Calibration Methodology for the Airborne Dispersive Pushbroom Imaging Spectrometer (APEX)

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and the APEX team

Recent publications:
Outline of the Talk

• APEX Project Background
• APEX Calibration Specifications (summary)
• APEX Calibration Tools
  • In-flight Characterization facility IFC
  • Calibration Homebase CHB
  • Vicarious and cross calibration
  • PAF (assimilation scheme)
• Conclusion
Scientific Goals

Scientific requirements for APEX have been derived using a performance model for at sensor radiance*.

Goal: Development of advanced methods for bio-geophysical parameter retrieval for

- Vegetation,
- Soils, rocks & minerals,
- Snow and Ice,
- Atmosphere,
- Coastal and inland waters analysis

and **cross calibration with spaceborne EO systems**

*Schläpfer & Schaepman, Appl. Optics 41(27), 2002*
Hyperspectral Applications

- Air Pollution
- Forest Fire Modeling
- Water Quality
- Precision Farming
- Natural Hazards
- Ecology Modeling
APEX Selected Calibration Specifications

- Total FOV 28° deg, IFOV 0.49 mrad (spatial resolution across slit)
- Total of across-track pixels: 1000 for both detectors
- Total spectral pixels on chip, prior to binning 312 (VNIR) & 199 (SWIR), may be read out for calibration purpose simultaneously
- Total spectral bands in operational mode ~ 300 programmable channels resulting in a spectral sampling interval (and width) of $\Delta \lambda \leq 5 \text{ nm}$ in VNIR (400 - 1050 nm) and $\Delta \lambda \leq 10 \text{ nm}$ in SWIR (1050 - 2500 nm)
- Instrument temporal radiometric uncertainty within a flight section: better 0.02
- Radiometric performance accuracy: instrument shall allow absolute calibration accuracy up to 0.03
- Interval for instrument re-calibration: after a complete flight season
- Center wavelength accuracy: < 0.2 nm
Schematic APEX Instrument Components
Instrument Set-up

ETC Box
OMU
TCU
intermediate insulation
ETC Frame
A/C-I/F
flight direction
Instrument Set-up in Aircraft

APEX Instrument
with Stabilizing Platform integrated in
Environmental Thermal Control Box

Aircraft I/F

- Operator Monitor
- Flight Management System
- Navigation Sub System
- Control and Storage Unit
- Power Distribution Unit
APEX Hyperspectral Imager

- Sealed spectrometer compartment
- Thermal stabilized during operation: Better 2 °C, gradient less 0.5 °C
- Max. deformation of Optical Base Plate (OBP) less 0.040 mm due to air pressure variations
- Co-registration error VNIR-to-SWIR channels about 0.5 pixel
- Overall mass: 72 kg, without counterweight for COG adjustment

Fits into PAV-30 Stabilizing Platform, Opening diameter 443 mm
Type CCD 55-30 from E2V Technologies (GB)

- Frame transfer mode,
- 1252 x 1152 pixel (used 1000 x 393)
- Pixel pitch 22.5 x 22.5 µm², fill factor 100%
- Back illuminated
- Operated in non-inverted mode
- Read out frequency 7 Mpix/s
- Operated in dither clocking mode without cooling
- Integration time independent from frame transfer time

**VNIR- Detector**

![Graph](image-url)
HgCdTe detector array - hybridized on CMOS multiplexer
1000 x 256 square pixel, 30 micron, addressable readout, fast operation
Integrated in cryostat cooler assembly
WL range: 0.94 – 2.50 micron
QE: > 55 % average
$T_{\text{op.}}$: 130 – 165 K
APEX Electronic: Data Streams Overview

Diagram showing data flow between POS/AV, FMS, CSU, OSU, Hard Disk, Hard Disk Array, Tape Drive, and GUI with bandwidth specifications.
APEX Calibration Methodology

APEX Calibration Tools:

- In-flight Characterization facility IFC
- Calibration Homebase CHB
- Vicarious and cross calibration
- PAF (assimilation scheme)
Opto/Mechanical Unit (spectrometer hermetic sealed) with IFC*

*In-Flight/on-board Characterisation facility
In-Flight/on-board Characterisation Facility - IFC

Filter wheel
Baffle
Stabilized QTH-lamp

Optical Beampath

Folding mirror
Diffuser
Detector
Lamp with Elliptical mirror and Diffuser
FOV adjustment optics
First lenses of APEX Pupil Position
Imaging Optics
Filter Wheel

APEX Airborne Prism Experiment
APEX Spectral Calibration VNIR (312 bands prior binning)
APEX Spectral Calibration SWIR (199 bands)
Calibration Home Base

The CHB will be established at DLR, Oberpfaffenhofen (D) for regular instrument recalibration during APEX exploitation phase.

For laboratory calibration a number of environmental prerequisites are met:
- **Foundation built as seismic block**
- **accessible by large trolleys (no stairs, steps or elevators)**
- **close to airfield**
- **large enough to host equipment, high ceiling and crane**
- **semi-clean environment**
- **dark room facilities**
- **heated and temperature controlled**
- **low humidity**
Calibration Home Base

- Optical bench (granite)
- APEX-instrument
  - Rotary stage with folding mirror, mounted on linear stage
  - Mirror-Collimators for spectral and spatial calibration (not shown)
APEX Instrument – Radiometric Calibration

Principle of the radiometric calibration of APEX instrument with DLR’s large integrating sphere
Vicarious and Cross-Calibration

Block diagram for the radiance-based calval method to compare TOA radiance predicted from APEX measurements (TOA radiance 2,3) with those measured by the spaceborne sensor (TOA radiance 1). Hsite is the altitude of the site, HAPEX is the flight altitude of APEX and the HTOA the top of atmosphere altitude.

TOA radiance 1

TOA radiance 2

TOA radiance 3

Calibr. Coeff. APEX

Calibr. Coeff. space. sensor

DC APEX

DC spaceborne sensor

radi. transfer model for H_{APEX} to H_{TOA}

radi. transfer model for H_{site} to H_{APEX}

Surface reflectance

Spectral reflectance correction

Calval site

H_{site}

H_{TOA}

H_{APEX}
APEX 312 Bands prior binning

APEX VNIR 312 Bands prior binning
(normalized Gaussian spectral response)
APEX Cross-Calibration Capabilities

Comparison of solar (E0) In-Band Irradiance values (APEX - MERIS, GLI)

Graph showing the comparison of solar (E0) In-Band Irradiance values for APEX, MERIS, and GLI. The graphs display the irradiance values across different wavelengths in nanometers (nm).
## Calibration Parameter Definition

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Parameterised by</th>
</tr>
</thead>
<tbody>
<tr>
<td>$G_{j,k}$</td>
<td>gain factor</td>
<td></td>
</tr>
<tr>
<td>$dc_{j,k}$</td>
<td>dark current factor</td>
<td></td>
</tr>
<tr>
<td>$dl_{j,k}$</td>
<td>bad/dead pixel map</td>
<td></td>
</tr>
<tr>
<td>$\lambda_{j,k}$</td>
<td>centre wavelength</td>
<td>$a_i^\lambda$</td>
</tr>
<tr>
<td>$\theta_{j,k}$</td>
<td>centre across-track angle</td>
<td>$a_i^\theta$</td>
</tr>
</tbody>
</table>

$\uparrow$ for each pixel $\uparrow$ for all pixels

vector of coefficients $b = \begin{pmatrix} G_{j,k} \\ dc_{j,k} \\ a_i^\lambda \\ a_i^\theta \end{pmatrix} + \text{their covariance matrix } S$
Calibration Coefficient Calculation

Sources of Information:
- heterogeneous calibration measurements
- system insight

Goal:
- combine all information in an optimal way

Solution:
- data assimilation
  - optimal combination according to covariances
  - accounts for temporal evolution
  - system insight quantified (correlations)
  - requires covariance matrix
Example: 1-d Kalman Filter

\[ \begin{align*}
    \text{observation:} & \quad b_0, \sigma_0 \\
    \text{analysis:} & \quad b_a, \sigma_a \\
    \text{background:} & \quad b_b, \sigma_b
\end{align*} \]
APEX PAF: The Processor Foundation

PAF Hardware: Linux, XML-tools, websh

Archiving System

PAF: IDL-emacs, CVS, TCL/websh

PAF Processor: IDL, XML, C

APEX PAF Search

Archive Server

Core Web Processor

Input Tools

Processing Tools

Collaboration Tools

Browsing Docs

Co-Developers

Users

Operators

CHB Data
Conclusions

APEX timeline is currently before the Critical Design Review (CDR) close-out meeting

- the PAF version 0.3 has been released in Aug. 2004
- design and breadboard activities of the In-Flight Calibration facility IFC were finalized
- bread boarding phase of the Calibration Home Base CHB is ongoing.

First data for the scientific user community shall be available in 2006!

We are proposing the APEX instrument as a cross-calibration tool to the science community!
Last but not least…

www.apex-esa.org