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Data acquisition with the APEX hyperspectral sensor

Abstract
APEX (**A**irborne **P**rism **EX**periment) is a high spectral and spatial resolution hyperspectral sensor developed by a Swiss-Belgian consortium on behalf of the European Space Agency. Since the acceptance of the instrument in 2010, it has been operated jointly by the Flemish Institute for Technological Research (VITO, Mol, Belgium) and the Remote Sensing Laboratories (RSL, Zurich, Switzerland). During this period, several flight campaigns have been performed across Europe, gathering over 4 Terabytes of raw data. Following radiometric, geometric and atmospheric processing, this data has been provided to a multitude of Belgian and European researchers, institutes and agencies, including the European Space Agency (ESA), the European Facility for Airborne Research (EUFAR) and the Belgian Science Policy Office (BelSPO). The applications of APEX data span a wide range of research topics, *e.g.* land-cover mapping (mountainous, coastal, countryside and urban regions), the assessment of important structural and (bio)physical characteristics of vegetative and non-vegetative species, the tracing of atmospheric gases, and water content analysis (chlorophyll, suspended matter). Recurrent instrument calibration, accurate flight planning and preparation, and experienced pilots and instrument operators are crucial to successful data acquisition campaigns. In this paper, we highlight in detail these practical aspects of a typical APEX data acquisition campaign.

Keywords
Hyperspectral • data acquisition • airborne • APEX • mission planning

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Introduction

Airborne flight campaigns comprise diverse activities, including site identification, mission planning, flight preparation, actual data acquisition and data downloading post flight (eds Manakos & Braun 2014).

The sites to be flown are defined solely by the users, who express their interest through an APEX Flight Request Form. The identified site, *e.g.* land/water/snow, also drives the selection of the instrument, with the main operational parameters being integration time and spectral binning mode.

Mission planning involves a yearly instrument calibration campaign, availability checks for aircraft, pilots and APEX operators and obtaining flight permits from aviation authorities. Flight preparation includes mounting the sensor into the aircraft (sensor build-in) and performing pre-flight testing of the sensor and its peripherals by the team of operators. The actual data acquisition depends heavily on the weather conditions. Ideally, flights are performed on days with clear sky (0 oktas) and as close as possible to solar noon (unless requested otherwise by the beneficiary) for maximum incoming radiation.

After a flight, all recorded mission data is written to tapes that are delivered to the VITO remote sensing department as soon as possible for further processing.

The APEX system

APEX (APEX 2015; Itten et al. 2008) is a dispersive pushbroom airborne hyperspectral sensor acquiring data in the spectral range 380-2500nm for 1000 across-track pixels. The main instrument specifications are summarized in Table 1. APEX contains a separate Visible and Near-InfraRed (VNIR) and Short Wave InfraRed (SWIR) detector and data can be acquired in two distinct spectral configurations. In the so-called *unbinned* mode, all the spectral channels sense data, resulting in a total of 533 spectral bands: 334 in the VNIR spectral region and 199 in the SWIR region. In *binned* mode, a customized binning pattern is applied to the VNIR spectral channels. The default binning pattern results in 114 VNIR spectral bands. The binning pattern is thus one of the major operational parameters to be baselined during mission preparation. Another main operational parameter is the integration time (IT), which is highly related to the spectral binning mode (higher IT in unbinned mode) and the target application (higher IT for water imaging).

In the aircraft, the APEX instrument is mounted on a Leica PAV-30 stabilized platform for aircraft movement compensation. Furthermore, the APEX system is equipped with a high-grade Applanix POS/AV navigation system, providing accurate sensor position and orientation data at a high frequency. Data originating from the GPS receiver, Inertial Measurement Unit (IMU) and gimbal platform are blended in real-time and logged for post-processing to allow proper georeferencing of the airborne imagery (Mostafa & Hutton 2001). Figure 1 shows the APEX instrument and the computer rack installed in the aircraft.

APEX calibration

Each year, at the beginning of the flight season, APEX is taken to the Calibration Home Base (CHB) (Calibration Home Base 2015) at the German Aerospace Centre (DLR, Munich, Germany)

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Table 1. APEX instrument specifications

Spectral Range	VNIR	380 – 970 nm
	SWIR	940 – 2500 nm
Spectral Bands	VNIR	default 114 bands, reprogrammable through customized binning pattern
		Max. unbinned bands: 334
	SWIR	199 bands
Spectral Sampling Interval	VNIR	0.55 – 8 nm over spectral range (unbinned)
	SWIR	5 – 10 nm over spectral range
Spectral Resolution (FWHM)	VNIR	0.6 – 6.3 nm over spectral range (unbinned)
	SWIR	6.2 – 11 nm over spectral range
Spatial Pixels	1000	
FOV (across track)	28°	
IFOV	0.48 mrad	
Spatial Sampling Interval (across track)	1.75 m @ 3500 m AGL	
Sensor dynamic range	VNIR	CCD, 14 bit encoding
	SWIR	CMOS, 13 bit encoding
Pixel size	VNIR	22.5 µm x 22.5 µm
	SWIR	30 µm x 30 µm
Smile (average over FOV)	0.35 pixels	
Keystone (frown, average over FOV)	0.35 pixels	
Co-Registration (average over FOV)	0.6 pixels	
Signal-to-Noise	SNR for various applications are available upon request Highest signal-to-noise ratio through advanced detector technology and pressure/temperature stabilization	
Output medium	LTO-2 tape	

Figure 1. APEX instrument and computer rack installed in the aircraft (photo credits: Bart Bomans and Johan Mijnendonckx, VITO)

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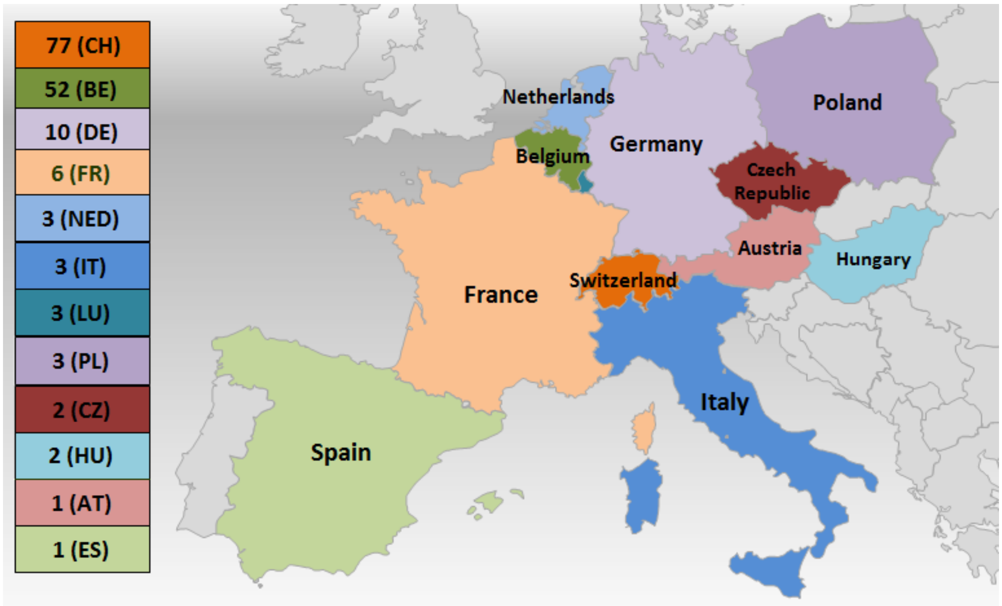

Figure 2. APEX areas covered across Europe

Table 2. Overview of raw data collected with the APEX instrument

# of areas covered	BE	CH	NL	AT	ES	IT	DE	LU	FR	PL	CZ	HU	raw data volume [GB]
2010	6	10											617
2011	7	11	2	1	1	1	5	1					644
2012	9	5					2	1	1	1	1		689
2013	8	28				1	1		3		1	1	1003
2014	10	6	1			1	2		1			1	529
2015	12	17						1	1	2			811

for a full geometric, radiometric and spectral characterization of the instrument. The parameters inferred from the CHB measurements are applied to the acquired data in order to perform full spectral and radiometric calibration (Schaepman 2015). Furthermore, after every installation of the instrument in the aircraft, a boresight calibration is performed, with the aim of measuring the misalignment (boresight) angles between the IMU axes and the sensor axes (Mostafa 2001). The IMU is fixed to the instrument, but its reference system is slightly rotated with respect to the sensor, requiring determination of the misalignment in terms of roll, pitch and yaw. In support of this calibration, a dedicated boresight flight is performed, usually above the city of Ostend (Belgium), since an extensive database of Ground Control Points (GCPs) is available for that region.

APEX missions

Between 2010 and 2015, several APEX flight campaigns were performed covering about 160 areas across Europe, as graphically presented in Figure 2. During these missions in 12 different European countries, over 4 Terabytes of raw data has been gathered, as shown in Table 2. In 2015-2016, APEX flights are also planned for two sites in Romania.

Mission planning is carried out using the TRACKER software from TRACK'AIR, which was integrated by Applanix in their POS AV system for position and altitude registration (see Figure 3).

The software enables detailed mission planning for the areas to be scanned, typically in the form of parallel flight lines at one altitude. During the flight, the operator will be able to monitor all flight variables relevant to the respective project (ground speed, off line distance (deviation from the planned flight path), altitude, pitch, roll and yaw). In mountainous areas, the software will also simulate ground coverage, taking a Digital Elevation Model (DEM) into account.

APEX data acquisition

The carrier used for the APEX flights is a Dornier DO 228-101 aircraft (D-CODE), adapted to remote sensing missions (Dornier 2015) and operated by the Flight Department of DLR-Braunschweig. Figure 4 shows the aircraft and the APEX crew. The availability of aircraft and pilots is one limiting factor in the airborne campaigns. The aircraft being used by several instruments, time windows are allocated to each of them after interactions between the users and DLR. Multiple APEX flight windows are established every year.

In preparation for the flights, the APEX operators are responsible for transporting the sensor, mounting it in the aircraft and pre-flight testing of the sensor and its peripherals. Weather forecasts from several institutions are continuously monitored by the mission responsible for making a go/no-go decision on the flights. Before the actual start of the flight, the so-called Mission

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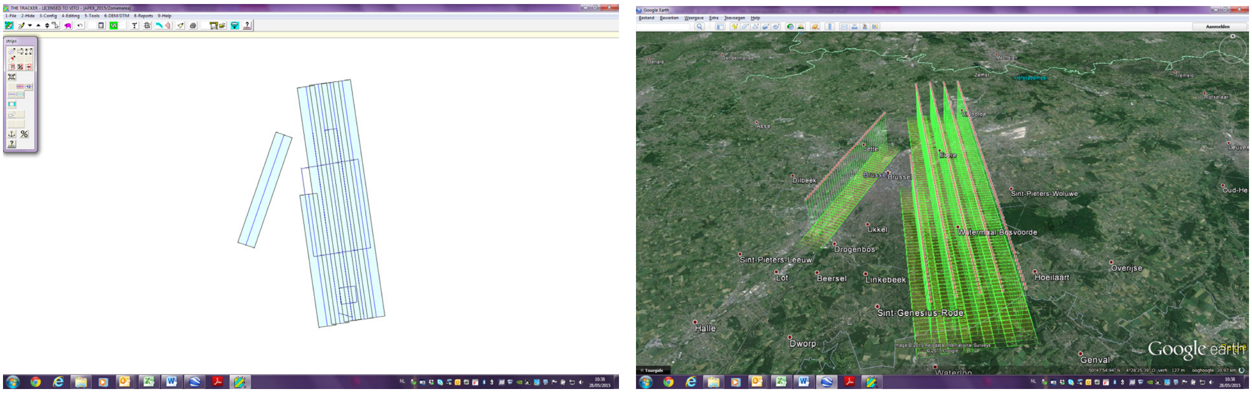

Figure 3. TRACKER for mission planning screenshot

Figure 4. APEX aircraft and crew (pilots, technicians and operators) photo credits: Hans-Jürgen Berns, DLR

Control File is uploaded to the instrument, thereby configuring the sensor according to the spectral/spatial requirements of the data to be acquired. In addition, flying altitude, aircraft speed and flight pattern are set according to user needs. During the flight, the actual flight line data is acquired, together with in-flight calibration data (dark current) and navigation data.

Concurrent with the APEX flight, ground teams are in charge of on-site data acquisition. The typical set of ground measurements is formed of atmospheric composition measurements (by means of sunphotometers such as MICROTOPS or CIMEL) (Microtops 2015; CIMEL 2015) and spectral ground control points (GCPs – spectra acquired on site using high spectral resolution devices such as ASD spectrometers) (ASD 2015). The most important physical parameters are the visibility, water vapour content, and aerosol type, which are used in the atmospheric correction of the data, an ensemble of algorithms used to remove atmospheric effects from the retrieved spectra. Other physical parameters can be measured, depending on the targeted application. While dedicated algorithms can be used to infer the atmospheric composition directly from the acquired images, the spectral GCPs are particularly important, as they serve as references for the accuracy of the final reflectance data products.

After the flights, the LTO-2 tapes containing the raw image data and the PCMCIA-cards containing the navigation data are brought to the VITO remote sensing department for further processing. The raw sensor data, along with metadata and positioning and orientation data, are gathered together to compile the so-called Level0 data. After radiometric calibration using the Processing and Archiving Facility (Hueni et al. 2009), the at-sensor radiance is obtained (Level 1 data) and, following geometric and atmospheric correction, the on-ground radiance or reflectance datacubes (Level 2 data) are obtained. These corrected hyperspectral images, projected in a user-defined coordinate system, are subsequently used in scientific applications. For a comprehensive overview of data processing levels, the reader can refer to Biesemans et al. (2007). A detailed description of the atmospheric correction and the geometric correction of APEX data are provided elsewhere in this journal (see the respective articles by Sterckx et al. and Vreys et al.).

Scientific applications of APEX hyperspectral data

Most of the APEX data beneficiaries prefer the binned spectral mode as the default acquisition parameter. While the unbinned mode offers a higher spectral resolution, binned mode is characterized by a higher signal-to-noise ratio.

APEX data acquired in binned mode has been successfully used in applications covering a wide range of research areas: high resolution urban land-cover mapping (Demarchi et al. 2014), the assessment of burn severity on vegetation in areas affected by wildfire (Haest et al. 2013), change detection in natural scenes (Erturk et al. 2015), mapping of vegetation species (Marcinkowska et al. 2014; Kempeneers et al. 2014), early detection of vegetation stress by means of unmixing-based fusion of hyperspatial and hyperspectral airborne imagery (Delalieux et al. 2014), biomass mapping of alpine grassland (Rapp et al. 2013), the evaluation of changes in the physiological status of trees in mountainous forests affected by long-term acidic depositions (Cervena et al. 2014), the simulation of new scientific missions (D'Odorico et al. 2013), and the fast retrieval of aerosol optical depth (Seidel et al. 2012), among others. Data acquired in unbinned mode is mostly used for applications in which spectral features need to be accurately identified, such as the NO_2 atmospheric absorption feature at 490nm, which allows for NO_2 monitoring using APEX data (Popp et al. 2012, Tack et al. 2015). For a much wider overview of APEX data applications, the reader is referred to Schaepman et al. (2015).

Data policy and accessibility

The APEX sensor is available to the user community for data campaigns. Users can express their interest by filling in a flight request form and sending it to the APEX coordinator[1]. On receiving this form, the APEX coordinator will contact the user to discuss and clarify the request and the possibilities for its realisation. In order to decrease costs, it is always preferable to combine requests from different applicants in so-called 'group shoots'. A Free Data Cube, APEX Open Science Data Set, is available from the APEX website in the "Data, Free Data Cubes" section (APEX 2015). It can be freely downloaded together with an APEX dataset information flyer.

[1]See "Data" section on www.apex-esa.org site

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APEX is one of the instruments in the EUFAR fleet[2]. Within their TA (Transnational Access) programme, successful applicants can be provided with an allocation of flight hours on the selected aircraft/instrument. Data sets of previously flown areas are owned by the user who financed the data acquisition and processing. Nevertheless, some of these data can be made available to interested users.

Conclusions

Data acquisition is a complex activity of crucial importance to hyperspectral imaging applications, being the starting point for qualitative information extraction. The description provided in this paper of the several stages involved in data acquisition campaigns reveals the multitude of factors required for successful completion of the task. APEX data acquisition, however, benefits from very well-established procedures, fine-tuned over several years of successful missions, having satisfied dozens of users. The wide range of applications for APEX data indicates the high quality of the final reflectance products and the potential of the APEX imagery to satisfy a large variety of user needs. Future plans include the extension of the applications portfolio, mainly in the field of atmospheric pollutant inference, based on atmospheric features detectable in spectrally unbinned data. Joint campaigns with other sensors are planned, *e.g.* the tracking of different atmospheric gases in the same plume, at the same time. In-depth studies related to the uncertainty propagation of the atmospheric parameters (measured during data acquisition) towards final products (*e.g.* distribution maps of materials in the scene, obtained by spectral unmixing) are currently being carried out at VITO.

[2]See www.eufar.net

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