APEX – AIRBORNE PRISM EXPERIMENT
A NEW CONCEPT FOR AN AIRBORNE IMAGING SPECTROMETER*

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ABSTRACT

The European Space Agency (ESA) has identified the necessity to initiate a study that concentrates on the definition of an airborne imaging spectrometer which could represent a precursor to the spaceborne PRISM (Process Research by an Imaging Space Mission). The study included the definition of an Airborne PRISM Experiment (APEX) that will contribute to the preparation, calibration, validation, simulation, and application development for the PRISM mission. The APEX instrument is defined as an airborne pushbroom imager with 1000 pixels across track and 200 user selectable spectral bands over the wavelength range from 450 – 2500 nm. The complete APEX system will include an aircraft, navigation data, laboratory and in-flight calibration as well as a data archiving and processing facility.

1.0 INTRODUCTION

After the successful operation of ERS–1 and ERS–2, the European Space Agency has set the scene for an environmental mission by preparing the satellite ENVISAT–1.

In formulating European Earth Observation missions beyond this, ESA is considering the development and launch of a high resolution Land Surface Processes and Interactions Mission [READINGS, 1996] and intends to develop a system to investigate land surface processes and their interaction with the atmosphere [DEL BELLO, 1996]. This includes the implementation of data acquisition from an advanced high resolution spectro-directional space sensor, and by supporting the development of the tools and techniques of data interpretation to:

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increase the understanding of biophysical processes and land/atmosphere interactions at the local scale; and
exploiting the increase in knowledge of (small scale) processes and to advance the understanding of these interactions on a global scale by extrapolating through time and space using process models.

The space segment would be characterised by:
• a single satellite in a near-polar orbit capable of enabling the payload to access all land areas with the required geometric and temporal characteristics;
• a hyperspectral imager with the required spatial and spectral resolution covering the optical range of the electromagnetic spectrum with good radiometric accuracy and with the capability to perform directional measurements providing the required accessibility and revisit characteristics.

A preliminary design at system level of satellite instrumentation fulfilling this goal started under the name Process Research by an Imaging Space Mission (PRISM) [POSSELT, 1996]. This instrument will combine the main features of a visible/short wave infrared imaging spectrometer and of a thermal infrared multi–channel imager. PRISM would cover two main wavelength regions, namely the visible-short-wave infrared from 0.45 to 2.35 μm, where the instrument works as an imaging spectrometer with a spectral resolution of about 10 nm and the thermal infrared range from 8 to 12.3 μm, divided into 3 spectral bands with a typical width of 1 μm, where the instrument works as an imaging radiometer. The spatial resolution at nadir is about 50 m over a swath (image size) of 50 km. Access to any site on earth could be provided within three days [ESAC, 1996].

In order to support such activities, ESA has identified the necessity to initiate appropriate studies and measurement campaigns. In this frame, the presented paper discusses a study that concentrates on the definition of an airborne imaging spectrometer which could represent a precursor of the spaceborne instrument and which will therefore be named APEX (Airborne PRISM Experiment)[DEL BELLO, 1995].

APEX is a project to develop an airborne PRISM simulator which will contribute to the
• preparation,
• calibration,
• validation,
• simulation, and
• application development
of the PRISM mission. In addition APEX will be an advanced imaging spectrometer serving as a testbed for other imaging spectroscopy applications.

2.0 THE APEX INSTRUMENT

APEX will be an instrument with the following uniqueness in technical, usage and applications standpoint:
• pushbroom imager with approx. 1000 pixels across track and a swath width of 2.5 − 5 km
• spectral wavelength range covering 450 – 2500 nm
• 200 user selectable and predefined bands, adapted to the specific mission and application
• a spectral sampling interval < 15 nm at a spectral sampling width < 1.5 times the sampling interval
• provides calibrated data and a suite of user oriented products up to fully geocoded and calibrated data.
2.1 THE IMAGING SPECTROMETER OPTOMECHANICAL SUBSYSTEM

The ground imager maps the ground (swath of \(\pm14^\circ\)) on the spectrometer slit of 50 mm height and 0.05 mm width. High image performance is required in order to provide maximum energy throughput at the slit and to define the swath width precisely. The ground image has to be colour corrected in the total spectral range between 450 and 2500 nm. Behind the ground imager a beam splitter will be placed to separate the spectral range in a visual and an IR channel. The use of a beam splitter in front of the collimators allows to choose more suitable glasses for the colour correction and for improving the transmission within the reduced number of spectral bands. The two collimators project the light coming from the slit towards the dispersive elements of the spectrometers.

Prisms will be selected as dispersing elements. The light scattering in a system containing gratings is considered to be a risk that cannot be taken. For the visual channel, the prism materials CaF\(_2\)/ZnS are selected, for the IR channel the prism materials are CaF\(_2\) and Sapphire.

Finally detector lenses are selected to provide spatially and spectrally resolved images on the matrix detectors. The VIS detector is tilted by 30° to correct for image height differences at the individual wavelengths. The IR detector lens consists of three off-axis aspherical mirrors. The use of reflective elements simplifies the color correction, supports the compensation for image bending and improves the total throughput for better signal to noise ratios.
2.2 DETECTORS AND FRONT END ELECTRONICS

In the APEX instrument two detectors are needed to cover the specified spectral range:

- A VIS detector, sensitive in the spectral range 450 - 950 nm (Si CCD)
- An IR detector, sensitive in the spectral range 900 - 2500 nm. (Choice of HgCdTe or InSb detectors)

The detectors for the APEX instrument have to be two dimensional array detectors. To meet the specification on resolution, in the spectral and spatial direction the detector arrays must at least have 1000 pixels in spatial, and 200 in spectral direction.

The FEE for the visual CCD detector will be realized by using photocapacitors and CCD readout structures. The analogue output signal of the CCD is sampled and converted to digital data by an ADC.

The HgCdTe detector will be read out by a CMOS circuit. The array consists of a number of addressable pixels using MOS transistors as switches, controlled by an x and y multiplexer.

The detectors will be glued in their holders. Alignment (translation) will be done making use of shims. To reduce dark current noise, the IR detector needs to be cooled to a temperature of -80°C. The cooling is achieved by means of a cooling engine. Care has to be taken that no vibrations caused by the cooling engine disturb the image quality of the system.

2.3 ELECTRONICS UNIT

The electronics unit consists of the video electronics unit, the framegrabber unit, the data storage unit and the user interface unit which incorporates four basic operating modes to control the APEX instrument.

- Mission preparation – before a data acquisition mission, all parameters and sequences are determined and stored in the system
- Calibration mode – the calibration sequence is initiated and the calibration data are stored
- Acquisition mode – the instrument stores the data coming from the detectors
- Stand–by mode – all the values stored or transferred into the instrument stay active but no acquisition is done

The proposed video chain of the systems consists of an analogue ASIC that grants for the necessary stability. The next device is an internal offset loop correcting the offset recorded from some darkened border pixels of the detectors. Finally the ADC converter will take care of the signal conversion to be fed into the framegrabber. The framegrabber itself is capable of transferring 200 lines of 1000 12 bit pixels each 40 ms. This throughput corresponds to a data–rate of 60 Mbit/sec.

In the mission preparation phase, the operator of the instrument must select 200 channels that will be recorded out of 400 lines accumulated by the detectors. The channel selection is stored in a PROM and multiple PROM’s can be selected within one data acquisition flight. The calibration mode will be used in the laboratory where the operator has the choice of addressing basically all moving parts and controls in the APEX system. During a real data flight, the instrument will be first in calibration mode and over the desired test site in acquisition mode. A moving window display will be used in the APEX control unit to monitor the functionality of the detectors. Two hundred frames corresponding to one scan line will be recorded continuously every 40 ms. The framegrabber unit, the data storage unit and the user interface unit are mounted in racks that are located in the cabin of the aircraft. The video electronics unit is a part of the APEX instrument.
3.0 AUXILIARY COMPONENTS

In order to make the APEX Imaging Spectrometer System operational, the following auxiliary components must be available:

• an aircraft platform
• a “closed” environment for the APEX instrument
• a stabilized platform
• a differential GPS and accelerometers
• in flight calibration means
• laboratory calibration hardware
• equipment for temperature and pressure control
• vibration and shock absorbers

3.1 THE AIRCRAFT AND NAVIGATION

The APEX instrument, when installed in an aircraft, will be in a protected and closed and temperature stabilized environment. The pod or box containing the APEX Instrument has an optical window made of sapphire. During take-off and landing a mechanical shutter will be closed in order to protect the window.

The PILATUS PC XII Eagle is the proposed survey aircraft for the operational missions of APEX. The crew will consist of an aircraft pilot and the APEX operator. In order to guarantee the geometric quality of the recorded scenes accurate navigation data have to be provided. At present the concept is to use the autopilot of the aircraft plus differential GPS and an inertial navigation system, and to record this data simultaneously to the actual scene. A geometric analysis has shown, that roll, pitch and yaw stabilization will be necessary in order to provide a precise geometric coverage of the area at stake. The vibration decoupling shall be effected by means of shock mounts.

3.2 THE CALIBRATION

An integrating sphere will be used in the laboratory as calibration standard for characterizing the radiometric response function. The sphere is used as a secondary calibration standard, traceable to NIST standards. An irradiance lamp source will be used in conjunction with a (double) monochromator to calibrate the spectral response function. The spectral response function for each channel covering the whole wavelength range (400 – 2500 nm) will be measured in 0.5 nm intervals using different diffraction gratings. The calibration of the geometric response function will be done using an illuminated slit that is projected perpendicular to the slit in the focal plane of a collimator. The calibration hardware will also include a PC that controls all the necessary devices and collects the calibration data. The same PC will be used to download the acquired data from the aircraft.

The pre– and post flight calibration is performed using a mobile diffuse lamp source for functionality tests and testing the stability of the calibration coefficients before takeoff and after landing of the aircraft. This lamp source will be moved under the aircraft and prior to a mission the stability and applicability of the calibration factors will be verified.

Similar to the laboratory calibration hardware, the in–flight calibration hardware of the APEX system consists of an integrating sphere calibration standard. The features associated to this sphere will be similar to the one evaluated for the laboratory use, but must – due to space constraints in the pod – be smaller in total diameter. In the laboratory, the system will be able to scan both the internal sphere and the laboratory sphere using a switchable mirror in the optical path. Built into the electronic part of the APEX, the compensation offset loop will subtract dark current estimated from the darkened border pixels of the respective detector lines during any data recording with the instrument. The in–scene calibration hardware used on Swiss test site flights consists of a field portable spectroradiometer that
will be used to measure calibrated radiance and absolute reflectance on selected reference targets during the overflight. The variation of the optical depth will be measured using a 10 channel sunphotometer. This instrument will be placed on the reference targets in the field during calibration flights only and monitors the changes of the atmosphere. Furthermore a radiosonde will be used in the field to measure atmospheric parameters (i.e. temperature, pressure, humidity, etc.) simultaneously to the overflight. The radiosonde data will be used to accurately describe the atmospheric conditions present at the overflight.

For data takes of other test sites, provisions must be made to provide on site reference measurements of selected targets and the atmosphere.

4.0 DATA HANDLING

4.1 CALIBRATION AND PROCESSING

The primary goal of the calibration strategy is to achieve absolute radiometric calibration for the acquired data. It is necessary to achieve the best possible radiometric accuracy performance in order to be able to calibrate PRISM and other imaging spectrometers. Further on it is considered to use standard hardware technology to reduce the amount of calibration costs for in–flight characterization. During the critical phases (takeoff, landing) of the aircraft, the instrument will be protected by a mechanical shutter. In general there is no in–flight calibration foreseen during data acquisition, but in–flight pre– and postdata acquisition calibration activities allow for the monitoring of the instrument performance.

During non–data acquisition times (i.e. winter) the instrument can be mounted on top of an integrating sphere to obtain the radiance calibration. The spectral calibration will be performed using a monochromator to determine the spectral sampling rate and the spectral response function for each channel. The use of a collimator is proposed for calibrating the geometric response function.

The pre–flight calibration will be more a general functionality test of the instrument than a calibration traceable to a standard. It is suggested to use a homogenous, diffuse artificial lamp source to illuminate the instrument from below the aircraft. The instrument must be fully operational and ready for data acquisition.

The in–flight calibration is divided into three parts. The pre–scene calibration will take place just before the data acquisition. The shutter of the sphere will be closed and dark current frames are recorded while pointing the FOV into the integrating sphere. Then the shutter of the instrument opens and the built in integrating sphere illuminates a mirror that deflects the beam of the FOV towards the ground imager. After these calibration tasks, image data from the scene can be acquired.

There will be no in–flight calibration during ground data collection. The image data acquired are only dark current subtracted using a compensation offset loop built in the electronic part of APEX. After having recorded one scene or a sequence of scenes, the internal mirror will switch and deflect the FOV towards the internal integrating sphere again.

The in–scene calibration will only be performed on selected calibration flights. The goal is to have a spectroradiometer on selected reference targets on the ground, a sunphotometer measuring the changes of the atmosphere over time and a radiosonde during the overflight. The at—sensor radiance can be modelled using radiative transfer codes (such as MODTRAN). A second calibration data set is generated and can be used to validate the laboratory calibration. The post–flight calibration will be the same procedure as the pre–flight calibration.

The data acquired will be processed with a given number of intermediate steps. Each of these processing steps will produce an output that is either given in a defined level (i.e. 0 to 3) that will be distributed to the customer with some restrictions or with undefined levels for internal use and archiving of raw data and intermediate processing steps only.
After downloading the data from the aircraft it will be transferred to the processing facility (Level 0). The first analysis of the data incorporates the generation of quicklooks. The data will then be reformatted to the scenes level (Level 1). After the predefined calibration is applied to the data, the sensor specific calibrated data are archived as Level 1A. The final Level 1D includes the spectral and geometric calibration. Level 2 data products include parametric geocoding and atmospheric correction. The final processing step (Level 3) will depend on user defined processing requests and require application specific analysis methods.

4.2 OPERATIONALIZATION

After a successful development phase of the APEX system, the experiment will be made available for an operational phase for a wide remote sensing community interested in hyperspectral imaging and beyond. During the realization phase of the APEX, assessments of the following points must be undertaken:

- definition of a concept for a reference mission
- definition of the costs associated for such a mission
- identification of potential customers
- planning of the APEX utilization phase

To a customer, the APEX will consist of the remote sensing project team. This team will be responsible for marketing the services and applications provided by APEX, assures the technical performance of the instrument, manages all the missions, and provides the customer with all the data according to the requested processing level. The aircraft operator is responsible for items such as flight planning, clearances, flight execution, etc. The flight crew will consist of the aircraft pilot and an operator associated with the correct recording of the requested scenes and the proper operation of the instrument during data acquisition.

5.0 CONCLUSIONS AND OUTLOOK

With this ESA/ESTEC initiated pre phase A study for the definition of an airborne imaging spectrometer it has been shown that the development of a well calibrated and operational imaging spectrometer within Europe can be realized. The presented concept provides an integral view of the experiment, including the calibration and data handling. The operationality of the experiment relies not only on the sensors performance in terms of SNR and other measures but also on the access to the data and the availability of the instrument to the remote sensing community.

Given that APEX is realized, not only PRISM data can be calibrated but also other (space borne) imaging spectrometers and multispectral scanners can be validated such as the HSI (Hyperspectral Imager), the ENVISAT–1 instrumentation and also airborne sensors such as the AVIRIS, DAIS, and other operational instruments.

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7.0 REFERENCES


