TROPOMI on the Copernicus Sentinel 5 Precursor: Ready for Launch

Pepijn Veefkind & the TROPOMI Team
The ESA Sentinel-5 Precursor (S-5P) is a pre-operational mission focusing on global observations of the atmospheric composition for air quality and climate.

The TROPOspheric Monitoring Instrument (TROPOMI) is the payload of the S-5P mission and is jointly developed by The Netherlands and ESA.

The planned launch date for S-5P is 2017 with a 7 year design lifetime.
EU Copernicus Sentinels

- Sentinel 1
- Sentinel 2
- Sentinel 3
- Sentinel 4
- Sentinel 5
- Sentinel 5P
- Sentinel 6
International Co-operation

• TROPOMI/S5P is part of the CEOS AQ Constellation
  – TROPOMI provides the global coverage
  – Act as a “travelling standard” between the GEOs

• S5P will fly in loose formation with Suomi NPP
  – Primary objective is to use the VIIRS data for cloud clearing
## Level 2 Data Products

<table>
<thead>
<tr>
<th>Product</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ozone column</td>
<td>Ozone layer monitoring</td>
</tr>
<tr>
<td>Ozone profile, incl. troposphere</td>
<td>Ozone layer, Climate and Air quality monitoring</td>
</tr>
<tr>
<td>Ozone tropospheric column</td>
<td>Climate and Air quality monitoring</td>
</tr>
<tr>
<td>Nitrogen Dioxide</td>
<td>Air quality forecast / Emission monitoring</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>Air quality forecast / Emission monitoring</td>
</tr>
<tr>
<td>Sulphur Dioxide</td>
<td>Volcanic plume warnings / Emission monitoring</td>
</tr>
<tr>
<td>Methane</td>
<td>Climate and Air quality monitoring / Emission monitoring</td>
</tr>
<tr>
<td>Aerosol</td>
<td>Volcanic ash warnings / Climate monitoring</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>Air quality forecast / Emission monitoring</td>
</tr>
<tr>
<td>Cloud</td>
<td>Climate Monitoring</td>
</tr>
<tr>
<td>Surface UV index</td>
<td>UV Forecast</td>
</tr>
<tr>
<td>Solar irradiance</td>
<td>Climate monitoring</td>
</tr>
</tbody>
</table>
From OMI to TROPOMI

- 6x higher spatial resolution
  7x7 km$^2$ vs. 13x24 km$^2$
- 1-5x higher signal-to-noise per ground pixel
- SWIR Band
  CO and Methane
- Better cloud information
  oxygen A band added
- Many lessons learned from 11 years of OMI data

Courtesy Henk Eskes & NITROSAT team
<table>
<thead>
<tr>
<th></th>
<th>UV</th>
<th>UVIS</th>
<th>NIR</th>
<th>SWIR</th>
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</thead>
<tbody>
<tr>
<td>Band</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Spectral coverage [nm]</td>
<td>270 – 320</td>
<td>320 – 495</td>
<td>675 - 775</td>
<td>2305 – 2385</td>
</tr>
<tr>
<td>Full spectral coverage [nm]</td>
<td>267 - 332</td>
<td>303 - 499</td>
<td>660 - 784</td>
<td>2299 - 2390</td>
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<tr>
<td>Spectral resolution [nm]</td>
<td>0.49</td>
<td>0.54</td>
<td>0.38</td>
<td>0.25</td>
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<tr>
<td>Spectral sampling ratio</td>
<td>6.7</td>
<td>2.5</td>
<td>2.8</td>
<td>2.5</td>
</tr>
<tr>
<td>Spatial sampling [km²]</td>
<td>7 x 28</td>
<td>7 x 3.5</td>
<td>7 x 7</td>
<td>7 x 7</td>
</tr>
</tbody>
</table>
Level 0-1B Processor

- Multi-threading
- Multi-pass
- Algorithms are pluggable at run-time
- Full error propagation: noise + systematic errors
- L1B product ~35 Gbyte / 100 min
- S/W design can be re-used
- Level 0-1B Processor was used for the analysis of the on-ground calibration data
On-Ground Calibration

• All analyses finalized and key-data delivered.

• Delta investigations:
  – Re-calibration of OGSE for absolute radiometry
  – Investigations on out-of-spectral band stray light in the NIR spectrometer
Phase E1 Planning

- All the measurements have been planned:
  - Several special measurements
  - Temperature variations
  - In-flight solar diffuser calibration
  - First light 6 weeks after launch

- L2 E1 activity plan will be completed in the coming month

Payload Commissioning Timeline

L-IFC: limited instrument functional checkout
F-IFC: full instrument functional checkout

1. On-ground Monitoring Block
2. Delta On-ground Monitoring Block
3. Radiance Optimization
4. Irradiance Optimization
5. In-Flight Calibration
6. Extended In-Flight Calibration
User Services

• **Data dissemination**
  – Near-Real-Time
  – offline data stream

• **Data volume**
  – Develop higher Level products (e.g. CAMS, GlobEmission)
  – Reliable and fast data access
  – Big data analyses and Cloud solutions

• **Data Quality**
  – Provide up-to-data information on the web
  – Routinely compare with ground based observations

• **Standard data format**
  – works with existing tools
  – ready for Sentinel 4 and 5
Validation

• The pre-launch CINDI-2 campaign organized in Cabauw, The Netherlands in September 2016, was very successful.
• ESA has organized 3 pre-launch campaigns in Romania and Germany.
• The community is involved in validation through the ESA Announcement of Opportunity.
• The preparation for the routine validation has started.
Spectrolite | Tropolite

• Ambition: develop an instrument for micro or cubesat that can observe trace gases with a resolution of $1 \times 1 \text{ km}^2$. 
Summary & Conclusion

• TROPOMI data will contribute to applications for societal challenges on climate change, air quality and the ozone layer.
• Sentinel 5P operational: we expect that this will attract new users.
• TROPOMI will be a major step forward for atmospheric composition observations due to improved spatial resolution & sensitivity.
• The large data volumes are challenging for users and data providers.
• *We are counting down for a launch in 2017!*
S5P Mission Performance Centre

• S5P-MPC : is an operational service that includes
  – Quality control of L1B and L2 data products
  – In-orbit calibration of L1B data
  – Routine validation against operational networks
  – Algorithm evolutions and processor maintenance
  – User support
CAMS IN A NUTSHELL

Forecasts and informs on impacts

Detests emissions and estimate surface fluxes

Quantifies transport, removal and transformations of atmospheric constituents

Air quality
Climate forcing
Ozone layer
Radiation
Emissions
Instrument Spectral Response Function

- Measured with tunable lasers and slit-function stimulus
- Different ISRF shapes due to the optical design of the instrument
- Parametrized as function of swath angle and wavelength
UVN Stray Light

• New stray light correction algorithm has been implemented.
• Good performance after stray light correction is applied.
• NIR out-of-band stray light is further investigated.
Dark Current

Dark currents in Bands 1-6 lower than 2 e/s

<table>
<thead>
<tr>
<th>band</th>
<th>dc e/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.622</td>
</tr>
<tr>
<td>2</td>
<td>1.477</td>
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<tr>
<td>3</td>
<td>1.593</td>
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<td>4</td>
<td>1.579</td>
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<tr>
<td>5</td>
<td>1.759</td>
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<tr>
<td>6</td>
<td>1.849</td>
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