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Analysis-Ready Data from Hyperspectral Sensors
The Design of the EnMAP CARD4L-SR Data Product

M. Bachmann, K. Alonso, E. Carmona, B. Gerasch, M. Habermeyer, S. Holzwarth, H. Krawczyk, M. Langheinrich, D. Marshall, M. Pato, N. Pinnel, R. de los Reyes, M. Schneider, P. Schwind and T. Storch

German Aerospace Center (DLR), Earth Observation Center (EOC), Münchener Str. 20, 82234 Oberpfaffenhofen, Germany

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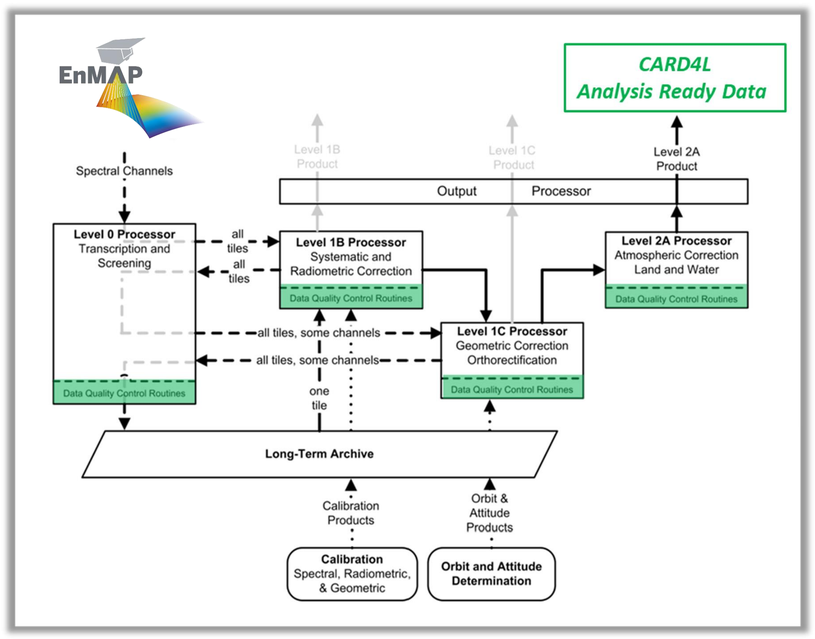
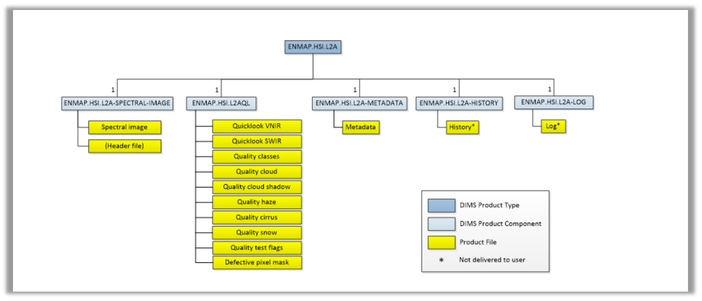
Introduction

With the increasing availability of data from operational and research-oriented spaceborne hyperspectral sensors such as EnMAP, DESIS and PRISMA, and in preparation for the upcoming global mapping missions CHIME and SBG, the provision of analysis ready hyperspectral data will be of increasing interest. In the following, the design of the EnMAP Level 2A Land product is illustrated, highlighting the necessary processing steps for CEOS Analysis Ready Data for Land (CARD4L) compliant data products. This includes an overview of the design of the metadata, quality layers and archiving workflows, the necessary processing chain (system correction, orthorectification and atmospheric correction), as well as the resulting challenges of this procedure. Thanks to this operational approach, the end user will be provided with ARD products including rich metadata and quality information, which can readily be integrated in analysis workflows, and combined with data from other sensors.



Processing Chain – Highlights

- **L0 (archived products):**
  - Product includes full metadata as temporary processing of L1B, L1C & L2A
  ⇒ Metadata incl. RPCs, spectral smile coefficients, AOT & WV information
- **L1B (calibrated at-sensor radiances):**
  - Corrections applied: non-linearity, dark signal & offset, response non-uniformity, straylight
  - Improved defective pixel interpolation and spectral smile correction (if required): PACO inversion (conversion to BOA_ref, interpolation, re-conversion to TOA_rad)
- **L1C :**
  - Ortho-rectification using Copernicus DEM (GLO-30)
  - LoS improvement by image-to-image matching using Sentinel-2 reference mosaic
  ⇒ per scene accuracy measure using ICPs
  ⇒ high relative consistency between EnMAP and S-2
- **L2A:**
  - Land: PACO using MODTRAN 5.4.0 & Fontenla 2011 solar irradiance
    - BOA reflectance incl. terrain correction
    - De-hazing and cirrus correction (user selectable parameters)
    - ATCOR heritage, see validation in ACIX, ACIX-2
  - Water: MIP (by EOMAP), 2 products:
    - BOA water leaving reflectance
    - BOA subsurface reflectance

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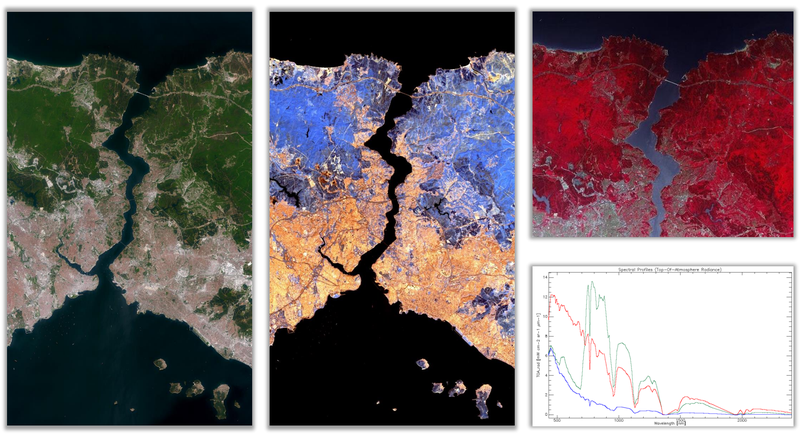


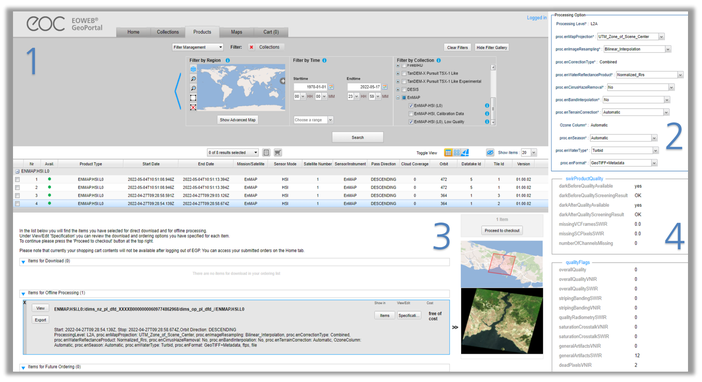
Access to Data and Metadata

www.enmap.org

- EOWEB® GeoPortal provides catalogue search and retrieval functions for orders and archived data
- Following OGC (Open Geospatial Consortium) standards:
  CSW (Catalog Service for the Web) and WMS (Web Mapping Service)
- Metadata is ISO 19119 / 19115-2 INSPIRE conform

Key to figure on right side:

1: product search and map overview
2: product order, incl. specification of processing options (processing level, map projection, interpolation method)
3: summary of order details and processing
4: extensive list of data quality information (for archived data)



CEOS CARD4L Compliant Metadata and Quality Layers

Full set of metadata and quality layers available within each processing level (L1B, L1C, L2A)

L0+ processing metadata
- Screening and housekeeping parameters (e.g., temperatures)

L1B processing metadata
- Overall quality rating (nominal-reduced-low)
- Radiometric quality rating (nominal-reduced-low)
- Per mille values for saturation & crosstalk, defective pixels, striping and other artefacts
- Absolute numbers of dead pixels
- If required: indication flag for spectral smile
- Summary of sensor & processor logs

L1C processing metadata
- RMSE (x, y, xy) based on ICPs
- RMSE & orthoResidual (x, y, xy) based on GCPs
- Number of matching points (GCPs, ICPs)

L2A processing metadata
- Overall L2A quality rating (nominal-reduced-low)
- Scene-averaged SZA, WV & AOT
- Cover percentages for cloud, cloud-shadow, haze, cirrus, snow, water, terrain shadows, sun-glint
- Information on processing (terrain correction & DDVs)

Per-pixel metadata (quality layers)
- Quicklook images for VNIR & SWIR, ortho-rectified
- Mask images: land, water, background, cloud, cloud-shadow, haze, cirrus, snow
- Defective pixel mask (3-D cube of defects)
- Quality flags: saturation, artefacts, interpolation and overall quality rating

	Threshold	Target
1. General Metadata		
1.1 Traceability	n.a.	no
1.2 Metadata Machine Readability	ok	ok
1.3 Data Collection Time	ok	no
1.4 Geographical Area	ok	ok
1.5 Coordinate Reference System	ok	ok
1.6 Map Projection	ok	ok
1.7 Geometric Correction Methods	n.a.	ok
1.8 Geometric Accuracy of the Data	n.a.	ok
1.9 Instrument	ok	ok
1.10 Spectral Bands	ok	ok
1.11 Sensor Calibration	n.a.	no
1.12 Radiometric Accuracy	n.a.	no
1.13 Algorithms	ok	partially
1.14 Auxiliary Data	ok	no
1.15 Processing Chain Provenance	n.a.	no
1.16 Data Access	ok	ok
1.17 Overall Data Quality	n.a.	ok
2. Per-Pixel Metadata		
2.1 Metadata Machine Readability	ok	ok
2.2 No Data	ok	ok
2.3 Incomplete Testing	ok	ok
2.4 Saturation	ok	partially
2.5 Cloud	ok	ok
2.6 Cloud Shadow	ok	ok
2.7 Land/Water Mask	n.a.	ok
2.8 Snow/Ice Mask	n.a.	ok
2.9 Terrain Shadow Mask	n.a.	no
2.10 Terrain Occlusion	n.a.	no
2.11 Solar and Viewing Geometry	ok	no
2.12 Terrain Illumination Correction	n.a.	no
2.13 Aerosol Optical Depth Parameters	n.a.	tbd
3. Radiometric and Atmospheric Corrections		
3.1 Measurement	ok	no
3.2 Measurement Uncertainty	n.a.	partially
3.3 Measurement Normalisation	n.a.	no
3.4 Directional Atmospheric Scattering	ok	ok
3.5 Water Vapour Corrections	ok	ok
3.6 Ozone Corrections	n.a.	ok
4. Geometric Corrections		
4.1 Geometric Correction	ok	ok

Final assessment on *threshold* level, see:

After an assessment by the Committee on Earth Observation Satellites (CEOS), EnMAP land surface reflectance (L2A) products have been found to be CEOS ARD (Analysis Ready Data) compliant. EnMAP land surface reflectance products reach the threshold specification (PFS v5.0) that is also reached by the ESA Sentinel-2 and the USGS Landsat products.

References and online resources

EnMAP ARD paper incl. further details
Remote Sens. **2021**, *13*, 4536.
https://doi.org/10.3390/rs13224536

EnMAP reference paper
Remote Sens. **2015**, 7, 8830.
https://doi.org/10.3390/rs70708830

CEOS ARD specifications
https://ceos.org/ard/

EnMAP test products
https://www.enmap.org/data_tools/testdata/

EUFAR Metadata Standards
https://www.eufar.net/cms/metadata-standards/

EnMAP 1st light
Press release

IEEE P4001 "Standard for Characterization and Calibration of Ultraviolet through Shortwave Infrared (250 nm to 2500 nm) Hyperspectral Imaging Devices

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in der Helmholtz-Gemeinschaft

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