Development of the CO2M NO₂ Retrieval Algorithm

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Planned developments for the CO2M NO₂ algorithm

- High resolution surface reflectance / BRDF data (MODIS/VIIRS)
- High resolution a priori NO₂ model data (CAMS global)
- Use of cloud information from CLIM instrument
- Combined O₂-O₂ (VIS) and O₂-A band (NIR) cloud information
- Scattering layer model for cloud and aerosol treatment

NO₂ as tracer for CO₂

- Better plume detection
- Improved hotspot CO₂ emission quantification

TROPOMI NO₂ zoom data set

- Similar resolution as CO2M (~ 2x2 km²)
- Scenes with plumes from power plants and cities
- Testing data set for algorithm development
NO$_2$ as tracer for CO$_2$ emission plumes

- NO$_2$ and CO$_2$ co-emitted in combustion processes
- NO$_2$ observations have a higher SNR due to shorter lifetime of NO$_2$ (lower background value), less problems with small cloud cover
- CO$_2$ emission estimations benefit from additional NO$_2$ observations:
  - Better constraint of hotspot emission plume shape and size
  - CO2M: 3x more CO$_2$ plumes detectable [Kuhlmann et al., 2019] / SMARTCARB

Example: TROPOMI trop. column NO$_2$ and OCO-2 XCO$_2$

NO$_2$ observations on CO2M

CO2M NO2I instrument:
- VIS imaging spectrometer with high spectral resolution
- Co-located NO$_2$ and CO$_2$ observations
- High spatial resolution: 2x2 km$^2$

Δt = 16 min.
Avg. 10m wind speed: ≈ 2 m/s

OCO-2 XCO$_2$

S5P tropo. NO$_2$ column

Image credit: OHB

TROPOMI trop. column NO$_2$ and OCO-2 XCO$_2$
CO2M NO₂ algorithm development

Based on TROPOMI (S5P) / Sentinel 5 NO₂ algorithm

**Planned improvements**

- High-resolution surface reflectance/BRDF information over land.
- Modelled surface reflectance over oceans.
- Use of the CO2M cloud imager (CLIM) geometric cloud fraction
- Combined O₂-O₂ (VIS) and O₂-A band (NIR) cloud information
- Use scattering layer model to represent scattering by aerosols and clouds
  - Simplified phase function (most likely Henyey-Greenstein)
  - Single layer with fixed pressure thickness
  - Determine cloud pressure and optical thickness
  - Consistent cloud model for VIS cloud retrieval and NO₂ AMF calculation
- Use of high spatial resolution NO₂ model information.
During the TROPOMI commissioning phase measurement were done with extra high spatial sampling (2.4 x 1.8 km²), current nominal sampling is 5.6 x 3.6 km². The spatial zoom measurement mode was used during 1st week of March 2018.

Integration time was reduced by factor 3 and the binning was disabled (factor 2) for the very center of the swath (310 out of 2700 km). To further compensate for the high data volume, only half of the detector channels were used.

Several interesting scenes captured with high resolution resulting in detailed mapping of NO₂ plumes.

Similar spatial sampling as CO2M NO₂

→ Good testbed data set for NO₂ algorithm development

Power plant plumes

Rihand Lake, India

Belchatów, Poland

Donetsk, Ukraine
High resolution surface reflectance database

The CO2M high spatial resolution requires the use of **km-scale surface information** for accurate air-mass factor calculation and cloud parameter retrieval.

CO2M will have a **Sun glint pointing mode**, utilizing the Sun glint spot over the ocean.

**Over land**: MODIS/VIIRS surface reflectance and/or BRDF products, visible band

**Over water**: BRDF model accounting for water-leaving radiance and specular reflection by sea surface roughness

Cloud retrievals and NO₂ retrievals require a **consistent approach w.r.t. surface reflectance**

Surface reflectance data can be **dynamic**, using a static fallback (climatology)

**BRDF surface treatment** in radiative transfer models instead of Lambertian surface assumption.

Air-mass factors stored in look-up table or neural network.

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Current albedo database for TROPOMI NO₂

Example comparison case

Example of MODIS product

Royal Dutch Meteorological Institute (KNMI)
A-priori NO$_2$ information

- For tropospheric – stratospheric separation of the measured columns, model stratospheric NO$_2$ columns are used.
- For the calculation of the air-mass factor, tropospheric NO$_2$ profile shapes are required.
- Using a model with higher horizontal spatial resolution for the NO$_2$ profile shape increases spatial representativeness of the air-mass factor and reduces NO$_2$ column bias.
- NO$_2$ stratospheric columns from CAMS global, optionally scaled in clean background regions to remove model bias.
- NO$_2$ tropospheric profile shapes from CAMS global, optionally in combination with CAMS regional for Europe.

**CAMS global model**
- 0.4 x 0.4°
- 137 levels up to 0.01 hPa
- 1 hour resolution
- Integrated into the ECMWF IFS

**CAMS regional European model**
- 0.1 x 0.1°
- 8 levels up to 5 km altitude
- 1 hour resolution
- Ensemble of 7 models