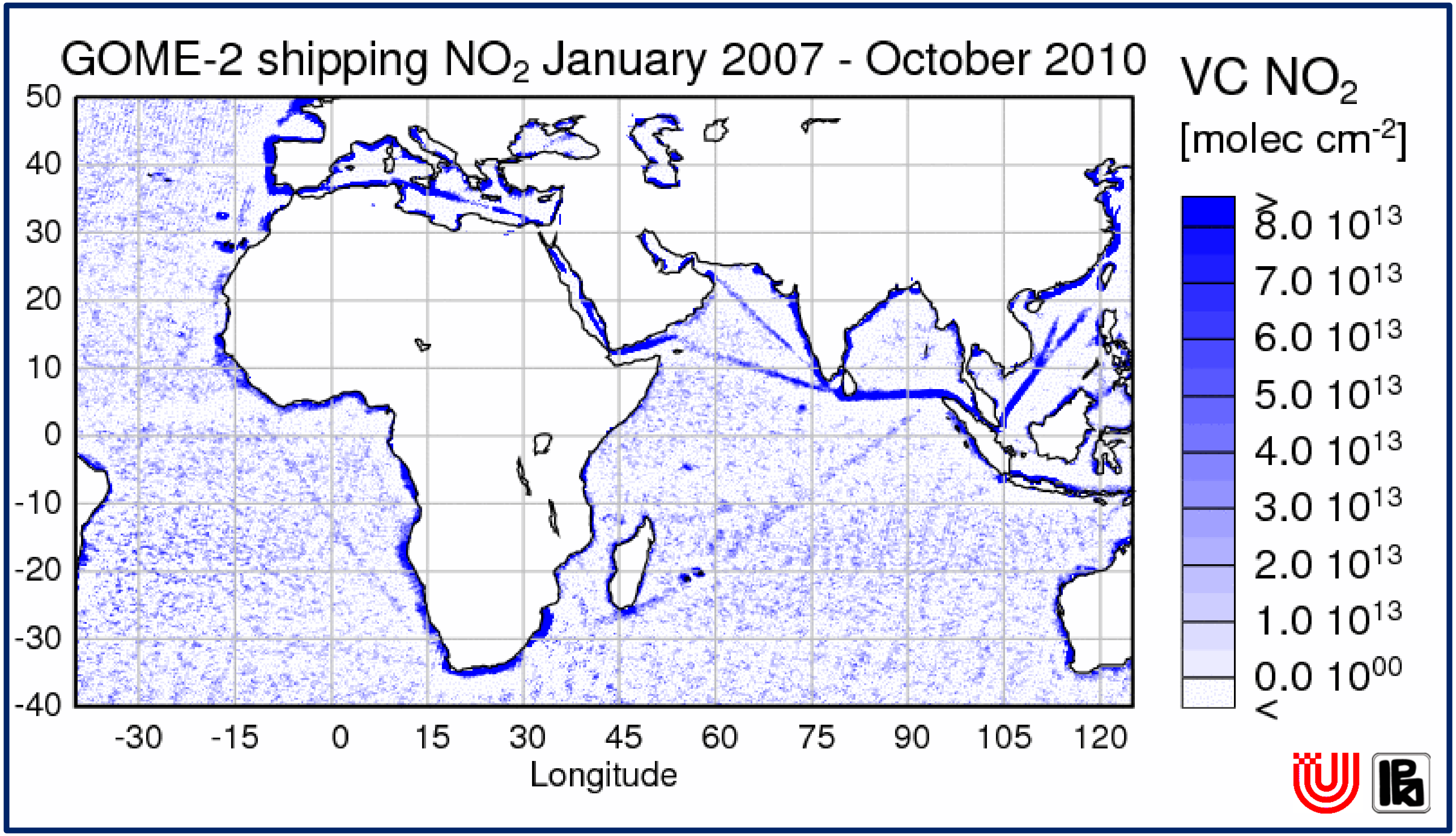
The Greece economic crisis



Courtesy: M. Verkoussis, IUP Bremen, Cyl

Air Quality Monitoring

NO_2 monitoring of the impact of the economy – ship tracks



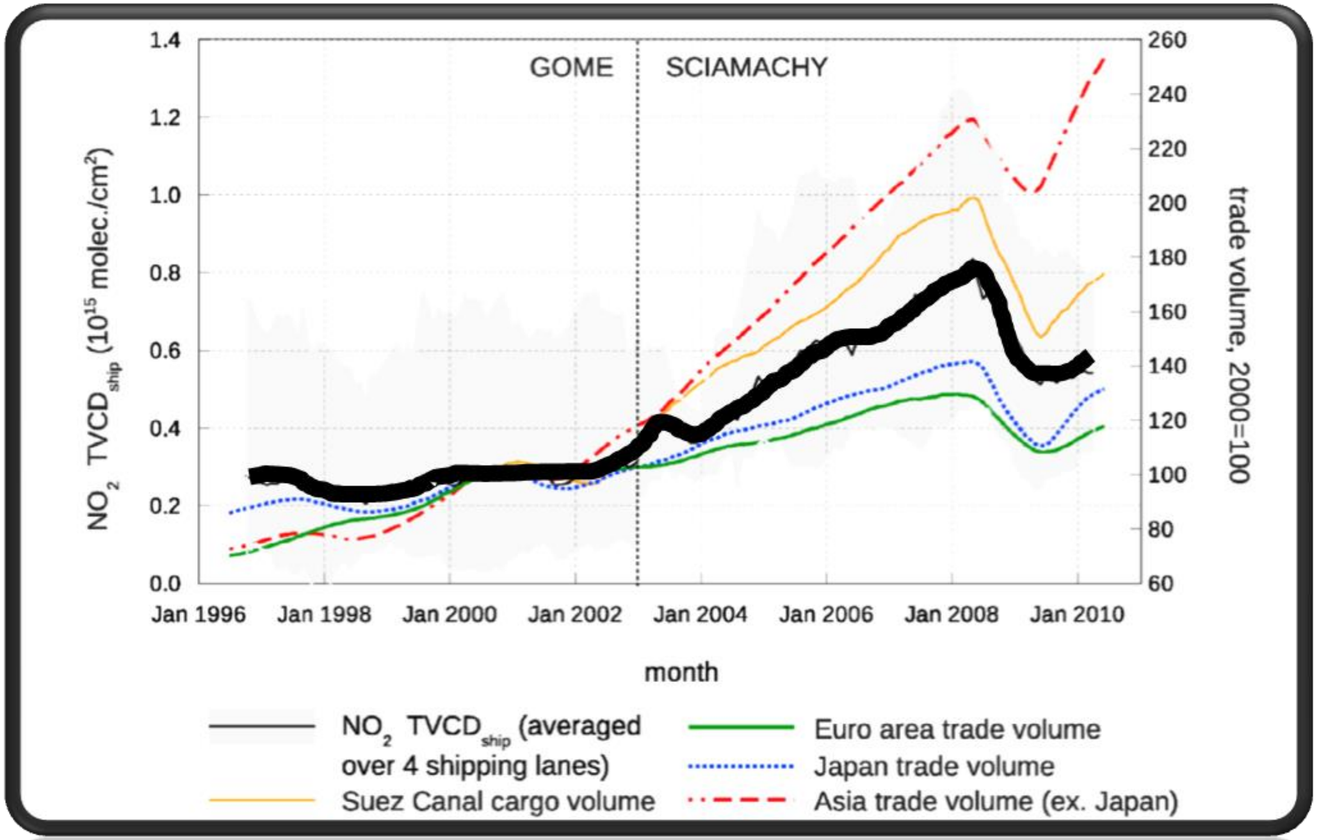
Courtesy: M. Verkoussis, IUP Bremen, Cyl

A. Richter et al., Satellite Measurements of NO2 from International Shipping Emissions, *Geophys. Res. Lett.*, 31, L23110, doi:10.1029/2004GL020822, 2004

A. Richter et al..: An improved NO2 retrieval for the GOME-2 satellite instrument, *Atmos. Meas. Tech.*, 4, 1147-1159, doi:10.5194/amt-4-1147-2011, 2011

Air Quality Monitoring

NO_2 monitoring of the impact of the economy – ship tracks

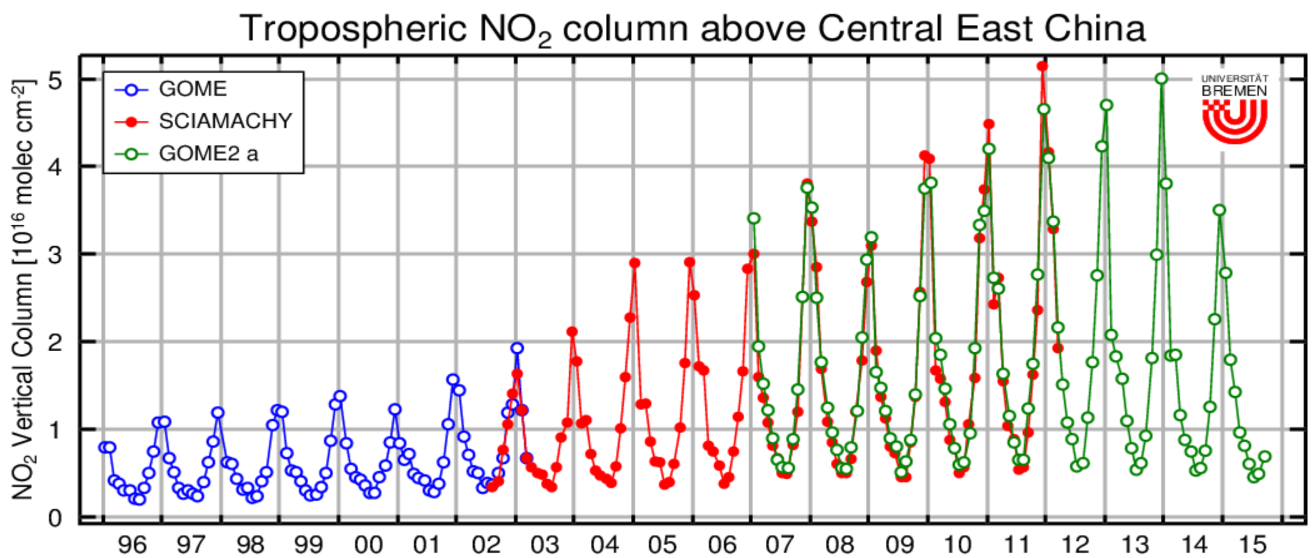


de Ruyter de Wildt, M., H. Eskes, and K. F. Boersma (2012), The global economic cycle and satellite-derived NO2 trends over shipping lanes, *Geophys. Res.Lett.*, 39, L01802, doi:10.1029/2011GL049541.

Courtesy: M. Verkoussis, IUP Bremen, CyI

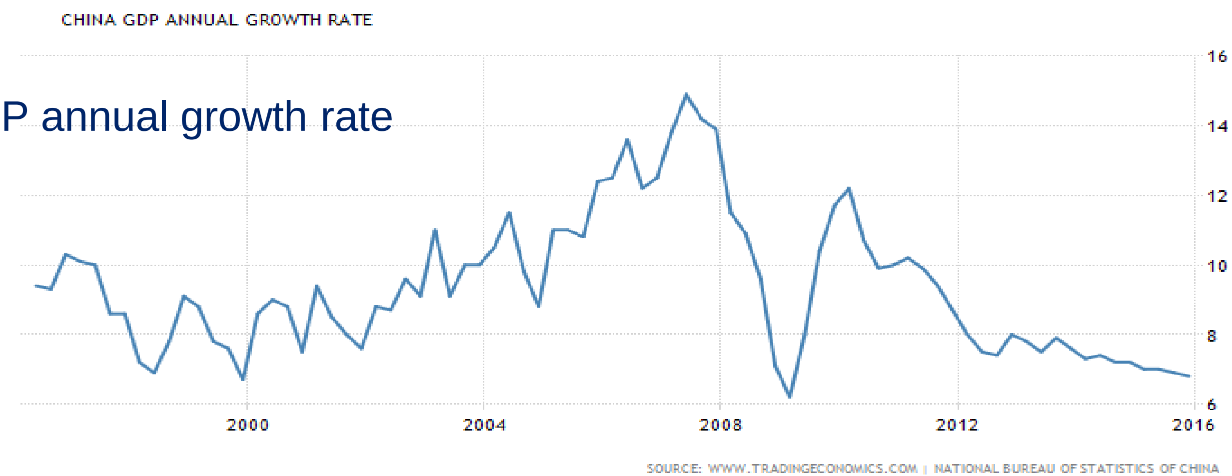
Air Quality Monitoring

NO_2 monitoring of the impact of the economy – Chinas GDP variations



Courtesy: University Bremen, IUP, Andreas Richter

China GDP annual growth rate



Source: www.tradingeconomics.com

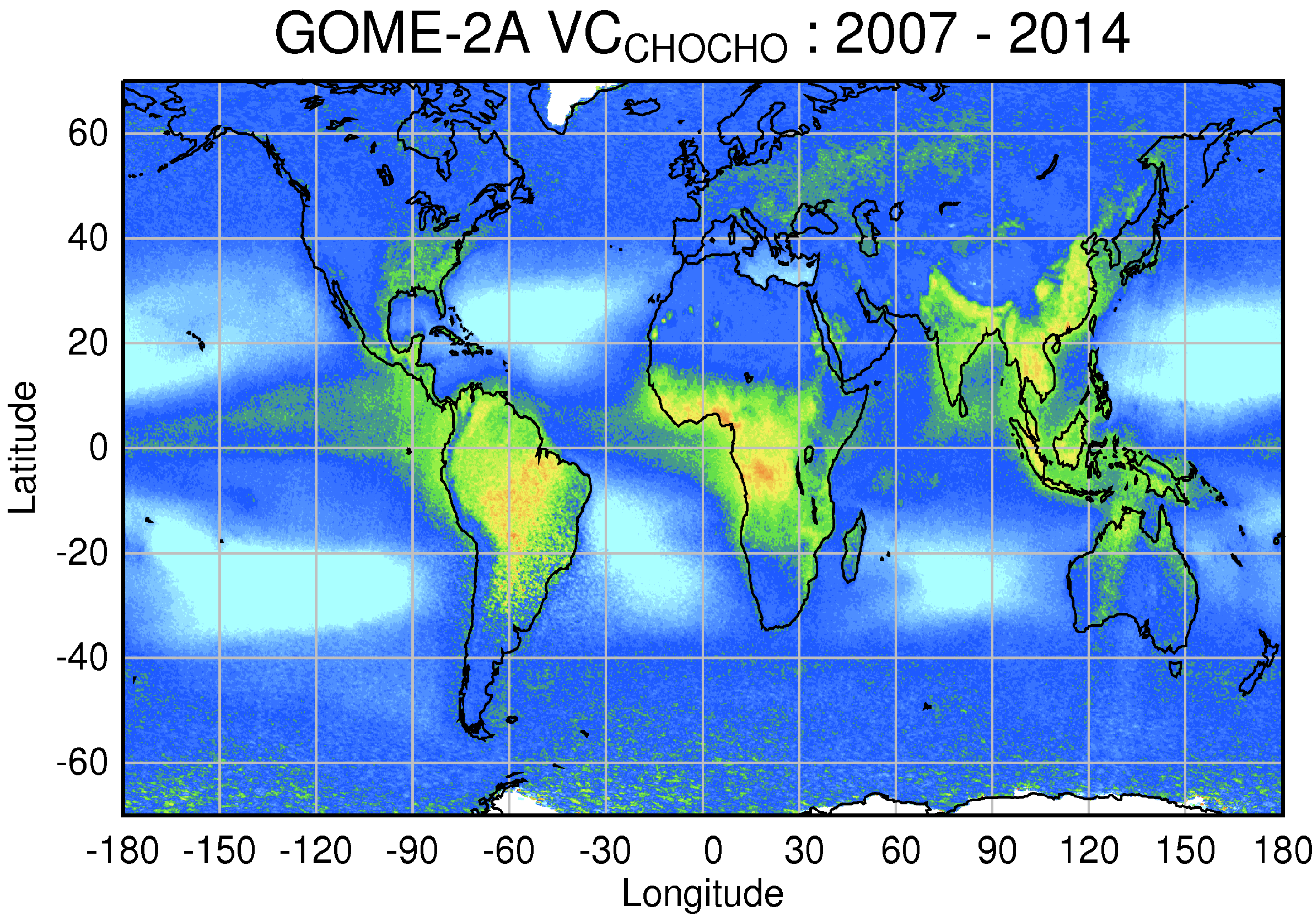
Air Quality Monitoring

Glyoxal monitoring – aerosol formation

Sources:

***isoprene* (biogenic)**
***acetylene* (mostly anthropogenic)**
***acetone* (biogenic)**

Formation of secondary organic aerosol (SOA) by glyoxal through aqueous reaction in (cloud/aerosol) droplets



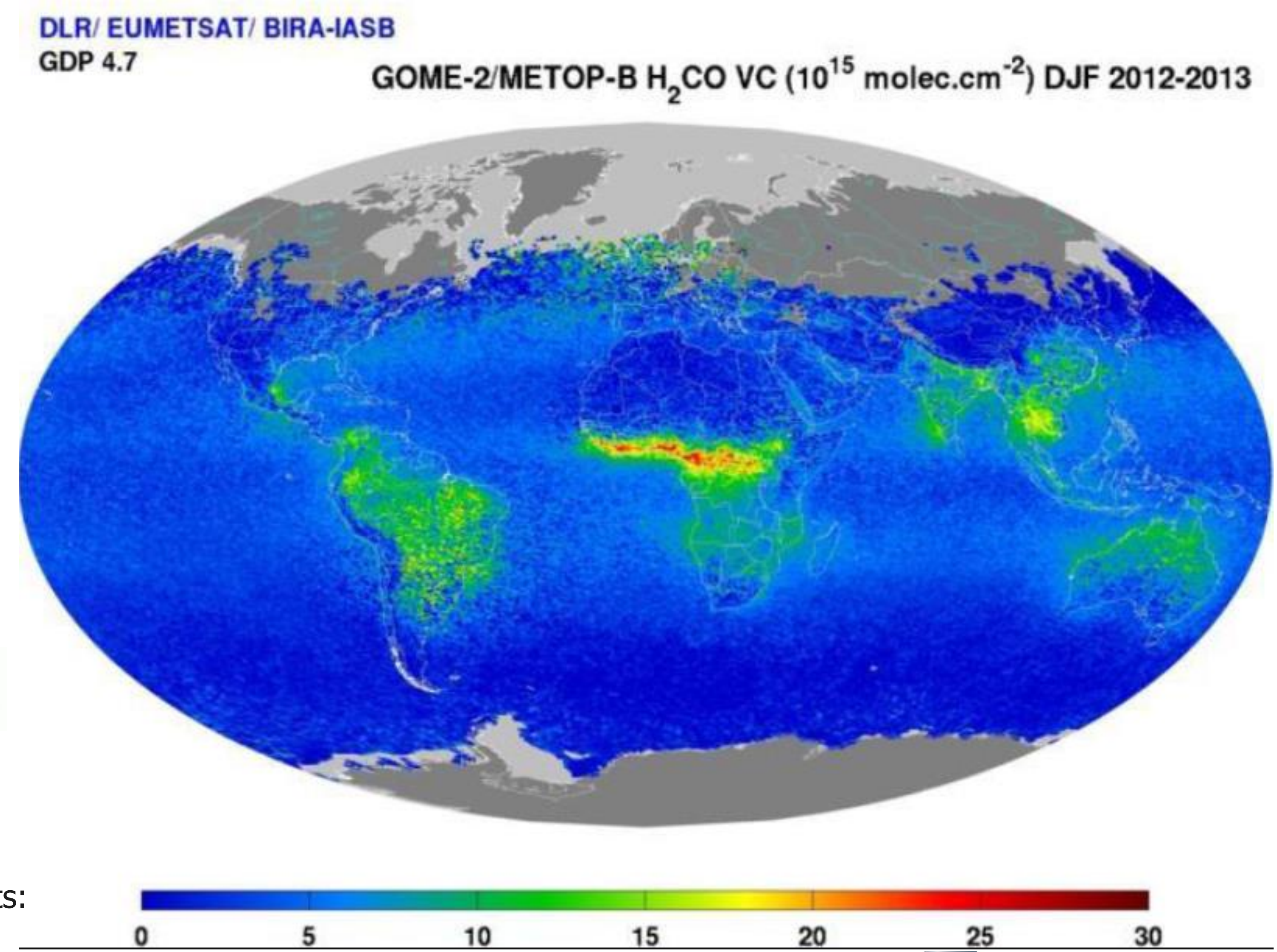
Air Quality Monitoring

Formaldehyde (VOC) monitoring of the impact of the economy

Hydro-carbons

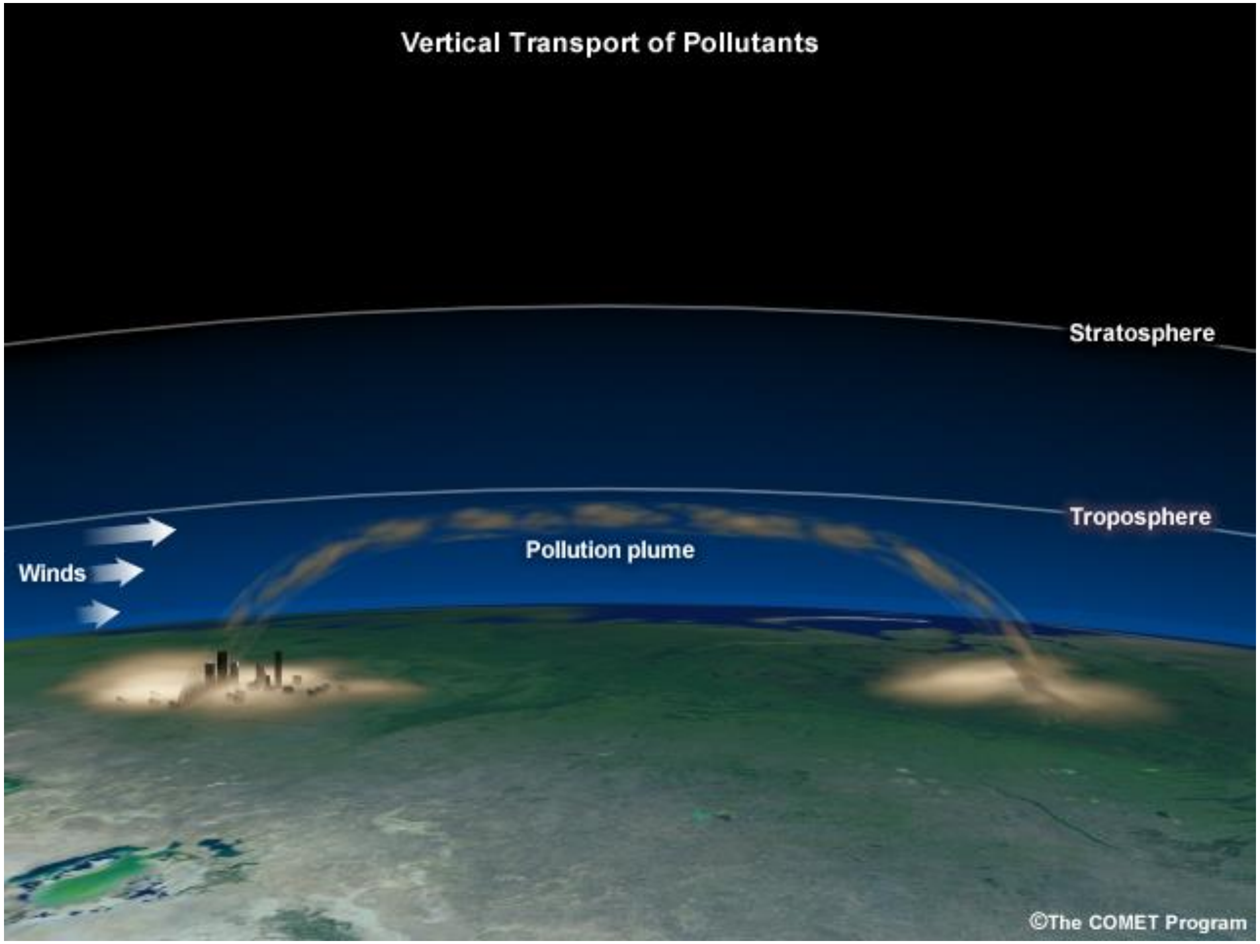
/ NMVOC

Ozone chemistry and aerosol formation



Extracted from the operational validation report for GOME-2 /Metop-B level 2 products: http://o3msaf.fmi.fi

Air Quality Monitoring
Long-Range Transport of Pollution – Long-lived species



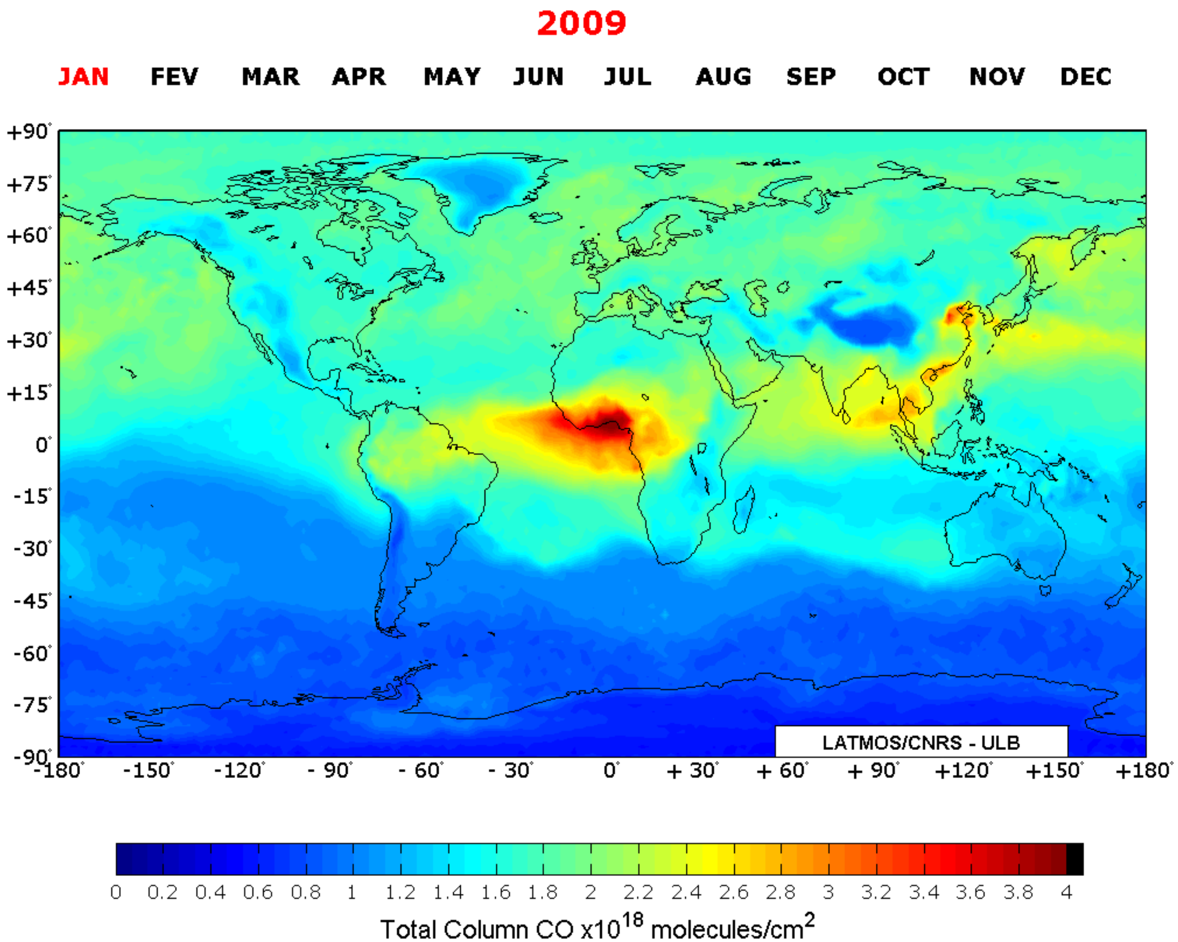
Long-range pollution transport occurs when pollutants are lifted from source regions near the surface into the free troposphere where they can be carried large distances.

Air Quality Monitoring
Long-Range Transport of Pollution – CO

Metop-IASI

Thermal infrared measurements of

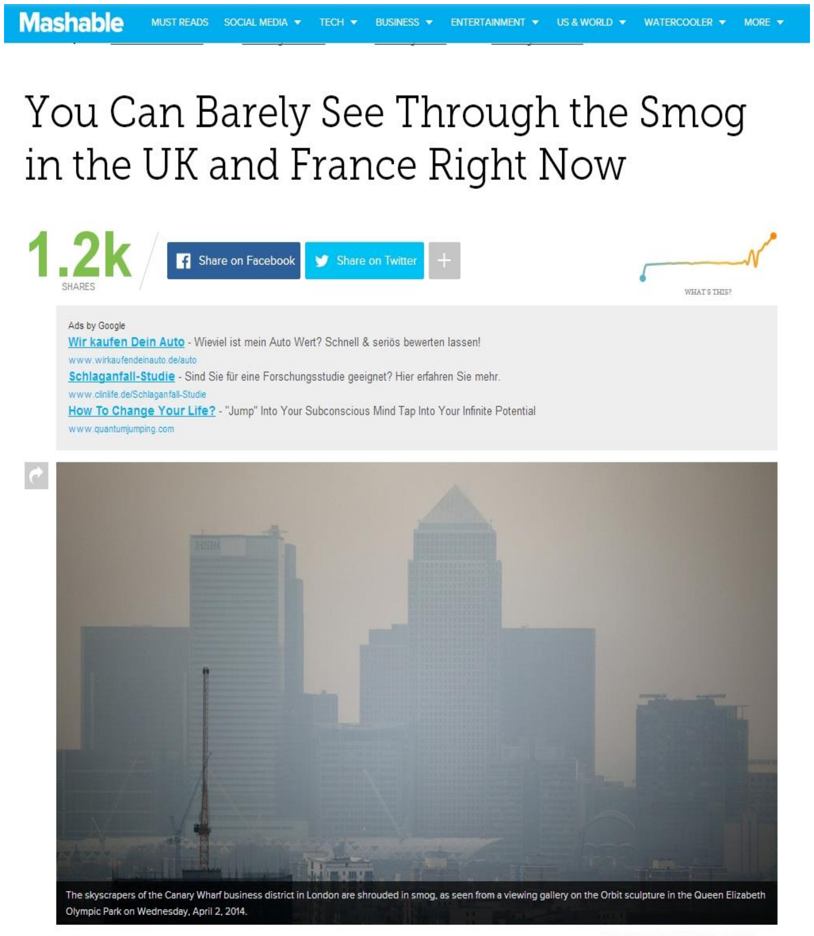
CO



Metop/IASI CO measurements provide daily global coverage of a number of species, so they are ideal for tracking the transport of large pollution plumes and any transformation of the plume.

Aerosols and Volcanic Emissions

Aerosol emissions and Volcanic eruptions can potentially cause significant damage and impact public health.


Mashable MUST READS SOCIAL MEDIA TECH BUSINESS ENTERTAINMENT US & WORLD WATERCOOLER MORE

You Can Barely See Through the Smog in the UK and France Right Now

1.2k SHARES Share on Facebook Share on Twitter WHAT'S THIS?

The skyscrapers of the Canary Wharf business district in London are shrouded in smog, as seen from a viewing gallery on the Orbit sculpture in the Queen Elizabeth Olympic Park on Wednesday, April 2, 2014.

IMAGE: MATT DUNHAM/ASSOCIATED PRESS


Creative Commons Gunnlaugur P. Briem

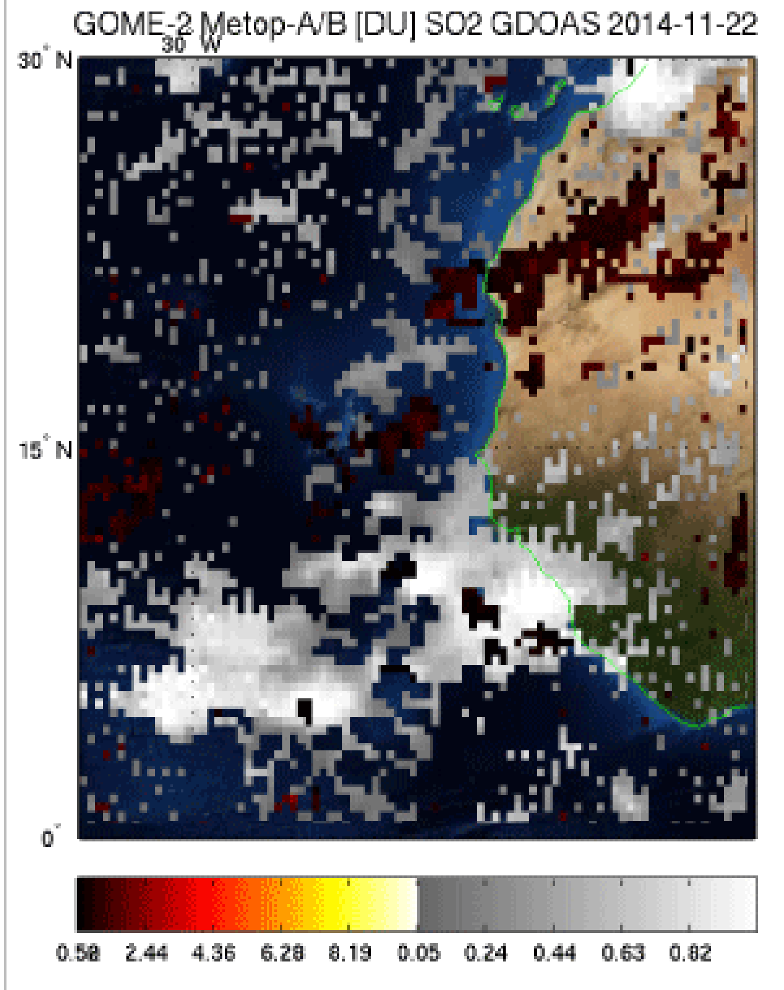
Regional and long-range transport of aerosols (like e.g. dust plumes) and volcanic plumes can influence the locale weather, may have a significant impact on radiative forcing and climate and may also disrupt air traffic.

SO_2 monitoring from Metop (GOME-2)

Observing volcanic eruption and dust events for aviation control

Cap Verde eruption
November 2014

GOME-2 Metop-A/B



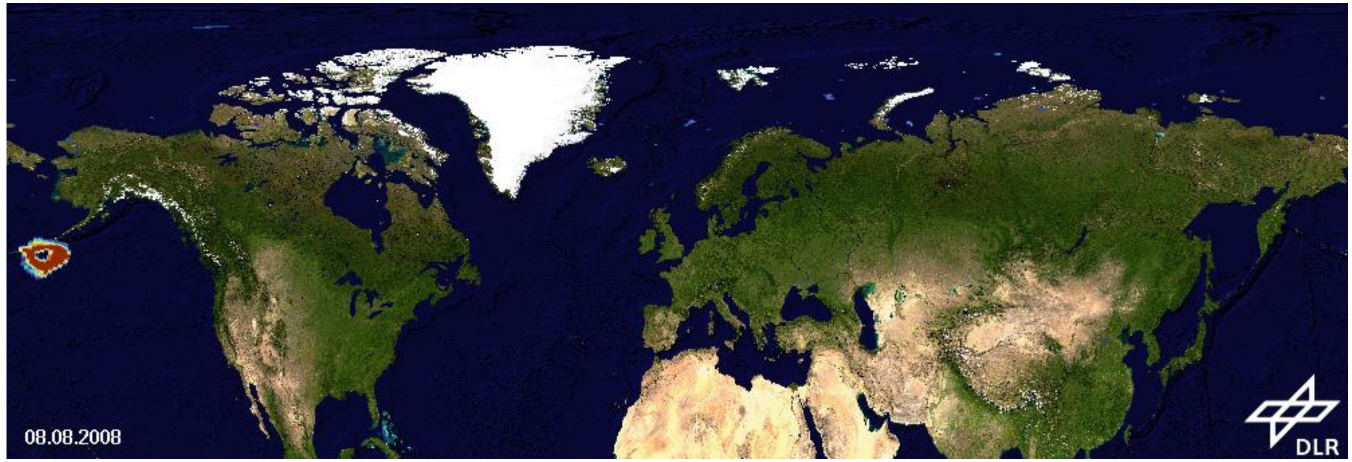
Volcanic ash monitoring from Metop (GOME-2)

Observing volcanic eruption for aviation control

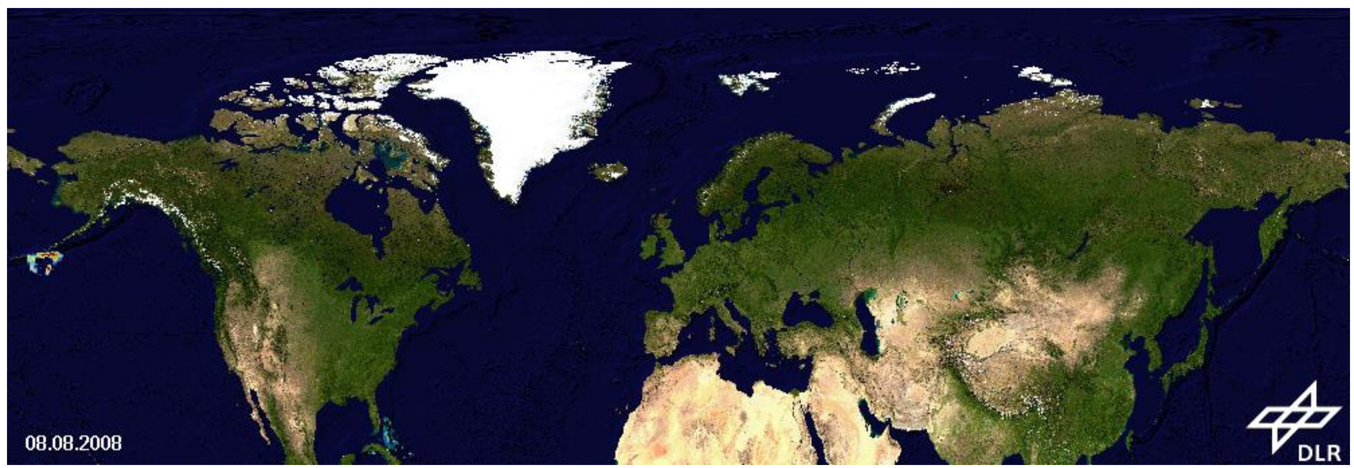
Sulphur dioxide (SO_2) concentrations in volcanic plumes are of interest because it reacts with water vapour in the atmosphere to form sulphuric acid, which is corrosive and can also damage aircraft.

BrO is a major contributor to stratospheric ozone chemistry.

SO_2 from GOME-2 on Metop-A , Kasatochi Erruption Aug 2008



BrO from GOME-2 on Metop-A , Kasatochi Erruption Aug 2008



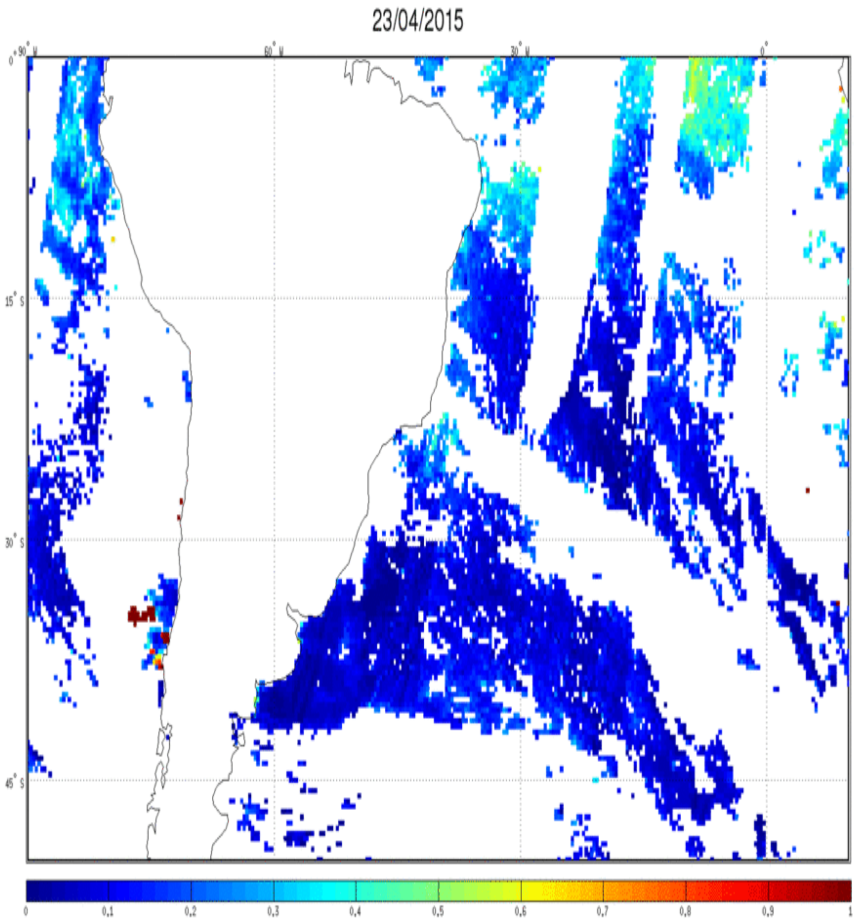
O3M SAF
Ozone and Atmospheric Chemistry Monitoring

Volcanic ash monitoring from Metop (GOME-2/AVHRR/IASI)

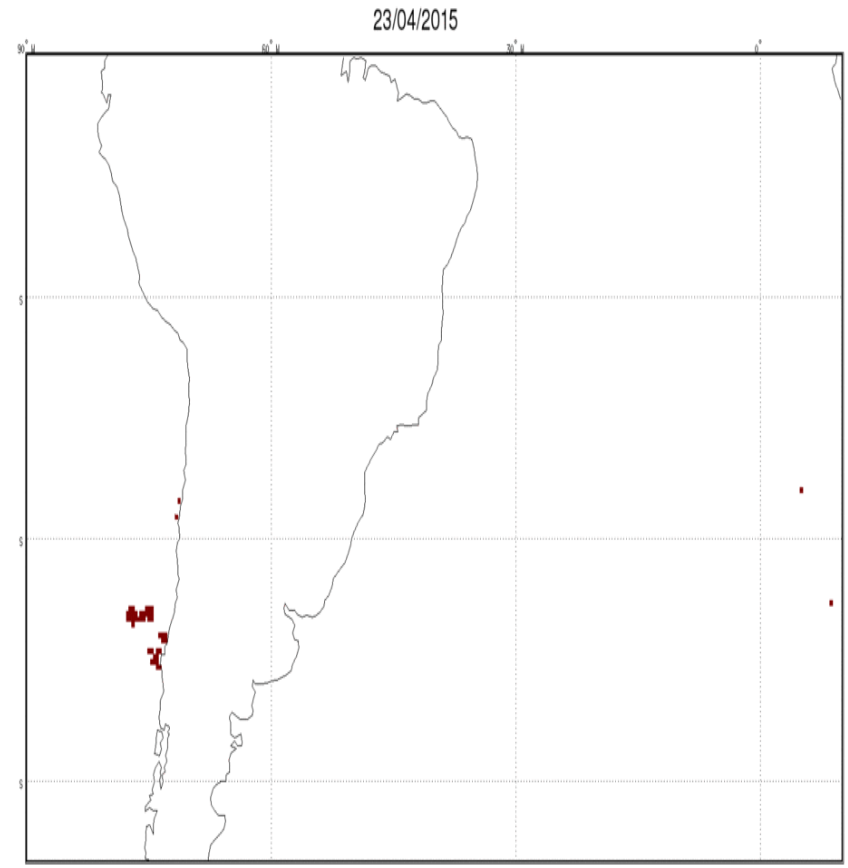
Observing volcanic eruption and dust events for aviation control

Puyehue eruption 2015

Aerosol optical depth



Volcanic ash detection flag

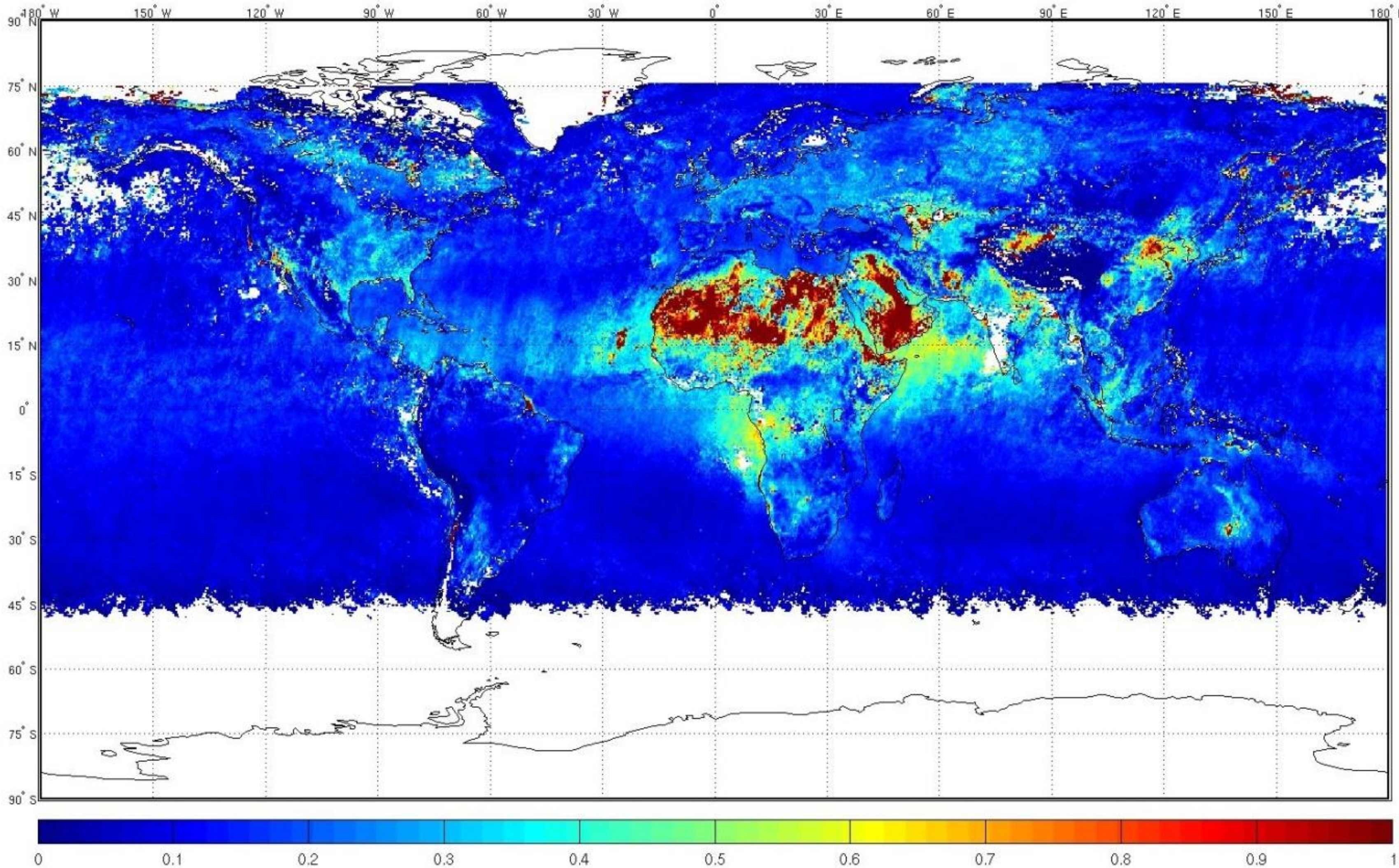


Multi-Sensor Aerosol product (PMAp) from Metop

Aerosol monitoring from Metop (GOME-2/AVHRR/IASI)

Polar Multi-Sensor Aerosol product (PMAp)

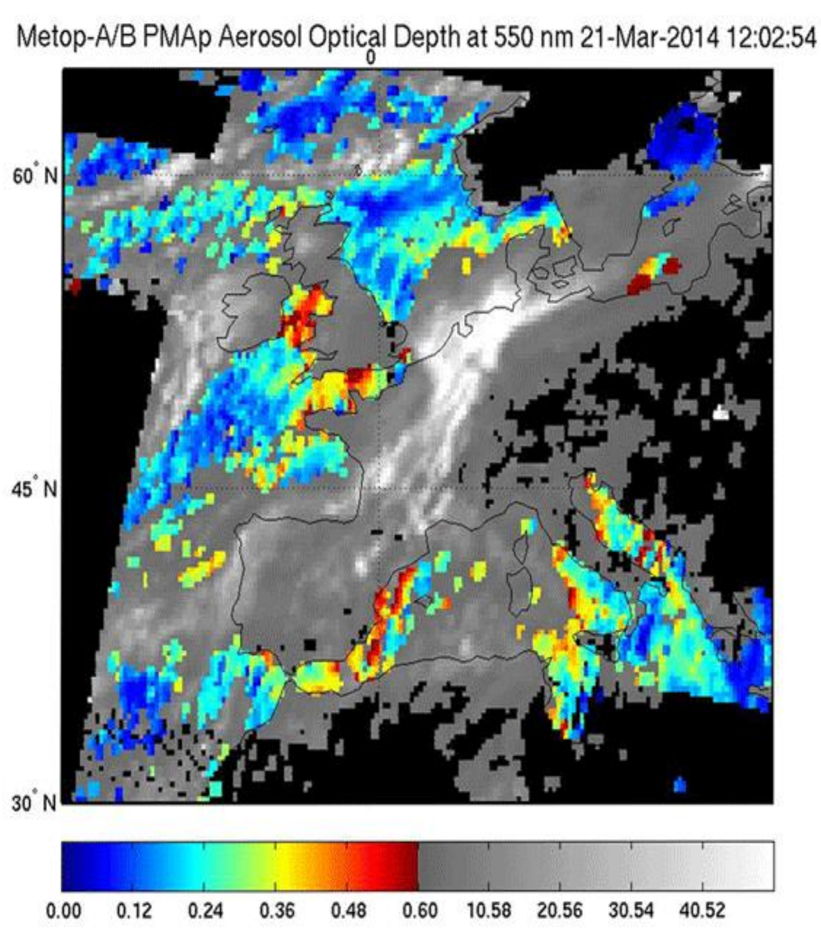
Aerosol Optical Depth from Metop-A: June/July 2013



EUMETSAT

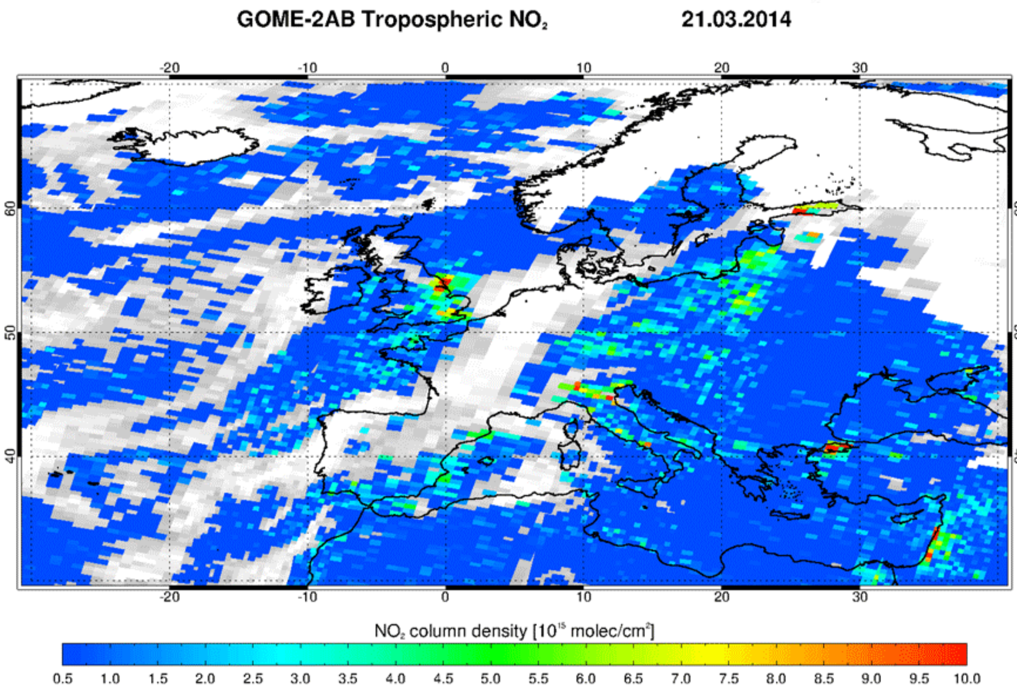
Aerosol monitoring from Metop (GOME-2/AVHRR/IASI)

Polar Multi-Sensor Aerosol product (PMAp) – London pollution event

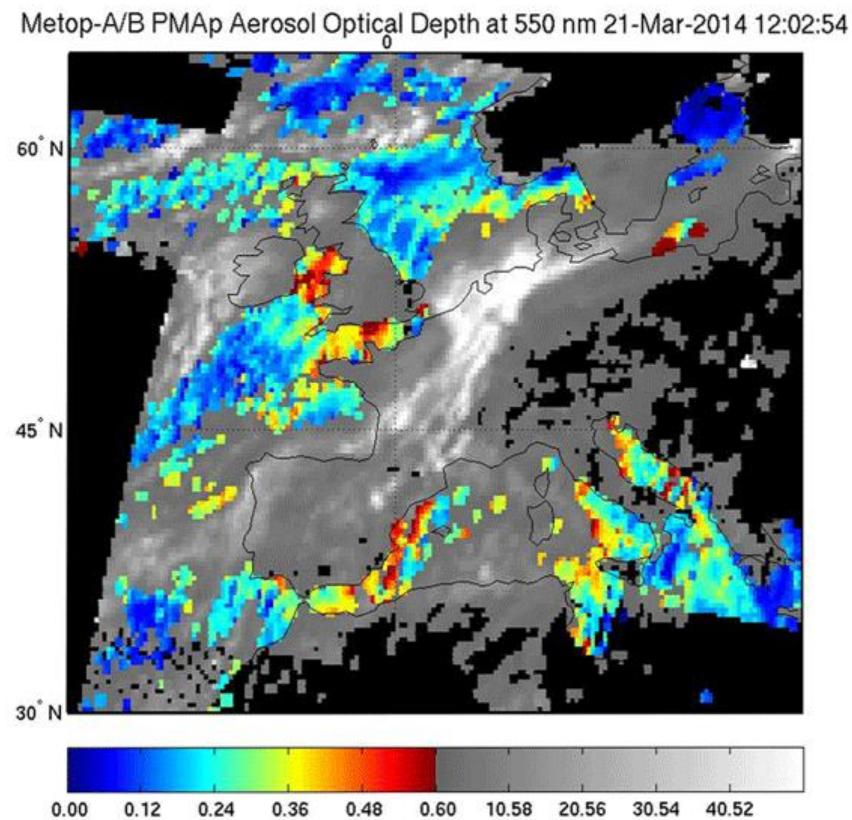


http://www.eumetsat.int/website/home/Images/ImageLibrary/DAT_2187633.html

Aerosol monitoring from Metop (GOME-2/AVHRR/IASI)
Polar Multi-Sensor Aerosol product (PMAp) – London pollution event



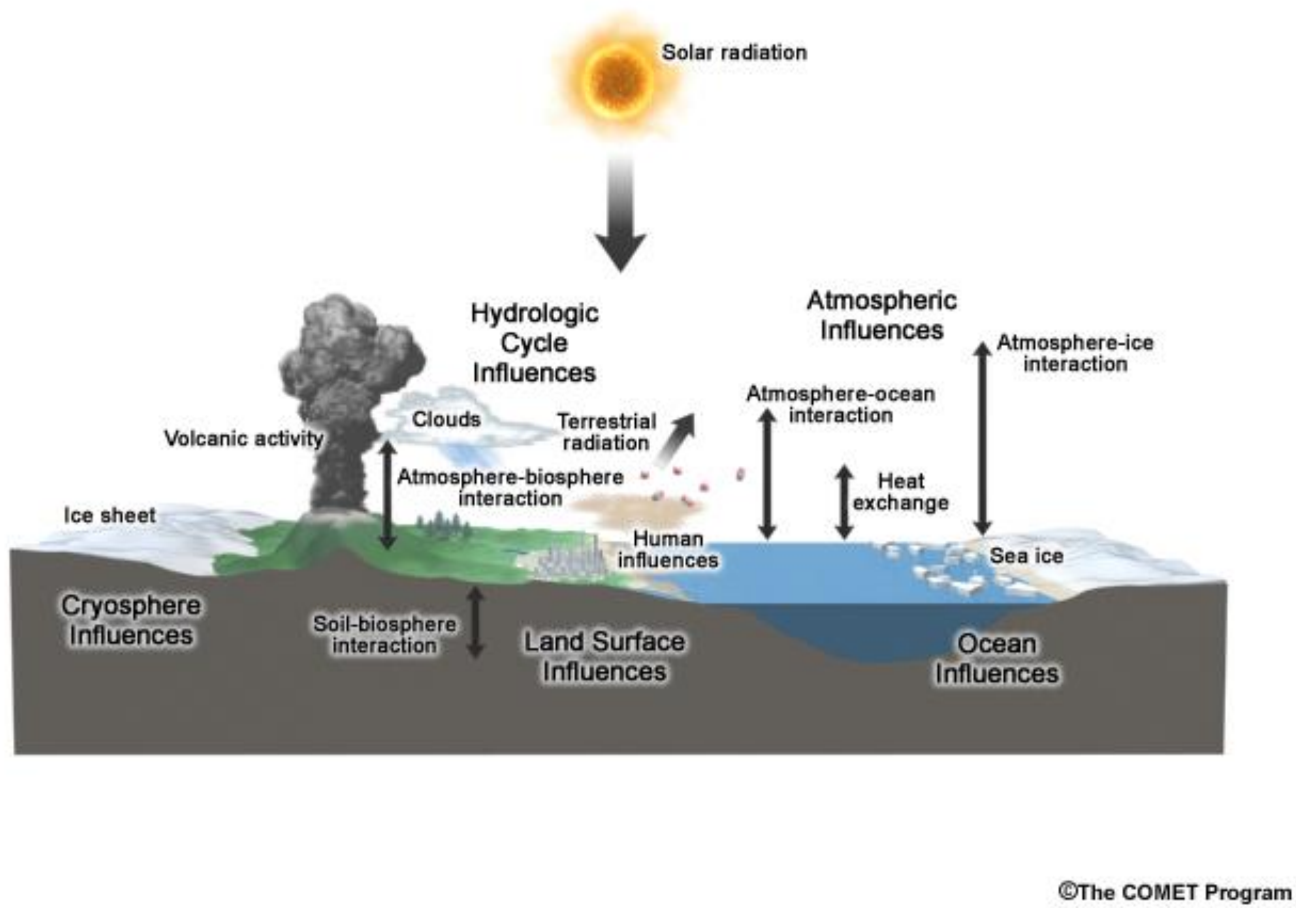
Courtesy Valks et al., O3MSAF/DLR



Persistent high pressure end March to beginning of April 2014 and a Saharian dust outbreak produced elevated levels of mixed anthropogenic and non-anthropogenic aerosol concentrations

http://www.eumetsat.int/website/home/Images/ImageLibrary/DAT_2187633.html

Atmospheric Composition-Climate Interaction



Numerous atmospheric composition related parameters monitor climate change in many parts of the Earth system.

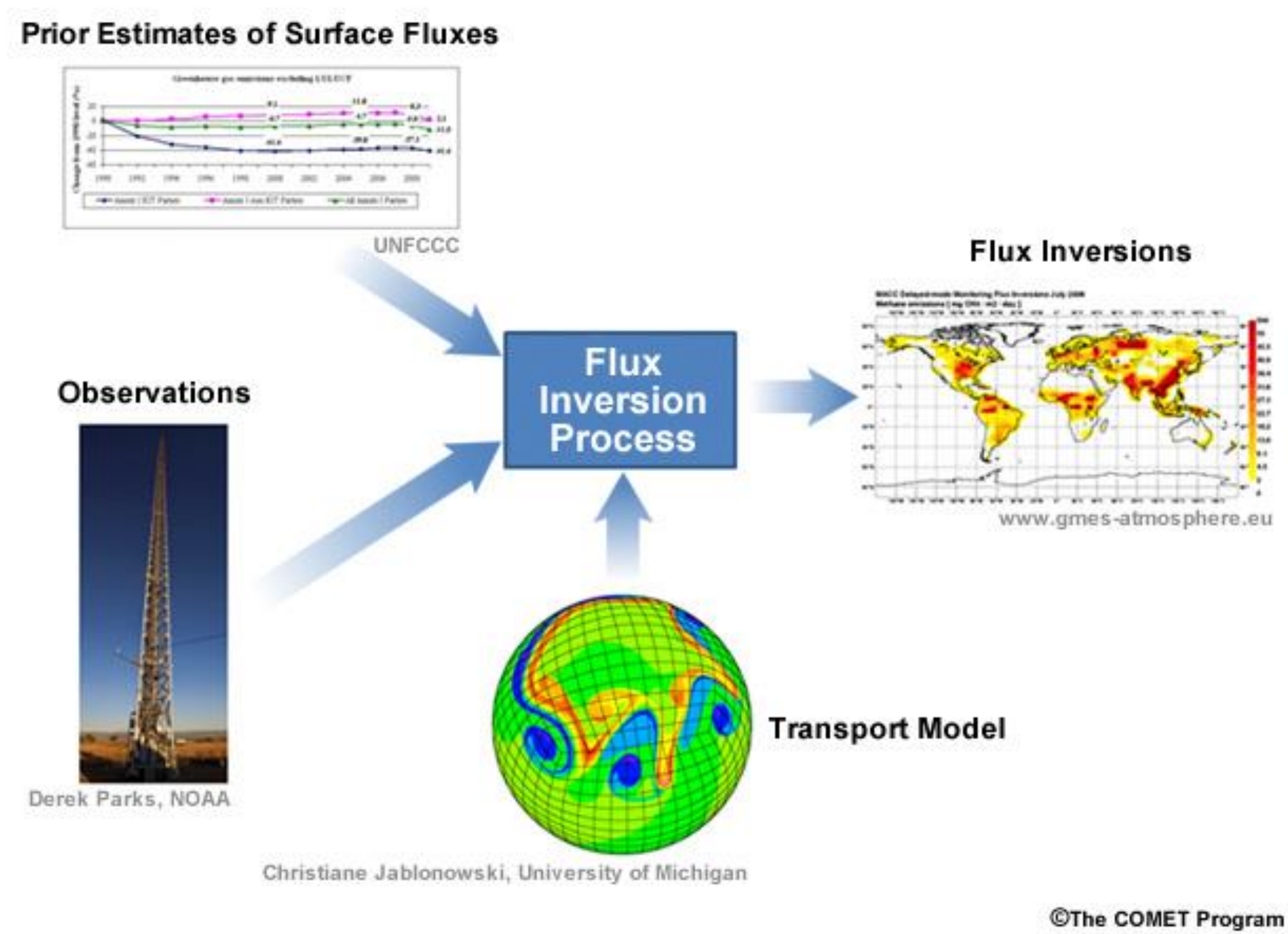
Greenhouse gas monitoring

How to retrieve emission fluxes – observations plus model!

30 YEARS 1986-2016

Current flux inversion products are based on ground-based often FTIR or *in-situ* flask measurements

- ➢Very high accuracy requried (0.5-1ppm)
- ➢Very high sensitivoty in the PBL required



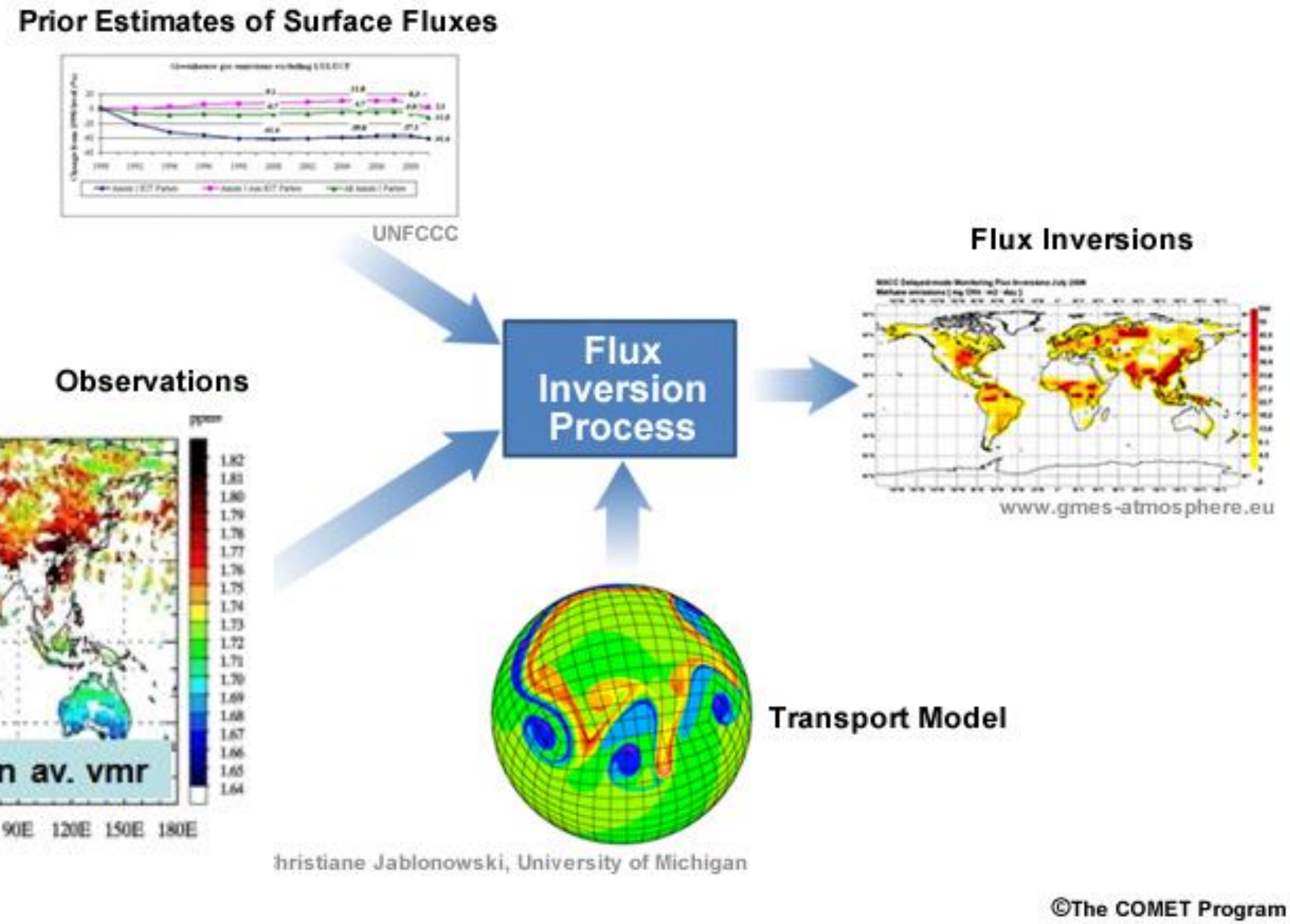
EUMETSAT

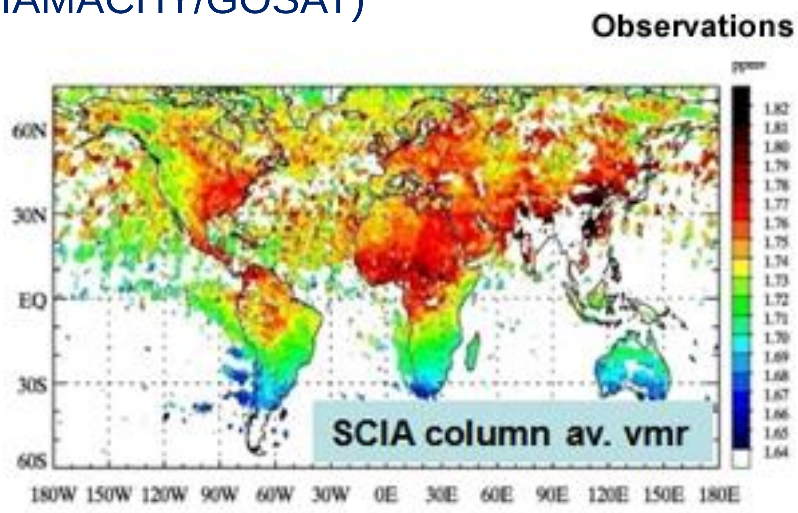
Greenhouse gas monitoring

How to retrieve emission fluxes – observations plus model!

Satellite data are only now beginning to be used, their strength being spatial coverage, and their weakness their accuracy.

Currently only SWIR measurements have the potential to achieve this level of accuracy (SCIAMACHY/GOSAT)





EUMETSAT

Greenhouse gas monitoring

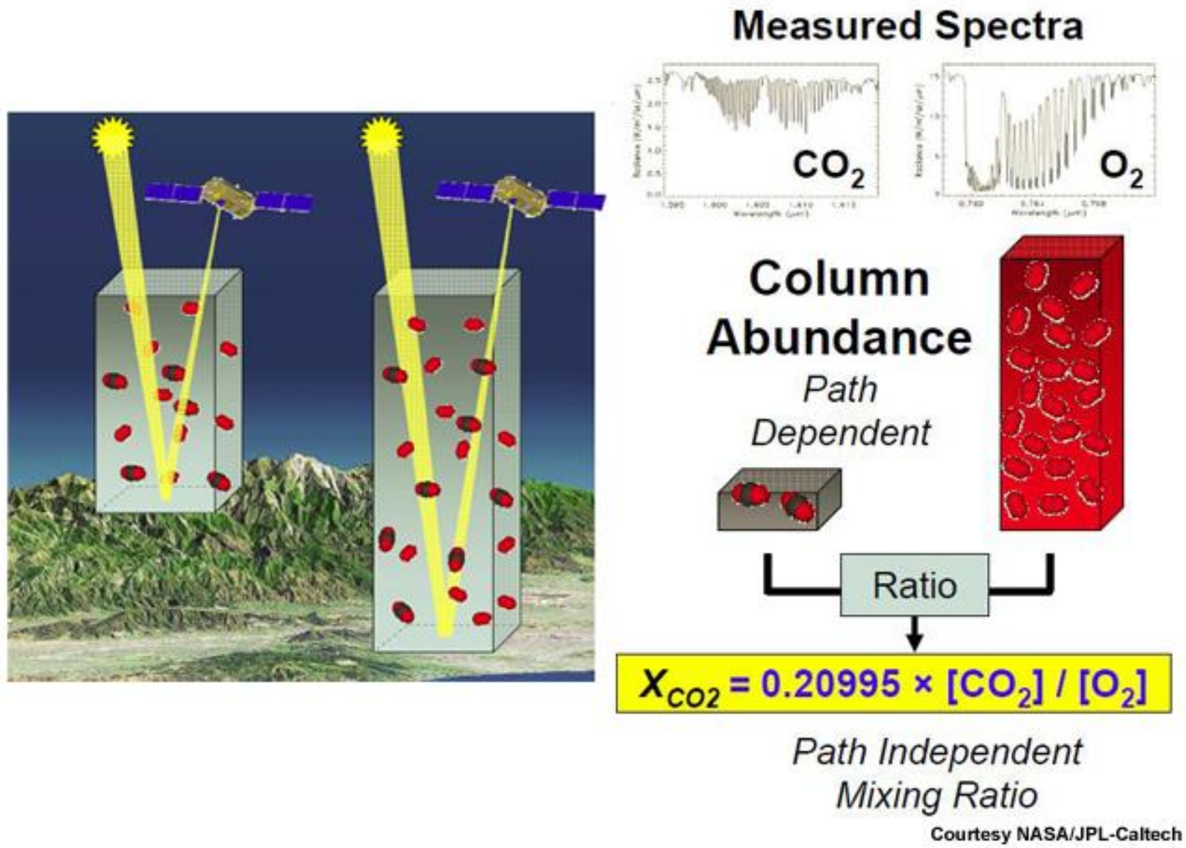
How to achieve higher accuracies – path-length weighted X-column results

Flux inversion modelling requires the dry air mole fraction relative to the total atmospheric column at the point of the measurement (e.g. of carbon dioxide — XCO_2 or methane — XCH_4).

This prevents variations in the air mass from being erroneously interpreted as variations in the greenhouse gas.

The dry air mole fraction can be obtained using the Oxygen A-band at 760 nm as a proxy for the atmospheric column.

Any residual wavelength-independent calibration effects in the measurements will be normalised out.



EUMETSAT

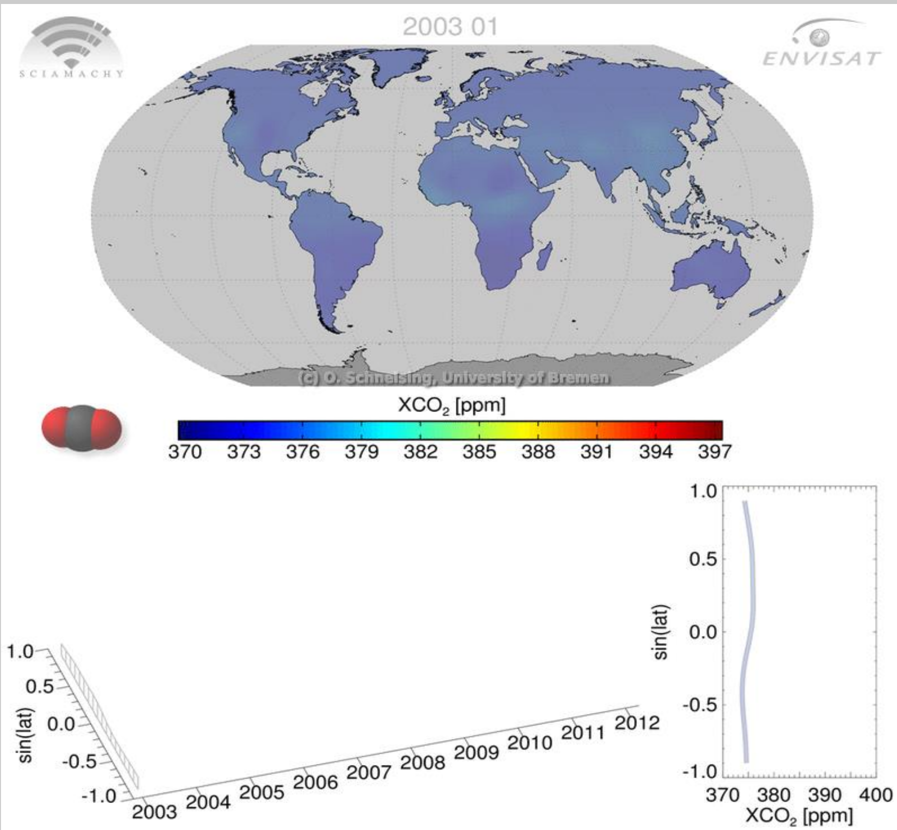
Greenhouse gas monitoring

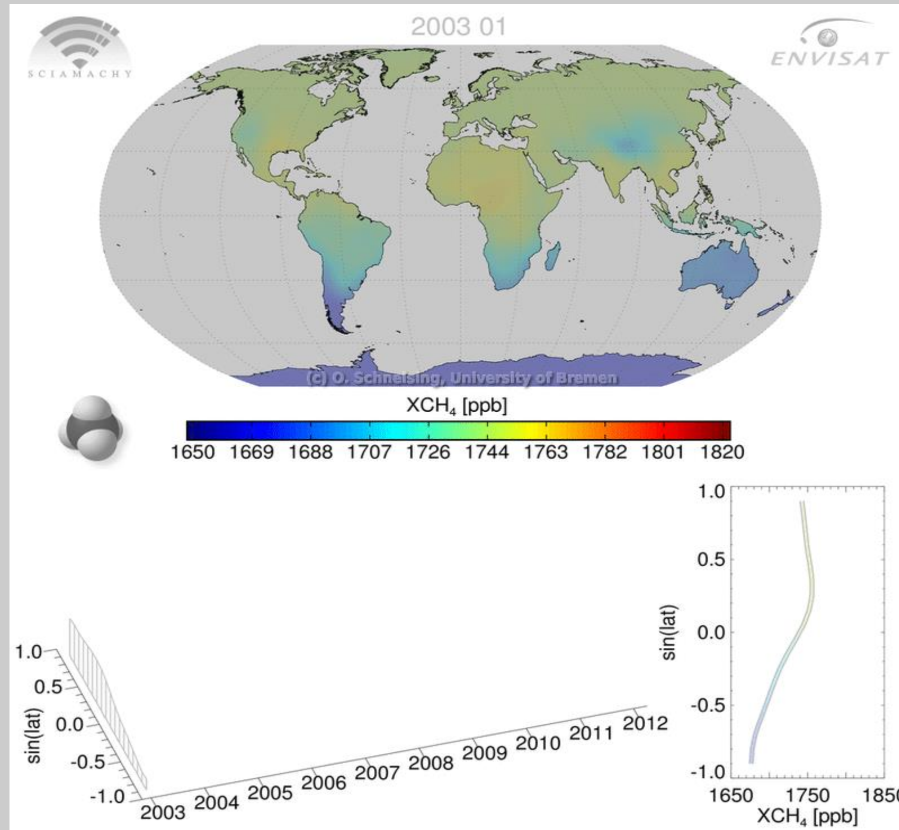
Path-length weighted XCO_2 and XCH_4-columns from SCIAMACHY SWIR

Courtesy: IUP Bremen, Buchwitz & Schneising

XCO_2

XCH_4





Smoothed & gaps filled

EUMETSAT operational products
NRT and offline data sources

EUMETSAT data is available in near-real time
via EUMETCast in EPS native (and netcdf4).

See our Product-Navigator under
www.eumetsat.int > Data

Full orbit offline data. Available from the EUMETSAT archive
http://archive.eumetsat.int

Documentation (user guides etc.):
www.eumetsat.int > Data > Technical documentation

The End

EUMETSAT Future Missions for atmospheric composition

Geo-stationary orbit

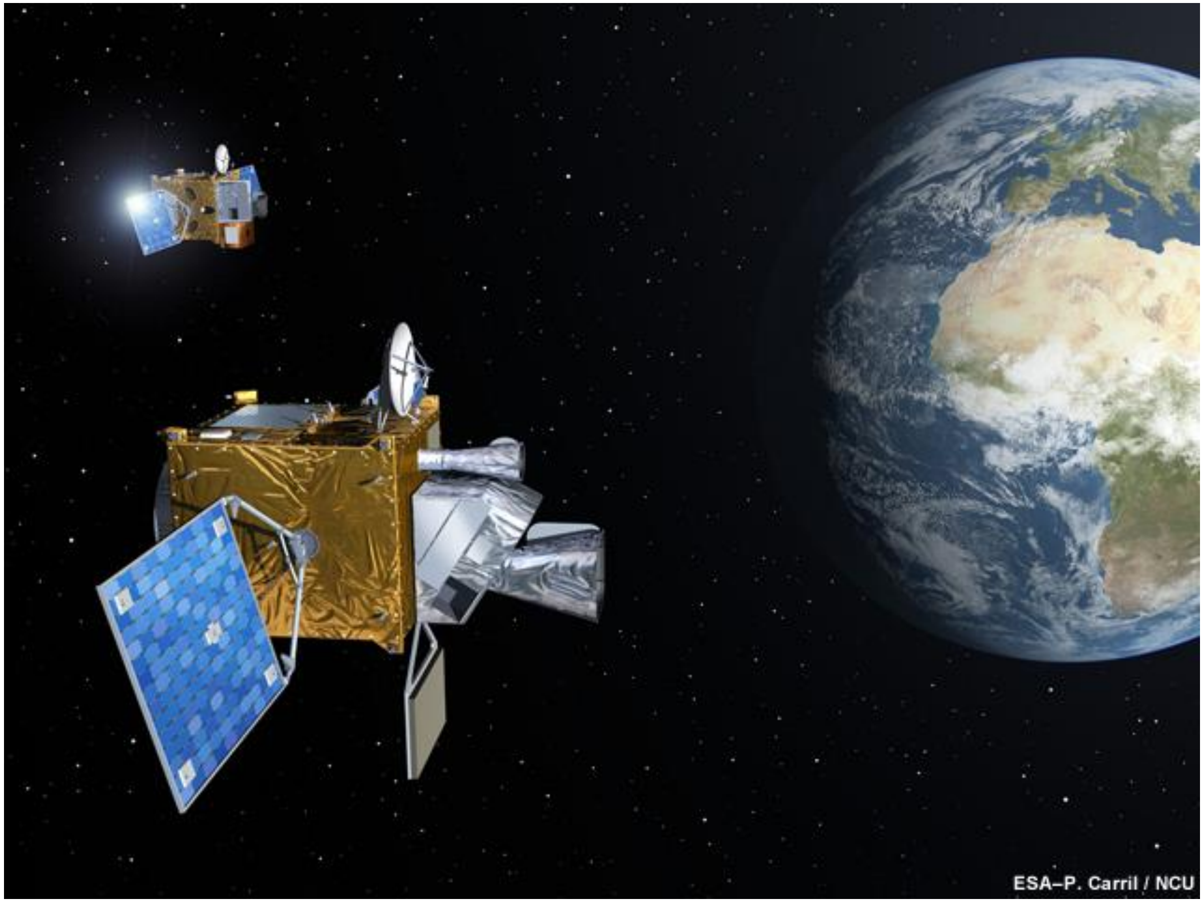
The Meteosat Third Generation (MTG) system is a two-platform system.

1st platform: The MTG Imaging platform will be launched in 2019.

- Flexible Combined Imager (FCI)
- Aerosol and volcanic ash

2nd platform: The MTG sounding platform will be launched in 2022.

- IASI-NG (Infra Read hyper-spectral sounder)
- Sentinel-4 UV-VIS-NIR hyper-spectral sounder
- Trace-gases, aerosol and clouds



EUMETSAT Future Missions for atmospheric composition

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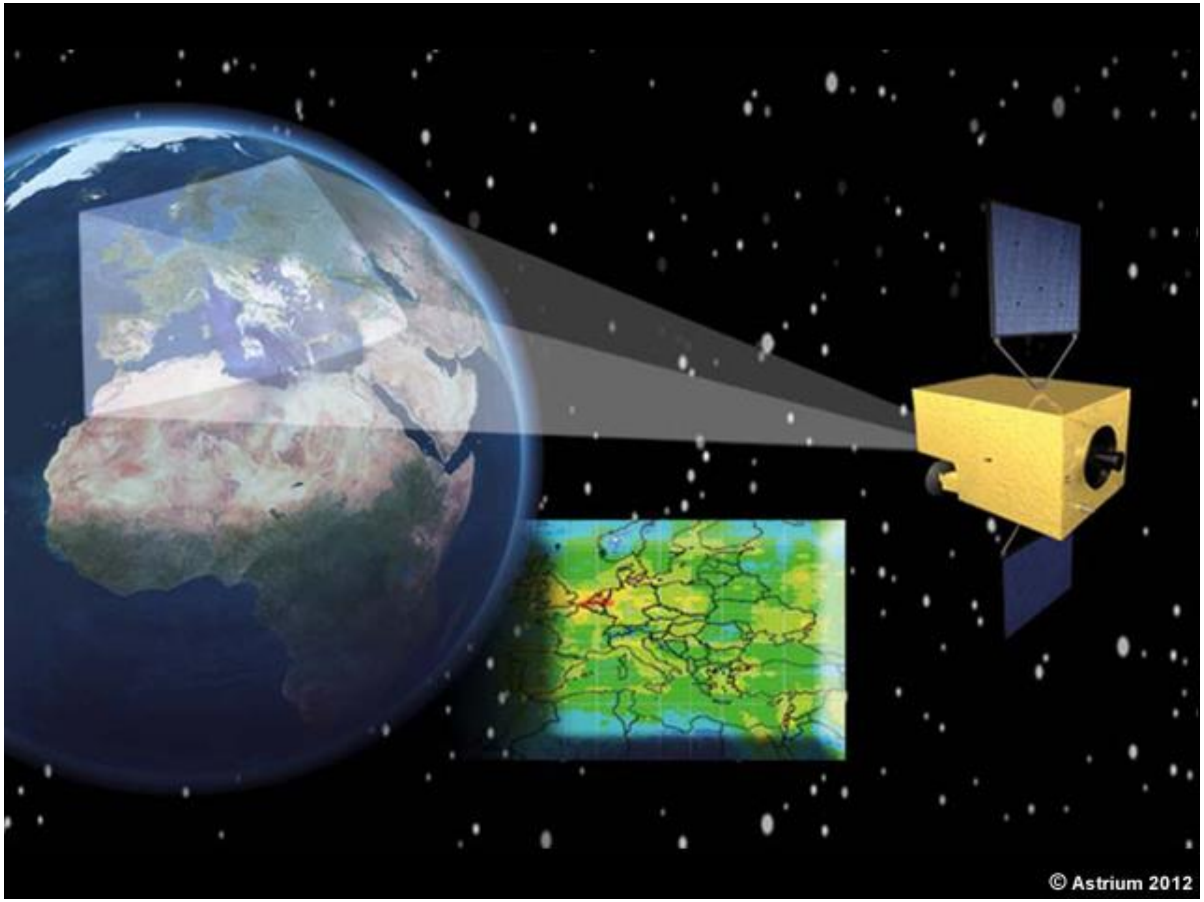
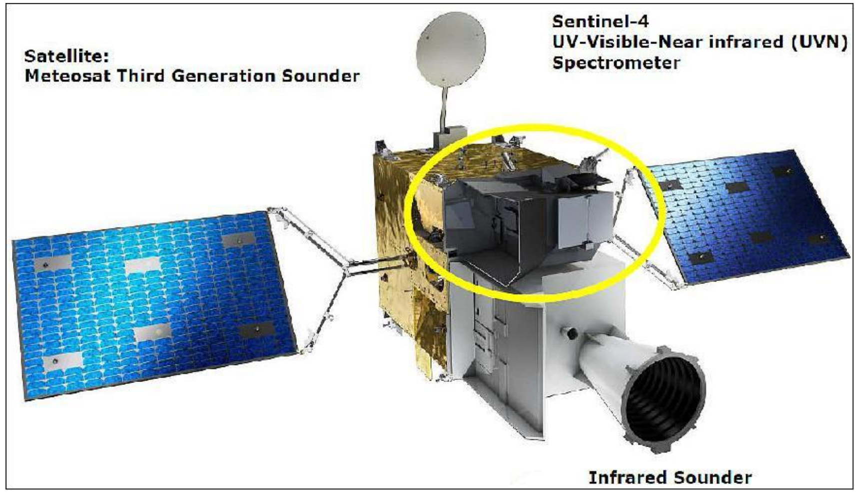
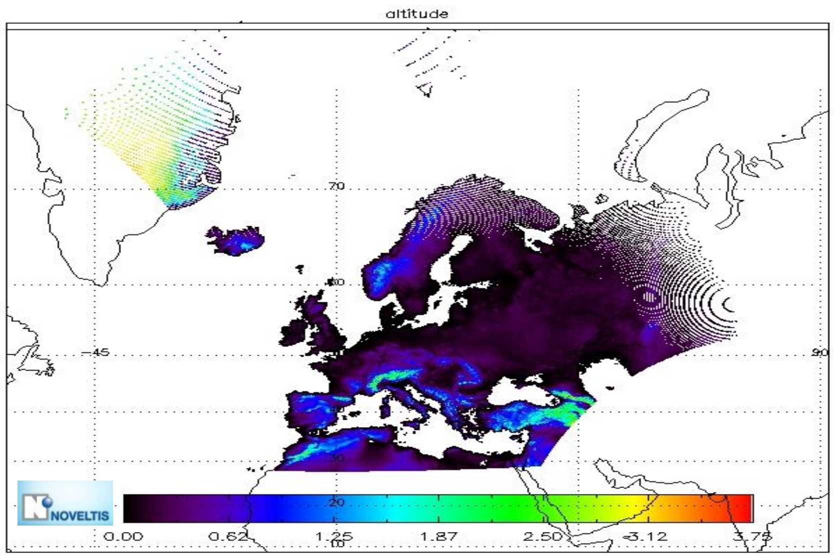


EUMETSAT Future Missions

MTG / Sentinel 4 hyper-spectral UV-VIS-NIR atmospheric composition

Parameter
Total O_3 column
Tropospheric O_3 sub-column
NO_2 total column, tropospheric sub-column
SO_2 total column
CH_2O total column
CHOCHO total column
Aerosol absorbing index
Aerosol layer height
Cloud optical thickness, fraction, altitude
Surface reflectance (Lambertian equivalent albedo and bi-directional reflectance factor), aerosol optical thickness
Cloud and scene characteristics from FCI re-sampled to S4 L1b spatial grid
Aerosol column optical thickness, type, layer height, absorbing index
Cloud optical thickness, fraction, altitude
O_3 with enhanced separation of the lower troposphere





Sentinel-4 on MTG-S:

Hyper-spectral

UV-VIS-NIR soundings

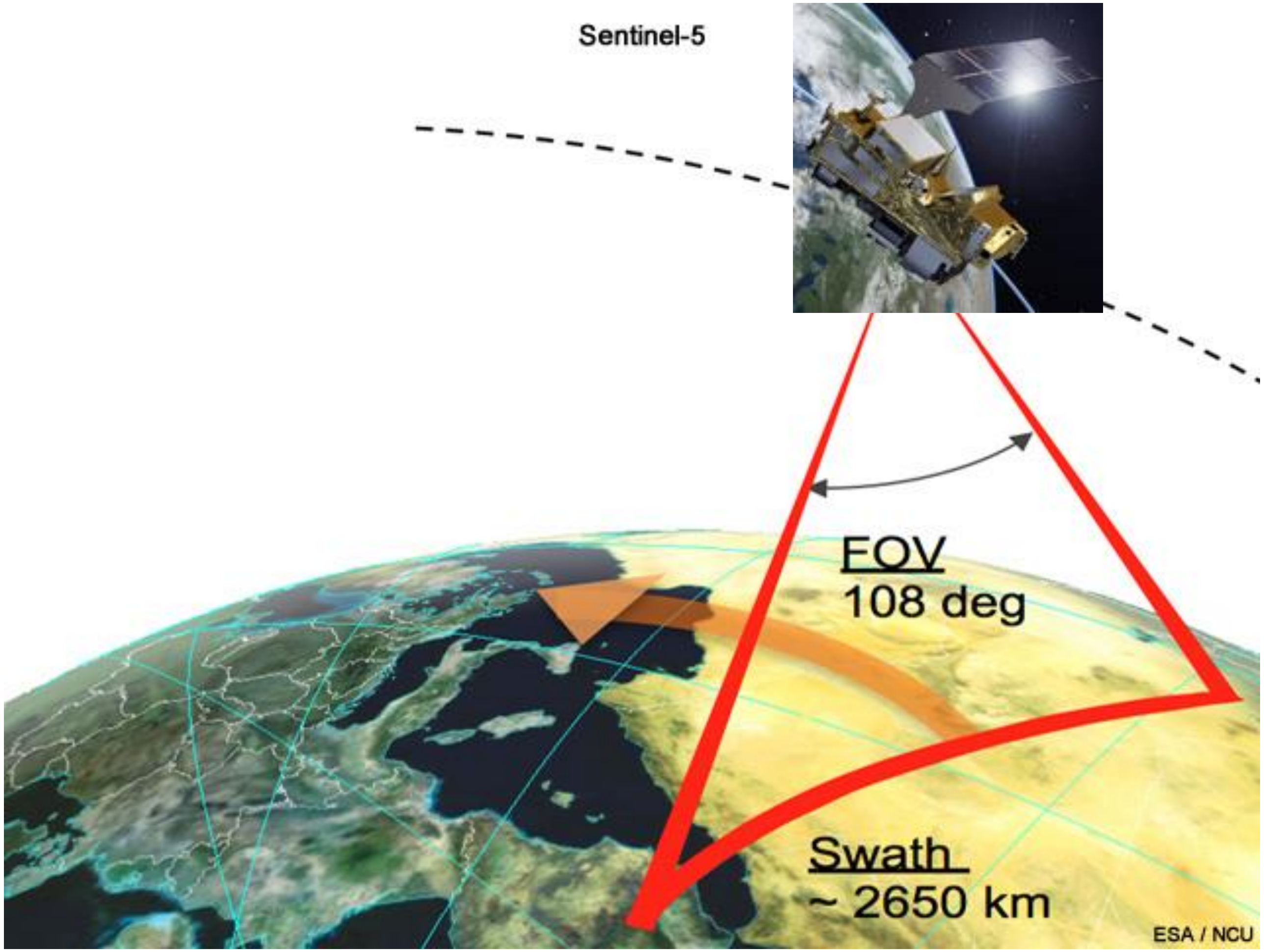
EUMETSAT Future Missions for atmospheric composition

Low-Earth orbit

The EPS Second Generation system is a two-platform system.

EPS-SG A platform: optical imaging, infrared and microwave sounding; aerosol imaging, radio occultation missions and the Copernicus Sentinel-5 mission

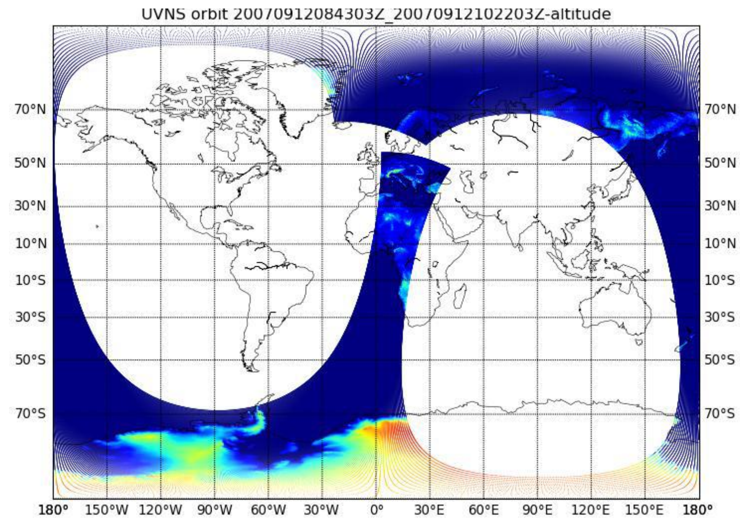
EPS-SG B platform: microwave and sub-millimetre-wave imaging, scatterometry and radio occultation.

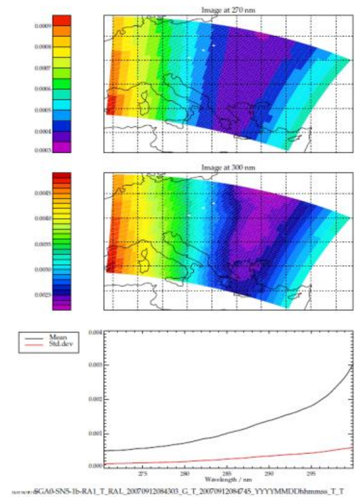


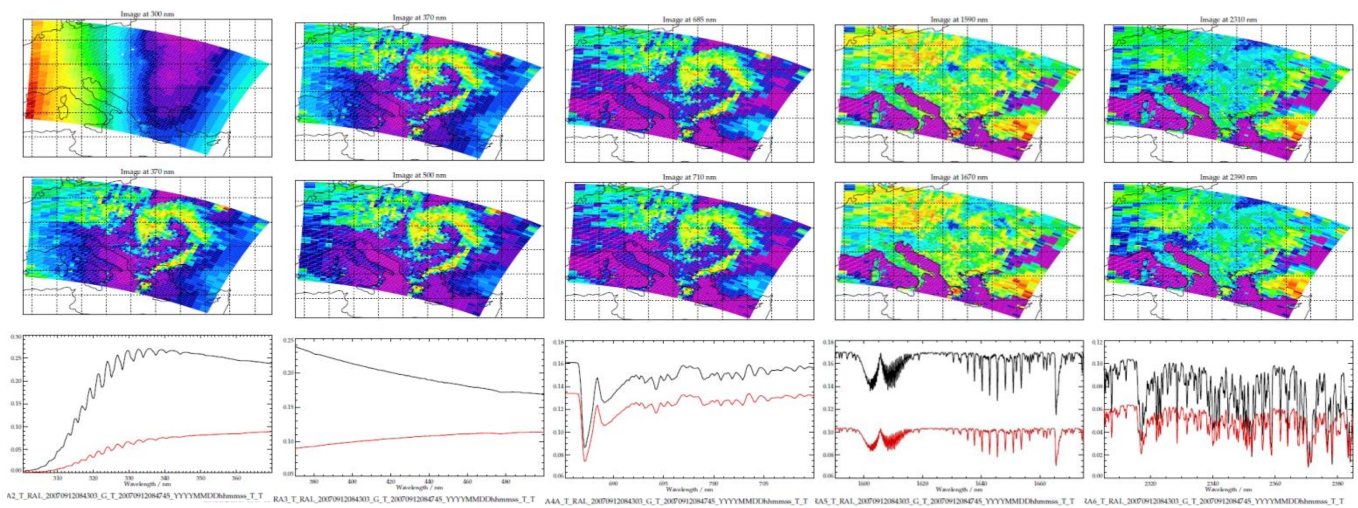
Sentinel 5 “Day-1” Trace-gas, Aerosol/Cloud Products

UV-VIS-NIR-SWIR hyper spectral instrument from low-earth polar orbit

Parameter	
Clouds	Effective Optical Depth (cirrus only)
	Effective Height
	Fraction/Mask from VII
Aerosol	UV Absorbing Index
	Layer Height
Surface Albedo	Surface Albedo
Ozone O3	Stratospheric Vertical Profile
	Tropospheric Column
	Total Column
Nitrogen dioxide NO2	Total Column
	Tropospheric Column
Sulfur dioxide SO2	Total Column and Height
Formaldehyde HCHO	Total Column
Methane CH4	Total Column
Carbon monoxide CO	Total Column
UV	Spectrally Resolved Irradiance at Surface and UV Index
Glyoxal CHOCHO	Total Column
Scene heterogeneity from VII	Scene heterogeneity from VII







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