12/05/2010

APEX Status: Instrument Performance, Operations and Product Generation

Koen Meuleman
VITO, Mol, Belgium
Airborne Prism EXperiment – APEX

» Background
» The Instrument
» Instrument Calibration
» Processing and Archiving Facility
» Measurements and Products
» Conclusions
Airborne Imaging Spectrometers

GERIS, 1982
AIS
AVIRIS

CASI
DAIS7915
ROSIS

SFSI
HYDICE
HYMAP
Pushbroom Principle
Image Cube
Spectral Data Richness

![Graph showing spectral data richness with data points for Total Radiance at Sensor (MODTRAN 4), Imaging Spectrometer (10 nm FWHM), Landsat 7, and SPOT 4.](image)
APEX – Project Background

» APEX is a joint Swiss/Belgian project funded by ESA PRODEX with support from ESA Earth Observation.

» APEX is an airborne pushbroom dispersive spectrometer for the support and development of future spaceborne Earth Observation systems, supported by a Processing and Archiving Facility (PAF) and a Calibration Home Base (CHB).

» APEX is able to simulate, calibrate, and validate existing and planned spaceborne optical missions.

» APEX will foster the use of imaging spectrometer data and will support the application development for imaging spectroscopy products.
Background

1991  APEX was initiated by Klaus I. Itten, following the MacEurope campaign
1994  ESA identified as funding agency
1996  Belgium was asked to join the project, VITO joined the APEX team
1998  First instrument concept identified
2001  Phase A: Requirements, specifications, feasibility studies
2003  Phase B: Breadboarding activities (detectors, optical parts)
2006  Phase C/D: Critical Design Review
2007  … instrument prototype realized
2008  Spring: contamination due to cooling liquid leakage
         »  Autumn: first tests at full system level, first test flight
2009  Acceptance flight campaign in June  Performance assessment, acceptance procedures
2010  SWIR detector failure: recovery action ongoing. New acceptance flights in June 2010
2011-2016  Phase E: Exploitation Operations
APEX Schedule as of April 2010

Institutes Phase C/D

- Supporting Industry Activities
- Performance Assessment
- PAF End to End Testing and Finalisation

Industry Phase C/D

- System Tests
- Characterization & Testing activities
- Recovery action

- Test Flight
- Acceptance Flight Campaign
- AR
- FRR
- YR

2009

2010

Phase E (5+5 years)

- Characterization & Testing Activities
- Acceptance Review 2
- Delivery

2011

Today

- First Data delivery

- SWIR detector replacement
- Calibration and Characterisation

Oct. 2010
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# APEX Performance

## Spectral Performance

<table>
<thead>
<tr>
<th></th>
<th>VNIR</th>
<th>SWIR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spectral Range</strong></td>
<td>380.5 – 971.7 nm</td>
<td>941.2 – 2501.5 nm</td>
</tr>
<tr>
<td><strong>Spectral Bands</strong></td>
<td>Up to 334 (default: 114)</td>
<td>198</td>
</tr>
<tr>
<td></td>
<td>(number of VNIR spectral rows programmable via binning pattern upload)</td>
<td></td>
</tr>
<tr>
<td><strong>Spectral Sampling Interval</strong></td>
<td>0.5 ÷ 8 nm (default: 11 ÷ 8 nm)</td>
<td>5 ÷ 10 nm</td>
</tr>
<tr>
<td><strong>Spectral Resolution (FWHM)</strong></td>
<td>0.6 ÷ 6.3 nm</td>
<td>6.2 ÷ 11 nm</td>
</tr>
</tbody>
</table>

## Spatial Performance

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td><strong>Spatial Pixels (acrosstrack)</strong></td>
<td>1000</td>
</tr>
<tr>
<td><strong>FOV</strong></td>
<td>28°</td>
</tr>
<tr>
<td><strong>IFOV</strong></td>
<td>0.028° (ca 0.5 mrad)</td>
</tr>
<tr>
<td><strong>Spatial Sampling Interval (across track)</strong></td>
<td>1.75 m @ 3500 m AGL</td>
</tr>
</tbody>
</table>

## Sensor Characteristics

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td><strong>Type</strong></td>
<td>CCD (Si)</td>
</tr>
<tr>
<td><strong>Dynamic Range</strong></td>
<td>14 bit encoding</td>
</tr>
<tr>
<td><strong>Pixel Size</strong></td>
<td>22.5 μm x 22.5 μm</td>
</tr>
<tr>
<td><strong>Smile</strong></td>
<td>Average, less than 0.35 pixel</td>
</tr>
<tr>
<td><strong>Keystone (Frown)</strong></td>
<td>0.35 pixel</td>
</tr>
<tr>
<td><strong>Co-Registration</strong></td>
<td>0.55 pixel</td>
</tr>
<tr>
<td><strong>CMOS (HgCdTe)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Dynamic Range</strong></td>
<td>13 bit encoding</td>
</tr>
<tr>
<td><strong>Pixel Size</strong></td>
<td>30 μm x 30 μm</td>
</tr>
</tbody>
</table>

## Other Information

<p>| | |</p>
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td><strong>Data Capacity</strong></td>
<td>500 GB on SSD</td>
</tr>
<tr>
<td><strong>Data Transfer</strong></td>
<td>Spectral frames 30 MB/s via Optical Link</td>
</tr>
<tr>
<td></td>
<td>Housekeeping Data 20 kB/s via Serial Cable</td>
</tr>
<tr>
<td><strong>Data rate for default configuration</strong></td>
<td>0.4 GB/km (1250 km max)</td>
</tr>
</tbody>
</table>
APEX Optical Sub-Unit

- VNIR Detector (380 - 1000 nm)
- SWIR Detector (940 - 2500 nm)
- SWIR Cryo-Cooler
- VNIR Optics
- SWIR Optics
- Main Collimator
- Beam Splitter (dycroc layer)
- Ground imager, slit and spherical mirror
- folding mirror
Detector Technology

CCD 55-30 from E2V Technologies (GB)
- Frame transfer mode,
- 1252 x 1152 pixels (used: 1000 x 335)
- Pixel pitch 22.5 μm x 22.5 μm,
- fill factor 100%,
- Back illuminated,
- Read out frequency 7 MS/s,
- 14 bit encoding

HgCdTe CMOS from SOFRADIR (F)*
- hybridized on multiplexer,
- 1024 x 256 square pixels (used: 1000x199)
- Pixel pitch 30 μm x 30 μm
- addressable readout, fast operation,
- Integrated in cryostat cooler assembly,
- wavelength range: 0.94 – 2.50 μm,
- QE: > 70 % average, T_{op.}: 150 K
- 13 bit encoding

*custom development under ESA-EOP contract
VNIR FWHM and Binning

![Graphs showing VNIR FWHM and Binning](image)
SWIR FWHM

![Graph of SWIR FWHM](image)
APEX Aircraft Installation

Environmental Thermal Control (ETC) Box
Thermal Control Unit (TCU)
Optical Subsystem Unit (OSU)
Stabilising Platform (Leica PAV30)
APEX Aircraft Installation

Operator’s Interface
Flight Management System (FMS, TrackAir)

Navigation Sub-System (Applanix POS/AV)

Power Distribution Unit

Main Control Computer (CSU)

Storage Unit (SSD and tape)
SWIR Detector Failure

Failure of the SWIR detector in November 2009

Root cause:
Lost vacuum tightness detector dewar

Impact on sensor:
- Operating temperature not reachable
- Condensation on the detector housing
- possible contamination of the HgCdTe matrix due to partial air content on the FPA

Impact on schedule: 5 months delay
- Failure identification by Sofradir
- Handling/substitution under French military regulations
- Partial sensor realignment
- Instrument validation (characterization, calibration, flight validation) to be partially repeated
System improvements

By means of IFC, spectral and geometric performance have been traced back on differential pressure and environmental conditions

>> to avoid mechanical stress induced by pressure differences during flight maintaining a nitrogen environment, a new pressure regulation system is under implementation

>> to avoid thermo-mechanical stresses and condensation/frosting induced by the flight environment, the climate system effectiveness of the ETC box must be increased

![3D CAD model of the pressure regulator to be integrated on the aircraft](image1)

![FEM model to investigate frosting/condensation in flight conditions](image2)

![Climate chamber tests of the new climate system](image3)
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APEX - Calibration Approaches

» CHB – Calibration Home Base (DLR Oberpfaffenhofen (GER))
  » Calibration and characterization activities are time consuming
  » A full spectral calibration for each pixel takes 110 measurements, each requiring slight parameter adaptations (overall calibration matrix: 1000 x 534 pixels + temporal component)

» IFC – In-flight Characterization
  » Allowing reference measurements before and after each data take during flight

» Vicarious calibration activities
  » Field reference targets, also including directional characterization

Spectral Calibration for 1 pixel: 2’30”
Overall Laboratory session: 10 days
The Calibration Home Base @ DLR München*

* Developed under ESA-EOP Contract;
Status: Acceptance review successful in Jan. 2007
In-Flight Characterization Facility

The IFC is a tool designed to investigate the overall instrument (radiometric, spectral, geometric) stability during flight.

Spectral filters:
- 3 Bandpass (color) filters
- 1 Rare Earth Material (NIST) filter
- 1 Neutral Density (grey) filter
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Schematic APEX Processing Flow

1. **Level 0 ImageData**
   - **Flight data**
     - **Level 0 Image Data**
     - **DC Data**

2. **Calibration Parameters Cube**
   - **Radiometric Calibration**
     - **SWIR**
       - **Linear Dark Current Correction**
       - **Smear correction**
   - **VNIR**
     - **Spectral shift modelling**

3. **Calibration Coefficients Preparation**
   - **Rad Gain Rad Offset**
     - **Across center WVL**

4. **Instrument model**
   - **Broken Pixels replacement**
   - **Spectral/Spatial Misregistration Resampling Process**
   - **Quality Layer Generation**

5. **Post Calibration Destriping Module**
   - **Level 1C Calibrated Image Cube BSQ/BIL**
   - **QISP (Quality Indicator Spatial)**
   - **QIFR (Quality Indicator Frame)**

6. **Products**
   - **Level 1C Calibrated, Destriped Image Cube BSQ/BIL**
Processing and Archiving Facility (PAF)

Instrument Data Stream

APEX PAF Level 0 - 1C Processor

Calibrated Image Cubes

Level 1C Product

APEX PAF Level 3A – 3B Processors

APEX PAF Level 2A – 2C Processor

Level 2A-2C Products

Geolocated/Atmospherically Corrected cube

PAF HW hosted @ VITO (Mol, B)

PAF Version Evolution
(HCRF-BRDF-BHR)
1 empirical BRDF
2 NBAR
3 DHR/BHR/BHRiso

Level 3A-3B Products

Higher Order Products
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APEX Acceptance Campaign
2009 – Similar in 2010

Flight Window: CW24-26
(8-24 June 2009)
- Objective: Investigation of APEX performances in view of ESA Final Acceptance
- Instrument responsibility and property: Industrial Prime
- Base Airfield: DLR Oberpfaffenhofen (D)
- Aircraft: DLR Do-228 D-CFFU
- Ground support: extensive vicarious calibration campaign

Target Areas
Belgium
- Sea coasts (Oostende)
- Scheldt river (Antwerpen)

Switzerland
- inland water (Lake Konstanz)
- urban area (Basel)
- vegetation/crops (Vordemwald)
- mixed (Lägeren, Holderbank)
Aircraft

» APEX is currently certified to fly on DLR’s DO-228.

» Current activities are to certify APEX on several other platforms (CAE Aviation – Cessna; DLR Halo – Gulfstream; RUAG – DO-228NG; etc.).

» EUFAR – European Facility for Airborne Research offers aircraft and APEX within a EC FP7 project.

» Airworthiness certification costs per aircraft range from approx. 10 -100 kEUR depending on type and rules.

» Export licence rules apply for the operation of APEX in certain countries.
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Conclusions

» APEX is scheduled to be finalized in September 2010.

» Preliminary flight data from 2009 are delivered to selected customers.

» APEX is currently undergoing a hardware upgrade and revision (exchange of SWIR detector, upgrade of flight management system, improvement of thermal and environmental stability, etc.).

» A full recalibration and acceptance test is scheduled for June 2010, including the coverage of a variety of test sites across Europe.

» A structured programme will be available 2011 onwards for APEX flights to interested parties.
Perspectives

» APEX is the first airborne imaging spectrometer of ESA available to the user community from 2011 onwards.

» APEX will be operated by VITO & RSL on behaf of ESA for 5 years.
» RSL and VITO are cooperating during the exploitation phase of APEX.

» National funding (B & CH) and operations will secure APEX operations in the first period.

» Interested parties or contact:
  » Koen.Meuleman@vito.be
  » Michael.Schaepman@geo.uzh.ch
APEX – Airborne Prism Experiment

Thank you for your attention!