The EnMAP processing chain

P. Schwind, M. Pato, M. Schneider, R. de los Reyes, M. Langheinrich, M. Bachmann, B. Gerasch

What is the EnMAP processing chain?
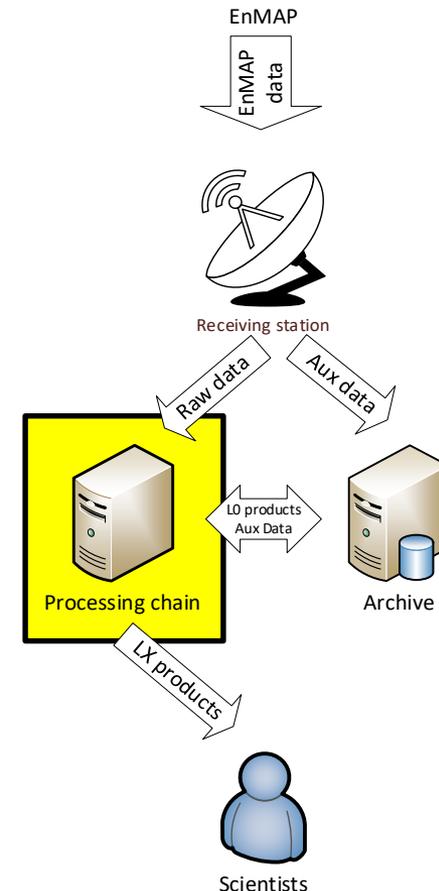
- EnMAP data is not directly usable:
    - It has to be unpacked, uncompressed, tiled, screened and radiometrically corrected.
    - Optionally it should also be corrected geometrically and atmospherically
- These processing steps are performed by the EnMAP processing chain before delivering the data to the users
- For details (ATBD, product specification), see also: https://www.enmap.org/data_access

EnMAP

EnMAP data

Receiving station

Raw data

Aux data

Processing chain

L0 products
Aux Data

Archive

LX products

Scientists

Processing overview

- The processing chain consists of 5 processors:
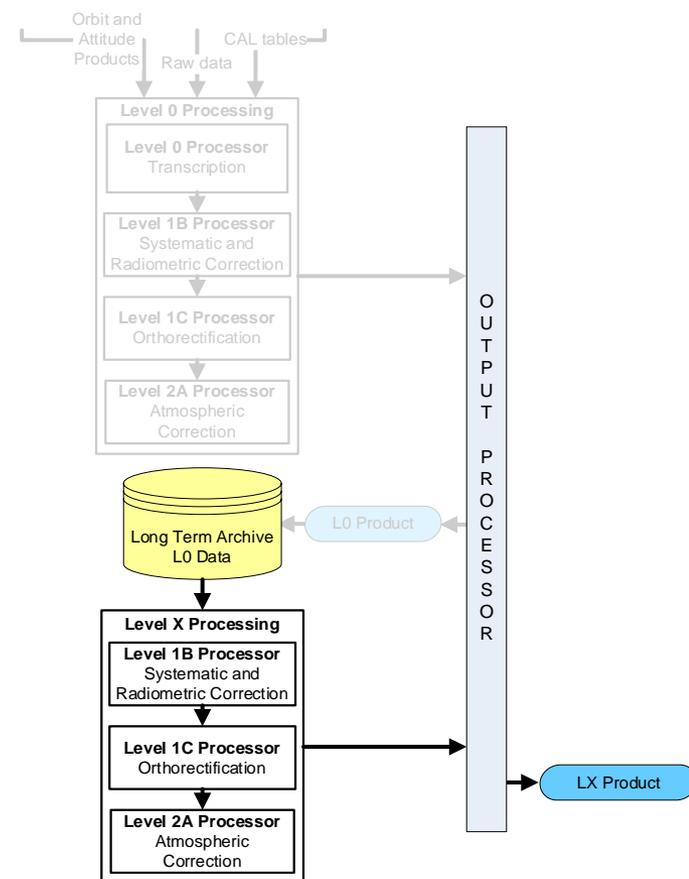 - L0, L1B, L1C, L2A, OP
- The chain can produce 4 different outputs:

Product type	Processing	Purpose
L0	Transcription	For archiving
L1B	Radiometric	For scientists
L1C	Geometric	For scientists
L2A	Atmospheric	

- Only L0 is archived, higher levels (LX) are processed on demand.
  - Delivered data is always based on latest processor version and CAL tables
  - LX processing taking into account user-defined processing options
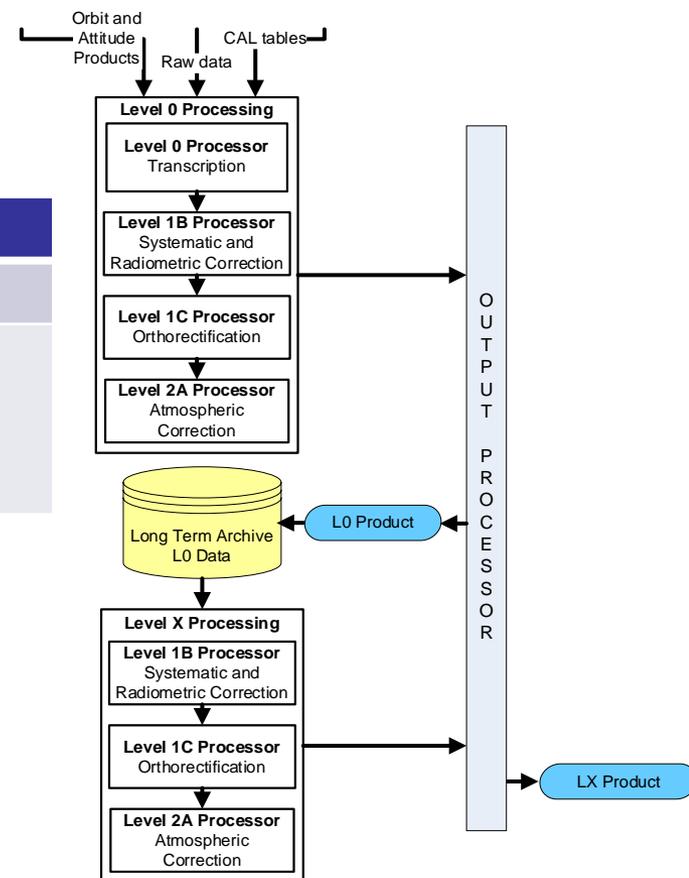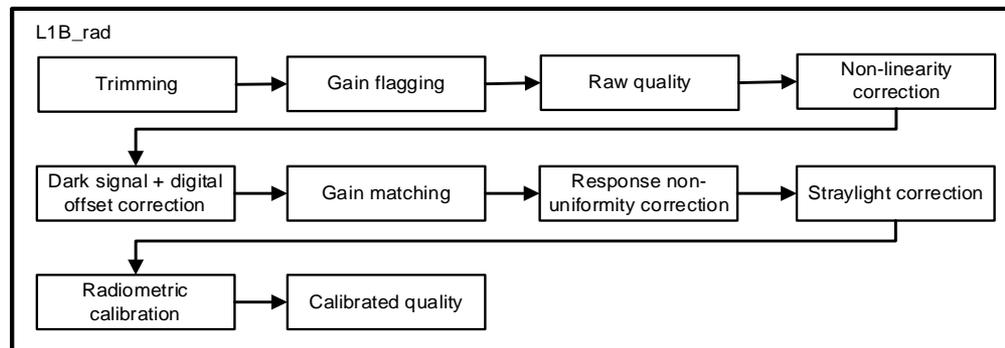
L1B processing overview

- Inputs:
  L0 tiles, CAL tables

- Processing steps:
  L1B, L1C, L2A, OP

- Output:
  Radiometrically corrected image at-sensor-radiance

L1B processing

```
┌─ L1B_rad ─────────────────────────────────────────────────────────────┐
│                                                                         │
│  ┌──────────┐    ┌──────────┐    ┌──────────┐    ┌──────────────┐      │
│  │ Trimming │ →  │   Gain   │ →  │   Raw    │ →  │ Non-linearity│      │
│  │          │    │ flagging │    │ quality  │    │  correction  │      │
│  └──────────┘    └──────────┘    └──────────┘    └──────────────┘      │
│                                                                         │
│  ┌──────────────┐ ┌──────────┐ ┌──────────────┐ ┌──────────────────┐  │
│  │ Dark signal  │ │   Gain   │ │ Response non-│ │    Straylight    │  │
│  │ + digital    │→│ matching │→│  uniformity  │→│    correction    │  │
│  │ offset corr. │ │          │ │  correction  │ │                  │  │
│  └──────────────┘ └──────────┘ └──────────────┘ └──────────────────┘  │
│                                                                         │
│  ┌──────────────┐ ┌──────────────┐                                     │
│  │ Radiometric  │→│  Calibrated  │                                     │
│  │ calibration  │ │   quality    │                                     │
│  └──────────────┘ └──────────────┘                                     │
└─────────────────────────────────────────────────────────────────────────┘
```

- For details, see L1B ATBD on https://www.enmap.org/data_access
- Processing options
 - Product Format: GeoTIFF, JPEG2000, BSQ, BIL, BIP

L1B product

- Spectral images
    - Units: W/m²/sr/nm (at sensor radiance)
    - Two data cubes for SWIR/VNIR in sensor geometry. SWIR/VNIR data is not aligned (~20 lines offset).
- Metadata
    - Also contains information of levels L1C and L2A.
    - RPC in metadata can be used to perform geometric correction. Attitude and orbit data is also available.
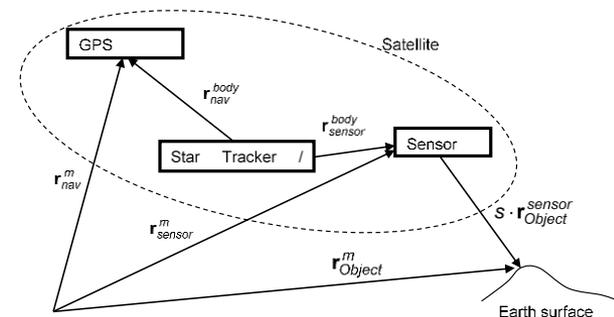- Masks/Quicklooks in sensor geometry

VNIR   SWIR

L1C processing overview

- Inputs:
  L0 tiles, CAL tables

- Processing steps:
  L1B, L1C, L2A, OP

- Output:
  Radiometrically and geometrically corrected image at-sensor-radiance

- Processing options

  - Product Format: Geotiff, JPEG2000, BSQ, BIL, BIP

  - Map Projection: UTM(+/-1 Zone), Geographic, European LAEA

  - Image Resampling: Bilinear, Bicubic, Nearest Neighbour
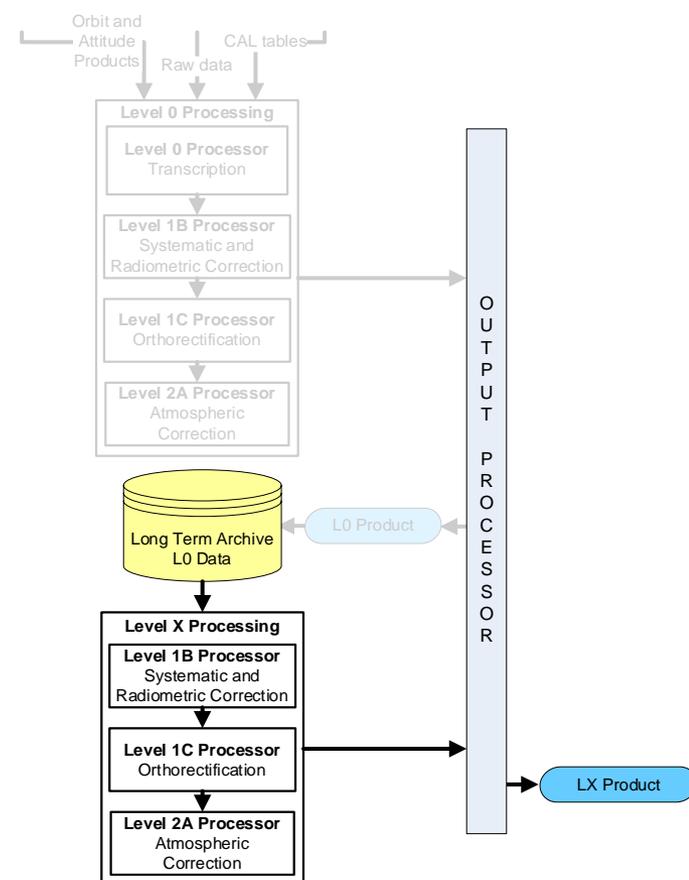
L1C processing

- Orthorectification
    - Direct georeferencing using detailed sensor model
    - Accuracy improved using GCPs (extracted from S2 reference in L0 before tiling the datatake)
    - Used DEM: Copernicus DEM with up to 30 m resolution (COP-DEM GLO-30)
- SWIR/VNIR data is aligned
    - SWIR/VNIR data cubes are merged to one image, with the bands ordered by increasing wavelength
    - Sensor to band mapping can be derived from metadata entry *expectedChannelsList*

GPS — Satellite
r_{nav}^{body}
r_{sensor}^{body}
Star Tracker / — Sensor
r_{nav}^{m}
r_{sensor}^{m}
$s \cdot r_{Object}^{sensor}$
r_{Object}^{m}
Earth surface

Band order before L1C:
V N I R   S W I R

Band order after L1C:
V N I R   S W I R

# L1C product

- Spectral image
    - Units: W/m²/sr/nm (at sensor radiance)
    - One data cube in ortho geometry containing all SWIR/VNIR bands
    - Tiles contain 10 lines from the neighboring tiles, to avoid problems when mosaicking.
- Metadata
  Also contains information of levels L1B and L2A.
- Masks/Quicklooks in ortho geometry

VNIR+SWIR

L2A processing overview

- Inputs:
  L0 tiles, CAL tables

- Processing steps:
  L1B, L1C, L2A, OP

- Output:
  Radiometrically, geometrically and atmospherically corrected reflectances

- For more details, see this talk:
  The EnMAP Ground-Segment L2A Processor - Products and Specifics
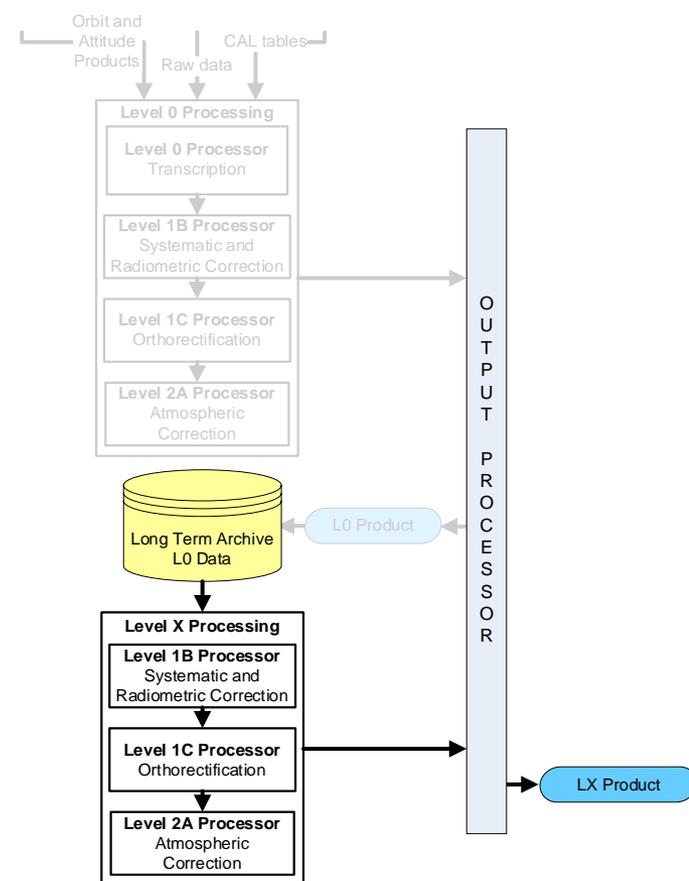
Notable processor updates

- V01.02.00 (07.03.2023)

  - Destriping in across-track direction implemented in L1B

  - Improvements in co-registration accuracy

- V01.03.00 (02.05.2023)

  - Absolute geometric accuracy improved
    => All EnMAP data before v01.03.00 is being reprocessed

- V01.03.02 (13.06.2023)

  - Changes to support band swap:
    SWIR bands with wavelengths 1939, 1949 and 1958 nm replaced by
    1450, 1767 and 1782 nm on 05.07.2023

- V01.04.00 (15.09.2023)

  - Re-activated adjacency correction in atmospheric correction over
    water

See https://www.enmap.org for news on important updates.

Processors Verification, Validation & Quality Control

- Products produced by the processing chain must fulfill strict mission requirements, for example concerning radiometric and geometric accuracy.

- These requirements were/are reviewed and validated (internally and externally) extensively during the development, commissioning and routine phases.

- Continuous Quality Control of processing chain and its products, see quarterly reports on website:
  https://www.enmap.org/mission/
  (also see talk *Operational data quality control and instrument monitoring for the spectral, radiometric and geometric data properties within the EnMAP Ground Segment*)