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Postprint available at:
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Originally published at:
Hyperspectral Workshop 2010, Frascati, IT, 17 March 2010 - 19 March 2010, 1-6.

APEX STATUS PT. 1: INSTRUMENT DEVELOPMENT AND PERFORMANCE

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ABSTRACT

ESA APEX (Airborne Prism EXperiment) is a project for the realisation of an airborne dispersive pushbroom imaging spectrometer, a dedicated data Processing and Archiving Facility (PAF, hosted at VITO) and a Calibration Home Base (CHB, hosted at DLR) for instrument calibration operation. It has been developed by a joint Swiss-Belgian consortium.

The APEX instrument is facing its finalisation phase undergoing intense experimental activities in view of its validation and performance assessment. Environmental tests were executed to simulate flight environment conditions. The first APEX airborne campaign has been held in June 2009 covering a variety of water targets over Switzerland and Belgium. Extensive pre- and post-flight characterisation and calibration campaigns were accomplished. Instrument data evaluation, performance analysis and optimisation of the data processing schemes adopted have followed.

This paper outlines the activities performed and presents the first products achieved.

1. INTRODUCTION

The Airborne Prism EXperiment (APEX) is a project being developed by a joint Swiss-Belgian consortium on behalf of the ESA-PRODEX programme and the support of the ESA-EO Programme. The project is carried out by industries (RUAG Aerospace AG, OIP Optical Systems NV and Netcetera AG) under the scientific lead of the Remote Sensing Laboratories (RSL) of the University of Zurich and VITO-TAP.

The consortium has engineered and developed an airborne imaging spectrometer [1] whose specification were designed [2] to provide a scientific platform that could actively contribute to the Earth remote sensing community by providing land coverage at local and regional scale in support of global products. The simulation, calibration and validation of spaceborne imaging spectrometers and their products is another targeted goal.

As APEX instrument is meant to support the scientific users by delivering remote sensing measurements [3] with uncertainty estimates the main focus is to provide airborne imaging spectroscopy data characterized by high spectral, radiometric and geometric accuracy and traceability. The targeted data accuracy relies upon three main factors: (a) provision of a highly precise instrument by the industrial partners, (b) detailed characterization and accurate instrument calibration of the performances by means of the Calibration Home Base (CHB) hosted at DLR Oberpfaffenhofen, Germany [4] and (c) data calibration process and higher level product generation at the APEX Processing and Archiving Facility (PAF) hosted at VITO in Mol, Belgium [5].

Another focus of the instrument design is to offer a flexible scientific platform for the acquisition and treatment of remote sensing data [6]. APEX supports the achievement of scientific requirements for an imaging spectroscopy mission by means of the extended customization of acquisition parameters. This is achieved by means of programmable binning patterns and the BinGO software. The APEX PAF supports the investigation and development of research products with flexible integration of processing modules into the workflow.

In view of the close-out of the project Phase C/D and in preparation to the official ESA Acceptance procedures, APEX has undergone in 2009 an intense testing season, focused on the flight campaign held in June. Full characterization and calibration campaigns pre- and post- flight campaign were carried out to investigate the instrument performances and their stability over operational conditions. Environmental tests at full system level were carried out to simulate the airborne conditions have been carried out as well.

Proc. 'Hyperspectral 2010 Workshop', Frascati, Italy, 17–19 March 2010 (ESA SP-683, May 2010)

2. THE APEX INSTRUMENT

2.1. The sensor

APEX sensor is a pushbroom spectrometer based on a dispersive principle. It has been realized by OIP Optical Systems and designed to provide spectra in the solar reflected radiation range between 380 ÷ 2500 nm. The sensor (Figure 1) comprises two optical channels that share the ground imager and the main collimator unit. The first of the two prism dispersive elements splits the radiation contribution into two channels by means of a dycroic beamsplitting coating. The radiation in the range between 950 to 2500 nm is dispersed by the first prism and imaged on the SWIR detector by means of a dedicated focusing lens assembly. The radiation in the range from 380 to 1000 nm is instead reflected toward a second prism dispersive element and imaged on the VNIR detector by means of a dedicated lens assembly.

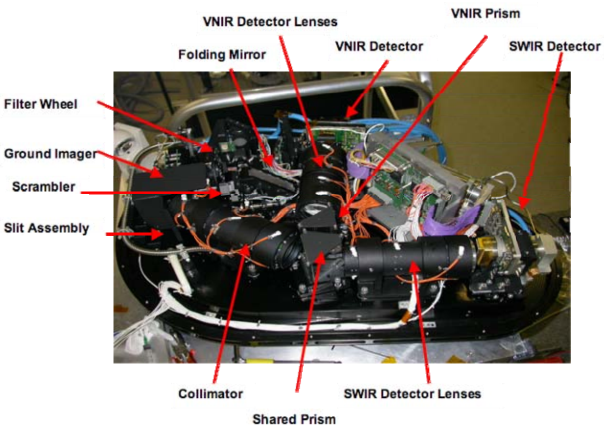

Figure 1 - an insight into the assembled APEX sensor

The SWIR detector is a CMOS based custom model realized on behalf of ESA EO by Sofradir, and provides 198 spectral rows. The VNIR detector is a CCD from E2V, and provides 334 spectral rows. These can be combined on chip by means of binning patterns. A default binning pattern is preset at APEX system boot, whereas any binning configuration can be uploaded when required, in order to achieve application tailored performances with specific spectral resolution (or Spectral Sampling Interval, SSI), selectivity (Full Width Half Maximum, FWHM) and improved SNR [3].
APEX has an across-track Field of View of 28°, sampled over 1000 pixels.

The APEX sensor is equipped with an In-Flight Characterization unit (IFC, Fig. 2 and Fig. 3). The objective of this unit is to support the instrument performance analysis during standard in-flight operations and compare them with those achieved during calibration activities. The IFC provides a stable radiometric, geometric and spectral input to the system. Methods to investigate the instrument performance are currently under development [7]. The IFC unit is composed of a stabilized 75 W QTH lamp installed in the spectrometer's baffle compartment and a filter wheel comprising filters with specific spectral features: a Rare Earth Materials, a neutral density (gray) and 3 band pass (color) filters. To investigate the geometric stability survey of the system, two thin wires have been glued on the instrument slit. The shadow of the wires projected on the detector will provide information to investigate the effects of environmental and internal factors (such as differential pressure differences and temperatures) on the system.

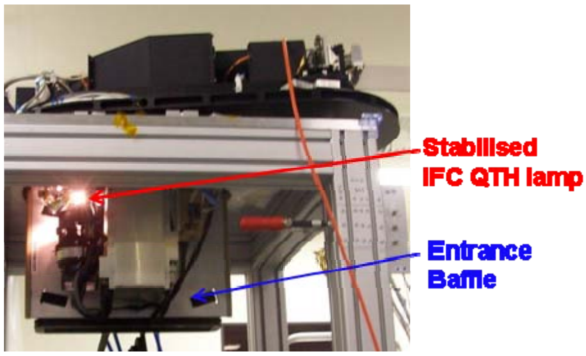

Figure 2 – the IFC lamp installed in the baffle

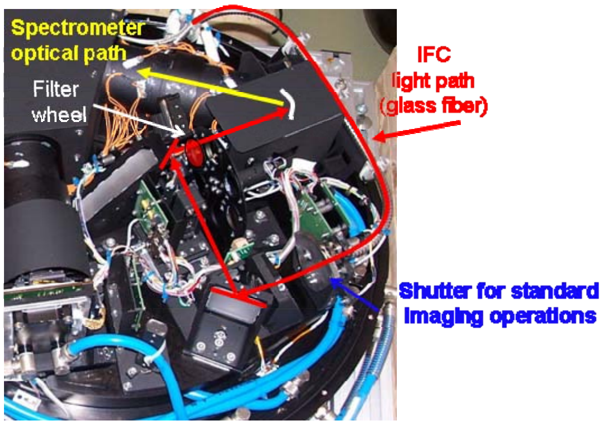

Figure 3 – the integration of the IFC optical path inside the APEX optical sensor.

The IFC lamp light is collected from the baffle compartment's housing and driven inside the optical sensor by means of a glass fiber. In order to achieve a distributed irradiance over the detectors' field of view, the light beam passes through a diffuser system, and is injected into the standard light path by means of a series of movable optical parts.

2.2. The APEX aircraft installation

The APEX system setup inside the aircraft is represented in the figures below. Two parts can be distinguished: the sensor mounting with its supporting units and the operator's rack. The sensor (Figure 4) is

installed on a customized Leica PAV30 stabilizing platform. To prevent the impact of thermal effects on the optical performance of the sensor, the Environmental Thermal Control box (ETC box, partially open in the picture) is part of the aircraft interface. The box creates a closed environment around the sensor. Both the ETC box environment surrounding the sensor and the sensor itself are controlled and stabilized by means of a Thermal Control Unit.
To avoid possible contamination by means of external factors (moisture, particles and chemicals) and eventual degradation of the optical performance the APEX sensor is sealed and the internal instrument atmosphere filled with nitrogen.

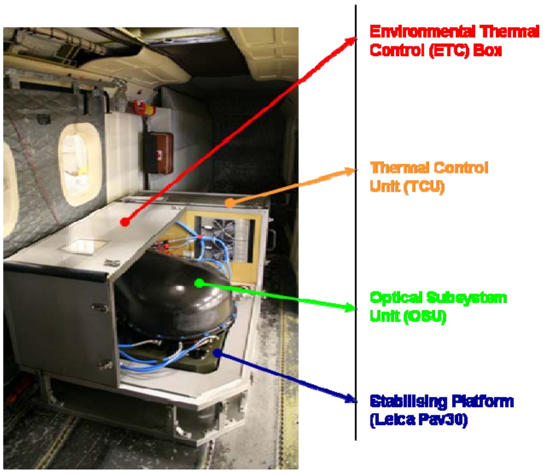

Figure 4 - the APEX sensor installed into the DLR Do-228

The operator's rack (Figure 5) is made of a rack shelf in which are integrated the APEX control system, the storage (based on solid state disks and tape driver) unit and the flight support units (Applanix positioning system and Track'Air aerial survey system). These units are interfaced via LAN to the user interface running on a ruggedized laptop.
The overall mass of the whole APEX aircraft installation is 350 kg.

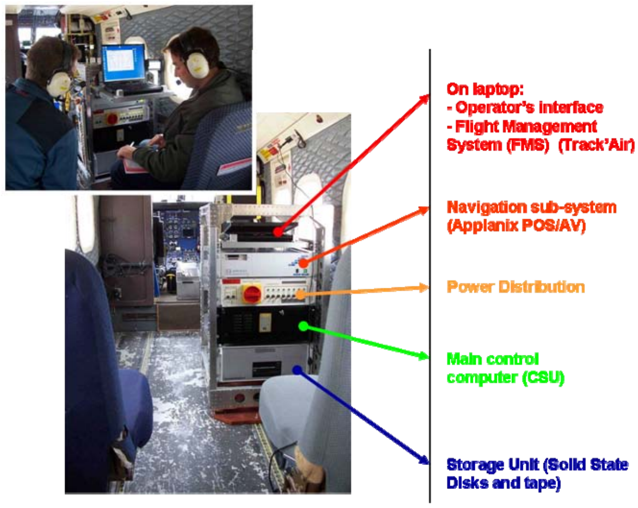

Figure 5 - the operator's rack installed into DLR Do-228.

3. ENVIRONMENTAL TESTS

The APEX system has undergone environmental tests in order to simulate the conditions experienced during airborne campaign (Fig. 6). The objective was to identify criticalities in the performance of systems supporting APEX functionalities, and to quantify the eventual impact on instrument performances within the given boundary conditions.
The tests, carried out in April 2009, were taking advantage of the climate chamber facility hosted at RUAG premises in Emmen (CH). A re-run of the environmental tests has been carried out in September 2009, to further detail the instrument model achieved.

Figure 6 – Environemental tests held at RUAG Emmen (CH), 22 April 2009

4. LABORATORY CALIBRATION

Prior and after the Flight Campaign, instrument characterisation and calibration campaigns were executed at the Calibration Home Base. The execution of the two separate sessions aimed at assessing the instrument performance, tracing its stability after having endured an intense deployment, suffering the harsh

environmental conditions of the exploitation campaign (temperature and pressure ranges, vibration).
The calibration of pushbroom spectrometers represents a challenge due to the amount of calibration data to be collected.
To achieve a description of the instrument performance within a reasonable amount of time, downscaling of the calibration problem to a limited number of spatial and spectral positions is mandatory.

5. FLIGHT CAMPAIGN 2009

The APEX flight campaign has been held in June 2009 and performed on board of the DLR Do228 D-CFFU with airfield located at DLR Oberpfaffenhofen (D). During the flight campaign a test flight and three flights over Swiss and Belgian target areas were carried out, achieving 19 flight hours in total.
Swiss and Belgian targets areas have been selected in order to cover at most the variety of possible scientific applications. Flight lines have been executed over forests, crops, inland water, urban and coastal areas in order to derive a wide spectrum of products of interest.
Vicarious calibration campaign with extensive ground truth measurements has been carried out for all flight lines.

6. IN-FLIGHT IFC RESULTS

The analysis of IFC data acquired during the flight campaign has evidenced a dependence of instrument performance on environmental parameters. In particular an empirical model based on the results achieved could be built for the spectral performance (spectral band position and spectral misregistration). The status of this model has been evaluated to be mature to be integrated into the PAF as a default sub-module for spectral information recalibration.

7. PAF RAW-L1C FINALISATION

The outcome of the Flight Campaign 2009 was 80 GB of APEX imaging spectroscopy data. The analysis of these data has been devoted to the assessment of the in-flight instrument performance, investigating its stability and verifying its quality at different product levels.
The processing scheme to calibrate imaging spectroscopy data from raw data stream to radiances has been systematically reviewed, implementing modifications based on the knowledge of the instrument model achieved at the CHB and by means of the IFC data.

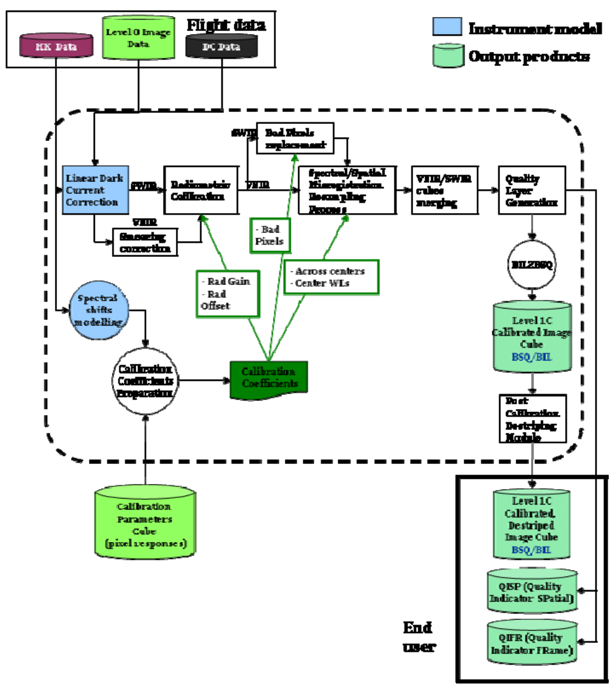

Figure 7 – simplified schematic of the APEX PAF software raw-L1C. the end users receives as a default the calibrated radiance cube with ancillary quality indicators.

A dedicated module for the assessment of the data quality based on Principal Components and MNF analysis is under finalization.
First quality indicators (saturation, bad pixels, dead pixels, interpolated pixels) have been implemented in the processor as a default.
The refinement of the data quality and the improvement of the overall process accuracy by identifying the margins for improvement represent the next challenge for the APEX team.

8. PAV L 2/3 PRODUCTS

The spectrally, geometrically and radiometrically calibrated data has been processed in order to derive indexes and products of scientific interest. Due to spectral resolution of the APEX instrument compared to other imaging spectrometers, a comparison of the atmospheric correction schemes applied to derive at ground HCRF is under evaluation.
First indexes and products derived from APEX flight lines are hereafter presented.
Assessment of the geocoding and georeferencing of the APEX imaging spectroscopy data has been generated.

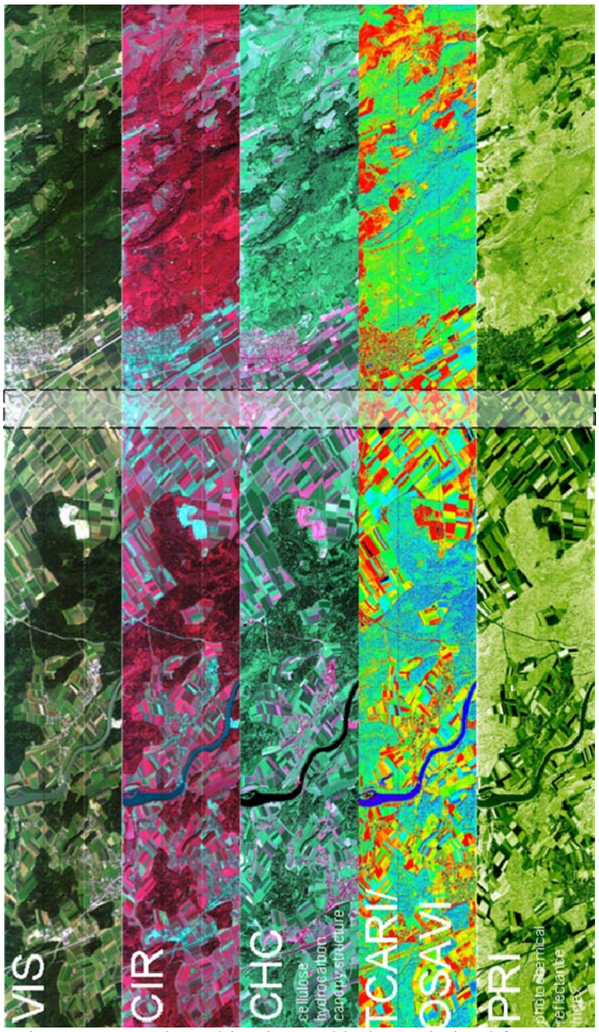

Figure 8 – Band combination and indexes derived from an APEX flight line (Oensingen, CH, 17/06/2009). From left to right: standard RGB combination (VIS), CIR, Cellulose Hydrocarbon Canopy structure (CHC), TCARI/OSAVI, Photochemical Reflectance Index (PRI).

9. CONCLUSIONS

During 2009, the APEX instrument has undergone the final phase of its development and testing.

The outcomes of the intense experimental activity (environmental tests, laboratory characterisation and calibration, flight campaign exploitation) have evidenced in the meanwhile that by means of some solutions at system level the instrument performance could be further improved and stabilised.

Due to the replacement of the SWIR detector in late November 2009, the APEX instrument will undergo a partial realignment. This will require the execution during 2010 of a new iteration of the whole testing procedure in order to achieve the successful instrument acceptance.

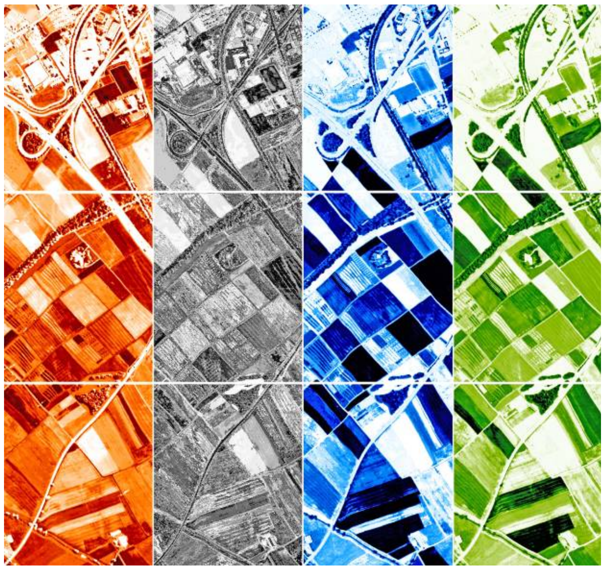

Figure 9 – Products derived from an APEX flight line transect (Oensingen, CH, 17/06/2009). From left to right: Leaf Area Index (LAI), dry matter content (CDM), water content (CW), chlorophil content (CAB). The two white lines are masking two wires, placed on the instrument slit to support the assessment of the geometric performance.

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