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Hyperspectral Instrument Calibration

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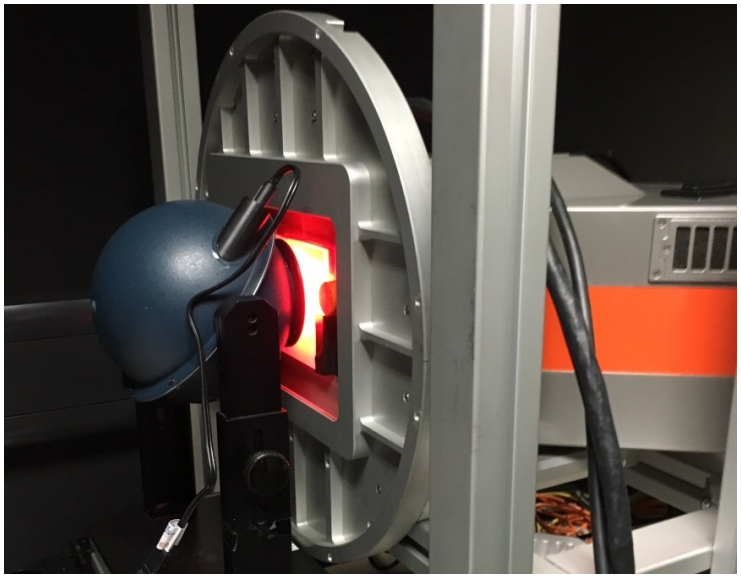
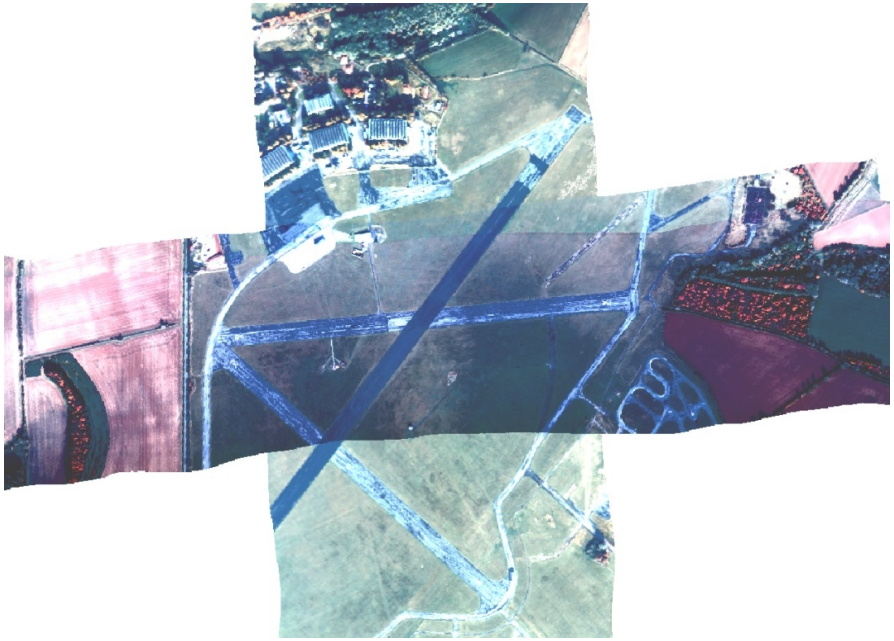
13th March 2018





NERC SCIENCE OF THE ENVIRONMENT Airborne Research Facility

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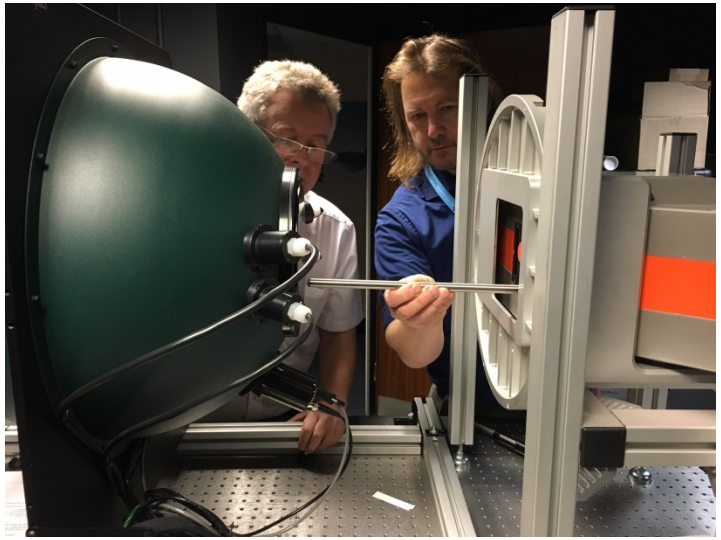

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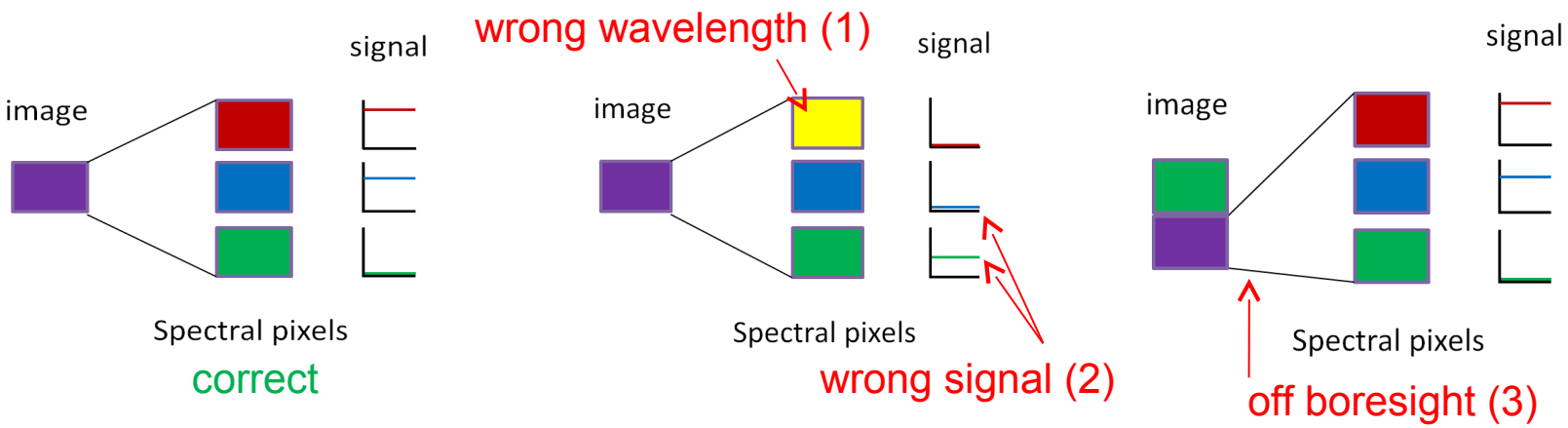
What is calibration?

"The act of checking or adjusting (by comparison with a standard) the accuracy of a measuring instrument" *-- The Free Dictionary*



In context of hyperspectral instruments, three things need calibrating:

1. Spectral (wavelength) calibration (what wavelength of light is each pixel measuring?)
2. Radiometric calibration (what radiance intensity entering the sensor gives a given recorded signal level?)
3. Boresight calibration (which direction is the sensor pointing in relative to the ideal "straight down"?)

Importance of Calibration

-Essential for remote sensing instruments to perform quantitative analyses
-Vital importance to ensure accuracy, stability and repeatability
-NERC-ARF Performs calibration at least annually (detect changes in performance or early degradation)
-Provides a better expertise of sensors performance and limitations
-Better transparency of the data provided to PIs
-Better troubleshooting solutions
-Problems found during calibration (in many cases) can be compensated during processing procedure

Bench Hyperspectral calibration includes:

-Wavelength Accuracy Calibration: Accuracy of each band wavelength
-Radiometric Calibration: Radiance intensity
-Bad Pixel Mapping: Identify pixels and wavelengths that are incorrect

Importance of Calibration (2)

Bad calibration = bad data!

Or worse, bad data *that you don't notice*

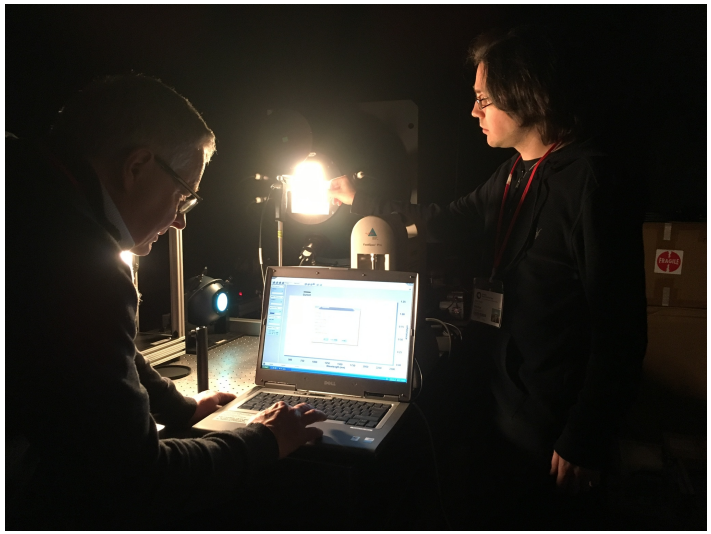
And data that you can't use with any other sensor

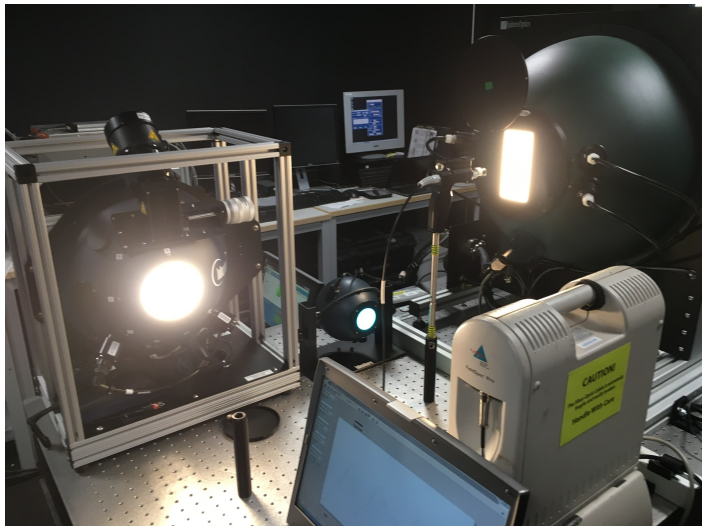
Photo: NCAVEO 2006, courtesy STFC Chilbolton. Multi-sensor cross-calibration, wrong calibrations would have caused problems!

Calibration Facilities and Equipment

Calibration lab currently at Cambridge:

- Established with NERC FSF
- Integrating spheres
- Spectral lamps
- Calibration jigs
- Double Monochromator
- Blackbody (for Owl)



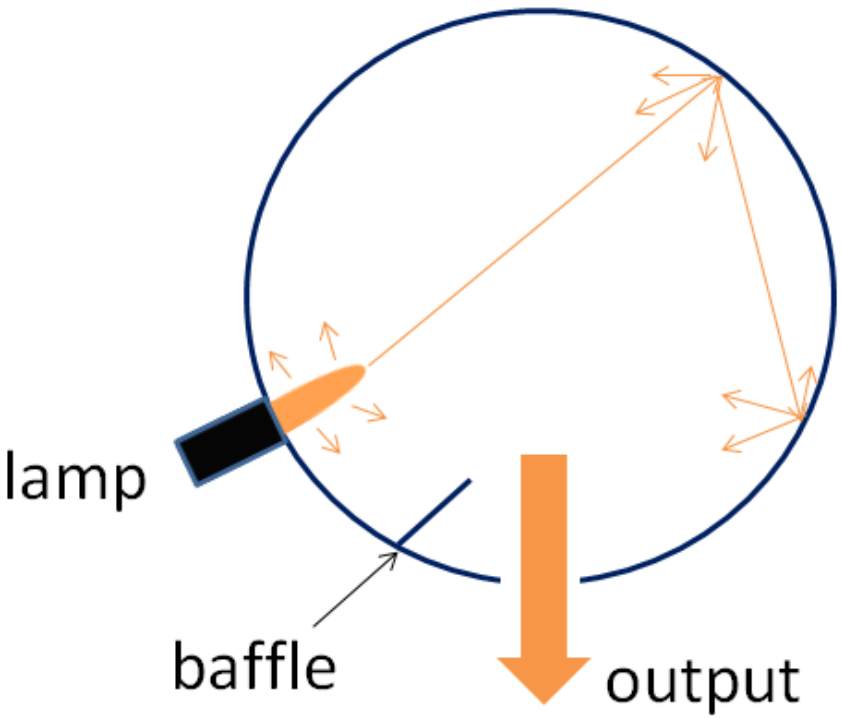


- First in-house calibration in 2008
- First “successful” calibration in 2010
- Have been using calibration files from these since end of 2011
- Boresight flying over a site with straight lines e.g. runway at Little Rissington

Integrating Sphere

An Integrating Sphere is designed to produce a light field that is as uniform as possible at the output port.

Means that the light intensity and spectrum should not change across the field of view of the instrument

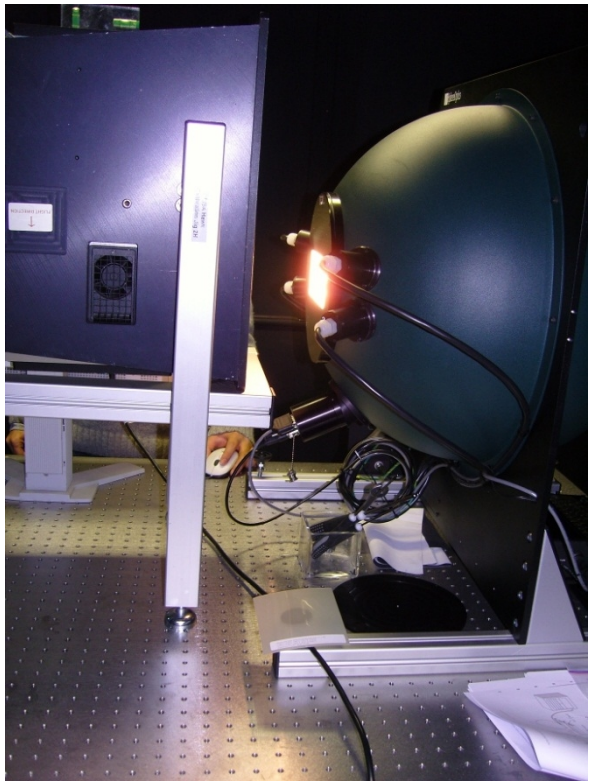


Integrating sphere (2)

NERC-ARF commissioned NERC FSF to manufacture and maintain our integrating spheres

- Calibrated by NPL every two years
- Coated with $BaSO_4$

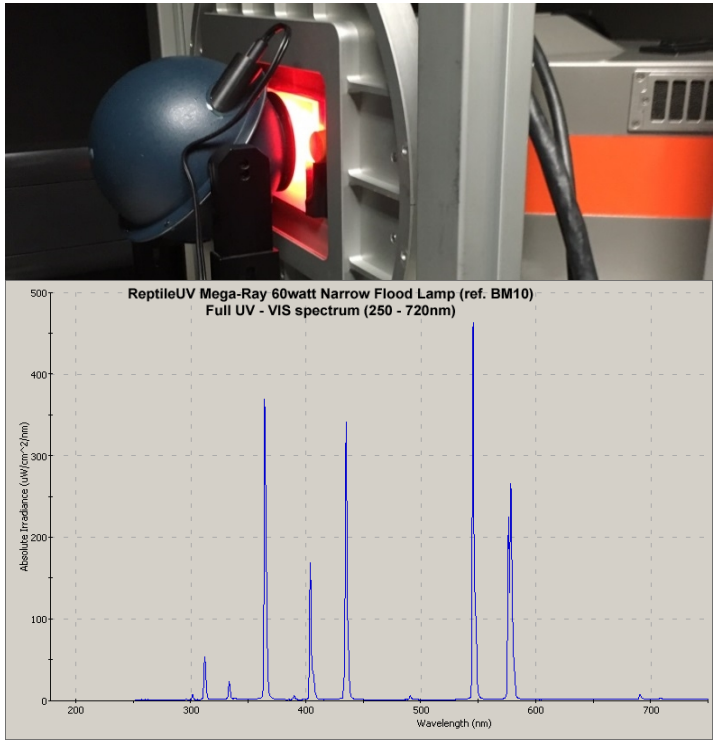
- Output port is rectangular to match FOV
- Lamps close to sphere equator to improve uniformity



Spectral lamps

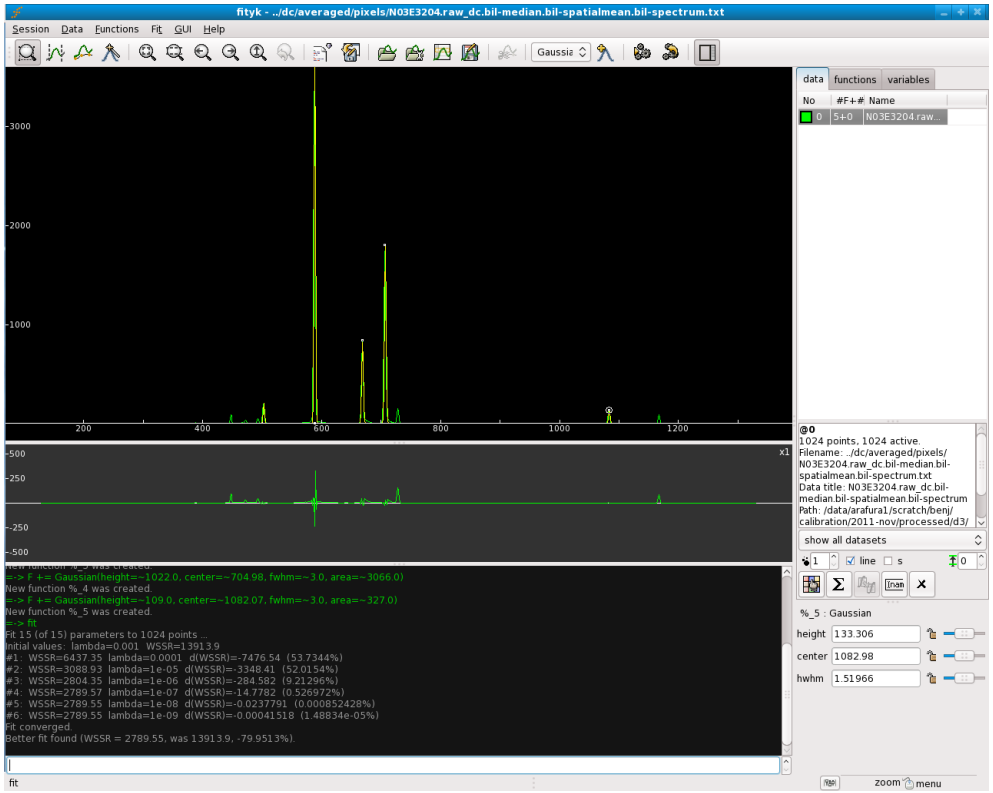
We use a small integrating sphere (to fill the sensor FOV) with pencil lamps containing particular elements, e.g. Hg-Ar, Kr, Ne, Xe, Ar, O, He, H

- These give very thin peaks at particular known wavelengths
- If we see a peak, we know we're looking at that particular wavelength

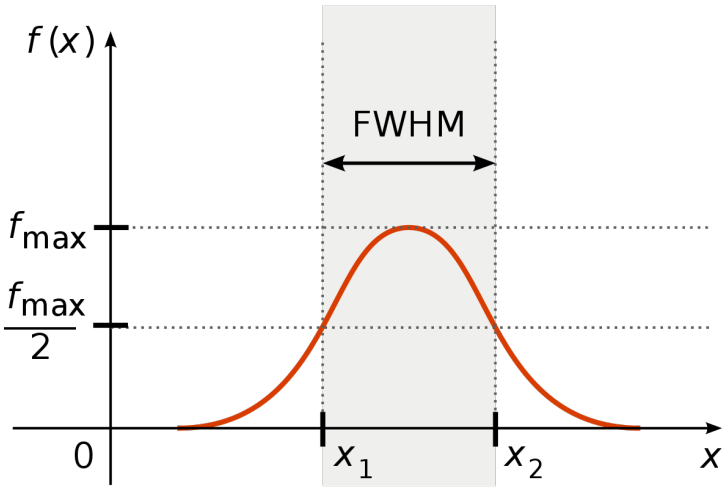


Wavelength Calibration Procedure

1) Image each spectral lamp
2) Identify peaks of spectral emissions in data using the curve fitting software “fityk”
3) Compare identified peaks to known emission lines
4) Shift wavelength scale to produce best fit

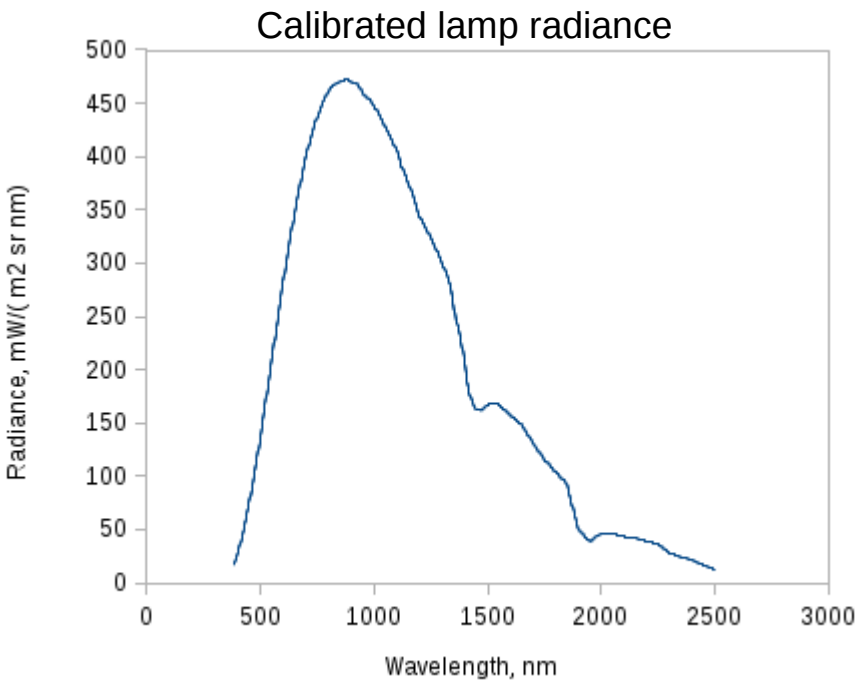


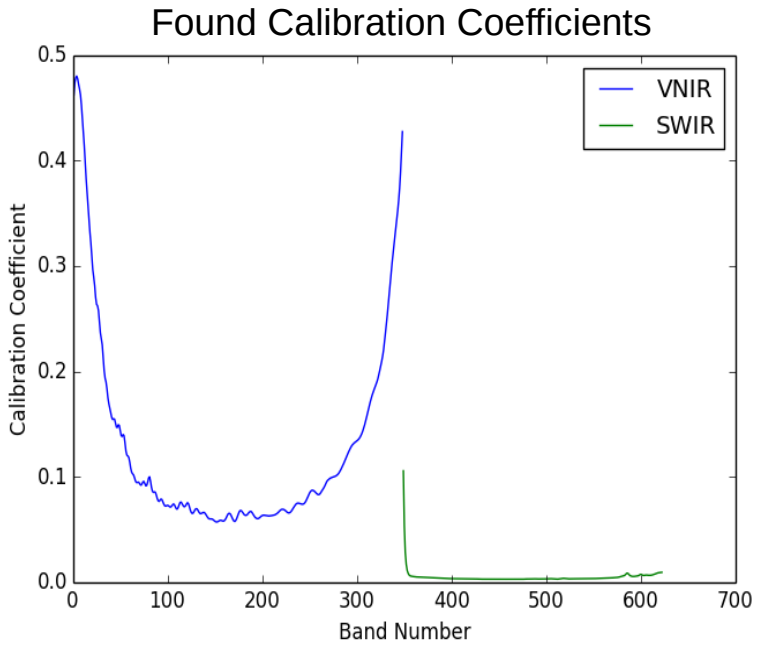
- Procedure provides an indicative value of the FWHM for those bands.



Radiometric Calibration

1) Light source of known radiance at each Fenix wavelength
2) Integrating sphere
3) For each pixel in the Fenix FOV, produce a radiometric curve
4) Compare measurements and obtain calibration coefficients



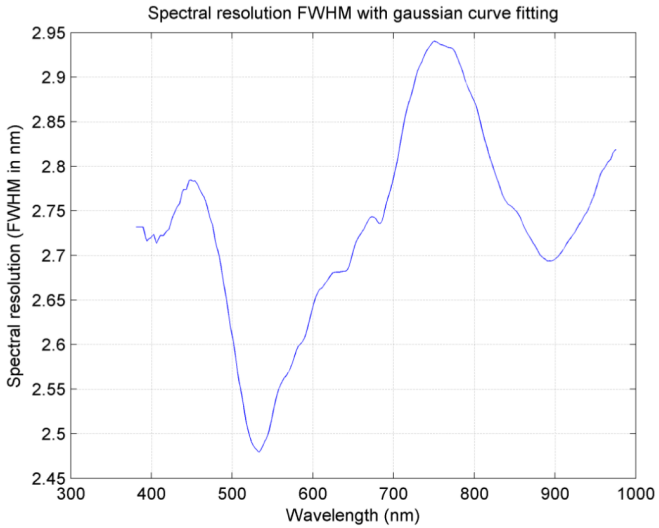


Additional tests: FWHM

-FWHMs allows to provide sensor spectral response, needed for derived products such as atmospheric correction.

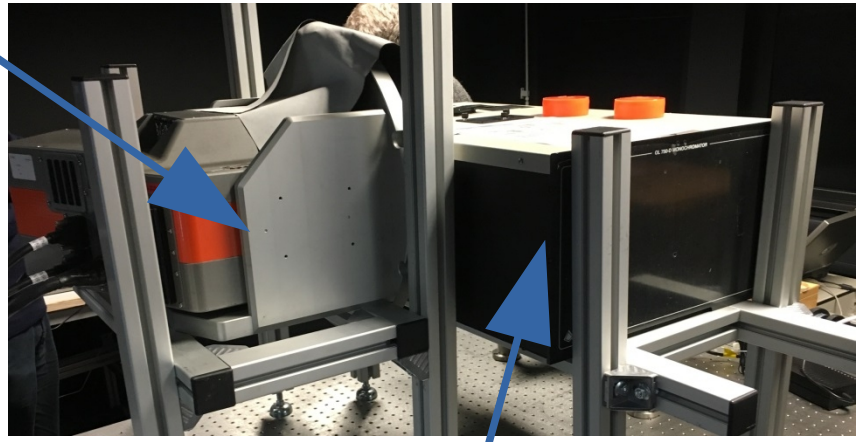
-Specim provided FWHMs measurements in 2016 using a monochromator.

-A double monochromator is recently available to examine the Fenix FWHMs and provide an independent characterisation.

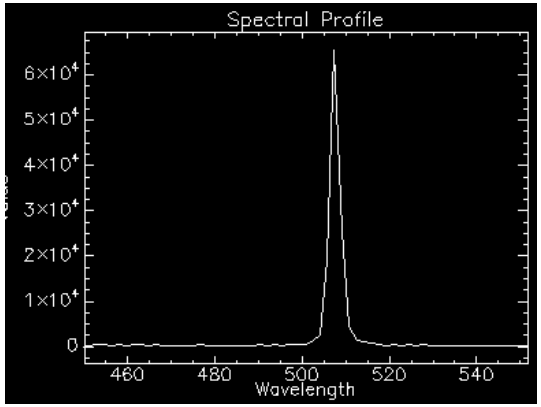


Specim's FWHMs for Fenix

Fenix Hyperspectral Sensor



Double Monochromator

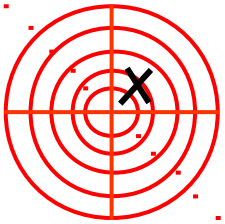


Spectra recorded on Fenix using the monochromator

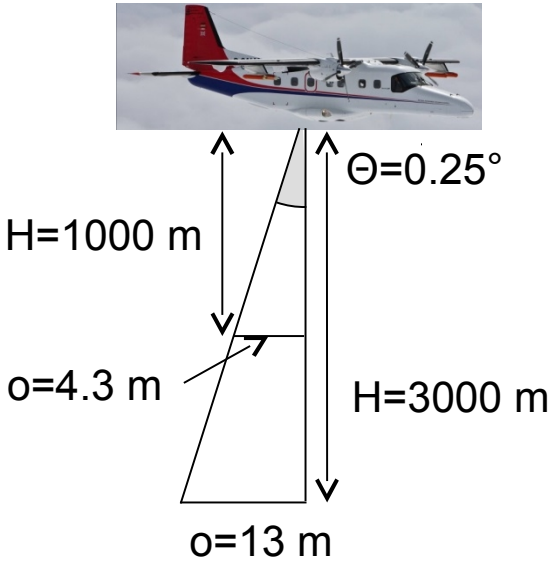
Boresight calibration

"Boresight" is actually a gunnery term

- Refers to the angle of offset between a gun's sight and its bore
- In our case, angle of offset between where we tried to aim the sensor and where we actually did aim it



Typically a few tenths of a degree



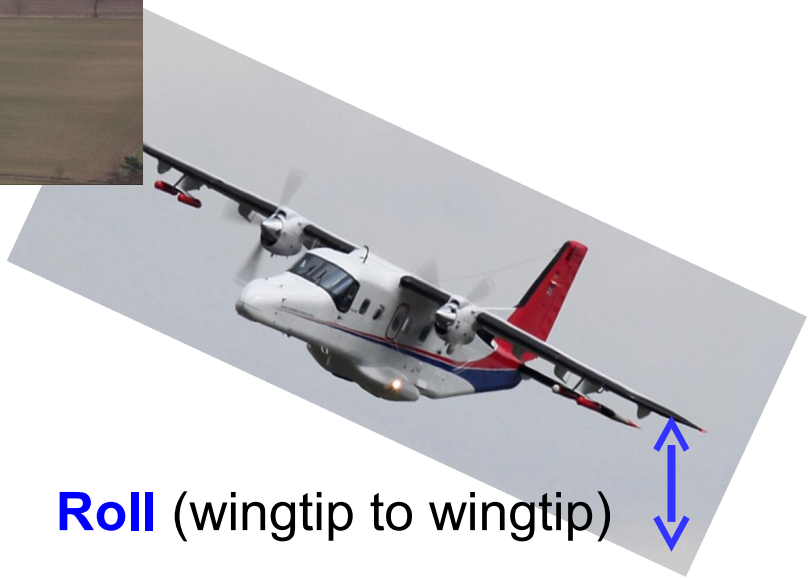
- Fenix pixel size at 1000 m is 1.45 m, so a 4.3 m offset is multiple pixels
- For two flightlines in opposite directions at 2300 m, not correcting for boresight misalignment might mean they disagree on the position of something by 20m or more!

The Three Degrees Of Freedom

GPS and IMU give plane position and orientation, just need sensor orientation relative to plane

Yaw (nose pointing)

Pitch (nose respect to tail)



Roll (wingtip to wingtip)

- Pitch and Roll are relatively easy to correct
- Yaw (heading) is a bit more complicate
- Intrinsically related: nothing comes easy

Boresight Procedure

A semi-automated recursive procedure involving trial and error:

1 – Adjust pitch until reached acceptance tolerance (overlapping parallel lines, opposite directions)

2 – Then adjust roll.

3 – That will likely mean that pitch needs some further correction, repeat step 1 and 2 until errors are within acceptance tolerance for both pitch and roll.

4 – Adjust heading (especially visible in the edges of parallel lines with ~50% overlap).

5 – Heading correction will introduce an error in pitch and roll corrections, go back to step 1 and repeat procedure. With each interaction the error to correct will be smaller until corrected values are found.

Method involves heavy workload of visual inspection and manual interaction. If you are very lucky and experienced, this processing can be done in a couple of working days.

Automated methods exist but… → Still developing!

The Data Quality Report

Data Quality Report - 2016

Hyperspectral

ARSF - Data Analysis Node

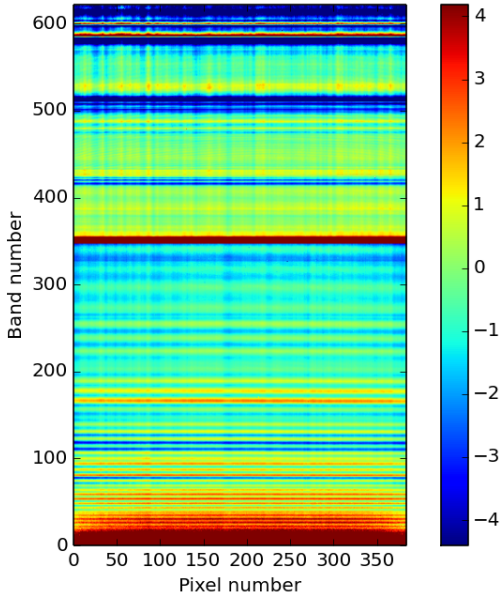
Updated on: February 22, 2016

Couple of metres ~ 1 pixel

Contents

Spectral Line (nm)	Measured Wavelength (nm)	FWHM (nm)	Error (nm)	Pass/Fail (<2nm Err.)
404.7	405.10	4.32	-0.40	Pass
435.8	436.19	2.79	-0.39	Pass
486.1	486.45	2.96	-0.35	Pass
849.5	849.82	2.81	-0.32	Pass
878.2	877.97	3.03	0.23	Pass
892.9	893.16	2.97	-0.26	Pass
	Mean	**3.44**	**-0.29**	

Table 1: *VNIR Wavelength calibration offsets for the February 2016 calibration of the Fenix.*



Fenix Hyperspectral Sensor Through Time

Data Quality Report - 2015

Hyperspectral

ARSF - Data Analysis Node

Updated on: October 16, 2015

Contents

Data Quality Report - 2016

Hyperspectral

ARSF - Data Analysis Node

Updated on: February 22, 2016

Contents

With each calibration, a new quality report is tailored

-December 2013 → February 2014: Sensor radiometrically stable over the period with an average change of ~0.15%.
-February 2014 → February 2015: Change of ~3.24% (*)
-February 2015 → February 2016: Change of ~0.42%

(*) The unexpected shift is believed to have occurred ~15th October 2014; a movement of ~8 nm in the SWIR bands leading to an overlap with the VNIR bands.

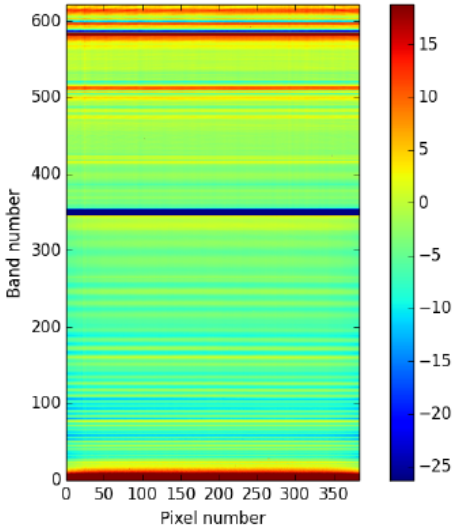
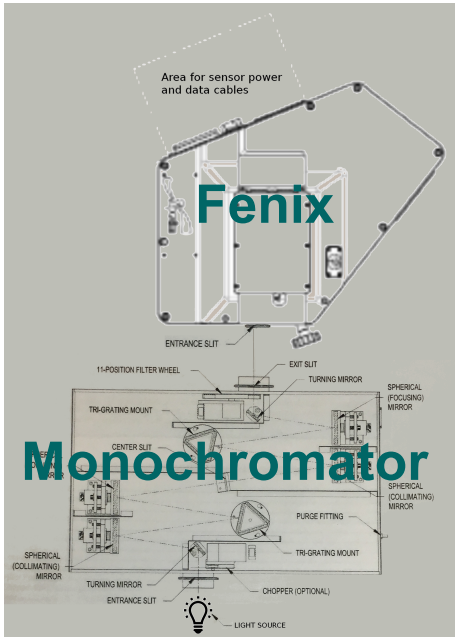


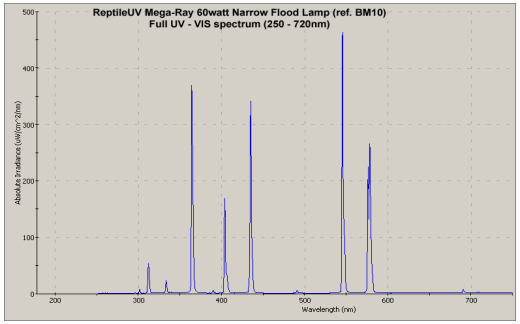
Figure: *Fenix calibration multiplier percentage differences between February 2014 and February 2015 calibrations. The overlapping region between the VNIR and SWIR detectors is clearly visible around band number 349.*

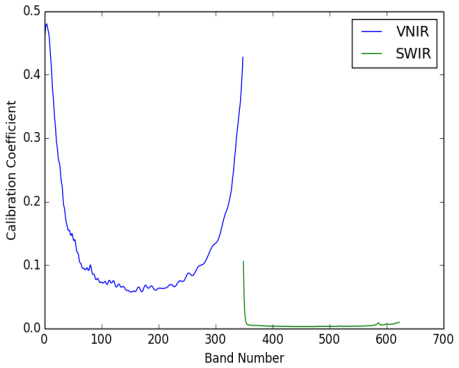
Outstanding issues & future improvements

- Analysis of double monochromator data to determine FWHMs
- Increase the number of SWIR spectral emission lines used as anchors
- Use in-flight integration spheres to check data
- Provide more sensor characterization data to PIs, such as spectral response...



…Any other requests?





Summary & Recap

Calibration must be conducted to ensure that collected data is correct, but can also provide greater understanding of a sensor

Characterising the sensor also highlights limitations and potential problems with the data that can be compensated for or, at least, identified and explained

Procedures are well established and have been discussed and accepted by Specim (manufacturer) and the NERC Field Spectroscopy Facility

Each pixel must be calibrated for:

- Wavelength - using spectral lamps with known emission lines
- Intensity - using a light source with radiance known at each wavelength
- Boresight - trial and error with roll, pitch and yaw offsets

@NERC_ARF_DAN

Thank you