Uncertainty Budget of the Airborne Imaging Spectrometer APEX

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Outline

Testing and Acceptance

2008 - 2010

Operational Flights (Exploitation)

2009 - ...

Flight OPs, PAF Development, Data Analysis & General Suspicions

2010-2011

Blueprint Deviations: Sensor Model

2012 - ...

Uncertainty Budget

2014 - ...
APEX Introduction: Optics & Electronics

- VNIR CCD
  - E²V, 22.5um
  - Back illuminated

- SWIR Detector
  - Sofradir
  - 30um
  - (Follow-on of this model now used in Sentinel 2)

- Wavelengths:
  - VNIR: 380 nm – 1000 nm
  - SWIR: 950 nm – 2500 nm

- Optical components:
  - Prism, common to SWIR and VNIR channel
  - Collimator
  - Beamsplitter coating

- Image dimensions:
  - Across-track: 1000 px
  - Wavelength: 950 nm – 2500 nm
APEX Introduction: Layout & Areas of Uncertainty

- Smearing $\rightarrow L$
- Pressure $\rightarrow \lambda$
- Temperature $\rightarrow (\lambda), L$
- SWIR Electronics $\rightarrow L$
- Dichroic Coating $\rightarrow L$

Legend:
1 VNIR detector
2 VNIR prism
3 SWIR detector
4 SWIR prism
5 Collimator
6 Ground imager
7 Filter wheel
8 In-flight calibration
9 Baffle
A short history ...

2008: First Flight

2008-...: Lab Calibration

2009: Calibrated Imagery

\[ L = \frac{(DN - DC)}{IT \times \text{gain} + \text{offset}} \]
A short history …

2010/2011: Spectral Shifts

2011-... : APEX Calibration Information System

- EAV (Entity-Attribute-Value) Paradigm based metadata storage
- Stores frames and metadata
- Can also store single spectra and cubes (multi-layered frames).
- Stores provenance data

2012: Spectral Shifts in Lab using Monochromator and pressure modifications

SWIR spectral shift due to 200mbar pressure change:
A short history ...

2013-2014: Optics of APEX and $N_2$ Pressure

Dispersion is a linear function of $N_2$ density and therefore roughly a function of aircraft flight level.

A short history …

2013-2014: Dichroic Coating and Results due to Pressure Change
2015: Thermal Impacts on Radiometry

Digital numbers are influenced by both the power supply temperature and the optical base plate temperature: up to 8% in the VNIR.
2015: SWIR Dark Current Anomaly

Signal falls below dark current for some bands while being higher than dark current for others: observed under partial illumination of two readout blocks.
2015: SWIR Dark Current Anomaly

Brightening in a SWIR band over water due to adjacent land in readout block.
**1st Uncertainty Budget (2014): Traceability Chain**

- **PTB certificate**
  - Provided uncertainty

- **Calibration of SVC against RASTA**
  - Stability since calibr. at PTB (age)
  - Short term stability
  - Stray light (external to SVC)
  - Uniformity (IFOV issues)

- **Sphere measured with SVC**
  - Stability of SVC (temp. sensitivity)
  - Wvl resolution changes compared to RASTA at PTB?
  - Interpolation within SVC?
  - Internal stray light (SVC)

- **APEX**
  - **Source stability (sphere output)**
  - Straylight + interreflections
  - Uniformity of sphere/filters and positioning

- **NPL Filter Calibration**
  - Provided uncertainty

- **Monochromator**
  - Provided uncertainty
  - CWL and FWHM estimate for selected pixels via Gaussian Fit

- **CWL and FWHM Estimate for all pixels via Inter/Extrapolation**

- **VNIR CWL and FWHM binning for standard binning pattern**

- **L_{computed} = \int L_{sphere} \times T_{ND \, Filters} \times SRF_{APEX \, pixel} \times dL**

- **Provided uncertainty by DLR:**
  - Wvl accuracy
  - Wvl repeatability

- **APEX system noise**
1st Uncertainty Budget (2014): Traceability Chain

\[ L_{\text{computed}} = \int L_{\text{sphere}} \times T_{\text{ND Filters}} \times SRF_{\text{APEX pixel}} \times dL \]

- APEX system noise
- {Temperature & Pressure effects on DN due to dichroic coating and spectral shifts}

Uncertainty of gain and offset incl. covariance.
Biggest uncertainty contributor is the sphere-filter inter-reflection!
Uncertainty estimate established for absolute calibration using small integrating sphere with neutral density filters.
2nd Uncertainty Budget (2016): Extended Traceability Chain

- APEX system noise
- Pressure: spectral shift estimation and correction by model
- Temperature: DN change and correction by model
- Smear
- Binning as part of smear
- DC Anomaly compensation (SWIR)

\[ L_{\text{APEX}} = \int L_{\text{sphere}} \cdot SRF_{\text{APEX}} \]
Spectral uncertainty mainly driven by system stability and repeatability.
Monte Carlo based Realisations of DNs for varying PSU (Power supply unit) temperatures using a Neural Network model.
Monte Carlo based Realisations of DNs for varying optical base plate temperatures using a Neural Network model: suboptimal training data! Extrapolation for flight temperatures quite uncertain: uncertainties of same magnitude as correction.
Uncertainty of model per band and temperature.
Prediction of anomaly works well for the laboratory case.
VNIR Smear Model Uncertainty

Validation of smearing model by laboratory measurements (Integration time linearity based).

Uncertainty of the desmearing is estimated to be 1%.
Conclusions

Current Sensor Model and Uncertainty

Sensor model complete all biases compensated and measurements fully traceable
DIC Effects in calibrated Radiance Data
APEX Data Acquisition to Product Chain
Iterative L1 Processing

APEX Flight

Segregate Raw Data & Bit Masking

IFC Data

IFC Housekeeping

DC Data

DC Housekeeping

Level 0 Image Data

Image Housekeeping

Calibration Parameters Cube

Level 1 Calibrated Image Cube Intermediate

Level 1 Calibrated Image Cube Final

L1 Data Calibration

DIC Corrected Shift Corrected

Spectral Shift

ATCOR Smile Retrieval
VNIR DIC Effect
Effect appears driven by maximum radiance spectrum per subdetector. Hence, low radiance signals are biased more heavily.
The Calibration Home Base @ DLR Oberpfaffenhofen*

* Developed under ESA-EOP Contract;
Status: Acceptance review successful in Jan. 2007
Optical Bench
Imaged Areas in CH
Example: Large Scale Mapping

Swiss National Park, 13 flight lines, 95 GB data, plant functional traits mapping, multiple continuous fields