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Technical Report

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An EnMAP Preparatory Flight Campaign

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- An EnMAP Preparatory Flight Campaign

Henning Buddenbaum, Joachim Hill

University of Trier, Environmental Remote Sensing and Geoinformatics, Trier, Germany

Universität Trier
Environmental Remote Sensing & Geoinformatics

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Abstract

The dataset contains hyperspectral imagery acquired during airplane overflights on 8th September 2016 consisting of 242 spectral bands, ranging from VIS to SWIR (423 - 2438 nm) wavelength regions. It covers an area of about 78 km² which is dominated by beech and oak forests. The flight campaign was part of several flight campaigns within the EnMAP project and focused on hyperspectral analysis of plant physiology in deciduous and coniferous forests in the Gerolstein region in Rhineland-Palatinate, Germany.

Approximate coordinates of the imaged areas:

center:	50° 13’ N / 6° 42’ E
NW:	50° 16‘ 36“ N / 6° 38‘ 12“ E
NE:	50° 16‘ 36“ N / 6° 45‘ 24“ E
SE:	50° 07‘ 40“ N / 6° 45‘ 24“ E
SW:	50° 07‘ 40” N / 6° 38‘ 12“ E

Keywords: Hyperspectral Imagery, Forest

Related Work:

An overview of the EnMAP mission is provided in Guanter et al. (2015):

Guanter, L., Kaufmann, H., Segl, K., Foerster, S., Rogaß, C., Chabrillat, S., Küster, T., Hollstein, A., Rossner, G., Chlebek, C., Straif, C., Fischer, S., Schrader, S., Storch, T., Heiden, U., Mueller, A., Bachmann, M., Mühle, H., Müller, R., Habermeyer, M., Ohndorf, A., Hill, J., Buddenbaum, H., Hostert, P., van der Linden, S., Leitão, P., Rabe, A., Doerffer, R., Krasemann, H., Xi, H., Mauser, W., Hank, T., Locherer, M., Rast, M., Staenz, K., Sang, B. (2015): The EnMAP Spaceborne Imaging Spectroscopy Mission for Earth Observation. - Remote Sensing, 7, 7, p. 8830-8857, https://doi.org/10.3390/rs70708830

The dataset has been used in the following publications

J. Hill, H. Buddenbaum & P.A. Townsend (2019): Imaging Spectroscopy of Forest Ecosystems: Perspectives for the Use of Space-borne Hyperspectral Earth Observation Systems. Surveys in Geophysics, 40 (3), 631-656. https://doi.org/10.1007/s10712-019-09514-2

H. Buddenbaum & J. Hill (2019): Transferability of Empirical Estimations of Foliar Nitrogen Concentration on Leaf and Forest Canopy Level. Living Planet Symposium, Milan, Italy, 13-17 May 2019.

H. Buddenbaum, S. Dotzler, M. Lusseau & J. Hill (2018): Ableitung der Blattstickstoffkonzentration aus pulverisierten Blattproben, frischen Blattproben und Bestandsspektren. Symposium Neue Perspektiven der Erdbeobachtung, Köln, 25.-27.06.2018.

1 Introduction

The Environmental Mapping and Analysis Program (EnMAP) is a German hyperspectral satellite mission that aims at monitoring and characterizing the Earth's environment on a global scale. EnMAP serves to measure and model key dynamic processes of the Earth's ecosystems by extracting geochemical, biochemical and biophysical parameters, which provide information on the status and evolution of various terrestrial and aquatic ecosystems. An overview of the EnMAP mission is provided in Guanter et al. (2015). In the frame of the EnMAP preparatory phase, pre-flight campaigns including airborne and in-situ measurements in different environments and for several application fields are being conducted. The main purpose of these campaigns is to support the development of scientific applications for EnMAP. In addition, the acquired data are input in the EnMAP end-to-end simulation tool (EeteS) by Segl et al. (2012) and are employed to test data pre-processing and calibration-validation methods. The campaign data are made freely available to the scientific community under a Creative Commons Attibution 4.0 International License (CC BY 4.0). An overview of all available data is provided in a specifically developed metadata portal on the project website (https://www.enmap.org/flights.html).

1.1 Flight Campaign "Gerolstein"

The study area is located in the Gerolstein region in Rhineland-Palatinate, Germany (50° 13' N / 6° 42' E, Figure 1) and mostly covered with forest. Rhineland-Palatinate is located in the west of Germany. 42.3% of the state area is covered by forests and together with Hesse they are the most densely wooded states (Stoffels et al. 2015). Main tree species are European beech (*Fagus sylvatica* L.), Sessile oak (*Quercus petraea* (Mattuschka] Liebl.) and Pedunculate oak (*Quercus robur* L.), followed by Scots pine (*Pinus sylvestris* L.), sycamore maple (*Acer pseudoplatanus* L.), Norway spruce (*Picea abies* (L.) H. Karst.) and other deciduous species. The mean annual precipitation is about 800–900 mm and the mean annual air temperature is 7–8°C. Geologically the area is underlain by a variety of bedrock types; mainly lower Devonian quartzite–sandstone–schist formations, middle Devonian limestones, Triassic sandstones, and Tertiary and Quaternary basalts. In parts of the area the underlying bedrock is mixed with Pleistocene loess cover or periglacial layers. From the extreme diversity of bedrock types manifold soil types developed in the area (Schlerf et al. 2010). Figure 1 shows the location of the study area.

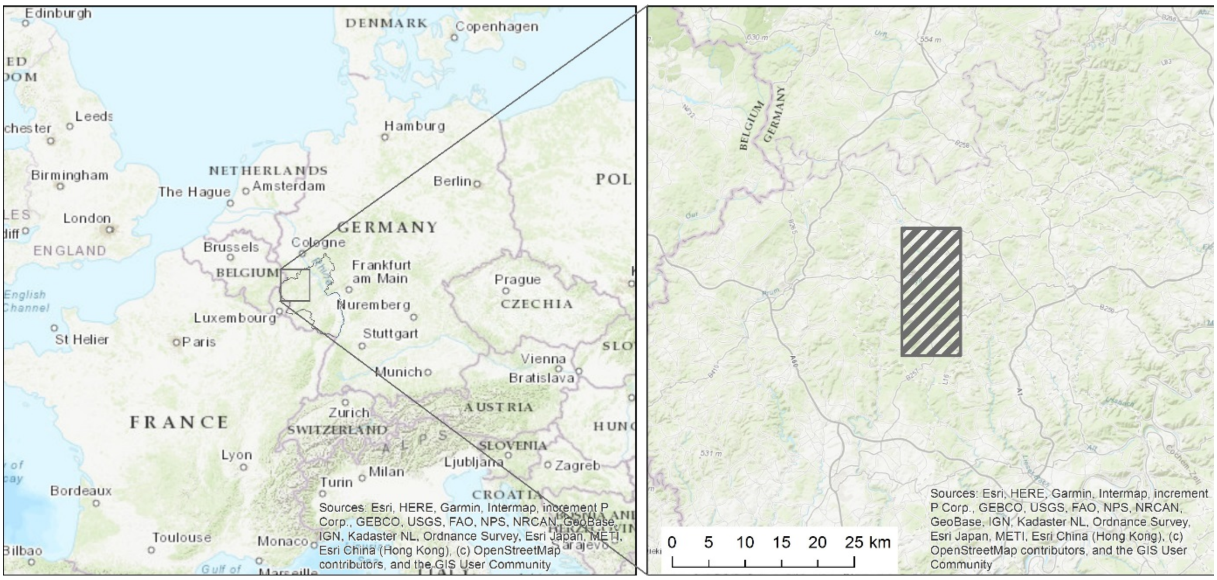

Figure 1: The Gerolstein region in Rhineland-Palatinate, Germany. The area of the hyperspectral flight is marked in the right panel.

2 Data Acquisition

Hyperspectral imagery was acquired during a flight campaign operated by the University of Trier. The camera system consists of one camera for the visible/near infrared (VNIR) spectral range and one camera for the shortwave infrared (SWIR) range: a HySpex VNIR-1600 and a SWIR 320m-e imaging spectrometer (Norsk Elektro Optikk, Skedsmokorset, Norway, Table 1) on board of a Cessna 172 aircraft. Aircraft position and attitude was recorded with an IMAR iTraceRT-F200-E inertial measurement and GPS unit (IMAR GmbH, St. Ingbert, Germany).

Table 1: Properties of the hyperspectral scanners used.

	VNIR-1600	**SWIR-320m-e**
Detector	Si CCD, 1600 x 1200 pixels	HgCdTe, 320 x 256 pixels
Spectral range	414 nm – 994 nm	967 nm – 2500 nm
Spatial pixels	1600	320
FOV across track	16.75° (0.29 rad)	13.30° (0.23 rad)
IFOV across track / along track (instantaneous field of view, pixel)	0.01035° / 0.0207° (0.18 mrad / 0.36 mrad)	0.043° (0.75 mrad)
Spectral sampling	3.7 nm	6.0 nm
Number of bands	160	256
Digitization	12 bit	14 bit

2.1 Campaign 2016-09-08:

Time: 8 September 2016, start of first flight line: 13:09; last line: 14:33 (Local Time)
Figure 2 shows the GPS track and the recorded image strips of the campaign, and a false-colour depiction of the cloud-masked SWIR mosaic. The Gerolstein mosaic consists of lines 1 to 14. Table 2 shows logged data of the strips.
The data was recorded under partly cloudy and windy conditions, so the mosaic contains some gaps. These are partly due to airplane movements and partly due to clouds.

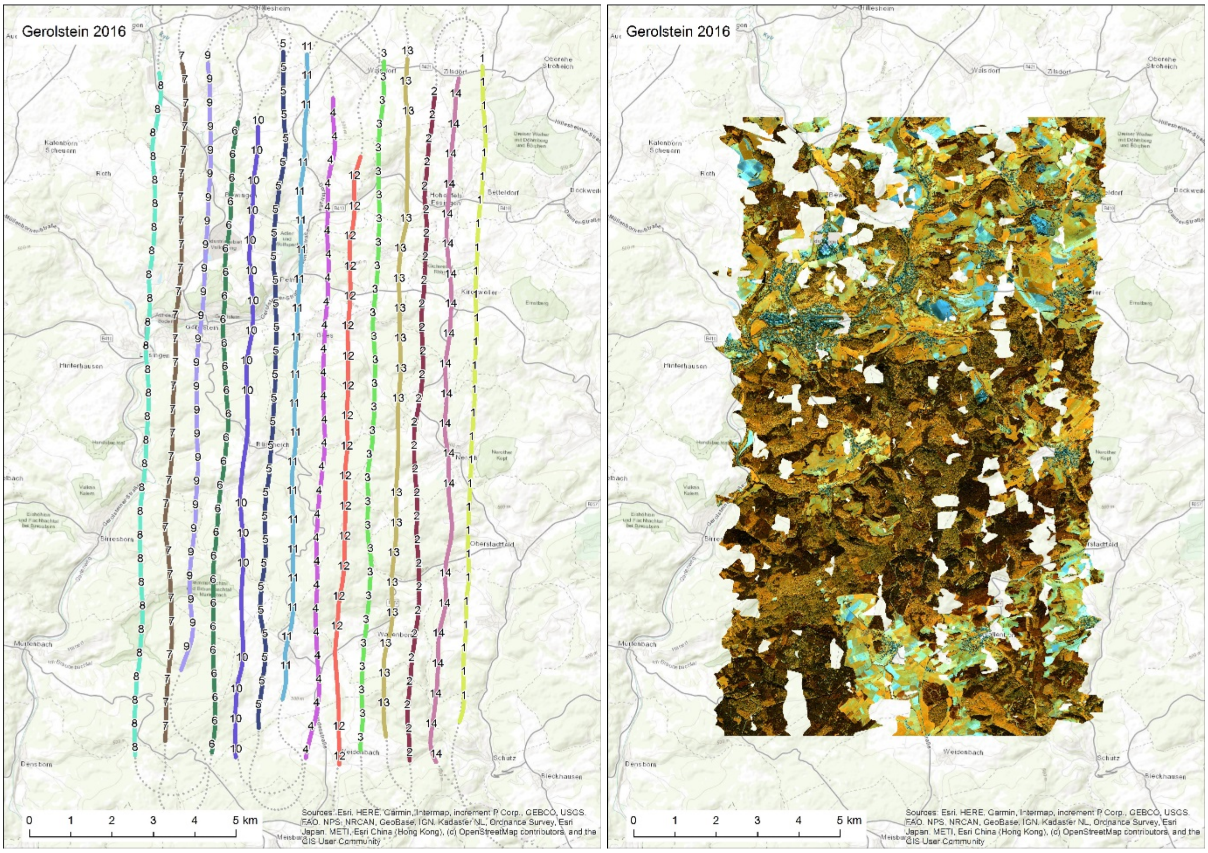

Figure 2: Left: Flight lines of the 2014-07-03 flight campaign. Right: SWIR-Mosaic (RGB = 1120, 1600, 2025 nm).

Table 2: Flight Strips. The SWIR sensor collects half as many lines as the VNIR sensor.

Strip No	# VNIR Lines	Starting Time	Start Lat.	Start Long.	Stop Lat.	Stop Long.	Flying Height [m]	Heading [°]
1	31893	13:09	50.1364	6.7486	50.2804	6.7501	2207	1
2	30789	13:15	50.2750	6.7345	50.1285	6.7326	2231	195
3	33981	13:22	50.1302	6.7159	50.2809	6.7166	2250	343
4	30222	13:28	50.2731	6.6996	50.1284	6.6974	2255	182
5	32018	13:35	50.1342	6.6812	50.2821	6.6823	2282	345
6	28665	13:41	50.2674	6.6678	50.1293	6.6655	2234	194
7	33221	13:48	50.1305	6.6496	50.2790	6.6480	2273	351
8	33836	13:55	50.2776	6.6402	50.1280	6.6396	2349	177
9	27482	14:02	50.1464	6.6540	50.2793	6.6568	2197	11
10	28715	14:08	50.2667	6.6744	50.1282	6.6737	2185	184
11	29991	14:14	50.1406	6.6887	50.2818	6.6904	2248	2
12	26850	14:20	50.2605	6.7098	50.1271	6.7087	2314	198
13	30050	14:27	50.1331	6.7245	50.2817	6.7245	2297	341
14	29849	14:33	50.2786	6.7424	50.1283	6.7418	2322	194

3 Data Processing and Products

3.1 Hyperspectral airborne data

Level 1[1]**:** At sensor radiance in W / (m^2 sr nm) converted from DN using laboratory radiometric calibration information provided by NEO.

Level 2 atm/geo/mosaic: Ortho-rectified reflectance data. All flight stripes have been resampled to 2.5 m spatial resolution and 242 EnMAP spectral bands and have been mosaicked to one data set. Orthorectification has been done in Parge (Schläpfer and Richter 2002), using GPS and IMU data recorded during the flight, manually selected ground control points, and a high-resolution digital surface model. Atmospheric correction has been done in AtcPro (Hill and Mehl 2003).

The major steps of the processing scheme are shown in Figure 3 followed by a detailed description.

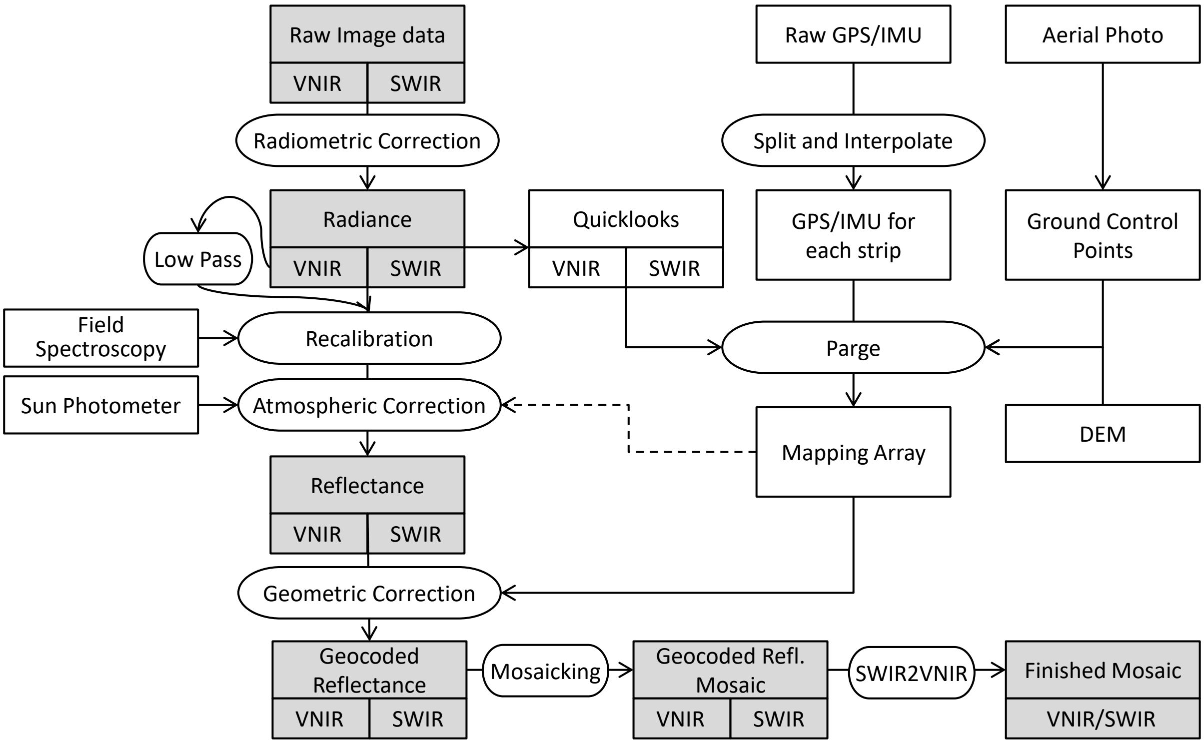

Figure 3: Processing scheme for airborne hyperspectral data.

The image data is recorded as dimensionless digital numbers, separately for the VNIR and the SWIR camera. Using software provided by the cameras' vendor, these data are transformed to radiance in the unit W m^{-2} sr^{-1} nm^{-1} using the vendor's calibration constants for every pixel and every wavelength. For quick visual inspection of the data and for saving processing time in the geocoding steps, 3-band quicklook images are created from every flight strip. The raw binary GPS and IMU data is converted and interpolated to ASCII files for each strip containing the position and attitude of the sensors for every row of the image data. These are used in the geocoding step, and can also be used for creating maps of the flight campaign like the one shown in Figure 2. Since no boresight measurement and no differential GPS is available in the setup used, ground control points (GCPs) are necessary for an exact geocoding. High resolution digital orthophotos are used for identifying GCPs. Parametric geocoding is done using the software Parge. A displacement model is calculated for every image pixel using the

[1] Data levels used here are out-dated and not in line with the future EnMAP data levels.

sensor model, IMU and GPS data, and a digital surface model (DSM) of the area. The model is optimized in several iterations using the GCPs. Figure 4 shows GPS and IMU data for the first flight strip.

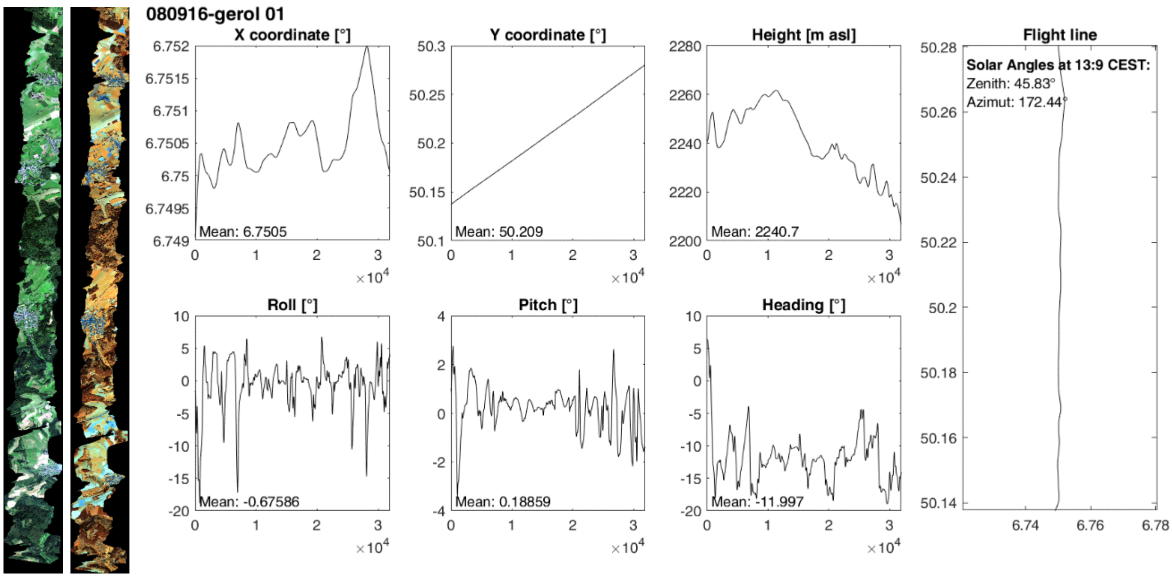

Figure 4: Left: True-color depiction of VNIR flight strip 1 and false-color depiction of SWIR flight strip 1. Right: GPS and IMU data of a flight strip shown above plotted against line number

The atmospheric correction was done using an updated version of AtCPro (Hill and Mehl 2003), an in-house developed software for radiative transfer modelling based on the Modtran.

In the next step, the radiometrically and atmospherically corrected image data sets are geometrically corrected using the previously created IGM. All images are resampled to a uniform pixel size. Since the pixel sizes of the VNIR and SWIR images are approximately 0.6 m and 2.4 m, respectively, both data sets are resampled to 2.5 m geometric resolution. A simple resampling of the geometric high resolution VNIR data to the lower target resolution would result in a large part of the pixels being discarded and a low signal to noise ratio. Thus, a low-pass filtering of the VNIR data using a window of 5×5 pixels is performed. This way, the resulting low resolution pixels contain spectral information of the whole area they cover in an improved signal to noise ratio.

All steps have to be done separately for each strip. Only after each strip is fully corrected, they are mosaicked. Because both cameras are never perfectly aligned and the geocorrection also is never perfect, the images from both sensors are not simply stacked, but an image matching (called SWIR2VNIR in the processing scheme) is performed to create mostly seamless spectra. In the image matching step, for each VNIR pixel, a 3x3 window of the nearest SWIR pixels is located. The mean reflectance of both datasets in the spectral overlap region of 960 to 990 nm is calculated and the SWIR pixel with the most similar reflectance in the spectral/spatial window is chosen. Figure 5 shows the resulting cloud-masked VNIR mosaic, Figure 6 shows some single-pixel spectra from the data set.

Figure 5: True-color depiction of the VNIR mosaic.

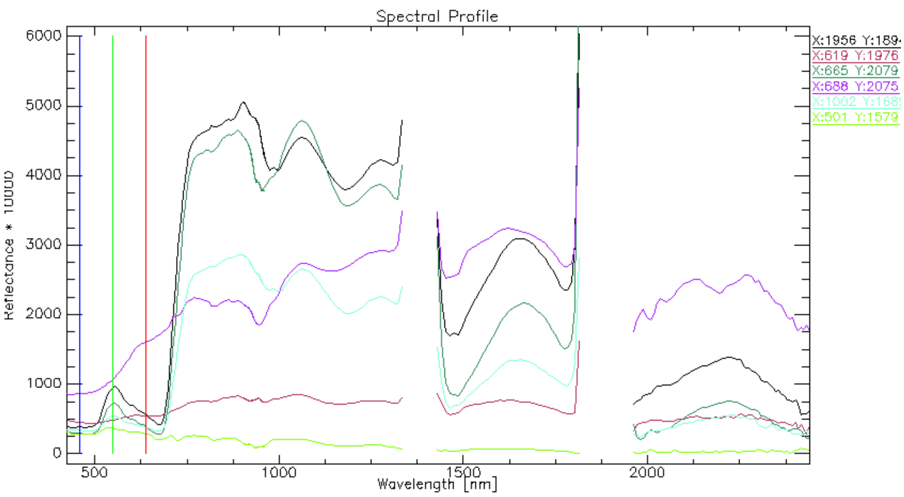

Figure 6: Some single-pixel spectra of the Gerolstein data set.

4 File Description

4.1 File Format

The data is available in Envi Band Sequential format [*.bsq] with respective file header [*.hdr].

4.2 Data content and structure

Image files are described in the header file by the following attributes:
ENVI description, samples, lines, bands , header offset, file type, data type, interleave, sensor type, byte order, map info, wavelength units, band names, wavelength, FWHM

5 Data quality/Accuracy

There is no quality assessment of the data besides the information given in chapter 3 of this report.

6 Additional Data

On September 12 to 14 2016 a field campaign with professional tree climbers was conducted. 14 stands were sampled. On each site, 3 trees were sampled. Reflectance spectra of leaves and needles were recorded. Afterwards, carbon and nitrogen concentration and carbon and nitrogen isotope ratios were measured. The data is collected in an Excel file that can be downloaded alongside the hyperspectral data. The Excel file contains more detail on data measurements.

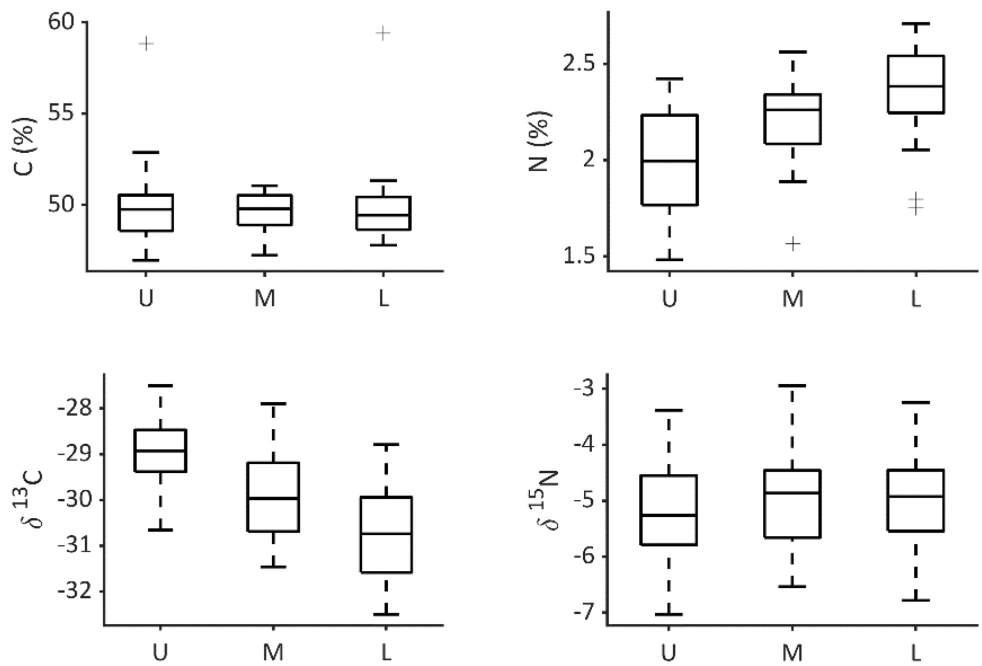

Figure 7: Boxplots of carbon and nitrogen measurements of broadleaves. U, M, and L are upper, middle, and lower crown leaves.

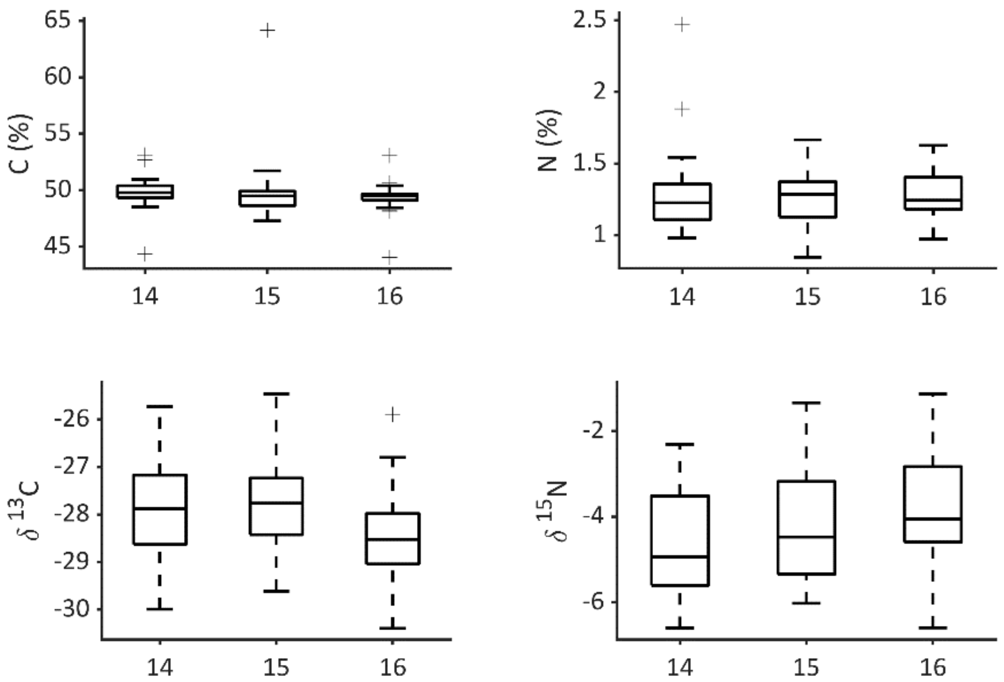

Figure 8: Boxplots of carbon and nitrogen measurements of needles. "14", "15", and "16" are needle years. During measurement in 2016, “16" was the current year, “15" the previous year, and "14" the year before that.

7 Dataset Contact

Henning Buddenbaum
Email: buddenbaum@uni-trier.de
Phone: +49 (0) 651 201 4729

Joachim Hill
Email: hillj@uni-trier.de
Phone: +49 (0) 651 201 4591

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10 Appendix

10.1 List of datasets

- **Combined VNIR/SWIR mosaic** at 2.5 m spatial resolution and EnMAP spectral resolution:

  File names: Gerolstein_2016-09-08-Mosaic_VNSWIR_EnMAP_2,5m.bsq
  Gerolstein_2016-09-08-Mosaic_VNSWIR_EnMAP_2,5m.hdr

  Type of data: ENVI band sequential file

  Approx. file size: 10.8 GB

- **Additional data**

  File name: gerolstein_2016_data.xlsx

  Type of data: Microsoft Excel table

  Approx. file size: 4 MB

10.2 List of abbreviations

VIS: Visible light (wavelength region 400 to 700 nm)

VNIR: Visible and near infrared (wavelength region 400 to 1000 nm)

SWIR: Shortwave infrared (wavelength region 1000 to 2500 nm)

EnMAP: Environment and Mapping Program (German hyperspectral satellite, to launch in 2021)

FWHM: Full width at half-maximum.