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

Air Quality Monitoring & Forecasting
Atmospheric composition

Stratospheric Ozone & Ozone Depletion Monitoring

Air Quality Monitoring & Forecasting

Biomass Burning
Atmospheric composition

Stratospheric Ozone & Ozone Depletion Monitoring

Air Quality Monitoring & Forecasting

Biomass Burning

Aerosols and Volcanic Emissions
Primary emissions that are responsible for anthropogenic climate change are:

- Greenhouse Gases (CO2, CH4, Halocarbons, N2O)
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
Primary emissions that are responsible for anthropogenic climate change are:

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

IPCC 2013
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

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

Trace gas signatures in UV/visible region

Optical depths

Wavelength / nm

Optical depth

10^2

10^0

10^-2

10^-4

0

300

400

500

600

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

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
EUMETSAT Current and Future Missions for atmospheric composition

Metop (2006 – present)

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
The GOME-2 instrument on Metop
Measuring atmospheric composition from space

GOME-2 main channel transmittance

- 4 channels with 4098 energy measurements of polarisation corrected radiances (40 x 80 km²)
- 2 channels with 512 energy measurements of linear polarised light in perpendicular direction (S/P) (40 x 10 km²)

GOME-2:

- SO₂
- HCHO
- NO₂
- BrO
- O₃
- OCIO
- O₂
- (O₂)₂
- O
- H₂
- Aerosol

Wavelength [nm]
EUMETSAT Current and Future Missions for atmospheric composition

- 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
- GOME-2: Global Ozone Monitoring Experiment
- GRAS: GPS Receiver for Atmospheric Sounding
- AMSU-A2: Advanced Microwave Sounding Unit-A2
- ASCAT: Advanced SCATterometer

Metop (2006 – present)
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 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).
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.

Stratospheric Ozone Monitoring & Ozone Depletion

Ozone profiles retrievals from nadir looking sensors like GOME-2/Metop
Stratospheric Ozone Monitoring & Ozone Depletion

Ozone profiles from GOME-2 Metop for ozone hole conditions

Ozone Absorption in the Atmosphere

RASA/Courtesy of Brian Kerridge, STFCRAL, UK

O. Tuinder, KNMI, O3MSAF/EUMETSAT
GOME-2 and Sentinel 4/5 are measuring trace gas information in the troposphere, particularly for tropospheric ozone and NO₂.

**Total amount of nitrogen dioxide (NO₂) 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\textsubscript{2} monitoring of the impact of the economy

The Impact of changes in the economy are very well observed NO\textsubscript{x} emissions

*The Greece economic crisis*


Courtesy: M. Verkoussis, IUP Bremen, CyI
Air Quality Monitoring

NO$_2$ monitoring of the impact of the economy – ship tracks


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, CyI
Air Quality Monitoring
NO₂ monitoring of the impact of the economy – China’s GDP variations

Tropospheric NO₂ column above Central East China

China GDP annual growth rate

Courtesy: University Bremen, IUP, Andreas Richter

Source: www.tradingeconomics.com

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

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
Sulphur dioxide (SO\textsubscript{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.
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
Aerosol monitoring from Metop (GOME-2/AVHRR/IASI) 
Polar Multi-Sensor Aerosol product (PMAp) – London pollution event

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

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!

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

- Very high accuracy required (0.5-1 ppm)
- Very high sensitivity in the PBL required
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)
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 — $X_{CO_2}$ or methane — $X_{CH_4}$).

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.
Greenhouse gas monitoring
Path-length weighted $\text{XCO}_2$ and $\text{XCH}_4$-columns from SCIAMACHY SWIR

Courtesy: IUP Bremen, Buchwitz & Schneising

Smoothed & gaps filled
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 Red hyper-spectral sounder)
   Sentinel-4 UV-VIS-NIR hyper-spectral sounder
   Trace-gases, aerosol and clouds
EUMETSAT Future Missions for atmospheric composition

Geo-stationary orbit

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

1\textsuperscript{st} platform: The MTG Imaging platform will be launched in 2019.
- Flexible Combined Imager (FCI)
- Aerosol and volcanic ash

2\textsuperscript{nd} 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

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

<table>
<thead>
<tr>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total O$_3$ column</td>
</tr>
<tr>
<td>Tropospheric O$_3$ sub-column</td>
</tr>
<tr>
<td>NO$_2$ total column, tropospheric sub-column</td>
</tr>
<tr>
<td>SO$_2$ total column</td>
</tr>
<tr>
<td>CH$_3$O total column</td>
</tr>
<tr>
<td>CHOCHO total column</td>
</tr>
<tr>
<td>Aerosol absorbing index</td>
</tr>
<tr>
<td>Aerosol layer height</td>
</tr>
<tr>
<td>Cloud optical thickness, fraction, altitude</td>
</tr>
<tr>
<td>Surface reflectance (Lambertian equivalent albedo and bi-directional reflectance factor), aerosol optical thickness</td>
</tr>
<tr>
<td>Cloud and scene characteristics from FCI re-sampled to S4 L1b spatial grid</td>
</tr>
<tr>
<td>Aerosol column optical thickness, type, layer height, absorbing index</td>
</tr>
<tr>
<td>Cloud optical thickness, fraction, altitude</td>
</tr>
<tr>
<td>O$_3$ with enhanced separation of the lower troposphere</td>
</tr>
</tbody>
</table>

**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**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Clouds</th>
<th>Aerosol</th>
<th>Surface Albedo</th>
<th>Ozone O$_3$</th>
<th>Nitrogen dioxide NO$_2$</th>
<th>Sulfur dioxide SO$_2$</th>
<th>Formaldehyde HCHO</th>
<th>Methane CH$_4$</th>
<th>Carbon monoxide CO</th>
<th>CO</th>
<th>UV</th>
<th>Glyoxal CHOCHO</th>
<th>Scene heterogeneity from VII</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Effective Optical Depth (cirrus only)</td>
<td>Effective Height</td>
<td>Fraction/Mask from VII</td>
<td>UV Absorbing Index</td>
<td>Layer Height</td>
<td>Surface Albedo</td>
<td>Stratospheric Vertical Profile</td>
<td>Tropospheric Column</td>
<td>Total Column</td>
<td>Tropospheric Column</td>
<td>Total Column and Height</td>
<td>Total Column</td>
<td>Spectrally Resolved Irradiance at Surface and UV Index</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Map and images of data products](image-url)