Sentinel-5 Precursor Mission and Cal/Val lessons learned

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Importance of the pre-flight calibration campaign!

- unexpected response observed in pre-launch calibration measurements; -> NIR channel (661 – 786 nm)
- origin & magnitude of effect initially unclear
- analyses of spectral filters & light sources revealed signals originated by emissions at wavelengths > 800 nm
Importance of the pre-flight calibration campaign!

All Sentinel-5 Precursor Products have been delivered so far to the public except the Ozone Profile – reason: problems during the pre-flight calibration campaign causing wrong calibration in the UV wavelength range for sun irradiance measurements

Solution: ‘adjustment’ of Sentinel-5P irradiance measurement to Suomi-NPP OMPS irradiance measurements
**The Mission Performance Center**

The Mission Performance Center is in charge of the **operational** and **overall validation** providing the synthesis of the results.

*MPC S1, MPC S2, MPC S3, MPC S5P have been set up.*

**Sentinel Validation Teams (SVT):**

The validation team complete the MPC activities by providing independent validation measurements or independent analysis. The team members are selected through an open call process. The intention of this call is to create scientific validation teams to provide structured coordination of international activities that contribute to Sentinel validation across the entire mission (i.e. Phase E1 and E2).

*S2VT, S3VT, S5PVT have been set up.*

**Fiducial Reference Measurements providers**

Specific activities need to be put in place for providing mandatory FRMs (e.g. for **atmospheric FRMs**, PANDONIA/PGM, FRM4DOAS, FRM4GHG).

**Quality Working Group (QWG)**

The information is then discussed, further processed in the **Quality Working Groups** which provide synthetic results to the **Mission Managers**, used for improving the products quality and the products knowledge.

**User Community and international forum:**

The validation program benefits from the feedback from:
- Workshops/conferences (ESA or international)
- Bilateral relation (NASA, NOAA, CNES, DLR, UKSA, JRC, EUMETSAT etc.)
- Coordination within **CEOS WGCV** and **CEOS VCs**
MPC Routine Operations Validation

http://mpc-vdaf.tropomi.eu

To the Automated Validation Server

Results and resources by product

Quarterly Routine Validation Report

Validation Web Articles produced jointly by S5P MPC and S5PVT AO projects
## Validation Data Streams into S5P MPC

**ESA FRM programme + WMO GAW contributing networks**

<table>
<thead>
<tr>
<th>S5P ID</th>
<th>S5P Data Product</th>
<th>Fiducial / Validation Reference Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>L2_O3</td>
<td>O₃ total column</td>
<td>Brewer, Dobson, ZSL-DOAS, PGN/Pandonia</td>
</tr>
<tr>
<td>L2_O3_PR</td>
<td>O₃ profile (incl. troposphere)</td>
<td>ozonesonde, stratospheric DIAL, tropospheric DIAL</td>
</tr>
<tr>
<td>L2_O3_TCL</td>
<td>O₃ tropospheric column</td>
<td>ozonesonde</td>
</tr>
<tr>
<td>L2_NO2</td>
<td>NO₂ stratospheric column</td>
<td>ZSL-DOAS</td>
</tr>
<tr>
<td></td>
<td>NO₂ tropospheric column</td>
<td>MAX-DOAS</td>
</tr>
<tr>
<td></td>
<td>NO₂ total column</td>
<td>PGN/Pandonia</td>
</tr>
<tr>
<td>L2_SO2</td>
<td>SO₂ total column</td>
<td>MAX-DOAS, PGN/Pandonia</td>
</tr>
<tr>
<td>L2_HCHO</td>
<td>HCHO total column</td>
<td>MAX-DOAS, NDACC FTIR, PGN/Pandonia</td>
</tr>
<tr>
<td>L2_CO</td>
<td>CO total column</td>
<td>NDACC FTIR (MIR), TCCON FTIR (NIR)</td>
</tr>
<tr>
<td>L2_CH4</td>
<td>CH₄ total column</td>
<td>NDACC FTIR (MIR), TCCON FTIR (NIR)</td>
</tr>
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<td>L2_CLOUD</td>
<td>Cloud Fraction</td>
<td>not available (satellite-to-satellite only)</td>
</tr>
<tr>
<td></td>
<td>Cloud Height (pressure)</td>
<td>Cloudnet lidar/radar, ARM</td>
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<tr>
<td></td>
<td>Cloud Optical Thickness</td>
<td>not available (satellite-to-satellite only)</td>
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<tr>
<td>L2_AER</td>
<td>UV Aerosol Absorbing Index</td>
<td>not available (satellite-to-satellite only)</td>
</tr>
<tr>
<td></td>
<td>Aerosol Layer Height</td>
<td>EARLINET aerosol lidar, EUMETNET/ALC ceilometer</td>
</tr>
</tbody>
</table>

**Colour code:**
- automated, full stream
- automated, partial stream
- manual
- in development

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| AC-VC-16 Meeting Slide | 7 |
Generic validation chain, state-of-the-art co-locators, harmonised terminology and comparison metrics... in permanent evolution

Cross GEOSS/cross-EO domains Cal/Val harmonization

Prototyping in Multi-TASTE and ESA CCI_Ozone

Community feedback & endorsement

Implementation and continuous development in FP7 QA4ECV, H2020 GAIA-CLIM, Envisat QWGs, ISSI Cross-EO Val., CCI+/C3S ozone, Sentinel-5p MPC

Lambert et al., JAS 1999, ISSI 2012
Keppens et al., AMT 2015, 2018
Langerock et al., GMD 2015
Verhoest et al., AMT 2015, EC TN 2016
Hubert et al., AMT 2016
Compernolle et al., EC TN 2017
Generic validation chain, state-of-the-art co-locators, harmonised terminology and comparison metrics... in permanent evolution

S5P TROPOMI validation and FRM programme contribute further progress in:

- Harmonisation of validation practices across networks
- Harmonisation of validation reporting across species
- Harmonisation of unified error/uncertainty reporting
- Validation of ex-ante satellite uncertainties
- Criteria of compliance with user/mission requirements

Lambert et al., JAS 1999, ISSI 2012
Keppens et al., AMT 2015, 2018, 2019
Langerock et al., GMD 2015
Verhoeest et al., AMT 2015, EC TN 2016, AMT 2020
Hubert et al., AMT 2016, LOTUS 2019, AMT 2020
Compernolle et al., EC TN 2017, ACP 2019, AMT 2020
Vigouroux et al., AMT 2020
Sentinel-5p Lessons Learnt about data

Satellite data uncertainties and QA/QC:
- State-of-the-art ex-ante uncertainties required for a successful validation
- Efficient Quality Control of Level-1b and Level-2 data production necessary before validation can start

FRMs (and other validation data):
- FRM data: fitness-for-purpose (representativeness, influence quantities...), reliable error bars
- FRM data streams: timeliness, sustainability, QA/QC of FRM streams (e.g., issue of ozonesonde network drop since 2016)
- Cooperation with ground-based networks fruitful
- Satellite-to-satellite to capture features and patterns like striping, sea/ice and cloud related outliers...
- Ancillary data: for changes in coordinates, end-to-end validation of retrieval... ⇒ campaigns, supersites
- Data governance (and acknowledgment, licence, redistribution etc.) is a key issue!
- Satellite perspective on FRM data developments: e.g., (why) is the lack of FRM sites in Africa a problem?
- Agreements necessary for guarantying access to national in situ/RS data
Validation methods and tools:

- Harmonized, state-of-the-art, fit-for-purpose validation methods still in development
- Challenges of high resolution validation (e.g. Sentinel-5p at 3.5 x 5.5 km²)
- Propagation of satellite and FRM uncertainties along data harmonization and validation chains
- Closure of comparison error budget, including co-location mismatch errors
- Verification of compliance with mission/user requirements not straightforward
- Full traceability (documentation) of validation data and of validation process

Additional challenges for GEO missions:

- Change in paradigm w.r.t. LEO: diurnal cycle, VZA, SZA, BRDF ("directional accuracy")...
- LEO-AQ satellites as “travelling standards” for GEO-AQ validation ⇨ implementation TBD
Sentinel-5p Lessons Learnt
and validation needs for the Air Quality Constellation

Recommendations

1. Consistently perform intensive campaigns dedicated to the validation of the capability of the Geo-AQ missions to observe the diurnal cycle of the target species. Such campaigns are conducted at several supersites within each Geo-AQ mission domain where a comprehensive suite of correlative reference measurements is made and a comprehensive set of auxiliary data from a variety of sources is exploited.

2. Conduct joint validation campaigns and exchange of reference airborne and ground-based instruments.

3. Further develop and eventually apply approaches to the radiometric inter-calibration of the Geo-AQ missions, based on comparisons of Earth radiance data acquired over known targets, SI-traceable test sites where available, precise and approximate ray matching between GEO and LEO pairs of missions, and by taking the LEO missions as a travelling standard. These activities should be pursued within the frame of the WMO GSICS initiative.

4. Further develop and eventually apply approaches to the inter-calibration of the Level-2 products of the Geo-AQ missions. These approaches include the comparison of products with inter-calibrated ground-based network data, cross-validation of Level-2 algorithms by exchanging Level-1b data, comparing zonal mean values of the stratospheric sub-column in the Level-2 ozone products, and taking validated LEO missions as a travelling standard.

5. Systematically process the Level-2 constellation products of the Geo-AQ missions, using one selected common algorithm per constellation product.

6. Further pursue the harmonization of the reference data used for validation and inter-mission consistency verification of core products, aiming at common measurement protocols, common QA protocols, common data formats, harmonized data policy and open access.

7. Implement a data centre for storage and exchange of all validation data collected for the Geo-AQ missions. Make these data accessible to the entire community involved in the validation of the Geo-AQ mission products and their inter-mission consistency, very soon after acquisition.

8. Implement a coordinating unit for ensuring the consistency of the approach and the metrics used for validating the Geo-AQ mission products and their inter-mission consistency.

in-depth validation campaigns essential
exhaustive pre-launch calibration essential
FRM-based satellite-to-satellite alternative retrievals
internal coherence of product families
round-robin to agree on constellation algorithm
sustained FRM programme
EVDC successful
harmonisation of validation to be continued