EnMAP – Calibration and Validation Activities

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¹DLR, ²OHB
### EnMAP – Mission

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral Accuracy</td>
<td>0.5 nm (VNIR); 1.0 nm (SWIR)</td>
</tr>
<tr>
<td>Radiometric Accuracy</td>
<td>5.0% (absolute); 2.5% (relative)</td>
</tr>
<tr>
<td>Geometric Accuracy</td>
<td>100 m (30 m with control points)</td>
</tr>
</tbody>
</table>

**SWIR**
- $900$ nm < $\lambda$ < $2450$ nm
- (135 spectral bands, 10 nm)
- SNR > 150 @ 2200 nm

**VNIR**
- $420$ nm < $\lambda$ < $1000$ nm
- (95 spectral bands, 6.5 nm)
- SNR > 500 @ 495 nm

- On-Board Calibration Equipment
  - Orbit: Sun-synchronous, 11:00, 398/27
  - Launch: 12/2021

**Satellite Ground Track**
- Pointing Range ± 30° off-nadir
- Swath 30 m x 30 m
- Ground Pixel Size 30 m x 30 m
- Covered Area/Day 5000 km x 30 km

Source: DLR, OHB
EnMAP – Hyperspectral Instrument

- Three mirror anastigmatic telescope ±1.3° across track
- Independent VNIR and SWIR spectrometers
- Curved prism design
- 2D focal planes acquiring 14 bit resolution data at 230 Hz

EnMAP – On-Board Calibration

- Closed Shutter [dark]
  - Deep Space [dark] →

- Sun Calibration [absolute radiometric]
  - White Spectralon [relative radiometric] →

- Doped Spectralon [absolute spectral]
  - Focal Plane LED [linearity] →
EnMAP – On-Board Calibration

- **Closed Shutter** [dark]
  - Monthly

- **Deep Space** [dark]
  - Every ~4 months

- **Sun Calibration** [absolute radiometric]
  - Monthly

- **White Spectralon** [relative radiometric]
  - ~Weekly

- **Doped Spectralon** [absolute spectral]
  - Monthly

- **Focal Plane LED** [linearity]
  - Monthly

Source: NASA

Source: ESA

Source: OHB
EnMAP – On-Board Calibration Equipment

- White Spectralon [relative radiometric]
- Doped Spectralon [absolute spectral]
- Focal Plane LED [linearity]

Source: OHB
**EnMAP – White Spectralon [In-Flight]**

- **White Spectralon** [relative radiometric]
  - Weekly
  - Full optical system: Not telesc.
  - Aging known: Medium
  - For Calibration Coefficients: No

Source: OHB

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dark between levels not considered

**Ground Segment**

SBG Cal/Val Working Group Webinar, 23-July-2020
**EnMAP – Doped Spectralon [In-Flight]**

- **High Definition spectra of doped spectralon**

- **Spectral Calibration [absolute spectral]**
  - Monthly (or less)
  - Full optical system: Yes
  - Aging known: Medium
  - For Calibration Coefficients: Yes

![Diagram of HSI system with timing and gain settings](image)

- Lamp switched on
- Switch SCM 10s
- Dark frames, 2 gains
- HSI 4min 45ss
- 5min 13s

- Calibration frames
  - 0.563s
  - 0.563s
- BUS 1s
- 128 x 128
- Dark frames, 2 gains
- Close SCM 1s

- Vivo-Vis Sensor

- VNIR sensor

- SWIR sensor

Source: OHB, DLR

**Ground Segment**

**SBG Cal/Val Working Group Webinar, 23-July-2020**
EnMAP – Sun [in-Flight] & Linearity [In-Flight]

• Sun Calibration
  • Monthly (or less)
  • Full optical system: Yes
  • Aging known: High
  • For Calibration Coefficients: Yes

• Linearity Calibration
  • Monthly (or less)
  • Full optical system: Not telesc.
  • Aging known: Medium
  • For Calibration Coefficients: No

\[ \Delta = \| DN_{\text{meas}} - DN_{\text{ref}} \|_{2} \text{min-max} \]

max. trend line: \( m_{\text{max}} \)
EnMAP – Processing Workflow

- In-flight calibration observations are processed to generate updated calibration tables
- Three level of users products can be ordered (L1B / L1C / L2A) from Earth observations
- User products annotated with quality information (metadata) plus periodic quality and validation reports
- Quality Control (GS) and Independent Validation (GFZ) performed on user products

Source: DLR
Dead Pixels Map \rightarrow Saturated and Dead Pixels Flagging

Non-Linearity LUT \rightarrow Non-Linearity Correction

Closed Shutter Measurements

Stray-Light Matrix \rightarrow Stray-Light Correction

Averaging for each Illumination Level

Relative Radiometric Reference

(1\textsuperscript{st}: based on (radiometric) pre-flight calibration campaign)

Gain Matching

Dark Signal Correction

Source: DLR, OHB

EnMAP White Spectralon [In-Flight]

Calibration Coefficients based on Sun Calibration

Update Relative Radiometric Reference

OK \rightarrow Repeatable: Yes

not OK \rightarrow Repeatable: No

Request for (repeated) White Spectralon or Sun Calibration

Relative Radiometric Reference Comparison Ref. and Measurement

Calibration Coefficients for VNIR (L), High Gain VNIR (H), and SWIR (S)
Saturated and Dead Pixels Flagging

Non-Linearity Correction

Shutter Thermal Emission Correction for SWIR

Dark Signal Correction

Gain Matching

Stray-Light Correction

Spectral Referencing

Conversion to At-Sensor Radiances

Data Quality

Source: DLR, ESA, JAXA, OHB

EnMAP
Earth Observation Calibration

Digital Number [instrument]

mW·cm⁻²·sr⁻¹·μm⁻¹ [at-sensor radiance]

e.g., spaceborne ALOS/AVNIR-2

Ground Segment 13
EnMAP – Geometry Calibration and QC

• Like spectral and radiometric characterization, extensive geometric pre-flight characterization in laboratory

• But launch, vibrations and gravitational release demand monitoring of geometric performance and the possibility of geometric calibration

• Boresight misalignment angles can be computed on Earth observations based on automatically extracted GCPs on EnMAP scenes and reference Sentinel-2 scenes

• Assessment on quality of geometric data based on automatically extracted GCPs

Source: DLR
EnMAP – Geometry Calibration and QC

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- But launch, vibrations and gravitational release demand monitoring of geometric performance and the possibility of geometric calibration
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- Assessment on quality of geometric data based on automatically extracted GCPs

EnMAP Geometric requirements

- Geolocation accuracy at nadir look <1 pixel (1σ) w.r.t. reference images
- VNIR / SWIR co-registration < 0.2 pixel

Source: DLR
### GENERAL METADATA

<table>
<thead>
<tr>
<th>#</th>
<th>Item</th>
<th>Threshold (minimum requirements)</th>
<th>COMMENTS BY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Traceability</td>
<td>Not required</td>
<td></td>
</tr>
<tr>
<td>1.2</td>
<td>Metadata</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.3</td>
<td>Data collection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.4</td>
<td>Geographical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>Coordinate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.6</td>
<td>Map projection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.7</td>
<td>Geometry</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.8</td>
<td>Geometrical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.9</td>
<td>Ozone correction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.10</td>
<td>Aerosol optical depth parameters</td>
<td>Not required</td>
<td></td>
</tr>
</tbody>
</table>

### RADIOMETRIC AND ATMOSPHERIC CORRECTIONS

<table>
<thead>
<tr>
<th>#</th>
<th>Item</th>
<th>Threshold (minimum requirements)</th>
<th>COMMENTS BY PCV</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Metadata machine readability</td>
<td>ok</td>
<td></td>
</tr>
<tr>
<td>2.2</td>
<td>No data</td>
<td>ok</td>
<td></td>
</tr>
<tr>
<td>2.3</td>
<td>Incomplete testing</td>
<td>ok</td>
<td></td>
</tr>
<tr>
<td>2.4</td>
<td>Aerosol correction</td>
<td>ok</td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td>Cloud</td>
<td>ok</td>
<td></td>
</tr>
<tr>
<td>2.6</td>
<td>Cloud shadow</td>
<td>ok</td>
<td></td>
</tr>
<tr>
<td>2.7</td>
<td>Land/water mask</td>
<td>ok</td>
<td></td>
</tr>
<tr>
<td>2.8</td>
<td>Snow/ice mask</td>
<td>ok</td>
<td></td>
</tr>
<tr>
<td>2.9</td>
<td>Terrain shadow mask</td>
<td>Not required</td>
<td></td>
</tr>
<tr>
<td>2.10</td>
<td>Terrain occlusion</td>
<td>Not required</td>
<td></td>
</tr>
<tr>
<td>2.11</td>
<td>Illumination and viewing geometry</td>
<td>Not required</td>
<td></td>
</tr>
</tbody>
</table>

### PER-PIXEL METADATA

<table>
<thead>
<tr>
<th>#</th>
<th>Item</th>
<th>Threshold (minimum requirements)</th>
<th>COMMENTS BY PCV</th>
<th>Target (desired) requirements</th>
<th>COMMENTS BY PCV</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Metadata machine readability</td>
<td>ok</td>
<td></td>
<td>As threshold, but metadata is formatted in accordance with ISO 19115-2.</td>
<td>ok, as ISO 19115 (plus ISO 19119) are INSPIRE, so conformity is given</td>
</tr>
<tr>
<td>2.2</td>
<td>No data</td>
<td>ok</td>
<td></td>
<td>As threshold.</td>
<td>ok</td>
</tr>
<tr>
<td>2.3</td>
<td>Incomplete testing</td>
<td>ok</td>
<td></td>
<td>The metadata identifies which tests have, and have not, been successfully completed for each pixel.</td>
<td>could be added by extending the quality flags</td>
</tr>
<tr>
<td>2.4</td>
<td>Saturation</td>
<td>ok</td>
<td></td>
<td>Metadata indicates which pixels are saturated for each spectral band.</td>
<td>can be easily done. But this would imply that the quality quicklook will largely increase in size.</td>
</tr>
<tr>
<td>2.5</td>
<td>Cloud</td>
<td>ok</td>
<td></td>
<td>As threshold, with referencing (DOI) to a peer-reviewed algorithm for cloud detection.</td>
<td>can be done - currently no publication available for &quot;land&quot;</td>
</tr>
<tr>
<td>2.6</td>
<td>Cloud shadow</td>
<td>ok</td>
<td></td>
<td>As threshold, with referencing (DOI) to a peer-reviewed algorithm for cloud shadow detection.</td>
<td>can be done - currently no publication available for &quot;land&quot;</td>
</tr>
<tr>
<td>2.7</td>
<td>Land/water mask</td>
<td>ok</td>
<td></td>
<td>The metadata indicates whether a pixel is assessed as being land or water. The metadata references a citable peer-reviewed algorithm expressed as a DOI.</td>
<td>could be done - currently no publication available for &quot;land&quot;</td>
</tr>
<tr>
<td>2.8</td>
<td>Snow/ice mask</td>
<td>ok</td>
<td></td>
<td>The metadata indicates whether a pixel is assessed as being snow/ice or not. The metadata references a citable peer-reviewed algorithm, as a DOI.</td>
<td>the mask is called &quot;snow&quot; but actually flags both snow and ice. Both are indistinguishable in the current software. Reference documentation the same as for the rest of masks.</td>
</tr>
<tr>
<td>2.9</td>
<td>Terrain shadow mask</td>
<td>Not required</td>
<td></td>
<td>The metadata indicates whether a pixel is not directly illuminated due to terrain shadowing.</td>
<td>can be done - but only possible when DEM is provided and the accuracy will depend on the DEM itself.</td>
</tr>
<tr>
<td>2.10</td>
<td>Terrain occlusion</td>
<td>Not required</td>
<td></td>
<td>The metadata indicates whether a pixel is not visible to the sensor due to terrain occlusion during off-nadir viewing.</td>
<td>currently not possible.</td>
</tr>
<tr>
<td>2.11</td>
<td>Illumination and viewing geometry</td>
<td>Not required</td>
<td></td>
<td>The solar incidence and sensor viewing angles are identified for each pixel, including coefficients used for terrain illumination correction.</td>
<td>Currently, we are providing these values for the corners and the center of the scene. Could be extended.</td>
</tr>
</tbody>
</table>
**EnMAP – Quality control and Validation**

**EnMAP GS (DLR): Operational**
- Delivers user products (L1B, L1C, L2A) to end-users using latest calibration
- Monitors and updates calibration parameters using in-flight calibration
- Performs Quality Control activities on user products
- Performs Monitoring of Instrument parameters

**Validation Entity (GFZ):**
- Comparison of user products to absolute references at selected reference sites
- Validation of atmospheric products
- Activities considered ‘scientific’ rather than ‘operational’
- Use of flight campaigns
EnMAP – GS Quality Control

• Checks:
  • Radiometric performance
  • Spectral performance
  • Geometric performance
  • Quality of L2A products
  • In depth analysis of selected scenes
  • Anomalies

• Combination of automated processes for each product
  • e.g. striping artefacts
  • meta and image data

• And interactive procedures for selected products
  • e.g. cloud classification
  • reports

Source: DLR
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Source: DLR

Left: CIR composite of affected area in [L1B-2], nonlinear image stretch. Center: Snow mask (empty) for same area. Right: Cloud shadow mask for same area containing terrain shadows.
EnMAP – Independent validation by GFZ

- Validation from scene-based data analysis
  - Sophisticated models / processing not part of operational activities by EnMAP GS
- Comparison of EnMAP user products to in-situ measurements (land or water)
- More data sources considered (Aeronet, RCN, AERONET-OC, MOBY, partners/collaborators)
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- Campaign information on the EnMAP campaign portal
www.enmap.org

Supported by the DLR Space Administration with funds of the German Federal Ministry of Economic Affairs and Energy on the basis of a decision by the German Bundestag (50 EE 0850).

Source: DLR, OHB
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