IDEAS+
Calibration and Data Quality Toolbox
WP 3520

December 2015

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EOSense

Introduction

- **Instruments**
  - MERIS
  - ATSR Series
  - Landsat 8

- **Methods**
  - Based on heterogeneous images alone (in some cases large data quantities)
  - Parameters to monitor
    - Absolute Calibration drift
    - Relative (detector to detector) calibration drift
    - SNR (Signal to Noise Ratio)
    - Instrument focus and MTF
    - Spectral calibration and spectral features

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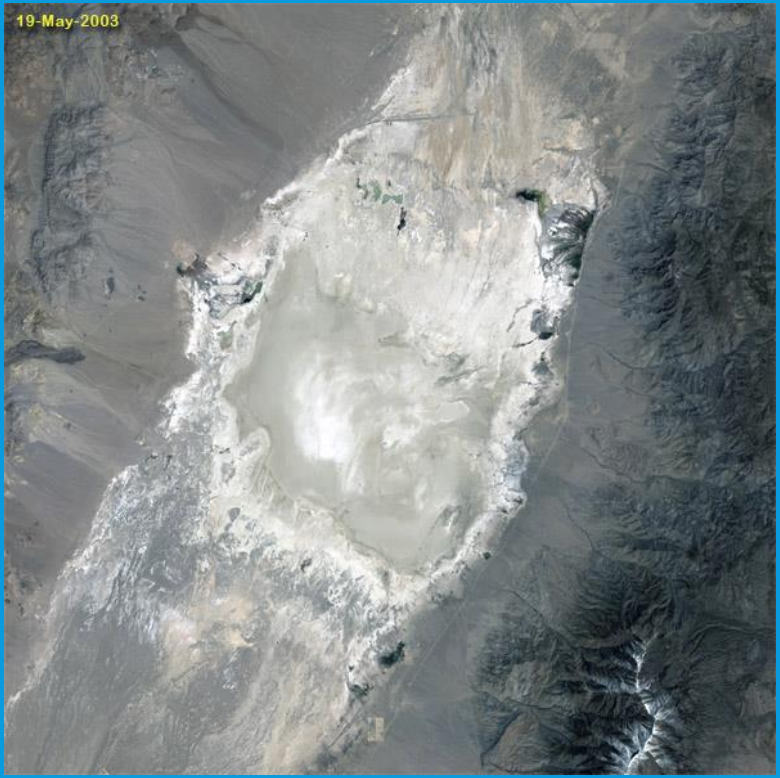
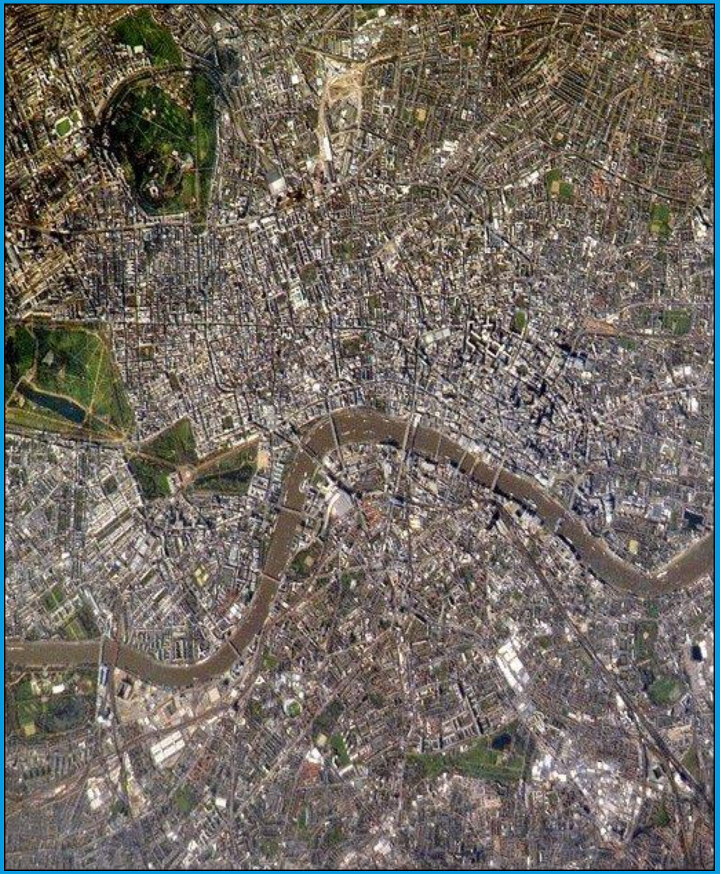
Which image is more useful for calibration and data quality assessment?



Railroad Valley, Nevada



London, UK

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Every image has more or less the same information…

- Signal to Noise Ratio (SNR)
- Relative Calibration
  - Detector non-uniformity
  - Vignetting effects
- Spatial Resolution (Modulation Transfer Function – MTF)
- Relationship between raw signal level and incoming radiant energy
- Instrumental or processing artefacts

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Is it feasible to find all these things in heterogeneous images?

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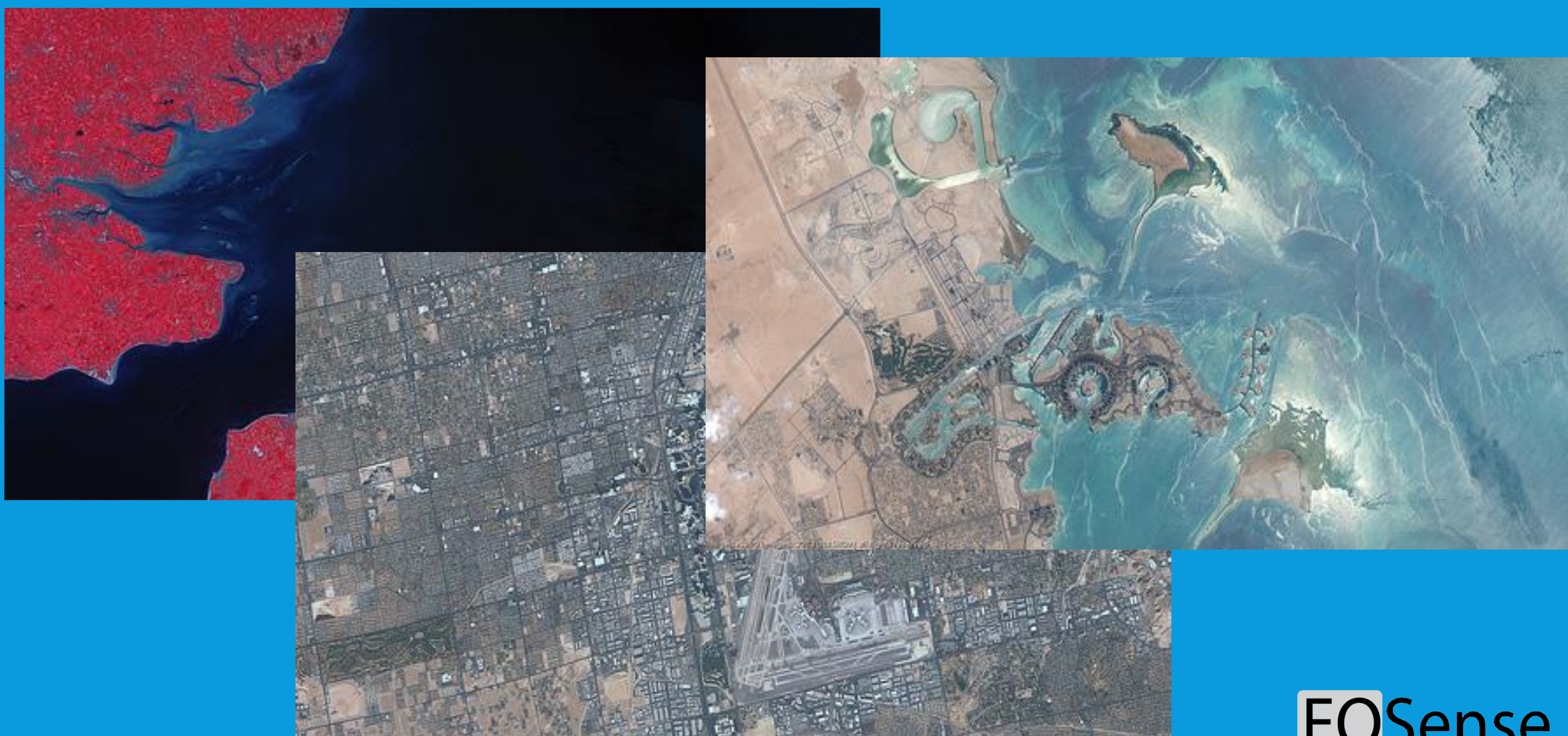
What do I mean by heterogeneous images ?

- Normally collected images of any target type.



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Decided to develop methods based on data alone – "Data Driven" methods

- Idea is that all these features, striping, banding and calibration drift are present in all images.
- Once we have this basic assumption, then we can use all images, including heterogeneous images to isolate, understand and remove or compensate for them.

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Signal to Noise Ratio (SNR)

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Signal to Noise Ratio (SNR)

- Not a new idea, deriving SNR from normal Images – (JACIE 2012) Automated Measurement of SNR of High Resolution Satellite Images (Satrec Initiative).
- However, our approach requires no pre-processing (for example selection of the most homogeneous parts of the image), images with cloud are acceptable. So no pre-selection of images
- Tested using modelling, it is now operational and has provided useful insights for correction of observed SNR issues. Currently writing a paper on its operation to be published in 2016, developing suitable mathematical model to try and assess the uncertainty in the estimation.

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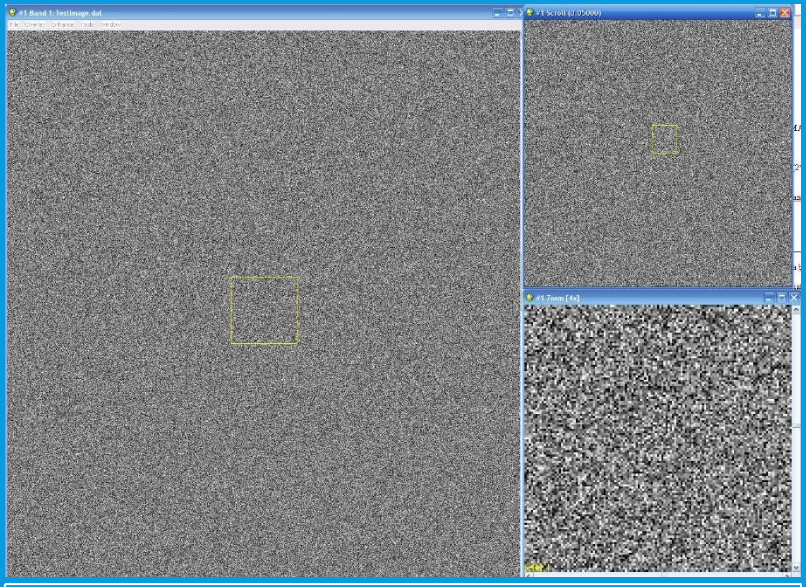
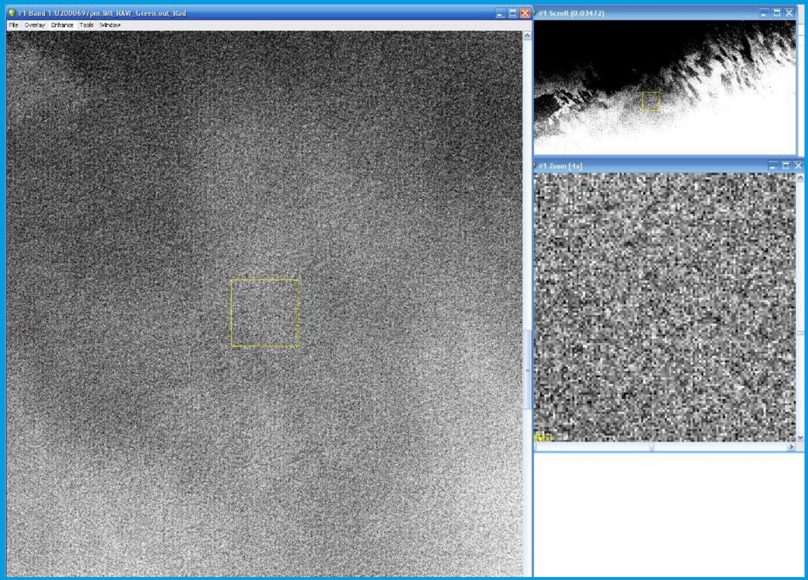
SNR Modelling and Measurement

1 – Create an artificial snow scene and use a real snow scene (Dome-C)



Mean 100, standard deviation 0.6395



Mean 175, standard deviation 0.67

Standard deviation known as input to simulation (left) or manually measured (right)

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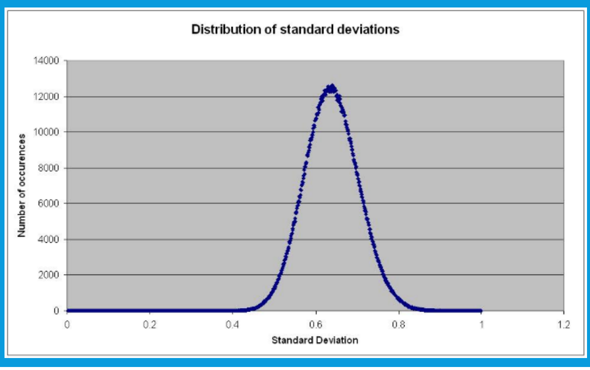
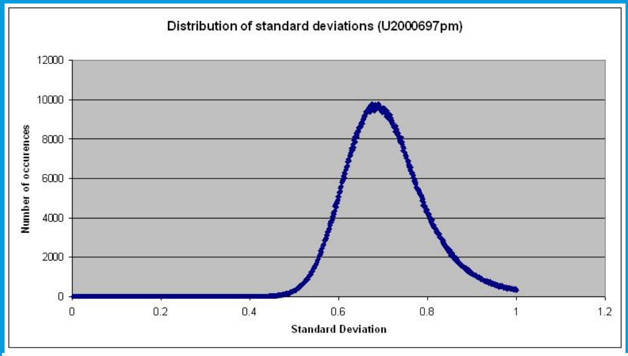
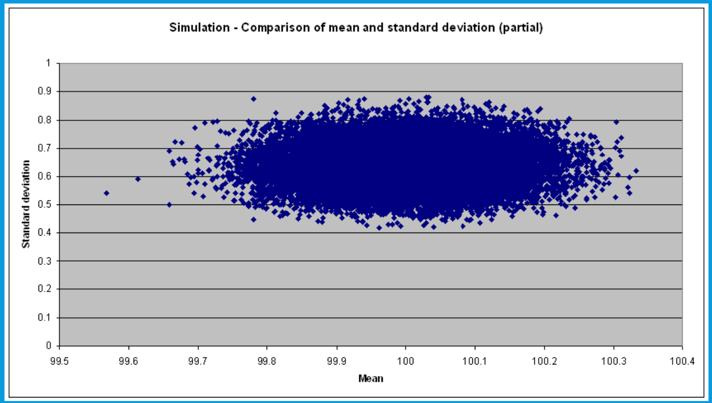
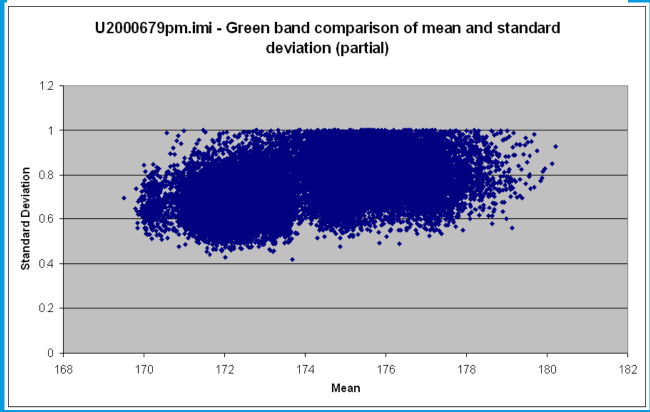
SNR Modelling and Measurement

2 – Look at statistics









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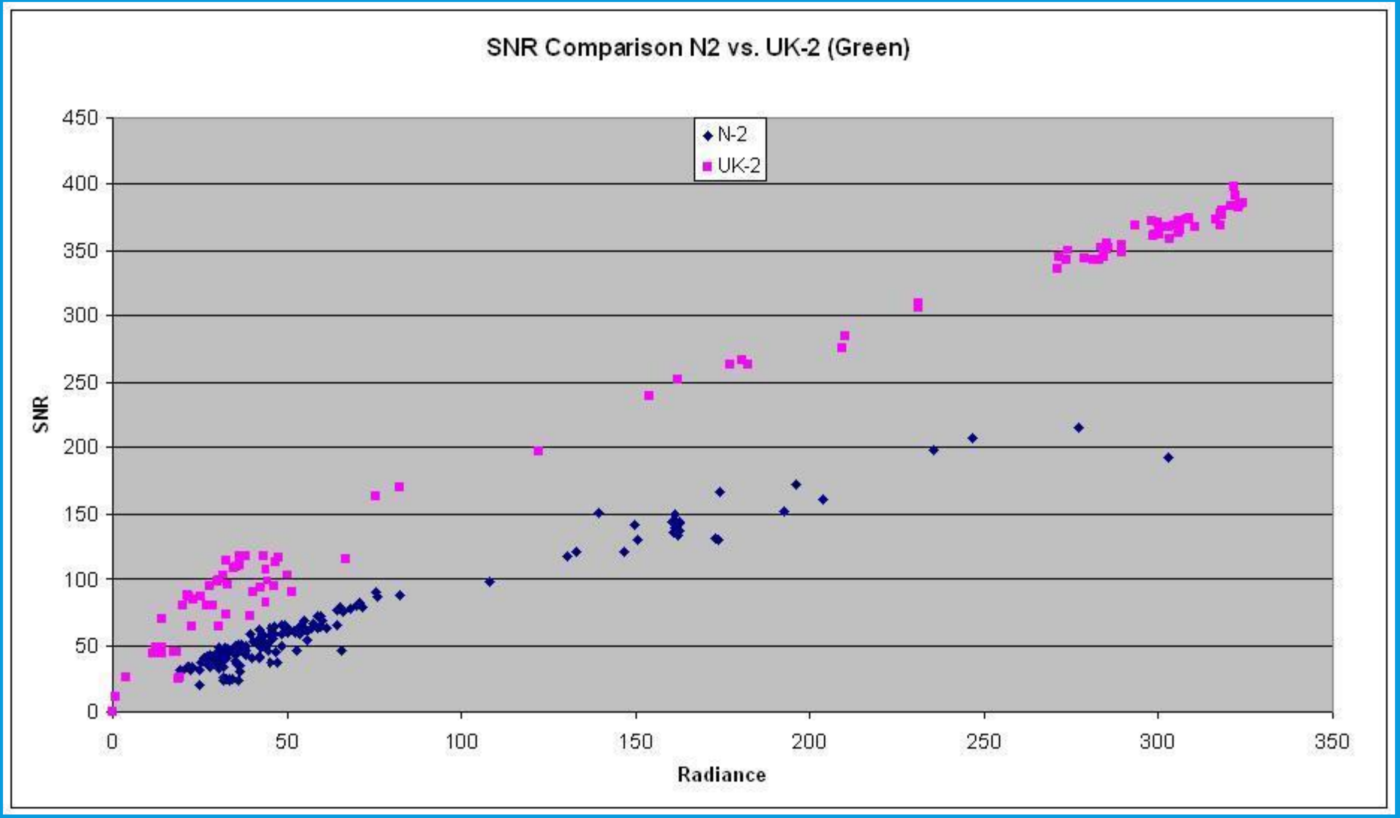
SNR Modelling and Measurement

3 – Test on real data and validate

As system responsivity drops we can see changes in SNR



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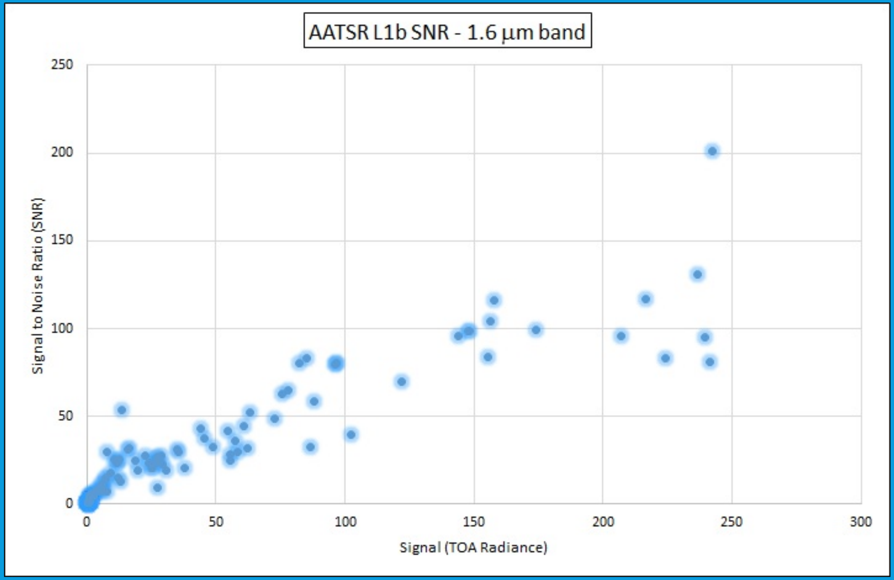
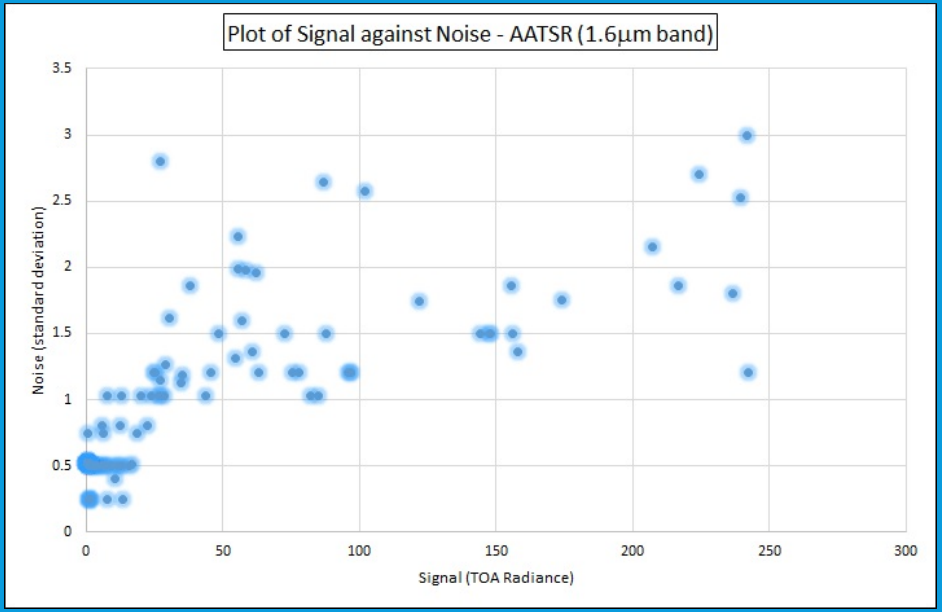
AATSR – SNR, it doesn’t always work well…!!!

The plot for AATSR SNR (below) is more “ragged”, but from only four orbits data and shows some effects of signal quantisation.





The plot above is of the signal against noise, note the clustering of values at specific noise intervals (0.25, 0.5, 0.75)

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Future plans for SNR

- Exploring modelling individual detectors
- This would provide lifetime stats and also information for estimating pixel level uncertainties in imagery as required by QA4EO (http://www.qa4eo.org/)
- So end users with imagery wanting to use them in applications, don't just get a "MODIS has an overall uncertainty of better than 2%", but has a knowledge of the uncertainties including that at the pixel level due to system noise.
- This feeds directly into higher level product uncertainties or in combining uncertainties from time series evaluation or combining data from multiple sources.

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Relative Calibration

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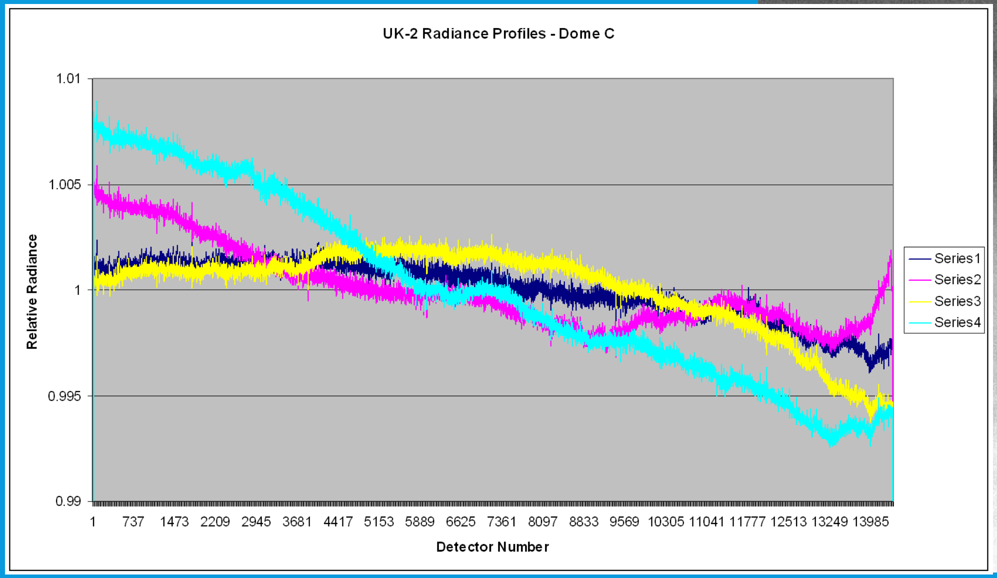
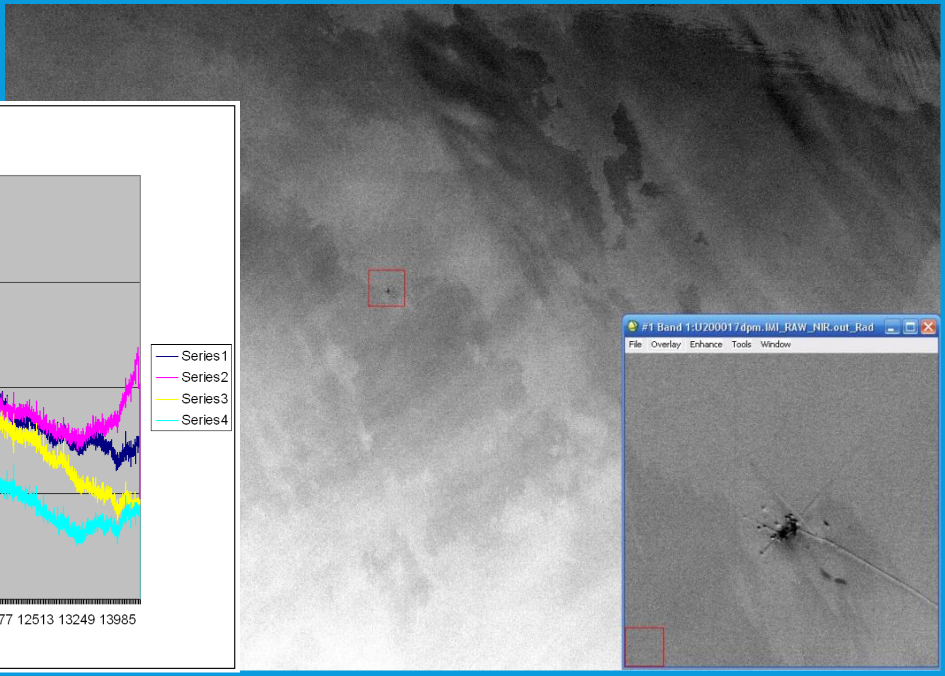
Relative Calibration using “flat-fields”

- Multiple white images over Antarctica or Greenland to derive relative gain terms, yawing the spacecraft, removing scenes with clouds or hoar frost effects.





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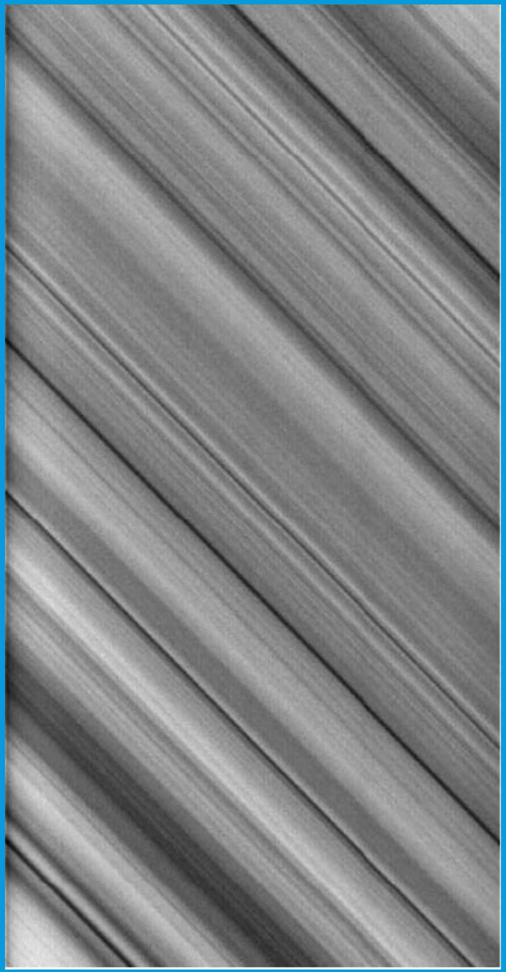
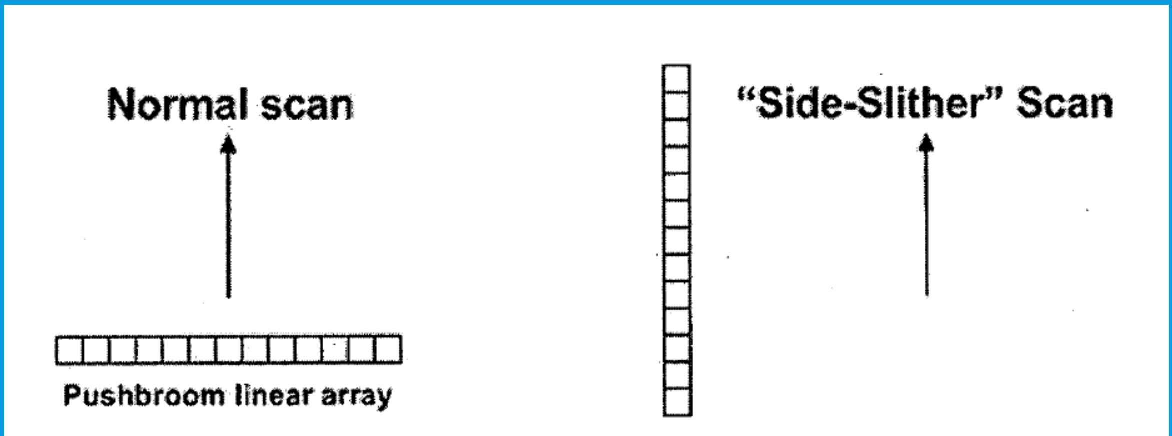
Relative Calibration using "Side Slither"





PROBLEMS :
Landsat 8 has a 15 degree FOV and the CCD relative azimuth to the sun will vary depending on acquisition. Many surfaces will show BRDF effects.

The Landsat 8 FPA has staggered arrays with around 1.5 degrees difference. This means you are looking at two targets and inducing a small BRDF difference.

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Relative Calibration using the on-board diffuser

Sentinel 2 Diffuser

As long as the diffuser does not vary spatially it should work.

The sensitivity to changes in the BRDF of the diffuser with time may be difficult to detect

Time between observations may be an issue

Possible point of failure

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Relative Calibration Curve – Heterogeneous images

- Again not a new idea (Relative Gain Characterization and Correction for Pushbroom Sensors Based on Lifetime Image Statistics (SDSU) – JACIE 2010)
- Currently we use 50 to 100 images. Ultimate aim is to get down to a handful of images to derive the relative gain curve.

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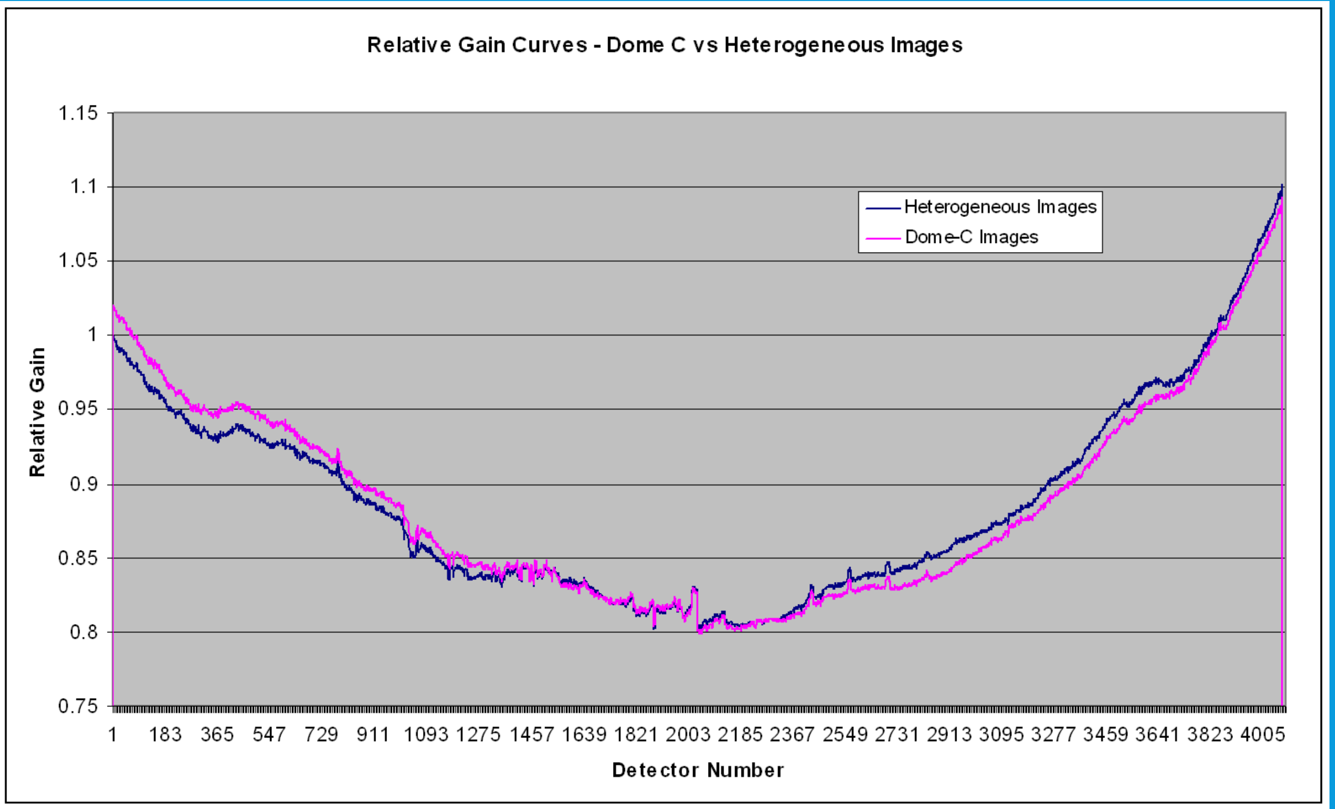
Relative Calibration Curve

- Established approach using averages of many images to create a “virtual” flat-field
- Usually 50+ images are used.



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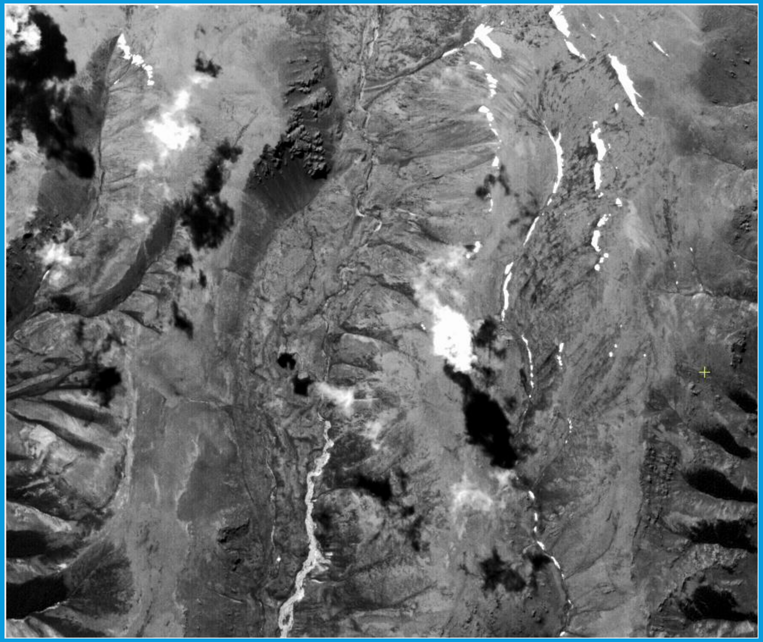
Can we get a Relative Calibration curve for every image?

- In theory…yes…!!
- Every image contains all the artefacts and deficiencies of the sensor
- We need to forget the averages and think about our data differently



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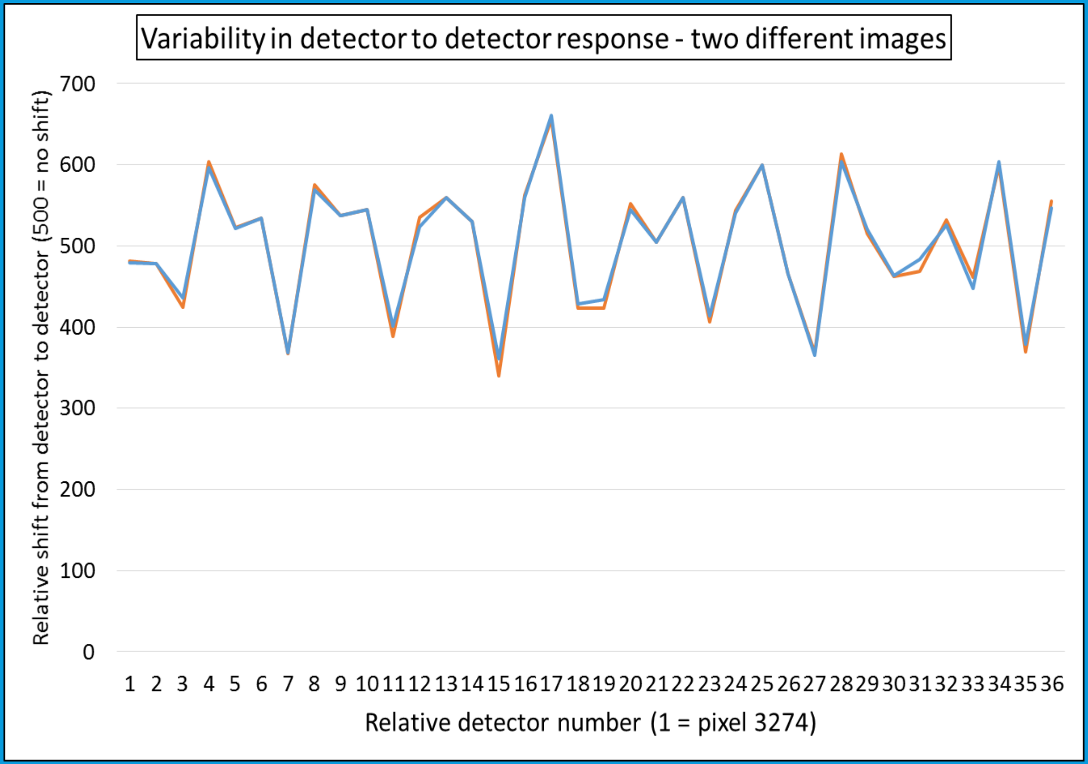
If we look at the data differently, forget averages…

- The two images on the previous slide generated the following relative detector responses (part of CCD)
- Repeatability is excellent (down at the 0.05% level in terms of variability). Need to increases the sample size as the estimate of variability was based on only 10 images.
- Content does have an effect, we need to understand it.



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Instrument focus and MTF

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Instrument focus and MTF

- Algorithm that uses any image to try and determine “best” focus


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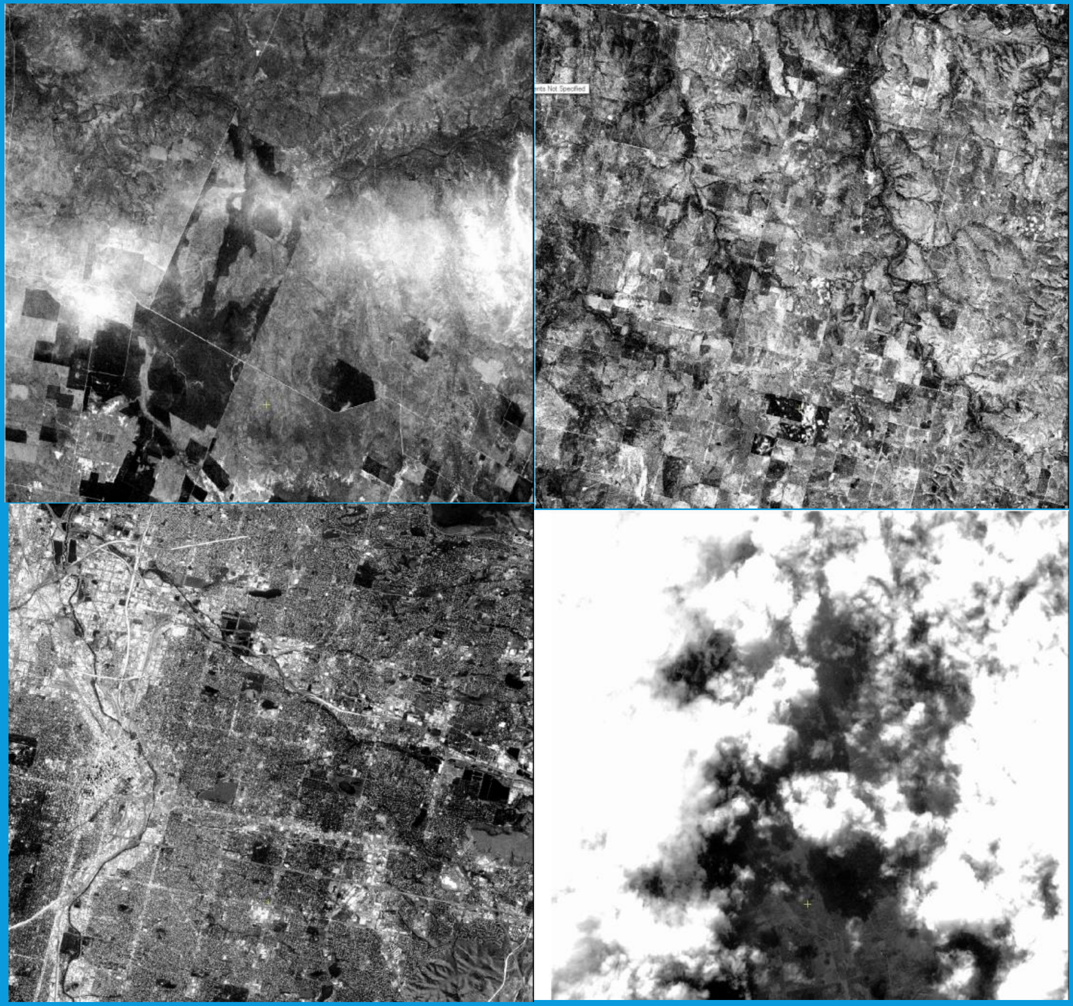
Instrument focus and MTF



These are the images we use, far more difficult.

There is no pre-selection (currently), so all these blue band images have been used in the analysis.

The bottom right image presents particular challenges, as you can imagine the atmospheric conditions do reduce the effective focus.

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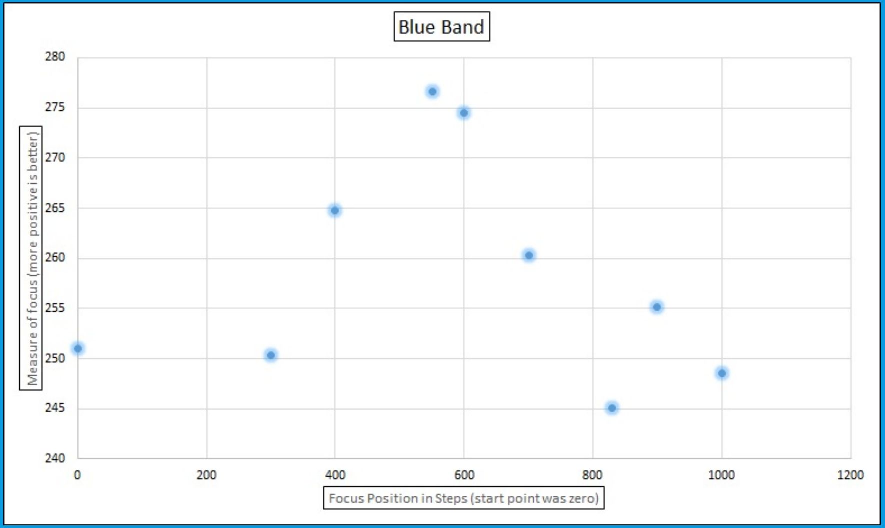
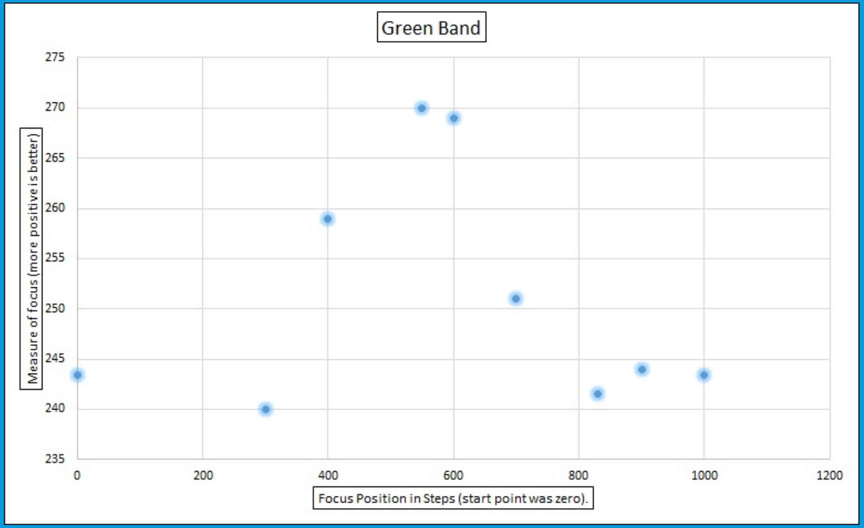
Instrument focus and MTF

- Study to determine best focus from a sequence





Uses all images. The values shown are averages of all images for a focus position.

There is scatter for any single focus position, some of which seems to be related to the path length (off-pointing) while some seems related to atmospheric condition, the algorithm can be expected to improve with further research.

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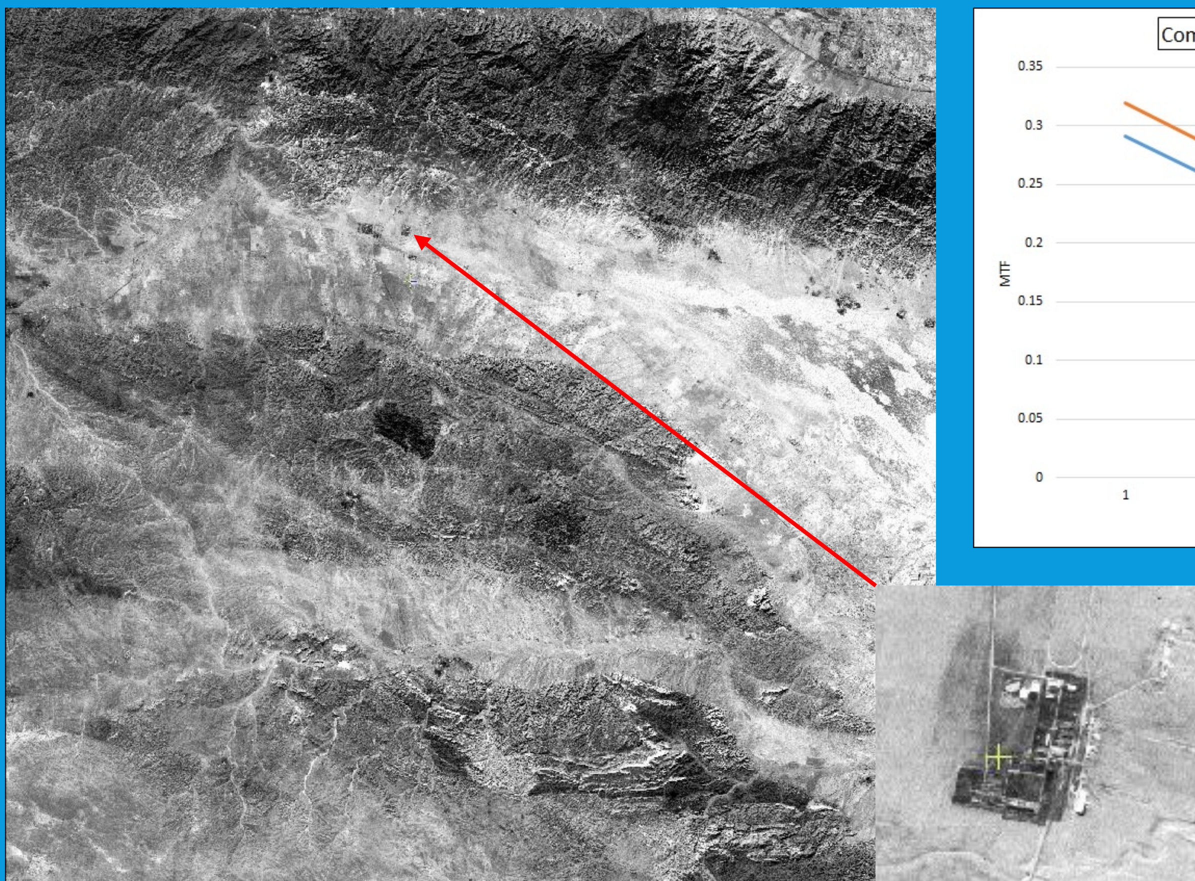
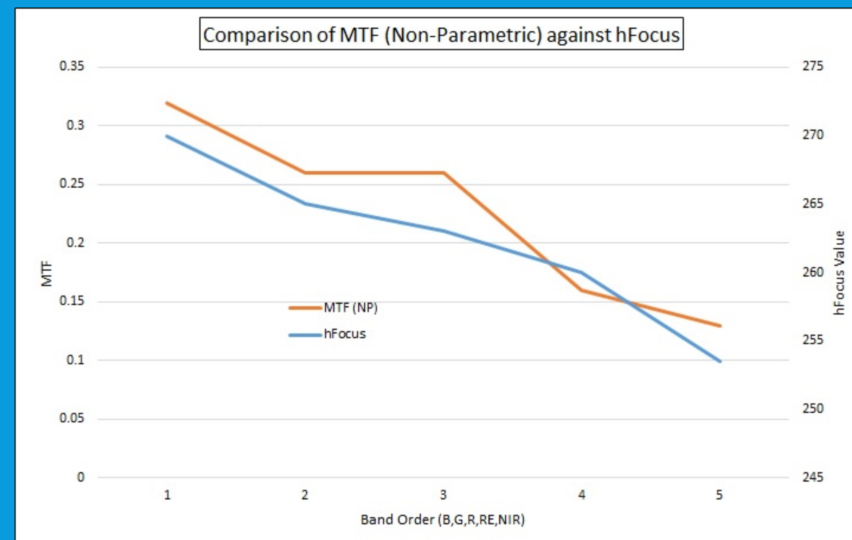
Instrument focus and MTF





Roll (11.65°)

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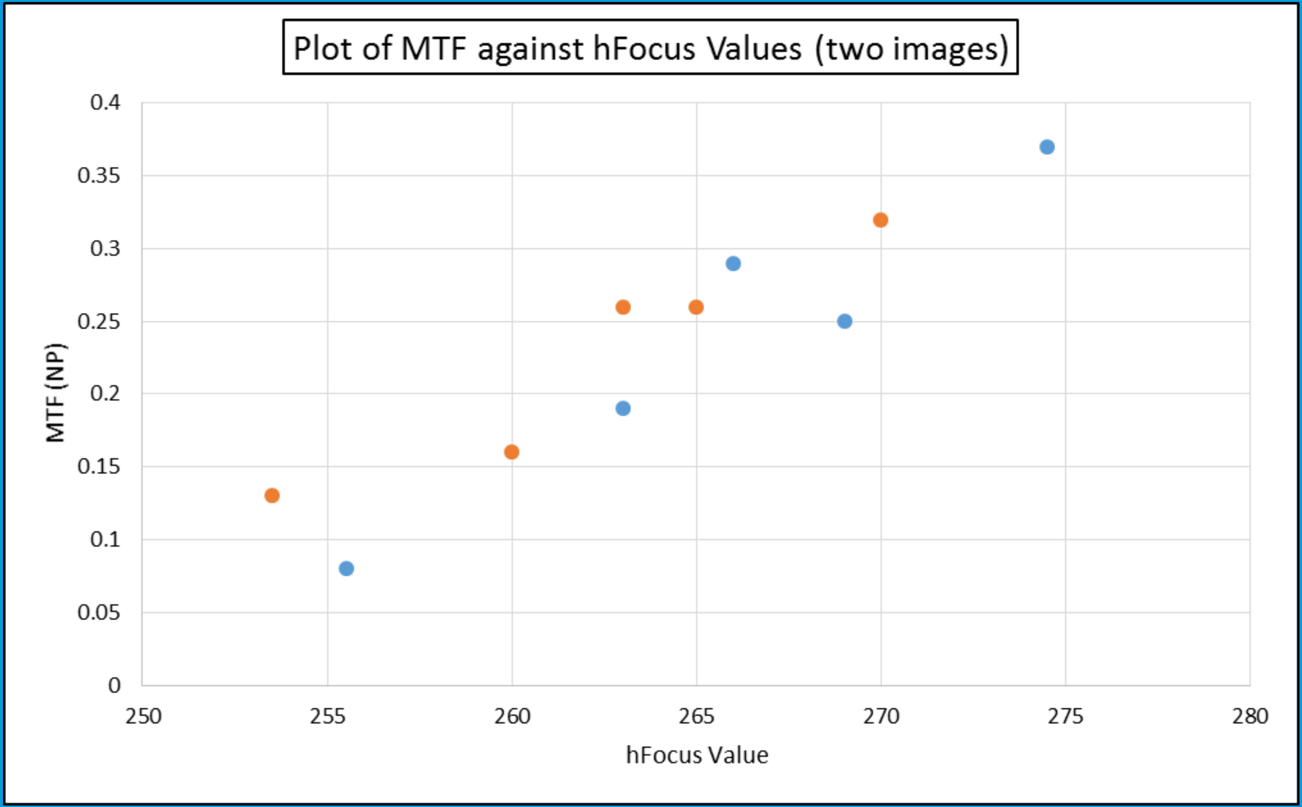
Instrument focus and MTF

- Can we convert hFocus values into an MTF equivalent ?



Knowing the correlation function between the MTF at Nyquist measurements and hFocus value from multiple MTF measurements

In theory, we can derive (assuming a linear relationship in this case) the uncertainties on the estimation.

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Absolute Calibration Drift

Absolute Calibration drift

- In 2014 EOSense received a contract to determine how acceptable were the procedures used to calibrate the reflectance channels (Bands 4 to 7) of AATSR

AATSR Spectral Bands

Band	Wavelength (µm)
Band 1 (MWIR)	3.7
Band 2 (TIR)	10.8
Band 3 (TIR)	12
Band 4 (VIS)	0.555
Band 5 (VIS)	0.659
Band 6 (NIR)	0.865
Band 7 (SWIR)	1.61

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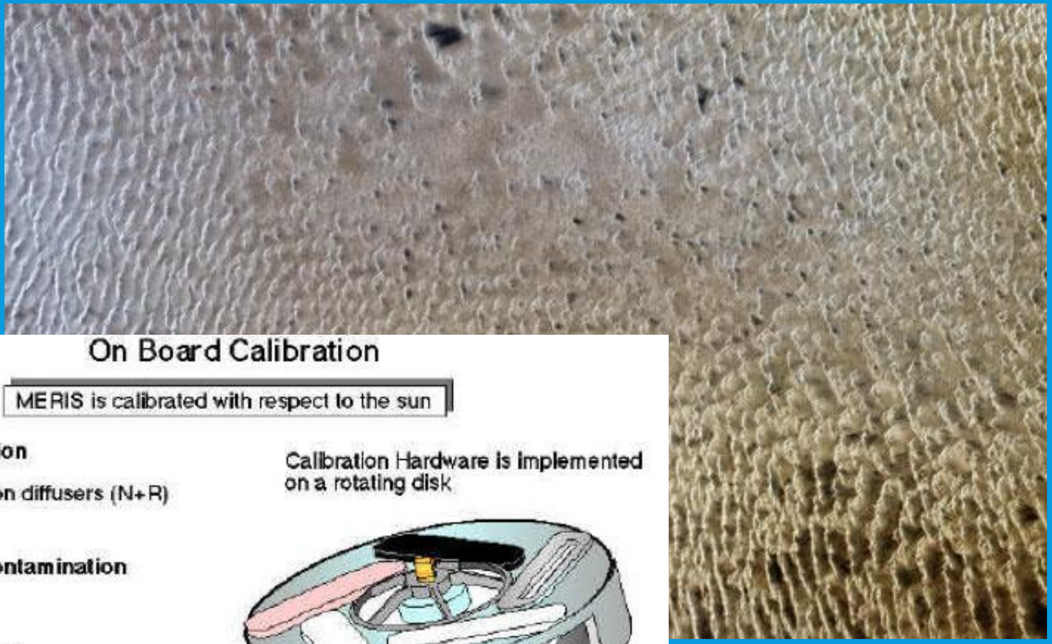
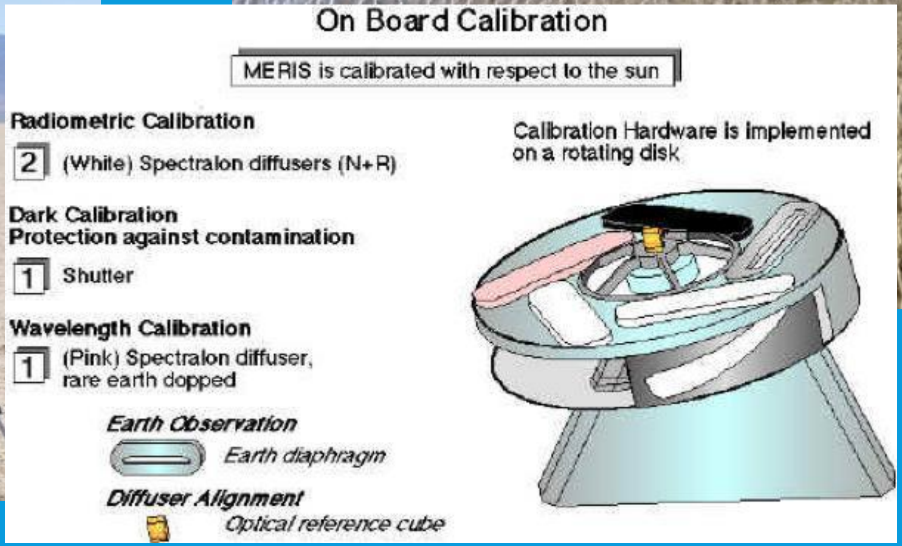
Absolute Calibration drift

- Normally measured against a reference





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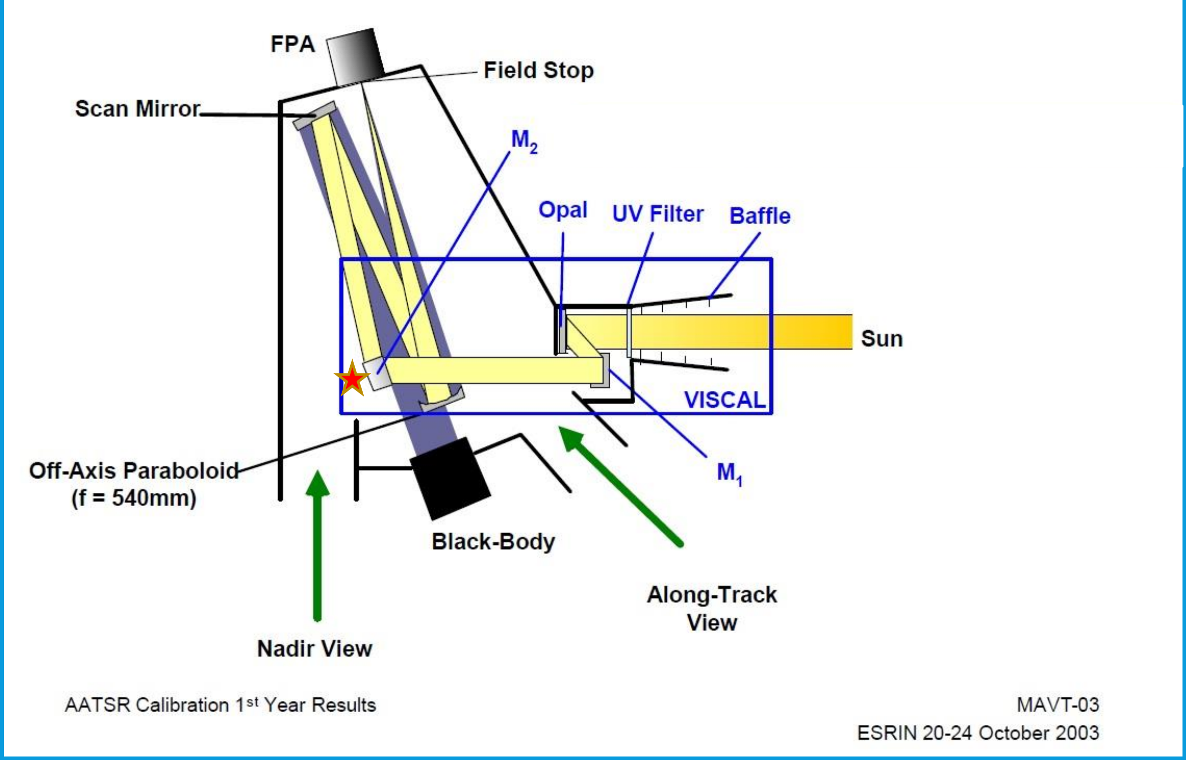
On-board calibration - VISCAL



- VISCAL is a calibration device for the VNIR bands and the 1.6 µm band.
- Piece of OPAL characterised by NPL in the lab under 0°/45° conditions.
- Photodiode placed by mirror M2 to monitor the signal, VISCAL data and photodiode information both recorded.

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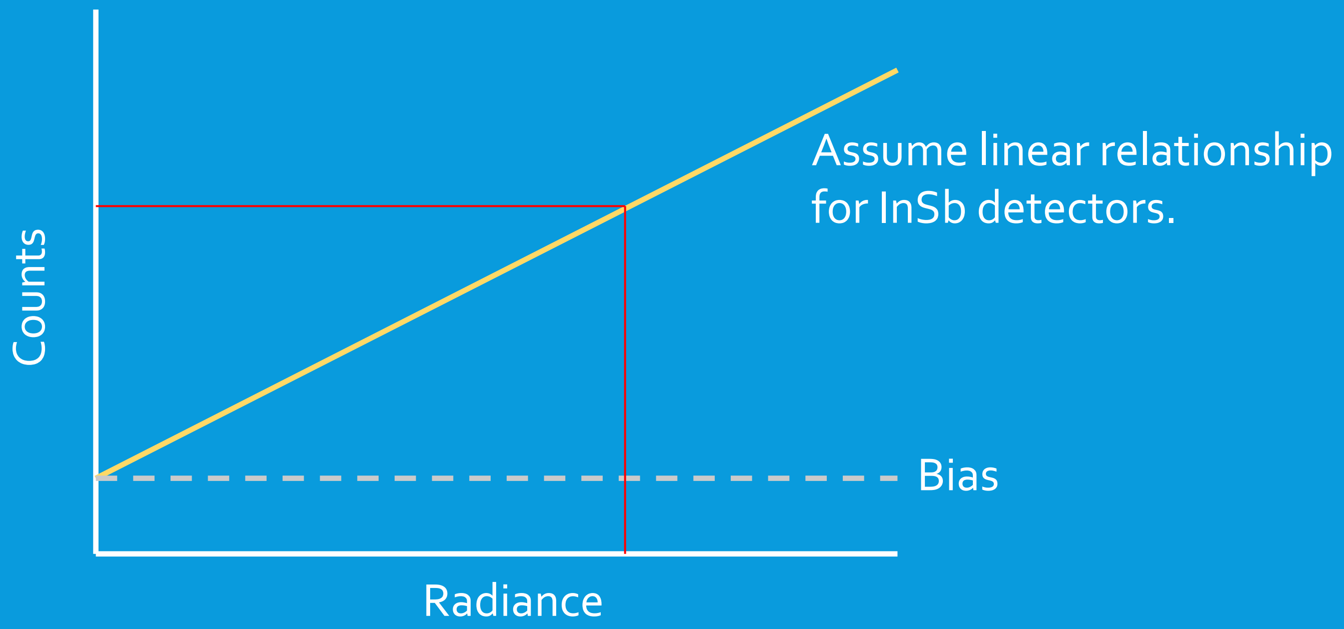
Simplified Calibration Equations (1)

Radiance = (Counts – Calibration Bias) * Calibration Gain



Only additional complexity is the electronic gain factor (Standard/ Target)

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Simplified Calibration Equations - VISCAL

$$\rho_{TOA,\lambda} = \frac{\pi \cdot L_{rad,\lambda} \cdot d^2}{E_{SUN,\lambda} \cdot cos(\theta_s)}$$

For VISCAL $\theta = 0$
Cos 0 = 1

We can rewrite the equation to be

L (Radiance) = (VISCAL Reflectance) / d^2

As all the rest of the items are constants.

Now since we know

Radiance = (Counts – Calibration Bias) * Calibration Gain

Then if assume the calibration gain is fixed and calibration bias is fixed, then we can see that the number of counts should vary with the earth-sun distance squared, assuming nothing changes.

Standard Calibration Equations – SCENE (TARGET)

$$\rho_{TOA,\lambda} = \frac{\pi \cdot L_{rad,\lambda} \cdot d^2}{E_{SUN,\lambda} \cdot cos(\theta_s)}$$

Over a year's worth of orbits we can assume we get an average θ = Constant. So (Esun Cos θ) becomes a constant.

If we assume the earth's albedo is constant then

We can rewrite the equation to be

L (Radiance) = (Earth's albedo) / d^2

As all the rest of the items are constants.

Now since we know

Radiance = (Counts – Calibration Bias) * Calibration Gain

Then if assume the calibration gain is fixed and calibration bias is fixed, then we can see that the number of counts should vary with the earth-sun distance squared, assuming nothing changes.

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Level 0 Processing

- So the counts we measure for the VISCAL instrument and the counts we measure for our surface (assuming the earths albedo does not change) should be consistent. The earths albedo does have seasonal trends, but on average (year to year) we can assume it is constant.
- If either the earths albedo changes or the VISCAL changes we should see a drift.
- Used external information (CERES data) to assess changes in earths albedo between 2003 and 2012, the peak to peak residual variation after removal of seasonal variation was given as 0.8% (a one sigma value would be smaller).
- There are 56.7 Billion AATSR individual measurements in each year per band in daylight.

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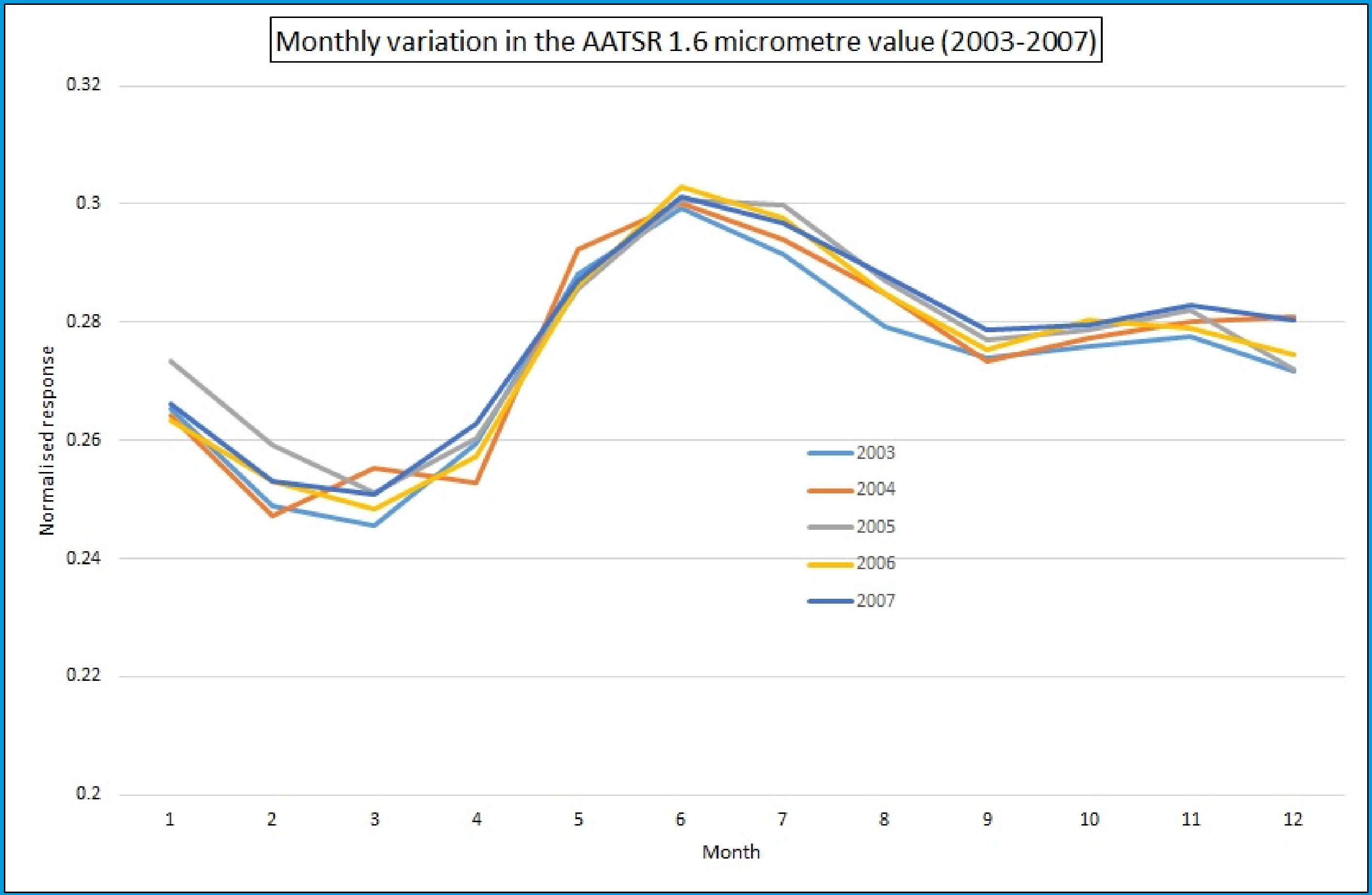
Can we treat the Earth's albedo as a constant?



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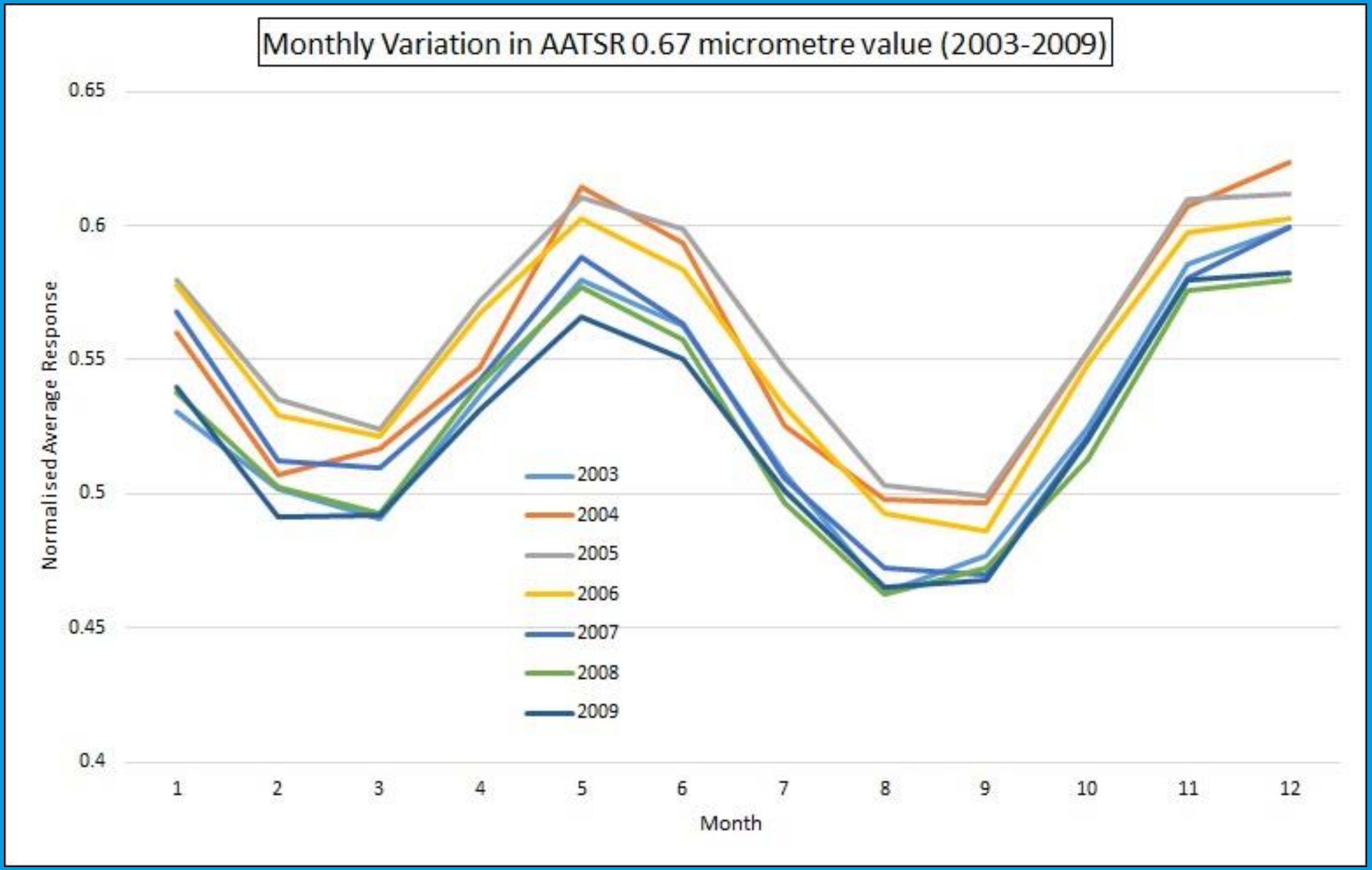
So what's happening here?



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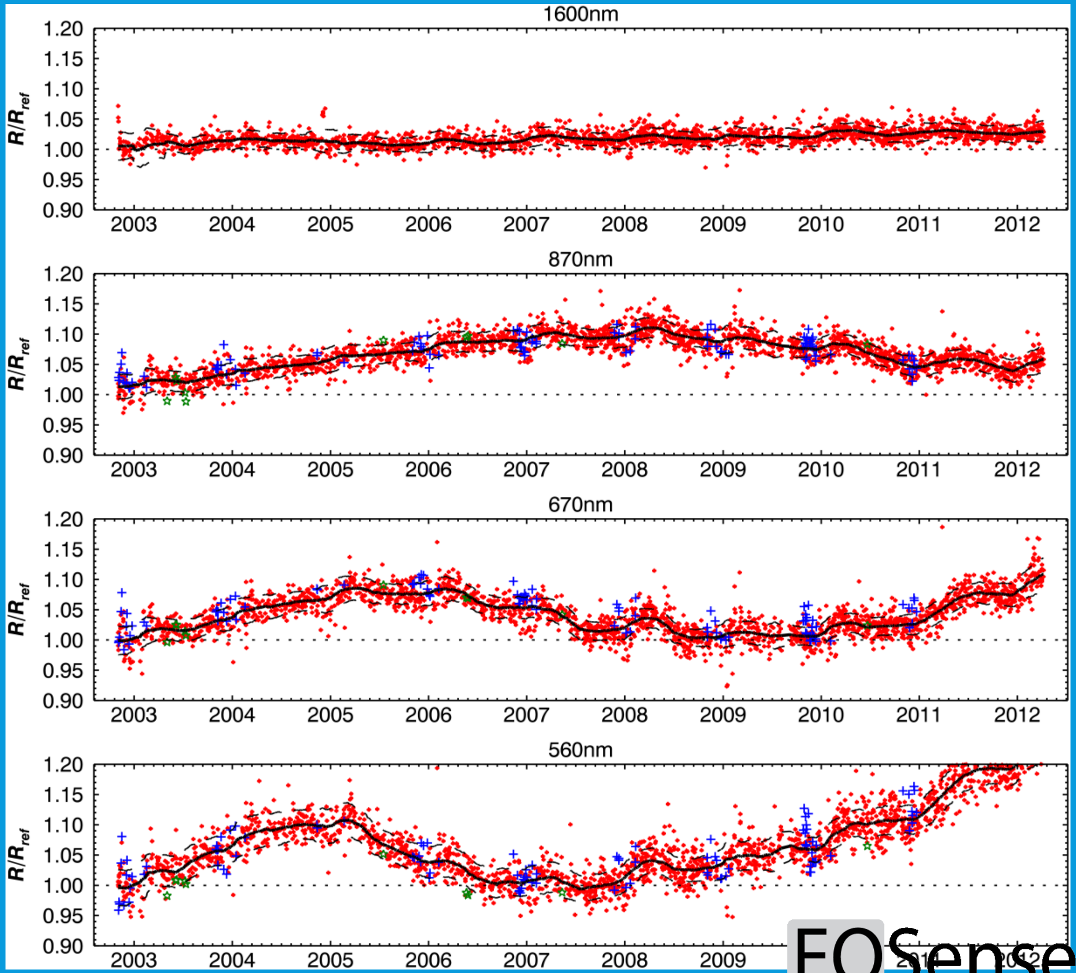
AATSR Drift Analysis – performed using data collected over PICS

To obtain drift RAL compared measured BRF against reference BRF for all sites

Trend is obtained by averaging drift for all sites of 120 day window filtering for values <2 sigma from mean (5 iterations usually to get stability)

AATSR drift does not follow linear trend as originally expected – suggested a more complex model for drift

Results provided input to drift correction look-up-table



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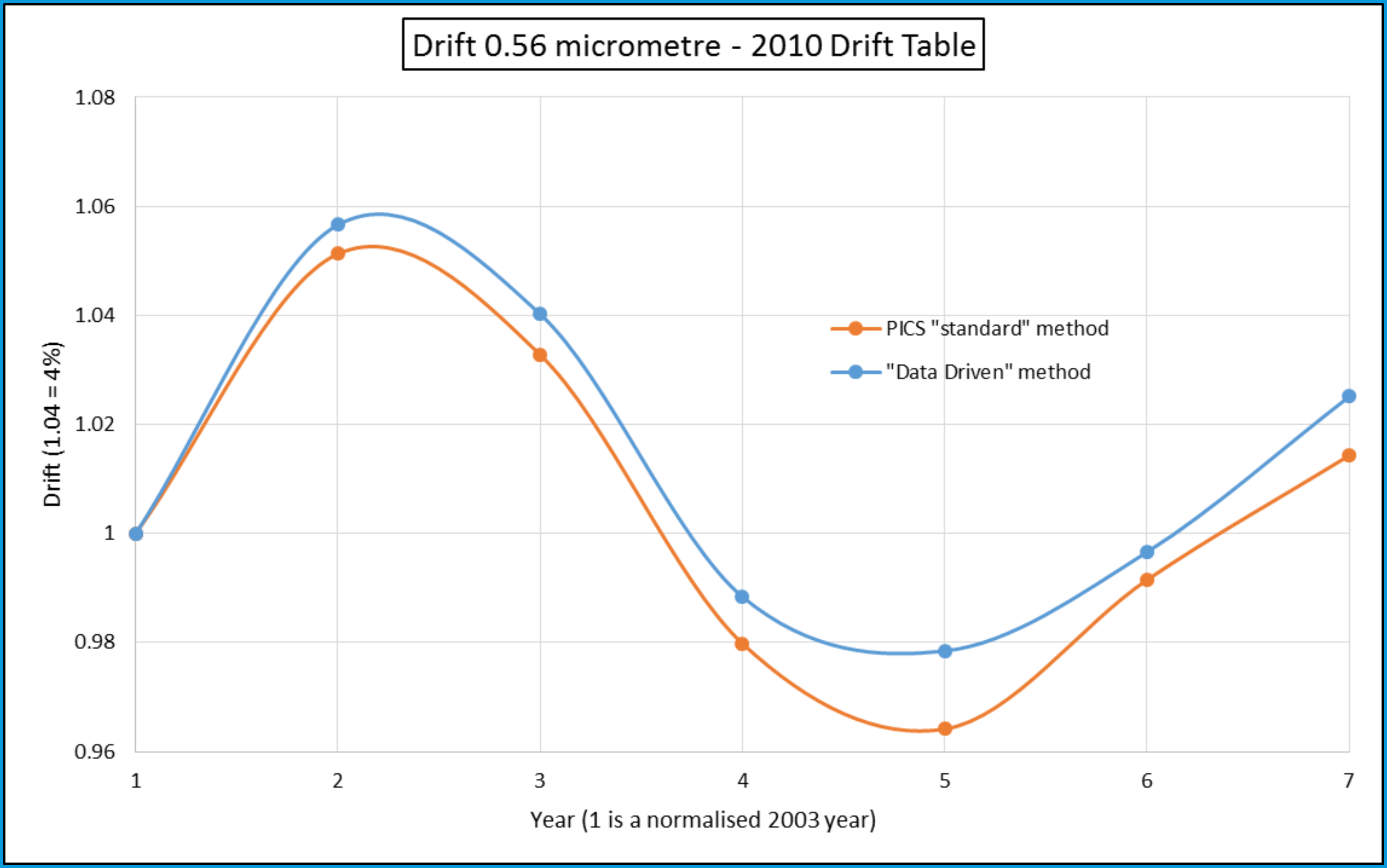
First results



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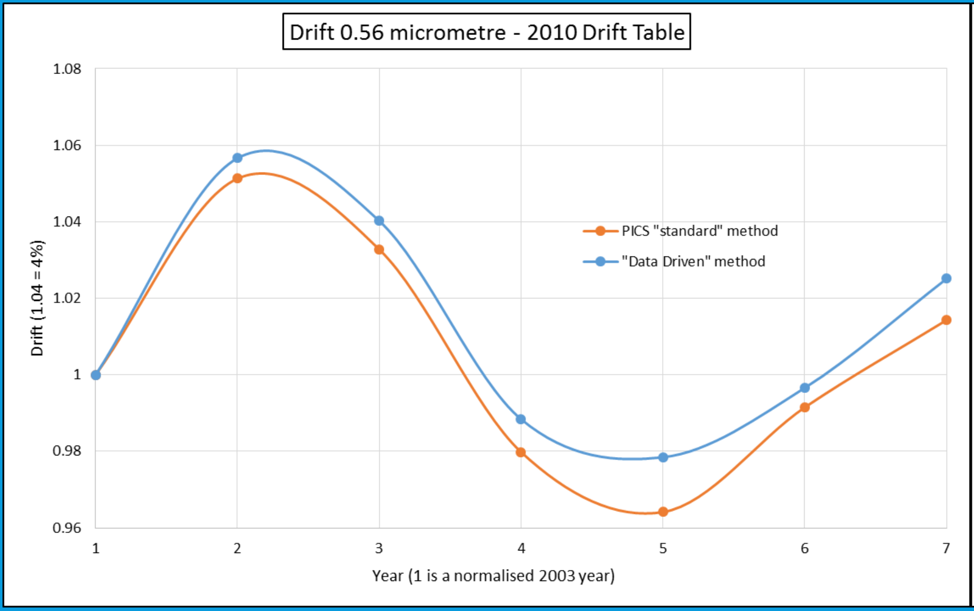
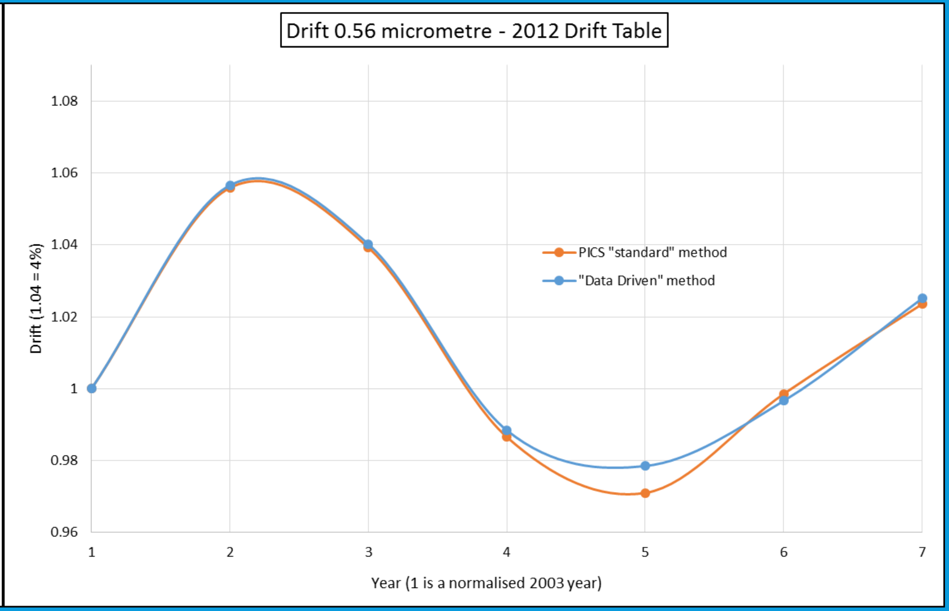
Results – using most recent drift table





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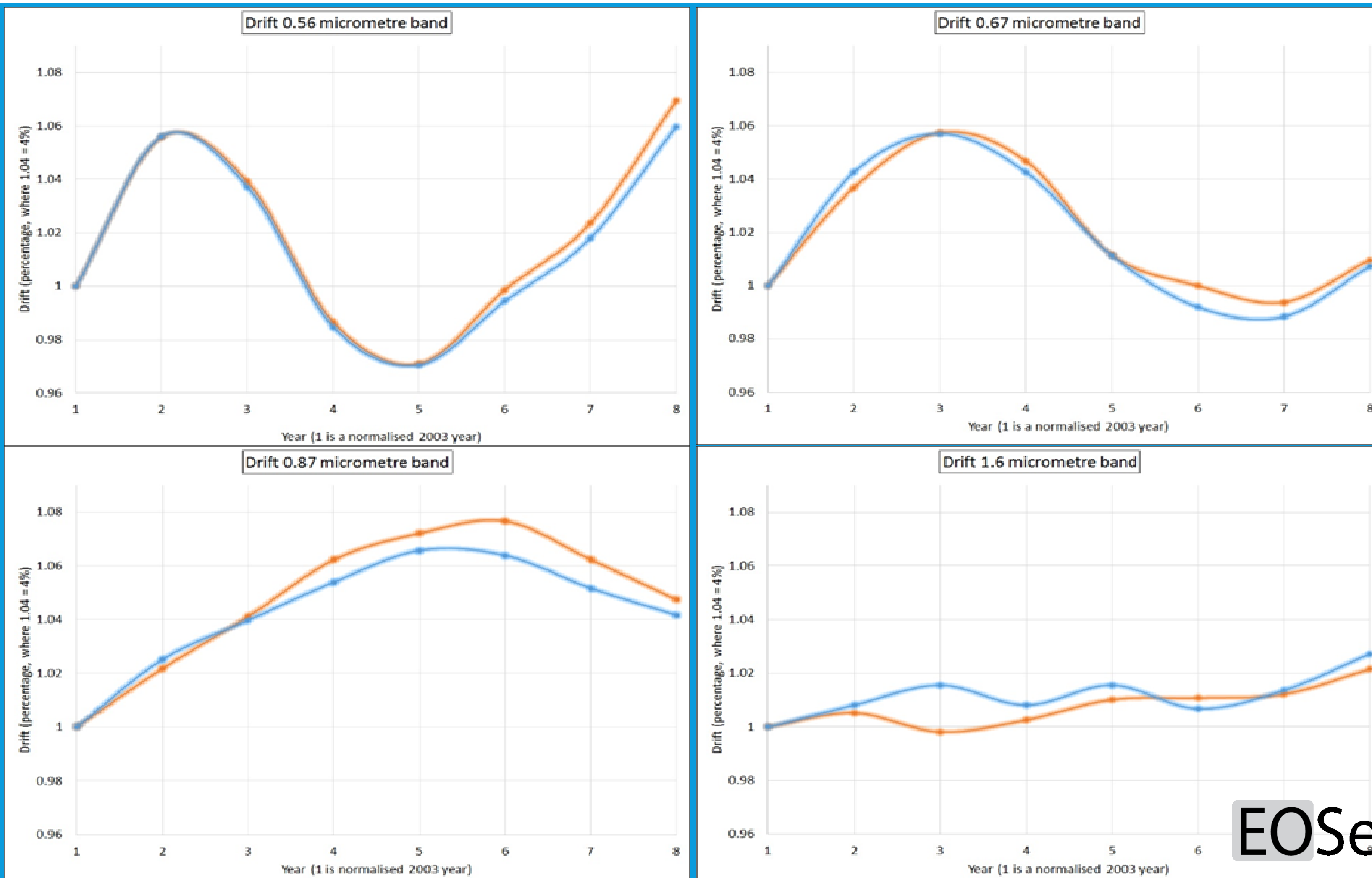
Results – All bands



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Uncertainties

TABLE II

UNCERTAINTY BUDGET FOR AATSR LONG-TERM DRIFT ESTIMATES. TYPE-A UNCERTAINTIES ARE DETERMINED BY STATISTICAL ANALYSIS OF THE DATA, WHILE TYPE-B ONES ARE ESTIMATED RANDOM UNCERTAINTIES

Component	Method of Determining Uncertainty	Type	Typical Values (%)			
			1600nm	860nm	660nm	555nm
Uncertainty in BRF model	Least squares fitting of model to ATSR-2 data over same sites – accounts for the seasonal variability of the site. Uncertainty is an indication of the short term variability of the site due to dust, atmospheric variability.	A	0.50	0.50	0.50	0.50
Uncertainty of site BRF values	Statistical analysis of the top-of-atmosphere BRF over site.	A	0.01	0.01	0.01	0.01
Uncertainty of drift values in 120 day window	Statistical analysis of all drift measurements. Note that there is some correlation with the BRF error, but there may also be other contributions not accounted for by the model.	A	0.25	0.20	0.22	0.32
Seasonal Variations in calibration signal	Determined from seasonal variations in the AATSR VISCAL monitor	B	0.75	0.75	0.75	0.75
Uncertainty in seasonal variations	Standard deviation of AATSR VISCAL monitor variations.	A	0.10	0.10	0.10	0.10
Stability of site	Assumed to be constant over long time period	B	1.00	1.00	1.00	1.00
Total	*Combined Uncertainty Estimate (Type A and B)*		*1.37*	*1.37*	*1.37*	*1.38*

(A)ATSR Solar Channel On-Orbit Radiometric Calibration

David L. Smith and Caroline V. Cox

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Possibilities

- The method should validate the calibration drift of sensors with on-board calibration devices that have global or near global coverage
  - MODIS
  - Landsat 7 ETM, Landsat 8 OLI
  - Sentinel-2 MSI
  - Sentinel-3 OLCI
  - Sentinel-3 SLSTR
  - ENVISAT MERIS
  - ENVISAT AATSR
- Advantage of using multiple sensors, enables extension of the technique to finer sampling (monthly, weekly?)

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Issues while carrying out this study

- Storage
  - MERIS archive is 150 TB
  - ATSR series more than 50TB
  - Additional sensors for testing around 10 TB
- Transfer of data
  - Currently we can transfer from some sites at speeds up to 30 Mbytes per second (240 Mbits per second). So 150 TB from this site still takes us assuming we run the FTP for 14 hours a day, a total of 104 days.
  - A physical transfer (Gigabit link) would still take 28 days.
- Data formats
  - Old data formats as well as some new formats (Landsat 8 OLI) cause issues in extracting the information we need, as we use Level 0 data.

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