Data Quality Assurance for hyperspectral L1 and L2 products

Cal/Val/Mon procedures within the EnMAP Ground Segment

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Background & Objectives

"All data and derived products must have associated with them a Quality Indicator based on documented quantitative assessment of its traceability to community agreed reference standards” (CEOS QA4EO)

- Growing request for highly reliable & well-documented data
  - to fulfill data needs for COPERNICUS services
  - need also shown by initiatives like GEOSS / CEOS, EUFAR, VDI guidelines, ISO 19115, INSPIRE, …
  - existing data Quality Control approaches (e.g., MODIS, MERIS, …)

- Objectives of this talk:
  - overview of the EnMAP mission
  - present EnMAP DataQC / Cal / Val / Mon activities
  - focus: DataQC within processing chain
Mission and Instrument Characteristics

EnMAP Satellite
- Operational Lifetime: >5 years
- Orbit: 643 km @ 48°N (Sun-Synchronous)
- Local Crossing Time Descending Node: 11:00 hrs ± 15 min
- Inclination: 97.96°
- Orbit Period: ~ 98 minutes

SWIR Detector Array
- 900 nm < λ < 2450 nm
- Signal-To-Noise: >170 @ 2200 nm
- Sampling: 10 nm
- Actively cooled: 150 K
- FPA: Mercury Cadmium Telluride
- Pointing Capability: ±30° (±5°)
- Target Revisit Time: 4 days (23 days)
- FOV Separation: 88 msec or 600 m
- Dynamic range 14 bit
- X-Band Downlink 320 Mbps

VNIR Detector Array
- 420 nm < λ < 1000 nm
- Signal-To-Noise: >500 @ 495 nm
- Sampling: 6.5 nm
- Thermally controlled to 0.1 K
- FPA: Complementary Metal Oxide Semiconductor CMOS
- Total Length per Day: > 5000 km
- Maximum Track Length: 1000 km
- Swath Width: 30 km
- Ground Pixel Size: 30 m × 30 m

Spectral 134
Spectral 94
Spectral 1000
Spatial 1090
Spatial 1040
Project Partners

Scientific Principal Investigator
GFZ Potsdam

EnMAP Science Advisory Group

Project Management
DLR Space Administration

Space Segment
Sensor
Kayser-Threde
Platform
OHB

Ground Segment
Operations
DLR-GSOC
Payload
DLR-DFD
Processing
DLR-IMF
History and Current Status

- 2005 Phase A study accomplished
- 2006 Start of phase B
- 2007 End of phase B
- 2008 Start of phase C/D
- 2010 CDR Ground Segment
- 2012 System CDR
- **2013 Start Phase D**
- **2017 Launch date**
Instrument Calibration & Monitoring
Parameter des Satelliten

Propellant Tank (50 kg) of hydrazine propulsion system

Gyros (10 Hz)

GPS (1 Hz)

Reaction Wheels (3 axis stabilized platform)

GPS Receiver (1 Hz)

Earth

Sun

SWIR Spectrometer
SWIR FPA redundant
SWIR FPA nominal
Calibration Assembly
VNIR FPA
VNIR Spectrometer
Vibration Test / Clean Room-Bench
Onboard Calibration Sources

- Redundant Photodiode
- Main Sphere (White Spectralon)
- Halogen Lamps (Redundant IPU)
- Redundant LED
- Nominal Photodiode
- Halogen Lamps (Nominal IPU)
- Nominal LED
- Cal Optics
- Doped Spectralon
- Halogen Lamps (Nominal IPU)
- Slit Assembly
- Shutter/Calibration Mechanism
# In-flight Calibration Frequencies

<table>
<thead>
<tr>
<th>Calibration type</th>
<th>Time</th>
<th>Frames Options</th>
<th>Data Volume</th>
<th>Expected Amount of Measurements</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark (shutter)</td>
<td>23 sec</td>
<td>2 * 128 (2 gains)</td>
<td>0.27 GB</td>
<td>~ 36500 each datatake</td>
<td></td>
</tr>
<tr>
<td>Dark (deep space)</td>
<td>30 sec</td>
<td>1 * 1024 (2 gains)</td>
<td>1.38 GB</td>
<td>~ 20 every 4 months</td>
<td></td>
</tr>
<tr>
<td>Relative radiance calibration</td>
<td>17 min 13 sec</td>
<td>1 * 512 (5 steps)</td>
<td>1.66 GB</td>
<td>~ 260 weekly</td>
<td></td>
</tr>
<tr>
<td>Sun calibration</td>
<td>140 sec</td>
<td>2 * 1024</td>
<td>1.38 GB</td>
<td>~ 60 monthly</td>
<td></td>
</tr>
<tr>
<td>Spectral calibration</td>
<td>5 min 13 sec</td>
<td>1 * 1024</td>
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<td>~ 120 every 2 weeks</td>
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<tr>
<td>Linearity measurement</td>
<td>&lt; 5 min</td>
<td>2 * 128 * 40 (2 gains)</td>
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in total: ~ 11 TB
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Sun Calibration using Shutter Mechanism
Life-Limited-Item: Measurement frequency optimized

\[ \Delta = \| \text{DN}_{\text{meas}} - \text{DN}_{\text{ref}} \|_2 \text{ min-max } \]

max. trend line: \( m_{\text{max}} \)

average trend line: \( m_{\text{av}} \)

new average trend line after calibration measurement at time \( t_n \) to determine current calibration table generation time in order to decide stop of data delivery or not

\[ \Delta t = \| \text{DN}_{\text{meas}} - \text{DN}_{\text{ref}} \|_2 \text{ min-max } \]

Commisioning phase

\( t_n \) new calibration measurement request

\( t < t_{n+1} \)

\( t = t_{n+1} \)

\( \Delta t: \) estimated time to generate calibration table (5-7 days incl. downlink)
Data Quality Control within Pre-Processing Chain
Overview Processing Chain

**Geometric Correction (Level 2geo Processor)**

- **Sensor Model Improvement**
  - Automatic GCP extraction
  - Least Squares Estimation
- **Orthorectification**
  - Direct Georeferencing
  - DEM Intersection
  - Map Projection
  - Resampling

- **Global Reference Image DB**
- **Global DEM DB**

**Level 0 Processor**
- Transcription

**Long Term Archive L0 Data**

**Level 1 Processor**
- Systematic and Radiometric Correction

**Level 2geo Processor**
- Orthorectification

**Level 2atm Processor**
- Atmospheric Correction

**Output Processor**
- L1 Product
- L2geo Product
- L2 Product
- L2atm Product

**Raw data**

**Orbit and Attitude Products**

**In-flight Calibration Calibration Products**
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**Atmospheric Correction (Level 2atm Processor)**
- Classification
  - Land-Water, Cloud-Cirrus-Haze-None, Snow, Shadow
- Look-Up Tables
- Over Land
  - with aerosol optical thickness and adjacency correction
- Over Water
  - with aerosol optical thickness and adjacency correction

**Long Term Archive L0 Data**

**OUTPUT PROCESSOR**
- L1 Product
- L2geo Product
- L2 Product
- L2atm Product

**Global Reference Image DB**

**Global DEM DB**
Overview Processing Chain

Ensuring data quality:
- Automated within processors
- Interactive procedures
- Independent validation @ GFZ

Level 0 Processor
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Orthorectification

Level 2atm Processor
Atmospheric Correction

Long Term Archive
L0 Data

Raw data

In-flight Calibration
Calibration Products

Orbit and
Attitude
Products

QC-related Metadata

Data QC routines

L1 Product

L2geo Product

L2 Product

L2atm Product

Interactive Data QC
for selected scenes
on a regular basis

Independent
Validation
for selected ground
reference sites

Data QC reports

Validation reports

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EnMAP Level 1 Processing – detailed steps

- Bad (dead & suspicious) pixel flagging
- Saturated pixel flagging (incl. blooming)
- Non-linearity correction
- Dark signal correction
- RNU correction
- Gain matching (VNIR)
- Spectral referencing
- Spectral / spatial straylight correction
- Radiometric referencing
- QL generation
- Cloud-haze and land-water masks generation

L2

- Geometric correction (incl. keystone correction)
- Atmospheric correction (incl. smile correction)
EnMAP – Data Quality Indicators

- **Radiometry**
  - Artifacts related to radiometric calibration (striping, banding)
  - Artifacts related to dual gain

- **Image properties**
  - Saturation (cross-talk, blooming)
  - Other artifacts / suspicious pixel / repetitive pattern
  - Error messages in virtual channel, sensor & processor log files

- **Environmental conditions** during acquisition
  - Sun elevation
  - Percentage of cloud, haze, cirrus and cloud shadow
  - Average scene visibility / AOT / WaterVapour
  - Problems in atm. correction (e.g., # DDV pixels, meaningful aerosol type, …)
  - Artifacts related to terrain correction / DEM

- …
Operational QC within pre-processing chains

- **Radiometry**

- Artifacts related to radiometric calibration (striping, banding)

Examples using the airborne HySpex scanner (SWIR camera depicted)

BACHMANN et al., 2013: *Extending DLR’s operational data quality control (DataQC) to a new sensor - Results from the HySpex 2012 campaign*  
Radiometry - “Detector Map”

Mean DN per column, band 40

Mean DN per column, band 200

Cross-track detector element

Mean DN

band nr.

spatial dimension

band 40

band 200

spatial dimension

1 320

1 256

column nr.
Radiometry - “Detector Map”

“Detector map“: mean DN for every band and cross-track detector element

Mean DN per column, band 40

Mean DN per column, band 200

spatial pix. 80

band 40

spatial dimension

band 200

spatial dimension

spectral dim.
Detecting Striping Artefacts in L1 Data

Anomalous pix. at band 31, pixel 237

Normalized detector map of scene “Lehrforst”
Detecting Striping Artefacts in L1 Data

Anomalous pix. at band 31, pixel 237

Difference of ~30% (in radiance) to spatially & spectrally neighboring detector elements

Normalized detector map of scene “Lehrforst”
Detecting Striping Artefacts

Anomalous pix. at band 31, pixel 237

Normalized detector map of scene "Lehrforst"

4x Zoom
Analysis of 82 L1 Datasets: Consistency in Bad Pix

Mean normalized radiance over 82 datasets, linear stretch, all pix with >20% derivation from mean in red

Anomalous detector element at band 31, pixel 237 is consistent over campaign i.e., decalibrated
Analysis of 82 L1 Datasets: Spectral Smile

Mean normalized radiance over 82 datasets, non-linear stretch

Bands near CO2 absorption

B. 178 @ edge of absorption

B. 175 @ max. absorption

82 datasets - normalized mean DN per column
Geometric Processing using Reference Images

Original images → Reference image database (Image2006/Landsat) → DEM database (w42)

Original image → Matching → Reference image

Matching → Tie points

Tie points → GCP / ICP

GCP / ICP → Improvements of model parameters

Improvements of model parameters → Generation of ortho image

Generation of ortho image → RMSE/CE90 check against Requirement (< 3 GSD)

Ortho image → Data Delivery

Metadata

• ephemeris
• attitude
• sensor
• time
• RPC
• ....

RMSE/CE90 check against Requirement (< 3 GSD)
## EnMAP Data QC for L2_geo products

<table>
<thead>
<tr>
<th>QC Entry</th>
<th>Parameter</th>
<th>Category</th>
<th>Report format</th>
<th>Metadata (DIMS IIF)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>(R)eport (L)ayer</td>
<td>Internal Public</td>
</tr>
<tr>
<td>orthoTerrain</td>
<td>DEM-related displacements</td>
<td>GEO</td>
<td>R</td>
<td>Y</td>
</tr>
<tr>
<td>orthoRMSE</td>
<td>Geometric accuracy of the orthoimage (I)</td>
<td>GEO</td>
<td>R</td>
<td>Y</td>
</tr>
<tr>
<td>orthoResidual</td>
<td>Geometric accuracy of the orthoimage (II)</td>
<td>GEO</td>
<td>R</td>
<td>Y</td>
</tr>
</tbody>
</table>

*Blue: implemented in L2_geo processor*
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Internal</td>
<td>Public</td>
</tr>
<tr>
<td>overallQuality</td>
<td>Overall data quality</td>
<td>all</td>
<td>R</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>processorLog</td>
<td>Warning messages in processor log</td>
<td>IMG</td>
<td>R</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>sceneSZA</td>
<td>Solar zenith angle</td>
<td>IMG</td>
<td>R</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>sceneSunglint</td>
<td>Sun glint / sun glitter probability</td>
<td>IMG</td>
<td>R</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>cloudCover</td>
<td>Percentage clouds</td>
<td>ATM</td>
<td>R, L</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>hazeCover</td>
<td>Percentage haze</td>
<td>ATM</td>
<td>R, L</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>cirrusCover</td>
<td>Percentage cirrus</td>
<td>ATM</td>
<td>R, L</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>cloudShadow</td>
<td>Percentage cloud shadow</td>
<td>ATM</td>
<td>R, L</td>
<td>Y</td>
<td>Y</td>
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<tr>
<td>sceneWV</td>
<td>Average scene WV</td>
<td>ATM</td>
<td>R</td>
<td>Y</td>
<td>Y</td>
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<tr>
<td>sceneVIS</td>
<td>Average scene visibility / AOT</td>
<td>ATM</td>
<td>R</td>
<td>Y</td>
<td>Y</td>
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<tr>
<td>sceneAtmParam</td>
<td>Validity of atm. correction</td>
<td>ATM</td>
<td>R</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>sceneTerrain</td>
<td>DEM artifacts in terrain correction</td>
<td>ATM</td>
<td>R, L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>internalMasking</td>
<td>Masks generated during processing (cloud, shadow, haze, land / water)</td>
<td>ATM</td>
<td>R</td>
<td></td>
<td></td>
</tr>
<tr>
<td>specCal</td>
<td>Artifacts related to spectral calibration / ATCOR LUTs</td>
<td>SPEC, ATM</td>
<td></td>
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Blue: implemented in L2_atm land / L2_atm water processor
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<td>R</td>
<td>Y</td>
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<tr>
<td>stripingBanding</td>
<td>Artifacts related to radiometric calibration</td>
<td>RAD</td>
<td>R</td>
<td>Y</td>
</tr>
<tr>
<td>dualGain</td>
<td>Artifacts related to dual gain</td>
<td>RAD</td>
<td>R, L</td>
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<tr>
<td>saturationCrosstalk</td>
<td>Saturation, cross-talk, blooming</td>
<td>IMG</td>
<td>R, L</td>
<td>Y</td>
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<td>generalArtifacts</td>
<td>Other artifacts / suspicious pixel</td>
<td>IMG</td>
<td>R, L</td>
<td>Y</td>
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<tr>
<td>sensorLog</td>
<td>Warning messages related to sensor</td>
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<td>R</td>
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<td>signalToNoise</td>
<td>Signal-to-noise estimate</td>
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**Blue:** implemented in L1 processor
External Validation @ GFZ
External Validation @ GFZ

- Establishing **international partnerships for EnMAP Cal/Val activities** (e.g., CEOS)

- **Ground-based** comparison of EnMAP user products to **in-situ reference** measurements:
  - Field campaigns with in-situ measurements of atmospheric and surface parameters.
  - Benefit from joint effort with ground-based science activities.

- **Scene-based** further validation from scene-based data analysis:
  - User products and intermediate parameters to be analysed.
  - Sophisticated models and image processing techniques involved.
  - **Activities considered “scientific” rather than “operational”**.
Summary – Cal/Val/Mon/DataQC for EnMAP

- **Calibration & monitoring**
  - On-board calibration sources & sun calibration
  - Procedures taking into account life-limited items

- **DataQC within pre-processing chain**
  - Integrated within L1 / L2geo / L2atm processors
  - Generation of QC-related metadata, QC flags + reports
  - Interactive procedures for additional parameters

- **Independent validation**
  - Incl. ground-based CalVal activities
Thank you very much for your attention!