Copernicus Sentinel-5:
Long-Term Global Monitoring of Atmospheric Composition

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The Copernicus Atmospheric Mission: Sentinels -4, -5p and -5

Environmental Themes
- air quality
- climate
- stratospheric ozone and surface UV

Missions and Services

Sentinel-4
- regional AQ at 1h temporal res.
  - emission and abundance monitoring
  - forecast
- first AQ mission approved for geostationary orbit (embarked on MTG-S)
- diurnal variation, e.g. NO₂, aerosol
- part of CEOS virtual constellation

Sentinel-5p
- global AQ at 1d temporal res.
  - emission and abundance monitoring
  - forecast
- bridging between OMI and S-5
- CO and CH₄
- x6 step in 2-D spatial resolution vs. OMI
- some diurnal information (with GOME-2)

Sentinel-5
- climate
  - GHG emission monitoring
  - aerosol
- ozone total column
  - long term total O₃ evolution
  - surface UV (health)
- continuity and long-term datasets
- synergies with meteo payloads (embarked on Metop-SG)
- CH₄ from 2 bands
- Some CO₂ (quality not sufficient for operational monitoring)

overview on S-4 S-5p S-5 system: see poster no. 55 by P. Ingmann et al.
S-5 instrument characteristics

- Nadir-viewing push-broom UVNS spectrometer, 2 telescopes
- Spectral ranges between 270 and 2385 nm
- Spectral resolution 0.25 – 1.0 nm, oversampling factor 2.5 – 3
- Daily coverage at latitudes > 12 deg
- Spatial resolution 7.5 km @ nadir (45 km at $\lambda < 300$ nm)
- High signal/noise
- Demanding requirements on radiometric accuracy, spectral calibration and spatial co-registration
Main performance issues (1)

- **Effective spectral radiometric accuracy (ESRA) for HCHO** (spectrally varying radiometric errors)
  - high sensitivity to errors due to small HCHO spectral signatures. Will require mitigation scheme in or after retrieval.

- **Radiometric offset in SWIR**
  - requirement 0.1% of maximum radiance in high latitude dark scene
  - accuracy limited by thermal sensitivity of dark current and thermal background radiation. A serious non-compliance is expected affecting the CH$_4$ retrieval.

- **Spectral stability ground-to-orbit and on-orbit**
  - requirements are 0.5/0.1 spectral sampling interval ground-to-orbit/on orbit
  - opto-mechanical stability insufficient. Significant non-compliance expected.
  - intention: mitigate situation by spectral calibration using radiance data. Computationally affordable?
Main performance issues (2)

- **combination of radiometric and spatial requirements in [300, 310] nm**
  - UV1 non-compliant to spatial requirements. Sample size 45 km, sub-sample 7.5 km but not compliant to geolocation knowledge and spatial PSF requirements.
  - UV2 partially non-compliant to SNR and radiometric accuracy (straylight)
  - UV2 signal might be re-calibrated, using spectrally overlapping UV1 data in homogeneous scenes

- **radiometric stability**
  - requirement is 0.5% over one orbit
  - serious non-compliance expected in UV1 (detector)

- **radiometric accuracy variation across track**
  - requirement is 0.25%
  - significant non-compliance expected.
  - measurement accuracy (on-ground) insufficient.
Project status

- EPS-SG programme to be endorsed by Eumetsat Council in summer 2015
- Sentinel-5 subscription 100% after ESA Council Dec 2014
- ITTs for S-5 sub-contracts well underway
- Preliminary Design Review on-going
- Level 1b prototype processor development to start soon
- list of L2 products being discussed between ESA and Eumetsat
### S-5 UVNS priority 1 data products

<table>
<thead>
<tr>
<th>Species</th>
<th>Characteristics</th>
<th>Wavelength range [nm]</th>
<th>Applications</th>
<th>L2 Requirement</th>
<th>S-5p (expected accuracy)</th>
<th>S-4</th>
<th>S-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>(O_3)</td>
<td>vertical profile</td>
<td>270 – 335</td>
<td>SO, AQ, CL</td>
<td>20% (strat. profile), 25% (trop. column), vert. res. reqt. in strat. TBD</td>
<td>10-30 % (strat. profile @6km vert. res.), TBD (trop. col.)</td>
<td>trop. column 3(^1) priority 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>total column</td>
<td>325 – 337</td>
<td>SO, CL</td>
<td>3%</td>
<td>3.5 – 5 %</td>
<td>x</td>
<td>priority 1</td>
</tr>
<tr>
<td>(NO_2)</td>
<td>total column and trop. column</td>
<td>405 – 500</td>
<td>AQ, AW</td>
<td>max (1.3 \times 10^{15}) molec cm(^{-2}), 20% (both)</td>
<td>strat. &lt; 10% trop. 25-50 %</td>
<td>x</td>
<td>priority 1</td>
</tr>
<tr>
<td>(SO_2)</td>
<td>total column and height</td>
<td>308 – 325</td>
<td>AQ, AW</td>
<td>max (1.3 \times 10^{15}) molec cm(^{-2}), 30%, height reqt. TBD</td>
<td>30 – 50 %</td>
<td>x</td>
<td>priority 1</td>
</tr>
<tr>
<td>(HCHO)</td>
<td>total column</td>
<td>337 – 360</td>
<td>AQ</td>
<td>max (1.3 \times 10^{15}) molec cm(^{-2}), 30%</td>
<td>40 – 80 %</td>
<td>x</td>
<td>priority 1</td>
</tr>
<tr>
<td>(CHOCHO)</td>
<td>total column (averages)</td>
<td>430 – 460</td>
<td>AQ</td>
<td>max (1.5 \times 10^{14}) molec cm(^{-2}), 30%</td>
<td>x (^2)</td>
<td>x</td>
<td>priority 1</td>
</tr>
<tr>
<td>(CH_4)</td>
<td>total column</td>
<td>1590 – 1675 2305 – 2385</td>
<td>CL</td>
<td>precision (G/T): max (0.5/1.0%), 10/18ppbv regional bias (G/T): max (0.5/1.0%), 10/18ppbv (2305 – 2385 nm)</td>
<td>1.5 %</td>
<td>-</td>
<td>priority 1</td>
</tr>
<tr>
<td>(CO)</td>
<td>total column</td>
<td>2305 – 2385</td>
<td>AQ, CL</td>
<td>25%</td>
<td>&lt; 15 %</td>
<td>-</td>
<td>priority 1</td>
</tr>
<tr>
<td><strong>Cloud</strong></td>
<td>effective optical depth, effective cloud fraction, effective height</td>
<td>360 – 400 460 – 490 685 – 710 755 – 773</td>
<td>auxiliary</td>
<td>(auxiliary only)</td>
<td>&lt;20 % (fraction, optical depth, pressure)</td>
<td>x (^1)</td>
<td>priority 1</td>
</tr>
<tr>
<td><strong>Aerosol</strong></td>
<td>UV absorption index</td>
<td>336 – 340 360 – 400</td>
<td>AQ, CL, AW, auxiliary</td>
<td>TBD</td>
<td>~1 AAI</td>
<td>x</td>
<td>priority 1</td>
</tr>
<tr>
<td></td>
<td>layer height</td>
<td>755 – 773</td>
<td>AQ, CL, AW</td>
<td>TBD</td>
<td>&lt; 100 hPa</td>
<td>x</td>
<td>priority 1</td>
</tr>
<tr>
<td><strong>Surface</strong></td>
<td>effective reflectance</td>
<td>310 – 773 1590 – 1675 2305 – 2385</td>
<td>auxiliary</td>
<td>(auxiliary only)</td>
<td>x</td>
<td>daily map</td>
<td>priority 1</td>
</tr>
<tr>
<td><strong>UV</strong></td>
<td>spectrally resolved irradiance at surface, UV index</td>
<td>300 – 380</td>
<td>health</td>
<td>TBD</td>
<td>collaborative ground segment (FMI)</td>
<td>-</td>
<td>priority 1</td>
</tr>
</tbody>
</table>

1\(^1\) optional products use also FCI Level 1c data.
2\(^2\) funding not yet secured.
3\(^3\) optional synergy with IRS for enhanced sensitivity to lower troposphere

SO: stratospheric ozone
AQ: air quality
CL: climate
AW: alert warning

G/T: Goal / Threshold
### S-5 UVNS priority 2/3 data products

<table>
<thead>
<tr>
<th>species</th>
<th>characteristics</th>
<th>wavelength range [nm]</th>
<th>applications</th>
<th>L2 requirement</th>
<th>S-5p (expected accuracy)</th>
<th>S-4</th>
<th>S-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>H$_2$O</td>
<td>total column</td>
<td>685 – 710 2305 – 2385</td>
<td>AQ, CL</td>
<td>10%</td>
<td>$x^2$</td>
<td>-</td>
<td>priority 2</td>
</tr>
<tr>
<td>CO$_2$</td>
<td>total column</td>
<td>1590 – 1675</td>
<td>CL</td>
<td>0.75%</td>
<td>-</td>
<td>-</td>
<td>priority 2</td>
</tr>
<tr>
<td>BrO</td>
<td>total column</td>
<td>345 – 360</td>
<td>SO</td>
<td>TBD</td>
<td>$x^2$</td>
<td>-</td>
<td>priority 2</td>
</tr>
<tr>
<td>OClO</td>
<td>total column</td>
<td>363 - 391</td>
<td>SO</td>
<td>TBD</td>
<td>$x^2$</td>
<td>-</td>
<td>priority 2</td>
</tr>
<tr>
<td>IO</td>
<td>total column</td>
<td>415 – 430</td>
<td>science</td>
<td>TBD</td>
<td>$x^2$</td>
<td>-</td>
<td>priority 3</td>
</tr>
<tr>
<td>HDO</td>
<td>total column</td>
<td>2305 – 2385</td>
<td>science</td>
<td>TBD</td>
<td>$x^2$</td>
<td>-</td>
<td>priority 3</td>
</tr>
<tr>
<td>Aerosol</td>
<td>optical depth at ≥ 2 wavelengths</td>
<td></td>
<td>AQ, CL</td>
<td>0.05</td>
<td>$x^1$</td>
<td></td>
<td>priority 2</td>
</tr>
<tr>
<td></td>
<td>absorption optical depth</td>
<td>336 – 340 360 – 400 400 – 430 440 – 460</td>
<td>AQ, CL</td>
<td>TBD</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>fine mode optical depth</td>
<td>755 – 773 1590 – 1675 2305 – 2385</td>
<td>AQ, CL</td>
<td>TBD</td>
<td>x</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>
### S-5 relevant products of other MetOp-SG instruments

<table>
<thead>
<tr>
<th>Priority 1</th>
<th>IASI-NG</th>
<th>Priority 2</th>
<th>Priority 3</th>
<th>3MI</th>
<th>MetImage</th>
</tr>
</thead>
<tbody>
<tr>
<td>O₃ profile</td>
<td>CH₃OH</td>
<td>C₂H₂</td>
<td>multispectral AOD</td>
<td>cloud flag</td>
<td></td>
</tr>
<tr>
<td>CO profile</td>
<td>HCOOH</td>
<td>HCN</td>
<td>multispectral SSA</td>
<td>snow/ice flag</td>
<td></td>
</tr>
<tr>
<td>SO₂ (incl. height)</td>
<td>CFC-11</td>
<td>C₂H₄</td>
<td>bimodal size distribution</td>
<td>cloud optical depth, phase, height</td>
<td></td>
</tr>
<tr>
<td>NH₃</td>
<td>CFC-12</td>
<td>C₂H₆</td>
<td>effective radius (total, fine, and coarse modes)</td>
<td>Level 1b products</td>
<td></td>
</tr>
<tr>
<td>CH₄</td>
<td>N₂O</td>
<td></td>
<td>multispectral refractive index</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₂O</td>
<td>HONO</td>
<td></td>
<td>aerosol type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HNO₃</td>
<td>CO₂</td>
<td></td>
<td>AAI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PAN</td>
<td></td>
<td></td>
<td>aerosol height</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>surface BRDF</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Schedule + Long-Term Perspective

- **GOME-2 (Metop B/C at 9.30h) and OMI on Aura /TROPOMI on S-5p (~13.30h)** provide partial diurnal information, before S-4 takes over with hourly data.

- **S-4 and S-5**, together with IR sounders and 3MI, will be Europe’s long-term contribution to operational nadir-viewing atmospheric composition sounding.

#### Guaranteed provision of long-term datasets in synergy with meteorological payloads is based on identical instruments, however this implies

\[\rightarrow \text{no innovation until 2035/40}\]

- **Update of geophysical requirements for future successors is under EU responsibility:**
  - GMES-PURE contract (2013/14)
  - Requirements Framework for the next generation of the Copernicus Space Component (2015–18) (“small scale exercise” for atmosphere complementing PURE)
The Limb Gap

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**Sentinel-5**
- climate
  - GHG emission monitoring
  - aerosol
- ozone total column
  - long term total O₃ evolution
  - surface UV (health)

**climate**
- forcing
- NWP contribution

**stratospheric ozone**
- long-term 3-D evolution
- climate and NWP impact

**ozone total column**
- long-term total O₃ evolution
- surface UV (health)

**Limb-gap**

Programmatically not covered → limb gap

See presentation by M. v. Weele, Tue 17:00h