PROCESSING AND CALIBRATION ACTIVITIES OF THE FUTURE HYPERSPECTRAL SATELLITE MISSION ENMAP

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ABSTRACT:

The Applied Remote Sensing Cluster at the German Aerospace Center DLR has long lasting experiences with air- and spaceborne acquisition and processing of hyperspectral image data. Jointly with the German Space Operations Center it is responsible for the establishment of the ground segment of the future German hyperspectral satellite mission EnMAP (Environmental Mapping and Analysis Program) which is planned to be launched in 2013. The primary goal of EnMAP is to quantify and analyze diagnostic parameters describing key processes on the Earth's surface. Extensive calibration and validation activities are foreseen during the planned five years of operations to ensure high quality data products, which include radiometric, geometric and atmospheric correction. This paper focuses on the automatic processing chain, as well as the calibration and quality control activities for the generation of standard EnMAP products.

1. INTRODUCTION

The Applied Remote Sensing Cluster together with the German Space Operations Center is responsible for establishing and operating the ground segment of the future German hyperspectral satellite mission EnMAP. The EnMAP mission is the first German spaceborne optical Earth observing mission and is currently at the end of Phase C which is the detailed design phase.

This paper will first give a short overview of the mission, following with the description of the automatic processing chain, the onboard calibration and quality control activities.

2. ENMAP MISSION

The major objectives of the EnMAP mission are to measure and analyze quantitative parameters describing environmental key processes of land and water surfaces. Derived geochemical, biochemical and biophysical parameters serve as input for physically based ecosystem models and ultimately provide information reflecting the status and evolution of various terrestrial ecosystems. Applications comprise agriculture, coastal zones, land degradation, geology and forest themes.

The EnMAP satellite (Stuffler et al., 2007; Stuffler et al., 2009) will contain a pushbroom imaging spectrometer and will have a global revisit capability of 21 days under a quasi-nadir observation being operated on a sun-synchronous orbit at 653 km. Utilizing the off-nadir across pointing capability of +/-30° the target revisit time will be within 4 days. Besides the AOCS payload consisting of three star sensors, gyros and GPS the satellite bus will contain two imaging spectrometers (VNIR: Visual and Near InfraRed and SWIR: Short Wave InfraRed) operated in pushbroom configuration. During the five years of mission operations in the years from 2013-2018 data will be acquired with a spatial ground sampling of approximately 30 m × 30 m at nadir and a swath width of 30 km. The HyperSpectral Instrument (HSI) will be designed and realized by Kayser-Threde GmbH as a 2-dimensional CMOS (Complementary Metal Oxide Semiconductor) focal plane array for the VNIR spectral region and a 2-dimensional MCT (Mercury Cadmium Telluride) detector array for the SWIR channels (actively cooled down to 150 K and thermally controlled to 0.1 K). A spectral resolution of at least 10 nm will be achieved over the broad spectral range from 420 nm up to 2450 nm with a VNIR (94 spectral channels) and a SWIR (134 spectral channels) detector. The overlapping range from 900 nm to 1000 nm will enable the processing chain to improve the atmospheric correction by resolving the water absorption band around 950 nm with sufficient signal to noise performance which is, e.g. 500 at 495 nm and 150 at 2200 nm. The data acquisition of the two spectrometers is realized with the method of in-field separation utilizing two entrance slits. This leads to a time separation of 88 msec between the VNIR and SWIR channels and means that the SWIR instrument scans the same area on ground about 20 lines delayed with respect to the VNIR instrument (a small latitude dependent offset will be noticed in across direction due to the earth rotation). Therefore an increased effort in geometric processing is necessary in order to be better than the required co-registration accuracy of 0.2 pixel size. Based on the advanced spectrometer design keystone and smile effects can be neglected, but will be recognized in the processing chain.

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The ground segment consists of three systems (Müller et al., 2009) which are:

- The Mission Operations System (MOS) responsible for commanding and controlling the satellite and instrument.
- The Payload Ground System (PGS) responsible for data reception, handling, archiving and delivery as well as for the user interfaces for observation and product orders.
- The Processor, Calibration and Product Quality Control System responsible for instrument in-flight calibration, establishment of an automatic processing chain and product quality assurance.

3. PROCESSING CHAIN

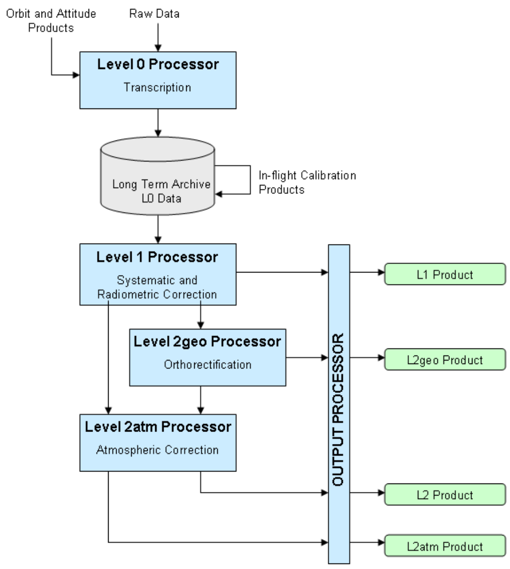

Figure 1. Processing chain

Figure 1 shows an overview of the EnMAP processing chain (Müller et al., 2010). The Level 0 (L0) Product is always generated for long-term archiving in DLR's Data Information and Management System (DIMS) (Mikusch et al., 2000). It is only used for internal purposes and will not be available for external users. The following products will be generated on user request:

- Level 1 (L1) Product: it is radiometrically calibrated, spectrally characterized, geometrically characterized, quality controlled and annotated with preliminary pixel classification (usability mask). The auxiliary information (e.g. position and pointing values, interior orientation parameters, gain and offset) necessary for further processing is attached, but not applied
- Level 2geo (L2geo) Product: it is derived from the L1 product and geometrically corrected (correction of sensor, satellite motion and terrain related distortions) and re-sampled to a specified grid (orthorectified). Auxiliary data for further processing are attached, but not applied.
- Level 2atm (L2atm) Product: it is derived from the L1 product, atmospherically corrected and the data converted to ground surface reflectance values. Auxiliary data for further processing are attached, but not applied.
- Level 2 (L2) Product: it is derived from the Level 2geo product, atmospherically corrected and the data converted to ground surface reflectance values.

3.1 Level 0 Processor

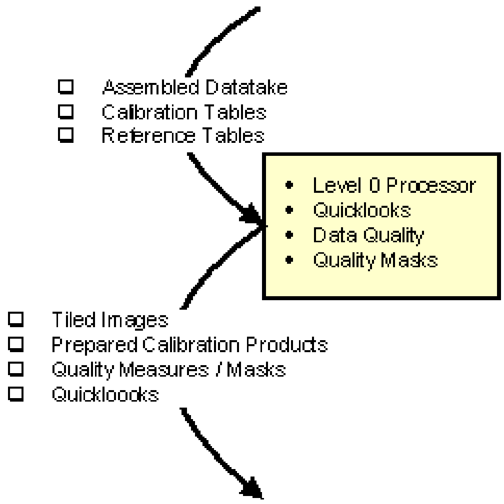

Figure 2. Level 0 Processor

Figure 2 shows a scheme of the Level 0 Processing. It collects the information from the different data streams, screens the image and housekeeping data quality, tiles the data take, annotates the tiles with quality and search information, and archives the raw data product. In particular, its tasks include:

- Extraction and evaluation of calibration values.
- Extraction, evaluation and transcription of available metadata to XML.
- Screening of HK data.
- Quicklook generation.
- Land/Water mask generation.
- Cloud/Haze mask generation.
- Derivation of quality masks and parameters.

This L0 Product is only intended for internal use and will not be available for the user community.

3.2 Level 1 Processor

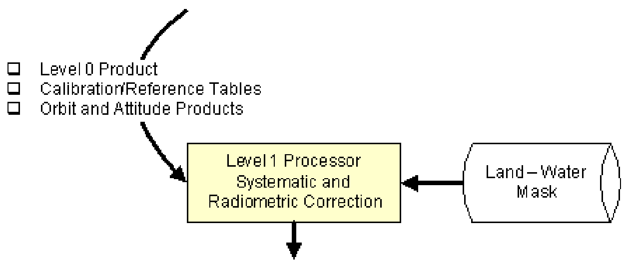

Figure 3. Level 1 Processor

The Level 1 Processor as shown in Figure 3 corrects the HSI image data for known systematic effects. It also converts the system corrected HSI image data to physical at-sensor radiance values based on the current valid calibration values and dark current information. The correction includes the following tasks:

- Dead pixel flagging and screening
- Saturated pixel flagging
- Non-linearity correction
- Dark signal correction
- Stray light correction
- RNU (Response non-uniformity) correction
- Gain matching for the VNIR detector
- Spectral referencing
- Radiometric referencing
- Product quality control

L1 products are not stored in a long term archive. They are processed on demand and directly delivered to the user (the same applies for L2geo, L2atm and L2 products).

3.3 Level 2geo Processor

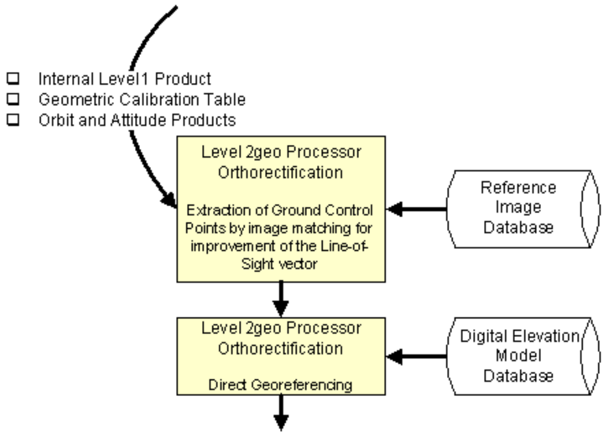

Figure 4. Level 2geo Processor

As shown in Figure 4 the method of Direct Georeferencing (DG) is applied for geometric correction. This physical method is based on a Line-of-Sight (LoS) model, which extensively utilizes on-board measurements from Star Tracker Systems (STS), Inertial Measurement Units (IMU), Global Navigation Systems (GNS) as well as the geometric sensor characterization by laboratory and/or in-flight calibration. The 4-step process of orthorectification consists of:

Direct Georeferencing Model

- Synchronization of attitude and position/velocity measurements with time tagged image lines using appropriated interpolation
- Establishment of the pixel view vectors (also called pixel Line-of-Sight LoS vector) using the sensor internal geometry, payload assembly geometry and time dependant satellite motion during image acquisition
- Setting up the colinearity equation to relate locations of image pixels with an earth reference coordinate frame

DEM Intersection Model

- Projection of the DEM to the coordinate frame specified in the DG model
- Interpolation of the DEM to generate a dense grid of height values appropriate for the orthorectification task
- Connection of the DEM and LoS vector by an iterative procedure in order to retrieve object point coordinates for each image pixel

Map Projection Model

- Provision of map projection functionality
- Transformation of the object points to a map projection like global (e.g. UTM) or continental (e.g. European LAEA ETRS89).

Resampling Model

- Provision of different resampling techniques (Nearest Neighbor, Bi-linear, Cubic Convolution) appropriate for further processing

The geometric accuracy of the orthoimages derived by Direct Georeferencing can be improved using Ground Control Point information to refine the parameter sets of the Line-of-Sight model. Image-to-image matching algorithms such as Intensity based Image Matching (Lehner et al., 1992; Kornus et al., 2000) and Shaded DEM Matching (Schneider et al., 2009) permit the automatic extraction of Ground Control Points provided that existing orthoimages of superior geometric quality as global or local reference images are supplied (Müller et al., 2007).

3.4 Level 2atm Processor

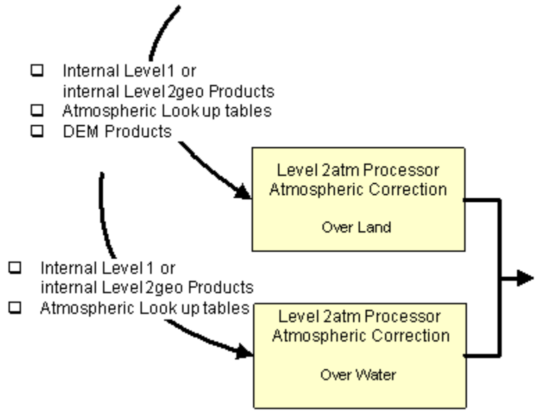

Figure 5. Level 2atm Processor

As can be seen in Figure 5, the Level 2atm Processor performs atmospheric corrections of the images employing separate algorithms for land and water applications. The choice of the land and/or water mode is made by the user. However, scenes may also be processed in both modes, e.g. for coastal areas or inland lakes that may contain a large percentage of land and water pixels.

In case of atmospheric correction over land, the Level 2atm Processor will make use of the ATCOR (atmospheric correction) code (Richter, 1996; Richter, 1998) which takes into consideration flat and rugged terrain, and includes haze/cirrus detection and removal algorithms. Output products will be the ground reflectance cube, aerosol optical thickness and atmospheric water vapor maps, and land, water, haze, cloud and snow maps.

Input for the atmospheric correction processors are the L1 or the L2geo product selected by the user. A combined atmospheric and topographic (taking as input the L2geo product) processing is possible for scenes with accurate geometric correction (geometric accuracy better than one pixel size) where no artifacts caused by the inaccurate registered DEM and orthorectified image are present.

In case of atmospheric correction over water, the Level 2atm Processor converts the top-of-atmosphere radiance imagery into water bulk reflectance values in the visible interval. The processing includes (Heege et al., 2005):

- Sun glitter map generation. This mask will be stored for the scene if the probability of sun glint exceeds a defined threshold (Rgl int = 2%).
- Correction of water mask
- Cirrus detection and correction for all water pixels not covered with clouds and not affected by sun glitter
- Adjacency correction
- Retrieval of aerosol optical thickness
- Atmospheric correction for all water pixels not covered with clouds and not affected by sun glint. Only the channels in the spectral region 400-900nm are processed.
- Quality assessment in percent for water pixels and clear water pixels in a scene as well as the mean value of retrieved aerosol optical thickness over water.

4. ONBOARD CALIBRATION ACTIVITIES

Onboard Calibration refers to all measurements and data analyses aiming to assess radiometric, spectrometric and geometric characteristics of the EnMAP HSI in orbit, more or less from an instantaneous perspective. It derives quantitative updates of calibration tables if the instrument's parameters should change during lifetime, e.g. due to aging or degradation of single elements.

The first task for in-orbit calibration after the Launch and Early Orbit (LEO) phase is to establish the post-launch calibration reference for all essential measurement modes, i.e. dark values (DSNU), pixel-related non-uniformity (PRNU), lamp values, sun calibration values, spectral calibration values.

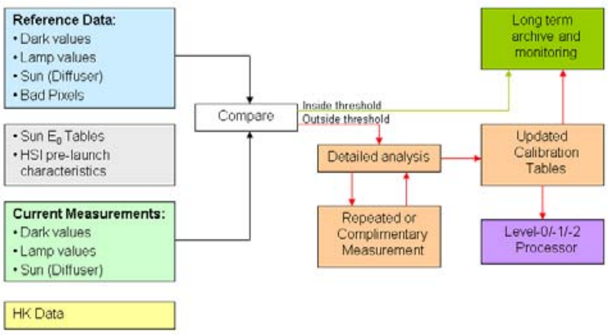

Figure 6. Onboard calibration general approach

Figure 6 shows the general approach and data flow for routine in-orbit calibrations using the different available measurements. The HSI instrument provides a series of tools and modes to perform measurements for the onboard calibration (Mogulsky et al., 2009):

- Shutter/calibration mechanism for dark value and calibration measurements
- Full aperture diffuser for sun calibration for absolute radiometric calibration
- Main radiometric sphere (white Spectralon) for relative radiometric assessment
- Secondary sphere (doped Spectralon) for spectral calibration assessment

The calibration measurements are performed periodically and on request with the highest priority. These measurements are compared to the available reference data and in case they are outside a predefined threshold a more detailed analysis has to be performed which can lead to an update of the calibration tables used by the processing chain.

5. QUALITY CONTROL ACTIVITIES

Data Quality Control (QC) comprises the assessment of geometric, radiometric and spectral properties of data products. By this process the valid function of the sensor and processing chain is investigated and thus ensured. In order to distinguish an anomalous from a nominal state of HSI and processor, the uncertainty budgets related to the spectral, radiometric and geometric data product properties must be known. Therefore this data uncertainty analysis is also included within QC.

Data QC is one part of the operational processing chain in order to investigate the specific quality of a data product ordered by the user. For this purpose, QC provides SW modules in order to produce the QC flag image (per-pixel quality measure) and the related metadata. Also contributions to the overall quality flag (i.e., the flag stating that data quality is good enough that the image can be delivered to the user) will be provided by QC (Bachmann et al., 2007).

On a regular basis an additional interactive QC analysis will be carried out. This is necessary since certain properties can not be analysed in a fully automated way.

Data quality control for L1 data products

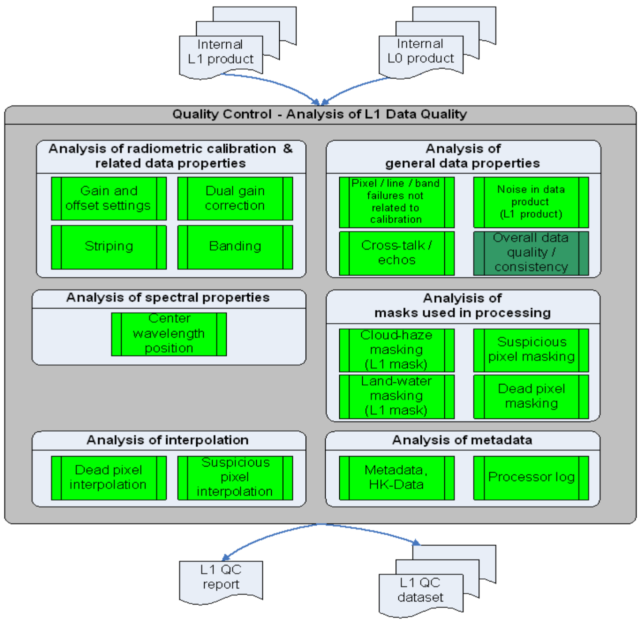

Figure 7. Overview of the parameters which are analysed within QC for L1 data

QC shall ensure the quality of data products, thus all components of each product must be included in the analysis. Also the investigation of temporary and internal products (i.e., which are created by the processor but are not delivered to the end user) is relevant since errors in these products affect the final product. In this context, the components of the internal L1 product are:

- Bad / suspicious pixel mask
- Cloud / haze mask
- Land / water mask
- Metadata files
- L1 image cube

Figure 7 shows the parameters to be analysed for L1 products which can be grouped in:

- Properties which are related to the HSI and the correction of system effects: data properties related to radiometric calibration and spectral data properties
- Properties only related to the processing: masks, data interpolation and metadata
- General properties related both to the HSI and the processing

Data quality control for L2 data products

As with L1 data, all components of the L2 data product shall be analysed, these being:

- Aerosol Optical Thickness (AOT) map
- Haze Cloud Water (HCW) mask
- Water Vapour (WV) map
- Metadata files
- Sun glint probability
- L2 image cube

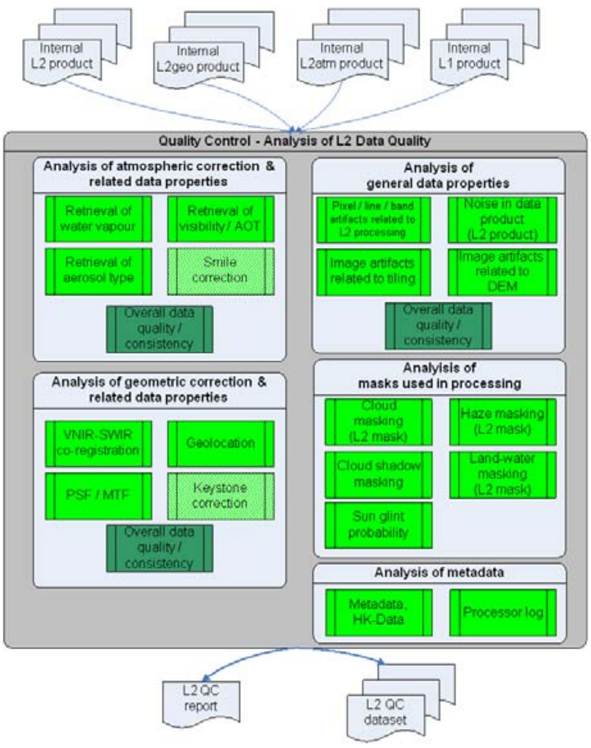

Figure 8. Overview of the parameters which are analysed within QC for L2 data

Figure 8 shows an overview of the parameters to be analysed for L2 products.

Based on this analysis, all data products delivered to users will be foreseen with quality flags. Examples are:

- overallQuality (aggregated quality rating for scene)
- stripingBanding (indication for radiometric defects)
- dualGain
- sceneSZA (solar zenith angle as estimate for scene illumination conditions)
- cloudCover, hazeCover, cirrusCover, cloudShadow as a percentage of the scene and as quicklook image
- sceneWV (average water vapour content of scene)
- sceneVIS (average visibility of scene)
- orthoRMSE (RMS error of geolocation based on independent control points)

When searching for products in the DIMS product library, the user will be able to see some of these quality parameters. It will also be possible to interactively display the quality flags in the quicklooks shown to the user, making it easier to interpret this information.

6. CONCLUSIONS

This paper presents the Processing, Onboard Calibration and Quality Control activities that will be implemented for the future hyperspectral satellite mission EnMAP. The status of the presented concepts corresponds to the current ending of Phase C. Only minor changes are expected until its final implementation. High level products will be derived by the processing chain. Detailed radiometric, spectral and geometric characterisation and calibration will be performed before launch as well as onboard calibration and data quality control during the whole mission to ensure high quality of the products.

7. REFERENCES

Bachmann, M., Habermeyer, M., Holzwarth, S., Richter, R., Müller, A., 2007. Including Quality Measures in an Automated Processing Chain for Airborne Hyperspectral Data. In: Proc. EARSeL-SIG-IS Workshop 2007, Bruges, Belgium.

Heege, T., Kisselev, V., Miksa, S., Pinnel, N., Häse, C., 2005. Mapping Aquatic Systems with a Physically Based Process Chain. In: Proc. SPIE Ocean Optics 2005, Fremantle, Australia.

Kornus, W., Lehner, M., Schroeder, M., 2000. Geometric inflight calibration by block adjustment using MOMS-2P 3-line-imagery of three intersecting stereo-strips. In: *SFPT (Société Francaise de Photogrammétrie et Télédétection)*, Bulletin Nr. 159, pp. 42-54.

Lehner, M. and Gill, R.S., 1992. Semi-automatic derivation of digital elevation models from stereoscopic 3-line scanner data. In: *International Archives of Photogrammetry and Remote Sensing*, Vol. 29, Part B4, Washington, USA, pp. 68-75.

Mikusch, E., Diedrich, E., Göhmann, M., Kiemle, S., Reck, C., Reißig, R., Schmidt, K., Wildegger, W., Wolfmüller, M., 2000. Data information and management system for the production, archiving and distribution of Earth observation products. In:

Proc. DASIA-2000 Data Systems in Aerospace, Montreal, Canada, pp. 401-406.

Mogulsky, V., Hofer, S., Sang, B., Schubert, J., Stuffler, T., Müller, A., Chlebek, C., Kaufmann, H., 2009. EnMAP Hyperspectral Imaging Sensor On-Board Calibration Approach. In: Proc. EARSeL SIG-IS Workshop 2009, Tel Aviv, Israel.

Müller, A., Braun, A., Mühle, H., Müller, R., Kaufmann, H., Storch, T., Heiden, U., Gredel, J., von Bargen, A., 2009. Designing the Ground Segment of EnMAP: Elements, Organisation, and Challenges. In: Proc. EARSeL SIG-IS Workshop 2009, Tel Aviv, Israel.

Müller, R., Krauß, T., Lehner, M., Reinartz, P., 2007. Automatic Production of a European Orthoimage Coverage within the GMES Land Fast Track Service Using SPOT-4/5 and IRS-P6 LISS-III Data. In: Proc. of the ISPRS Workshop High-Resolution Earth Imaging for Geospatial Information 2007, Hannover, Germany.

Müller, R., Bachmann, M., Makasy, C., de Miguel, A., Müller, A., Neumann, A., Palubinskas, G., Richter, R., Schneider, M., Storch, T., Walzel, T., Kaufmann, H., Guanter, L., Segl, K., Heege, T., Kiselev, V, 2010. The Processing Chain and Cal/Val Operations of the Future Hyperspectral Satellite Mission EnMAP. In: Proceedings of the 2010 IEEE Aerospace Conference, Big Sky, Montana, USA.

Richter, R., 1996. A spatially adaptive fast atmospheric correction algorithm. *International Journal of Remote Sensing*, 17(6), pp. 1201-1214.

Richter, R., 1998. Correction of satellite imagery over mountainous terrain. *Applied Optics*, 37(18), pp. 4004-4015.

Schneider, M., Reinartz, P., 2009. Matching of high resolution optical data to a shaded DEM. In: Proc. IGARSS 2009, Cape Town, South Africa.

Stuffler, T., Hofer, S., Leipold, M., Förster, K.-P., Sang, B., Schubert, J., Penné, B., Kaufmann, H., Müller, A., Chlebek, C., 2009. EnMAP – Space Segment – Instrument and Mission Parameters. In: Proc. EARSeL SIG-IS Workshop 2009, Tel Aviv, Israel.

Stuffler, T., Kaufmann, C., Hofer, S., Förster, K.-P., Schreier, G., Mueller, A., Eckardt, A., Bach, H., Penné, B., Benz, U., Haydn, R., 2007. The EnMAP hyperspectral imager—An advanced optical payload for future applications in Earth observation programmes. Acta Astronautica, 61(1-6), pp. 115-120.