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Cross-Calibration – Libya 4

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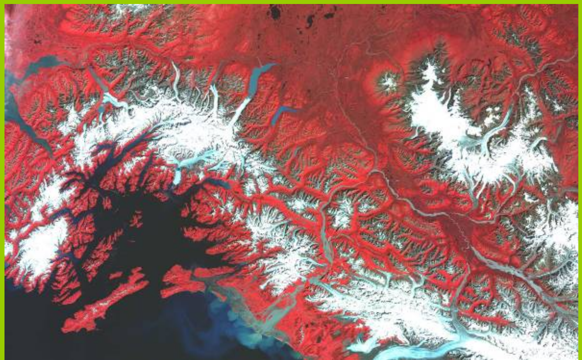
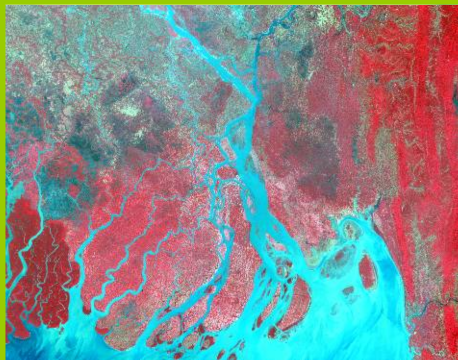




Introduction

- As part of the cross-calibration process we need (as a company) to both
  - Reduce the uncertainties of our calibration
  - Reduce the time taken to perform a calibration

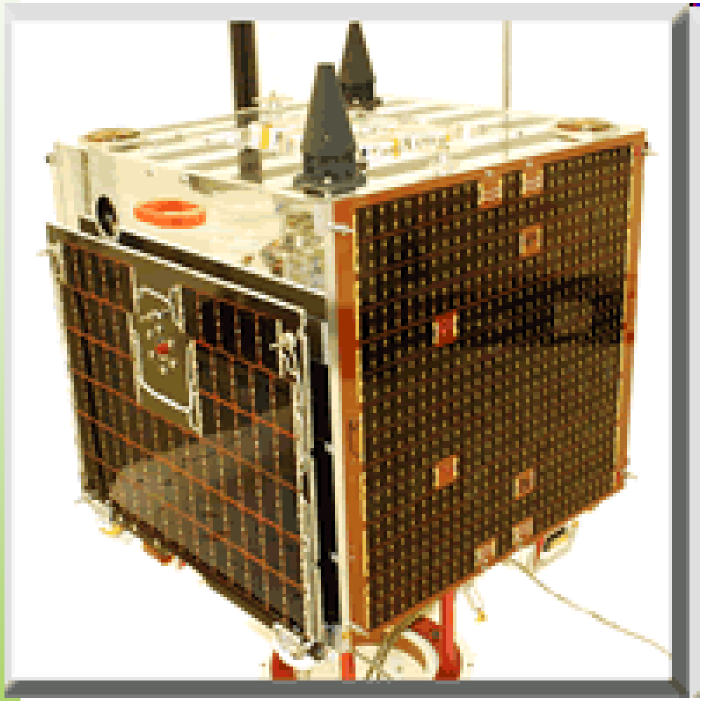
- This means to reduce the uncertainty due to surface variability, surface effects (BRDF) and atmospheric effects.

- This means we need to minimise the number of observations required to get a low uncertainty on our cross-calibration from long time series of tens or hundreds of observations to less than ten.

Why cross-calibration ?

- We have lots of satellites (currently five active) and want to get consistent results across all five.
- We have no on-board calibration equipment
- Vicarious calibration with ground teams is often difficult to manage, time consuming and expensive.
- We believe that we can achieve better consistency across our constellation in relative calibration and an absolute value of a similar order as that achieved using a ground team

DMC Constellation



- Three 22m GSD, one 32m GSD and one 5m GSD.
- Three/five spectral bands (Blue, Green, Red, NIR and PAN)
- Two imager banks, so six imagers in total (22m and 32m)
- FOV of 52 degrees (22m and 32m) and 1.67 degrees (5m).
- No on-board calibrator and drifting ground track

Intercomparison

- We have been working with the USGS (Chander) for several years, developing methods to cross-calibrate Landsat 7 ETM+ and the DMC satellites (UK-DMC-1 and UK-DMC-2).
- Two very different key sites. Dome-C (instrumented) and Libya 4 (non-instrumented). Cross-calibration over Dome-C in Antarctica against Landsat 7 ETM+
  - Correction for nadir viewing BRDF
  - Correction for Ozone (green and red bands)
  - Correction for water vapour variations (NIR)
- Cross-Calibration over Libya 4 against Landsat 7 ETM+
  - Correction of nadir viewing BRDF
  - Correction for view angle variation
  - Atmospheric variations are considered noise

Comparison Parameter

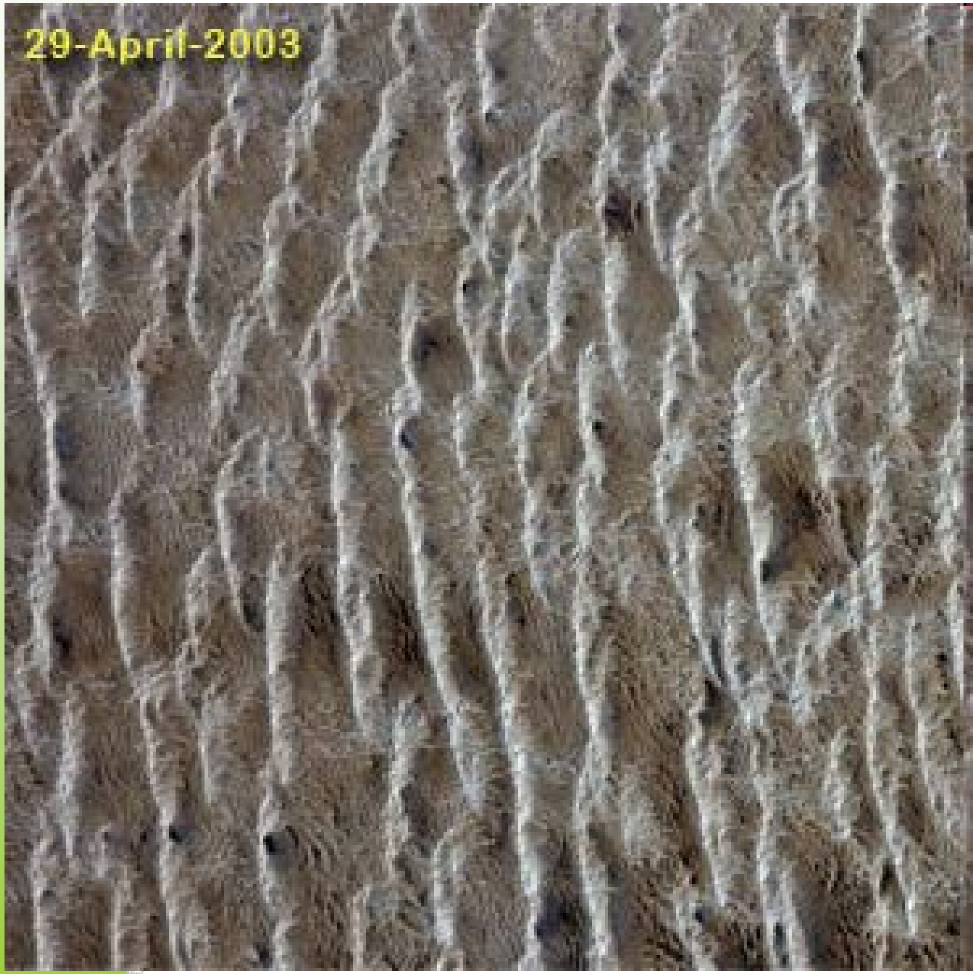
- TOA Reflectance used in comparisons

$$\rho_P = \frac{\Pi \cdot L_\lambda \cdot d^2}{\mathrm{ESUN}_\lambda \cdot \cos\theta_s}$$

where

ρ_P	unitless planetary reflectance;
L_λ	spectral radiance at the sensor's aperture;
d	earth–sun distance in astronomical units;
ESUN_λ	mean solar exoatmospheric irradiances;
θ_s	solar zenith angle in degrees.

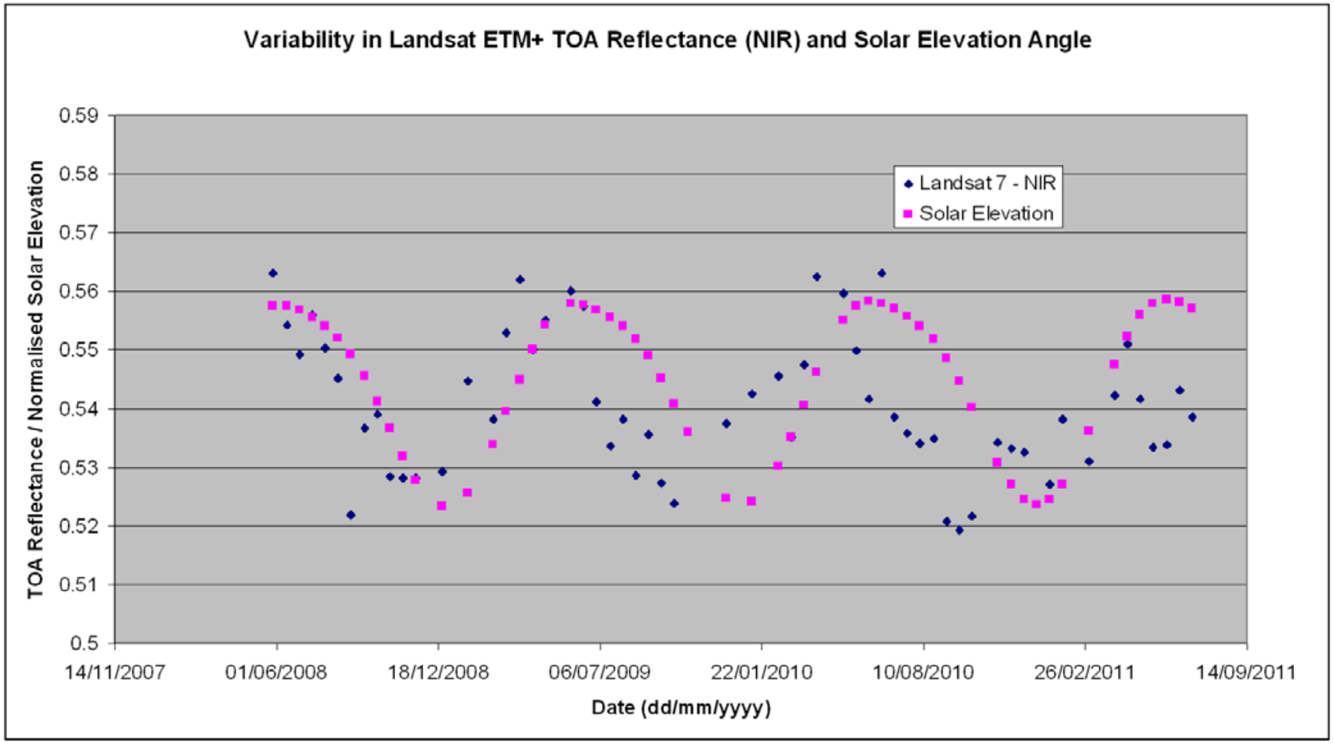
Libya 4 Site



- Detailed work began in 2009, cross-comparing data from Landsat 7 ETM+
- The cross-comparison is based on the data alone (no in-situ data)
- Roughly N-S trending asymmetric dunes.
- Assumed stable, although variable reflectance across site

http://calval.cr.usgs.gov/sites_catalog_template.php?site=lib4

Cross-Calibration Libya 4 – Nadir Element

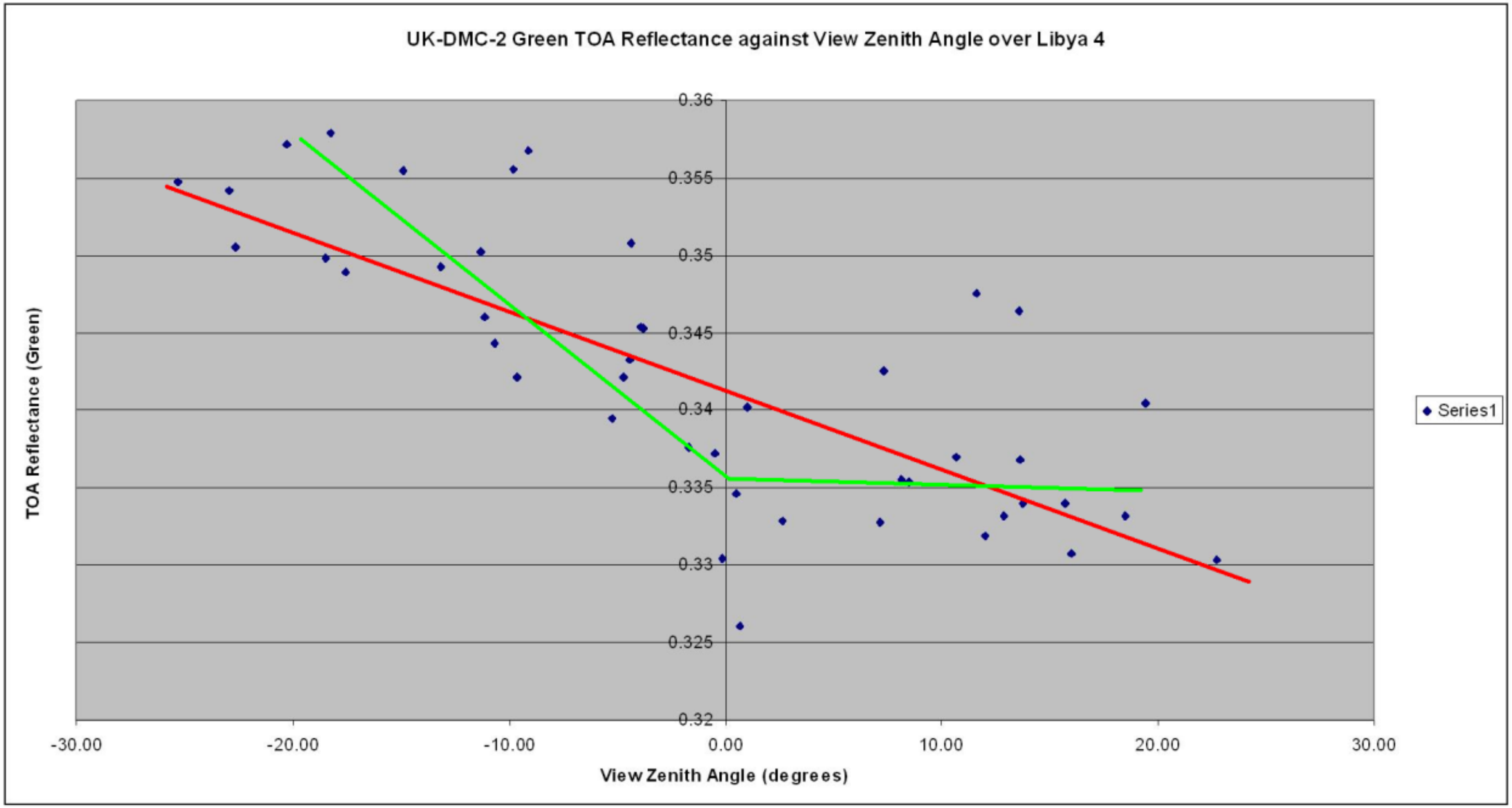


As solar elevation and azimuth changes the TOA reflectance follows a distinct pattern, with low values in the winter and high in the summer when looking at nadir, but out of sync.

The differences may be related to the complex surface and solar azimuth variations during the year and changes in earth-sun distance.

View Angle Effects

- Initially used linear when we had only five data points, but now fit using two linears.



Starting Point

- Know nothing about site or data, simple intercomparison to get a baseline uncertainty in TOA reflectance terms.

Uncertainties

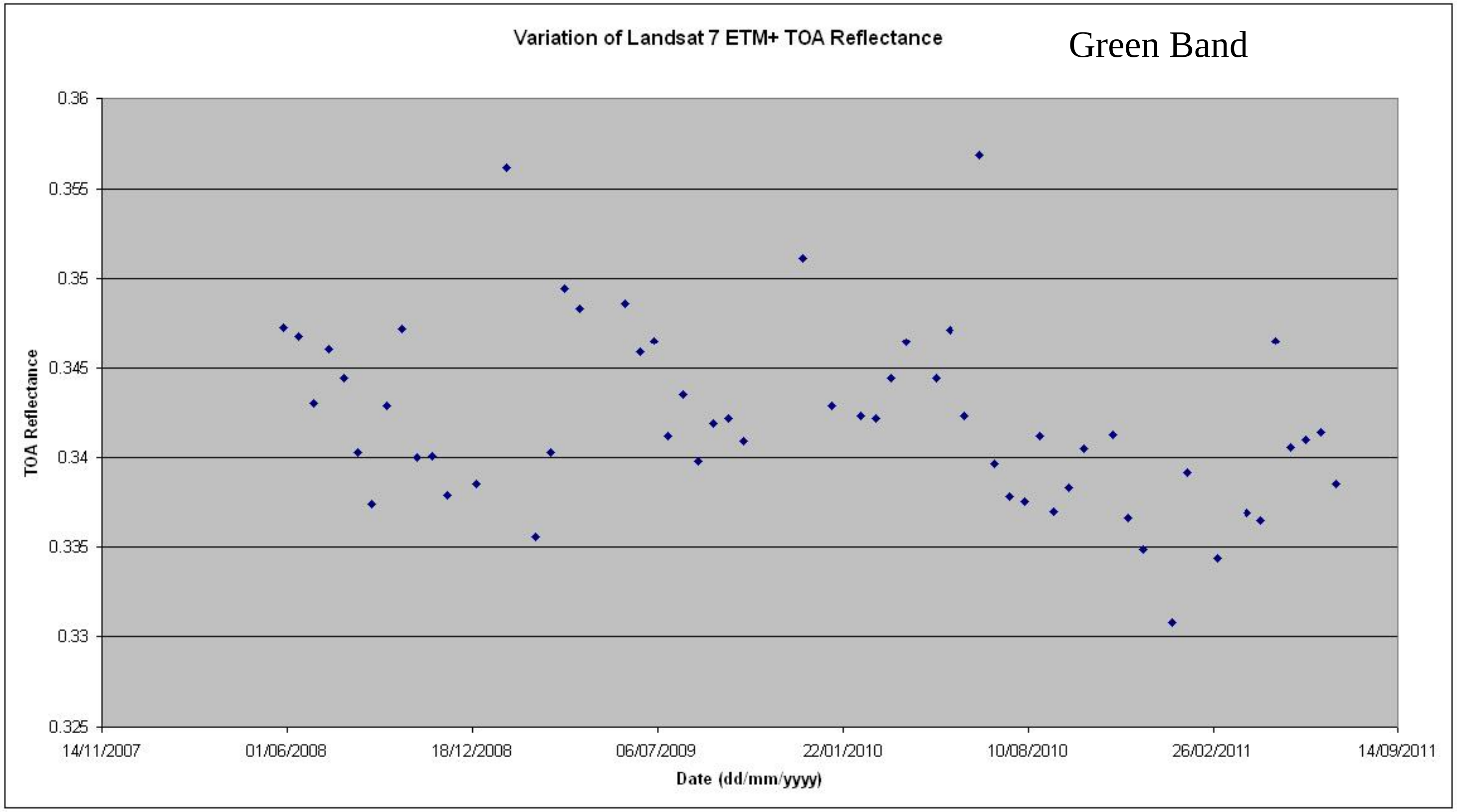
- The uncertainties are calculated in a series of steps shown below, first in terms of the TOA reflectance units (0-100) and then as a percentage variation of the mean TOA reflectance for each band.
- Uncertainties are based on the one sigma value.
- Uncertainties in the cross-calibration process are assumed to be independent for each sensor and are combined in quadrature.

Uncertainties 1

- No corrections to the data, just straight TOA Reflectance, but excluding obvious errors
  - Landsat TOA reflectance uncertainties are 0.56, 0.7 and 1.17 which equates to 1.62%, 1.52% and 2.17% of the mean TOA reflectance.
  - UK-DMC-2 TOA reflectance uncertainties are 0.87, 0.87 and 1.16 which equates to 2.54%, 1.89% and 2.14%
- The combined uncertainty of the cross-calibration in TOA reflectance terms would be 1.03, 1.12 and 1.65 which equates to 3.02%, 2.54% and 3.03% of the mean TOA reflectance for each spectral band.

Uncertainties 2

- We know that for all satellites there is a time varying component, this is not so well defined for the green band, a little better defined for the red band and clearly visible in the NIR.



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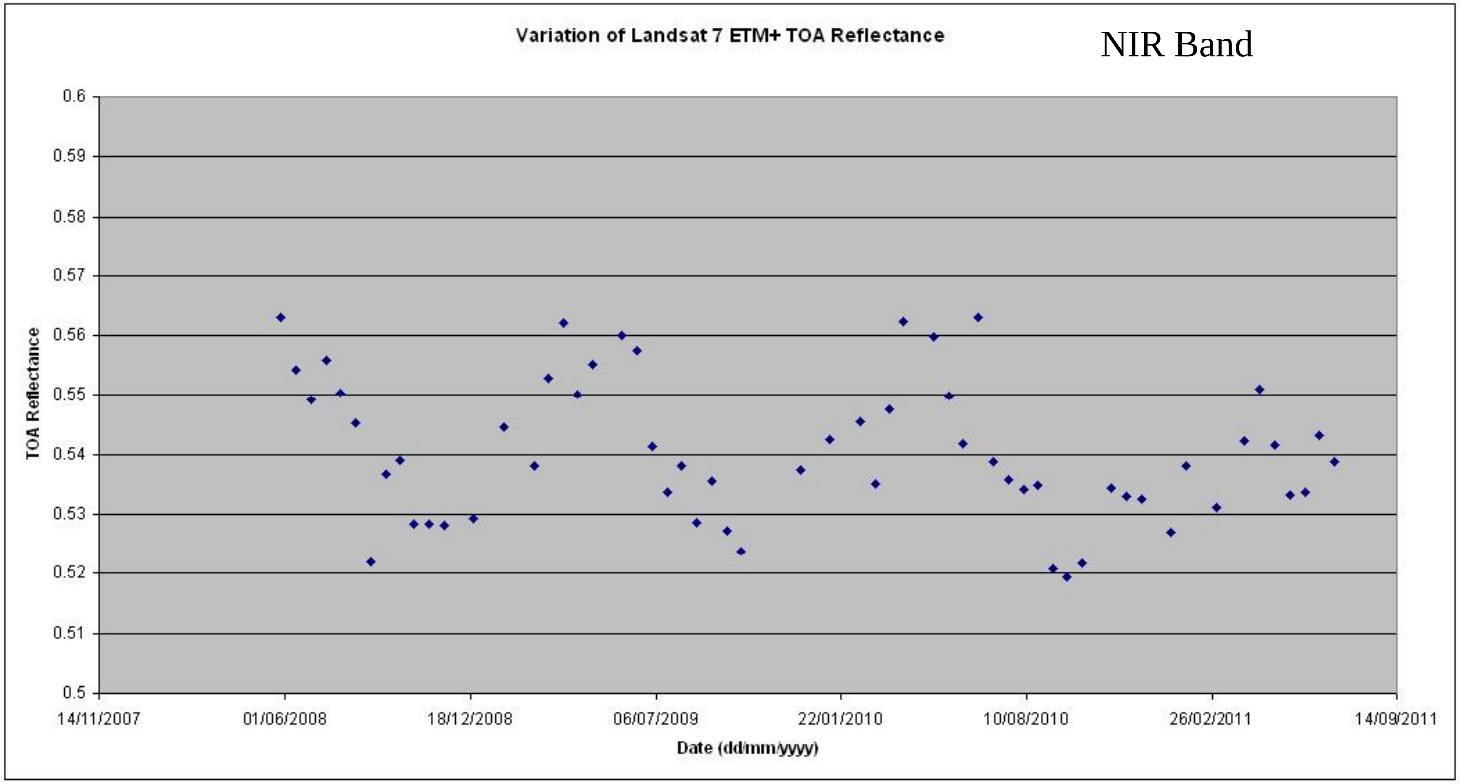
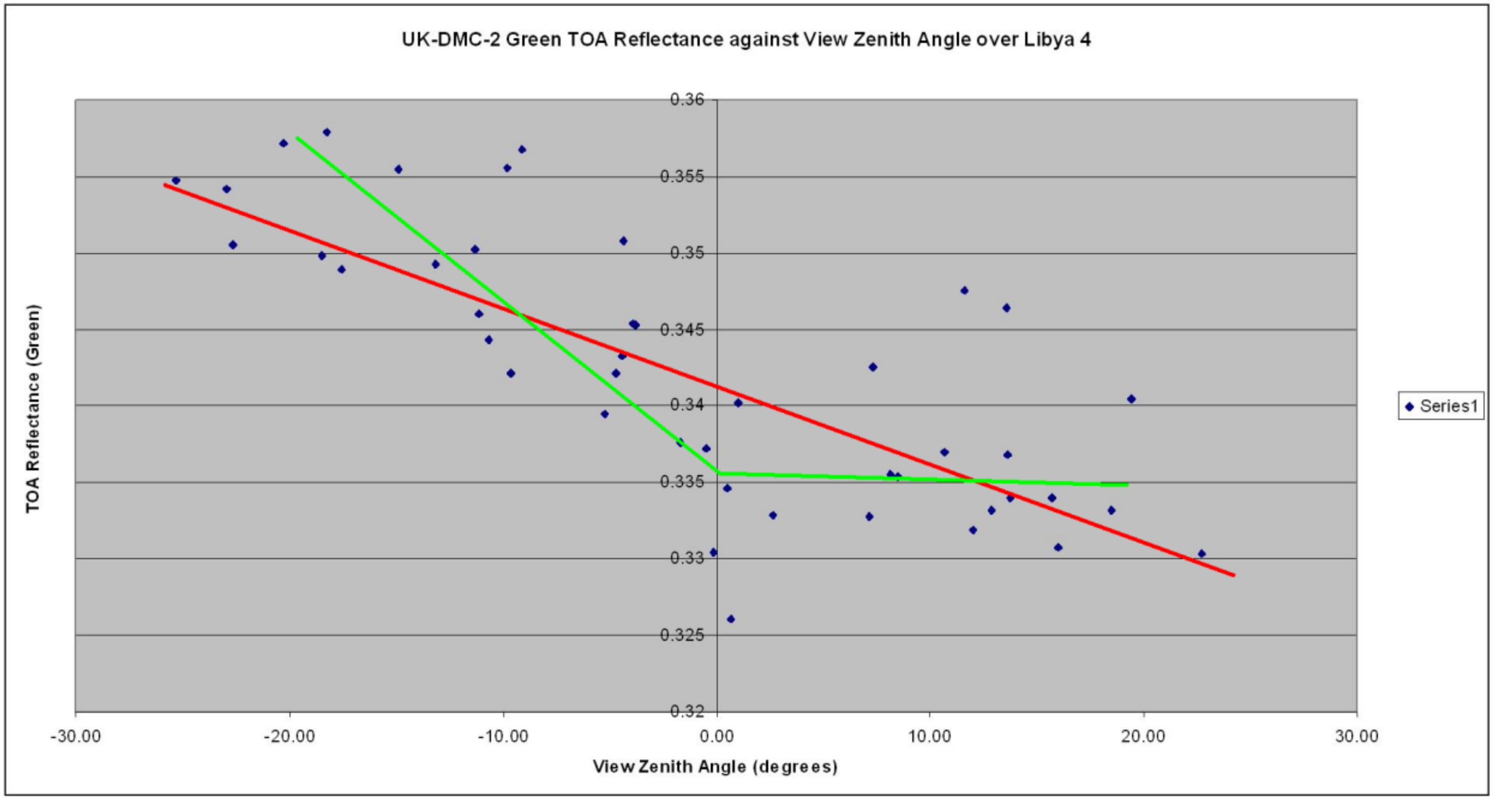


Uncertainties 2

- Correction for the seasonal variation
  - Landsat TOA reflectance uncertainties are 0.56, 0.66 and 0.86 which equates to 1.62%, 1.4% and 1.55% of the mean TOA reflectance.
  - UK-DMC-2 TOA reflectance uncertainties are 0.91, 0.91 and 1.1 which equates to 2.67%, 2.0% and 2.09%
- The combined uncertainty of the cross-calibration in TOA reflectance terms would be 1.07, 1.12 and 1.4 which equates to 3.13% (+0.11), 2.44% (-0.1) and 2.59% (-0.44) of the mean TOA reflectance for each spectral band.

Uncertainties 3

- The results suggest that the seasonal correction improved the Landsat 7 results, but there is another factor for the UK-DMC-2 data which has more impact, in this case the view angle effects

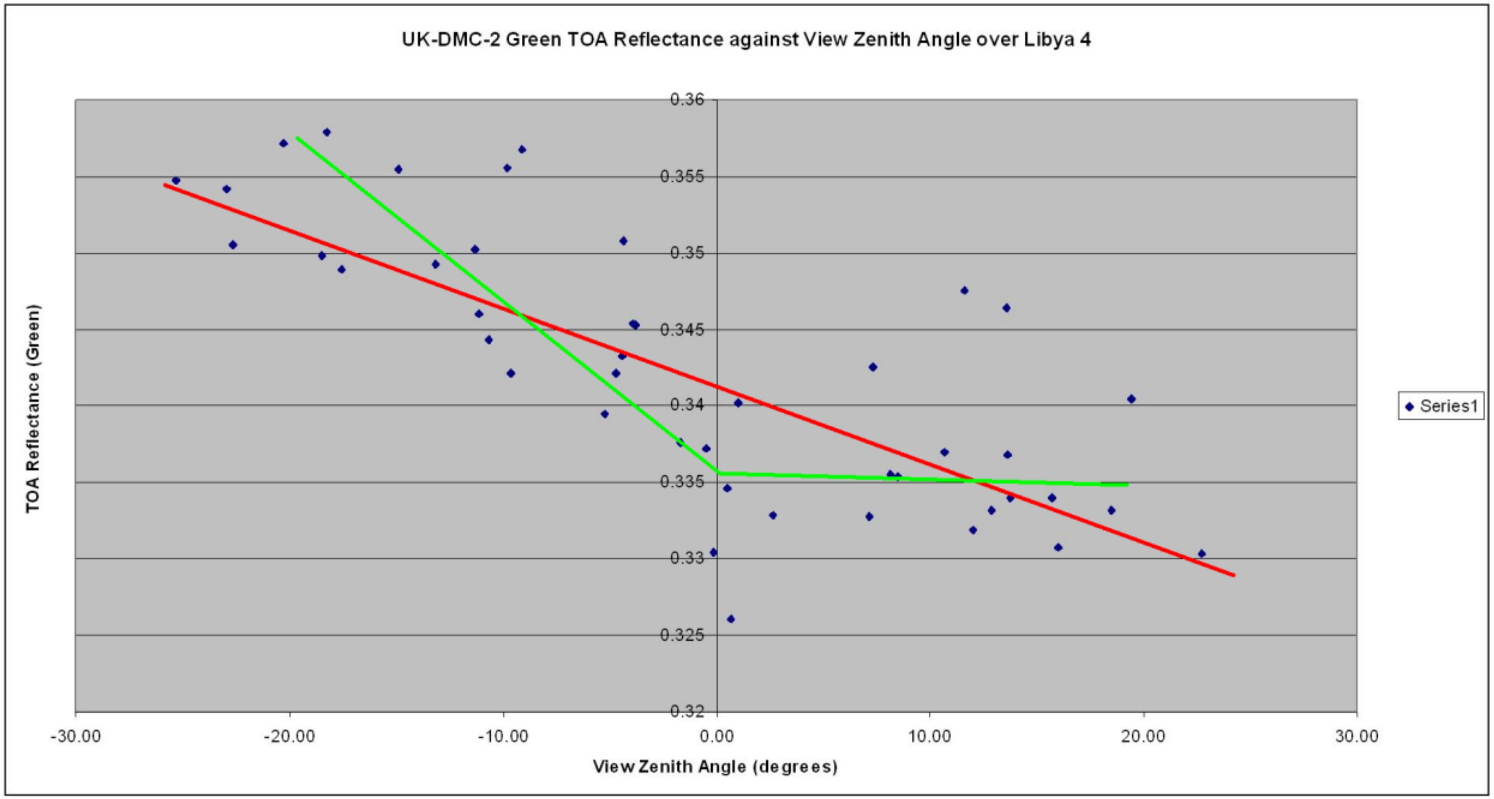


Uncertainties 3

- Landsat as before (seasonal correction) with simple linear correction for view angle for UK-DMC-2.
- Correction for the seasonal variation
  - Landsat TOA reflectance uncertainties are 0.56, 0.66 and 0.86 which equates to 1.62%, 1.4% and 1.55% of the mean TOA reflectance.
- Correction for view angle (UK-DMC-2)
  - UK-DMC-2 TOA reflectance uncertainties are 0.64, 0.72 and 1.0 which equates to 1.88%, 1.57% and 1.84% of the mean TOA reflectance
- The combined uncertainty of the cross-calibration in TOA reflectance terms would be 0.85, 0.98 and 1.32 which equates to 2.49% (-0.53), 2.12% (-0.42) and 2.43% (-0.6) of the mean TOA reflectance.

Uncertainties 4

- With a better model of the view angle effects, we can separate out each half of the sensor

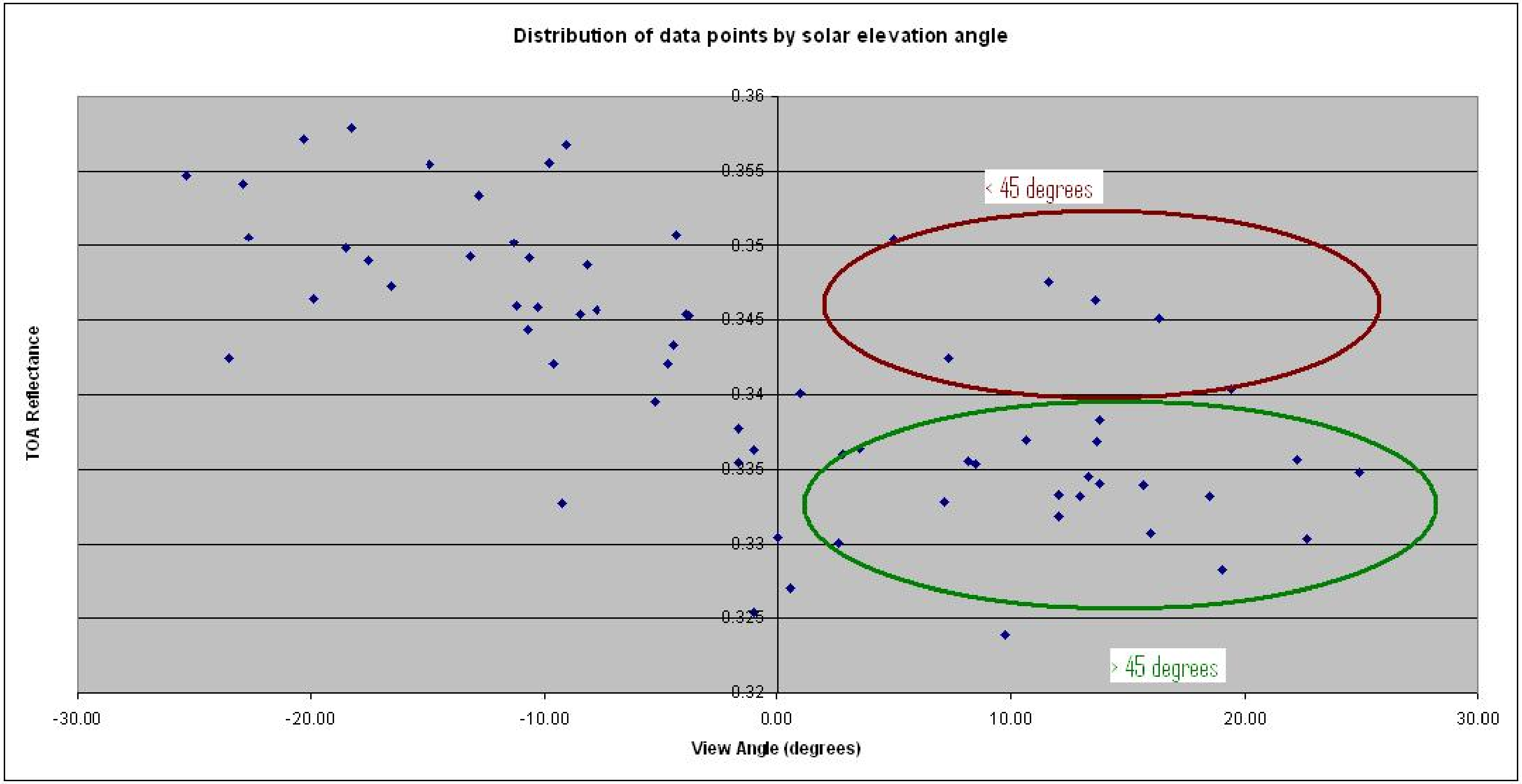


Uncertainties 4

- Landsat as before (seasonal correction) with a more complex linear correction for view angle for UK-DMC-2.
- Correction for the seasonal variation
  - Landsat TOA reflectance uncertainties are 0.56, 0.66 and 0.86 which equates to 1.62%, 1.4% and 1.55% of the mean TOA reflectance.
- Correction for view angle (UK-DMC-2)
  - UK-DMC-2 TOA reflectance uncertainties are (S)0.53, (P)0.61, (S)0.75, (P)0.52 and (S)0.78, (P)1.05. Taking the mean of each bank, this equates to a percentage of the mean TOA reflectance of 1.66%, 1.37% and 1.68%.
- The combined uncertainty of the cross-calibration in TOA reflectance terms would be 0.8, 0.92 and 1.26 which equates to 2.33% (-0.69), 1.99% (-0.56) and 2.32% (-0.71) of the mean TOA reflectance.

Uncertainties 5

- We know some scatter is due to the low sun angle observations.



Uncertainties 5

- Landsat as before (seasonal correction) with a more complex linear correction for view angle for UK-DMC-2 and removal of low sun angle values.
- Correction for the seasonal variation
  - Landsat TOA reflectance uncertainties are 0.56, 0.66 and 0.86 which equates to 1.62%, 1.4% and 1.55% of the mean TOA reflectance.
- Correction for view angle (UK-DMC-2)
  - UK-DMC-2 TOA reflectance uncertainties are (S)0.46, (P)0.42, (S)0.48, (P)0.38 and (S)0.86, (P)0.87. Taking the mean of each bank, this equates to a percentage of the mean TOA reflectance of 1.29%, 0.93% and 1.59%.
- The combined uncertainty of the cross-calibration in TOA reflectance terms would be 0.71, 0.79 and 1.22 which equates to 2.07% (-0.95), 1.71% (-0.84) and 2.25% (-0.78) of the mean TOA reflectance.

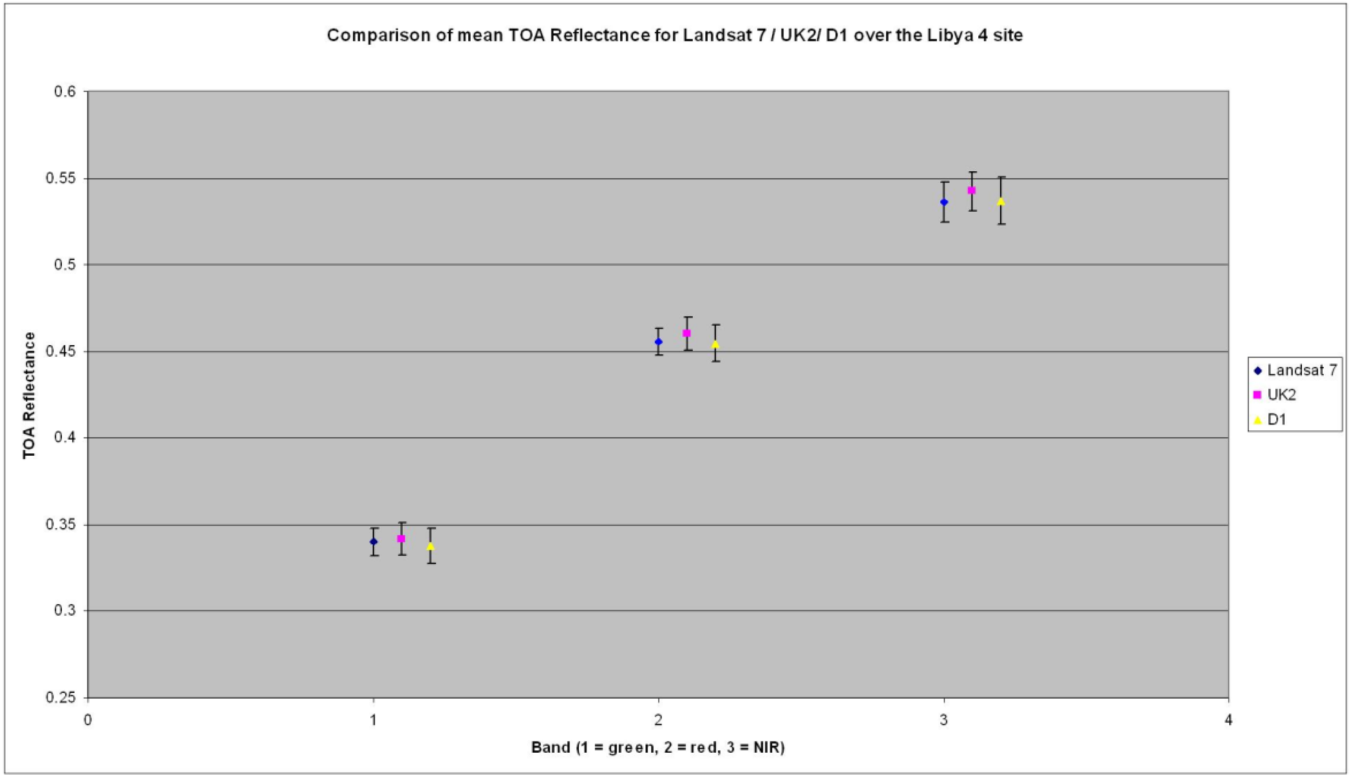
Uncertainties – Summary Table

	UK-2 Green	UK-2 Red	UK-2 NIR	Comb. Green	Comb. Red	Comb. NIR
U1	2.54%	1.89%	2.14%	3.02%	2.54%	3.03%
U2	2.67%	2.0%	2.09%	3.13%	2.44%	2.59%
U3	1.88%	1.57%	1.84%	2.49%	2.12%	2.43%
U4	1.66%	1.37%	1.68%	2.33%	1.99%	2.32%
U5	1.29%	0.93%	1.59%	2.07%	1.71%	2.25%

- Clearly the corrections for view angle effects (BRDF and geometry of the surface) have a huge impact on the uncertainty for UK-DMC-2.
- The uncertainties for Landsat 7 are still quite high, even though partially corrected.
- Further corrections for atmospheric effects and surface BRDF are necessary to improve the overall result for all sensors.

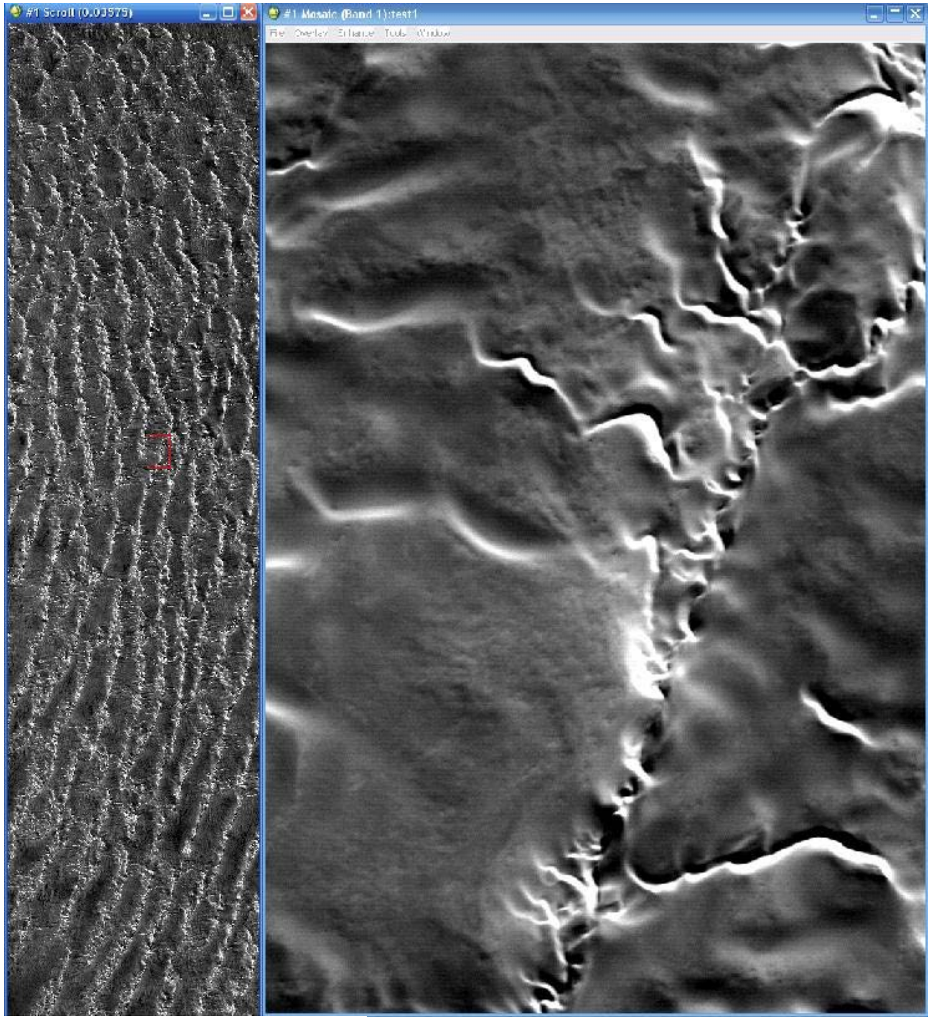
Libya 4

- Cross-Calibration over Libya 4 with Landsat 7 has continued.
- Now collecting more intensively at all view angles so 6-8 images per month for UK-2
- Using images to assess uncertainty related to the surface variability.
- Further work underway to fully understand causes of variability over the Libya 4 site

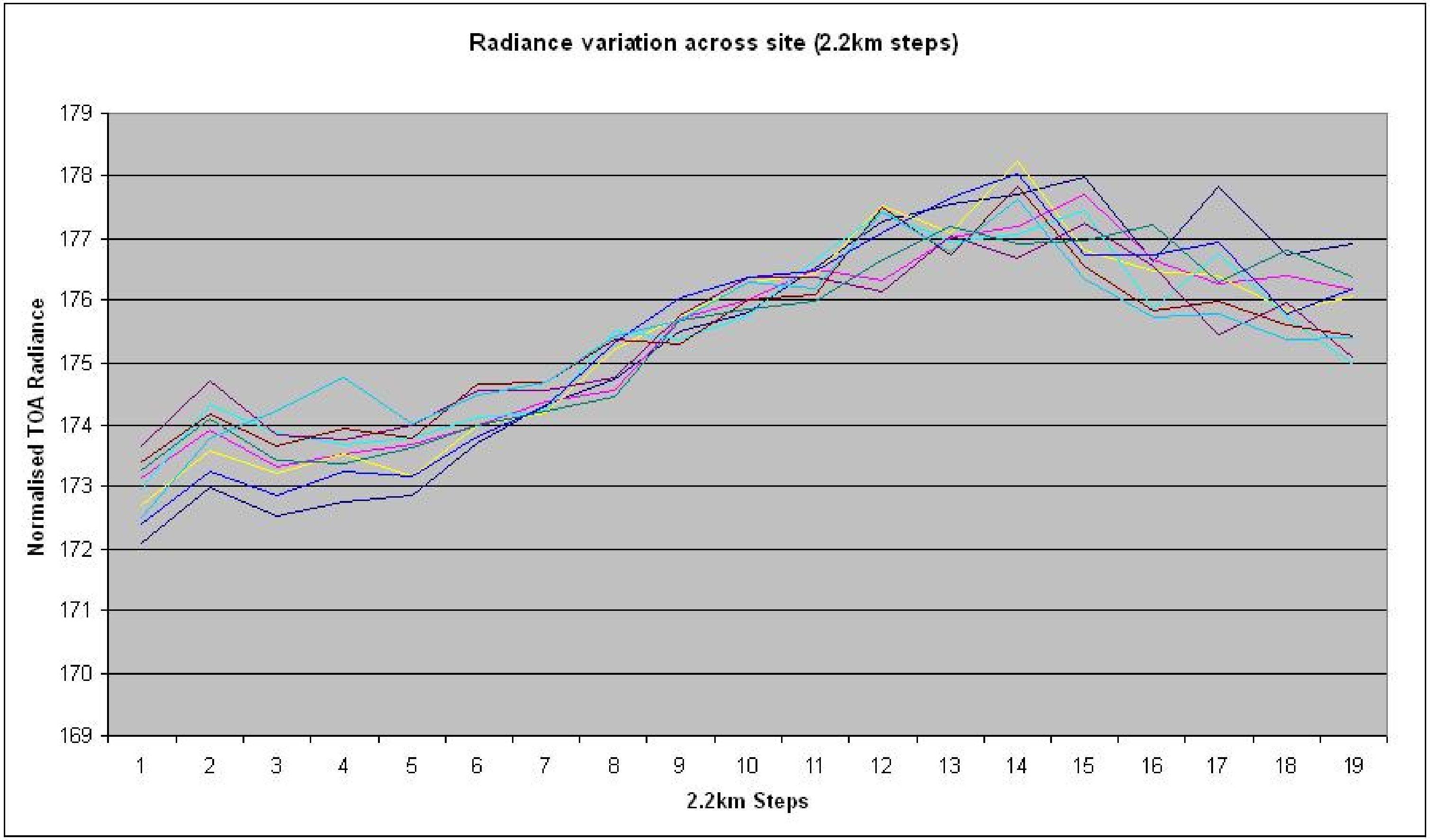


Cross-Calibration Libya 4

- Compared NigeriaSat-2 to Landsat 7 ETM+
- Now a 20km swath, so only covers part of the site during each observation.
- Initial images hit different parts of site, but now star cameras are calibrated, consistently hits centre.

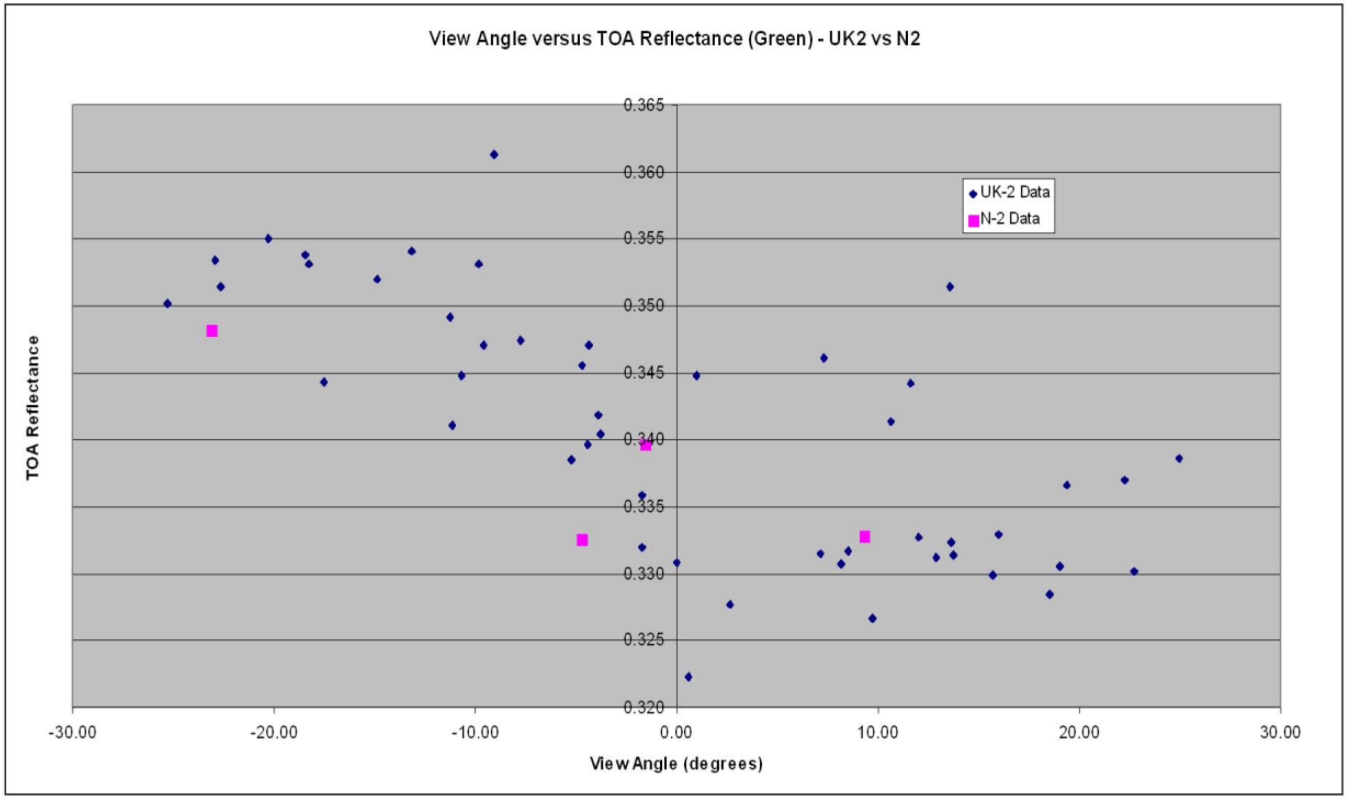


Libya 4 – Variability across site



- Site seems stable but not uniform in terms of its reflectance (2.2km wide x 20km long strips)

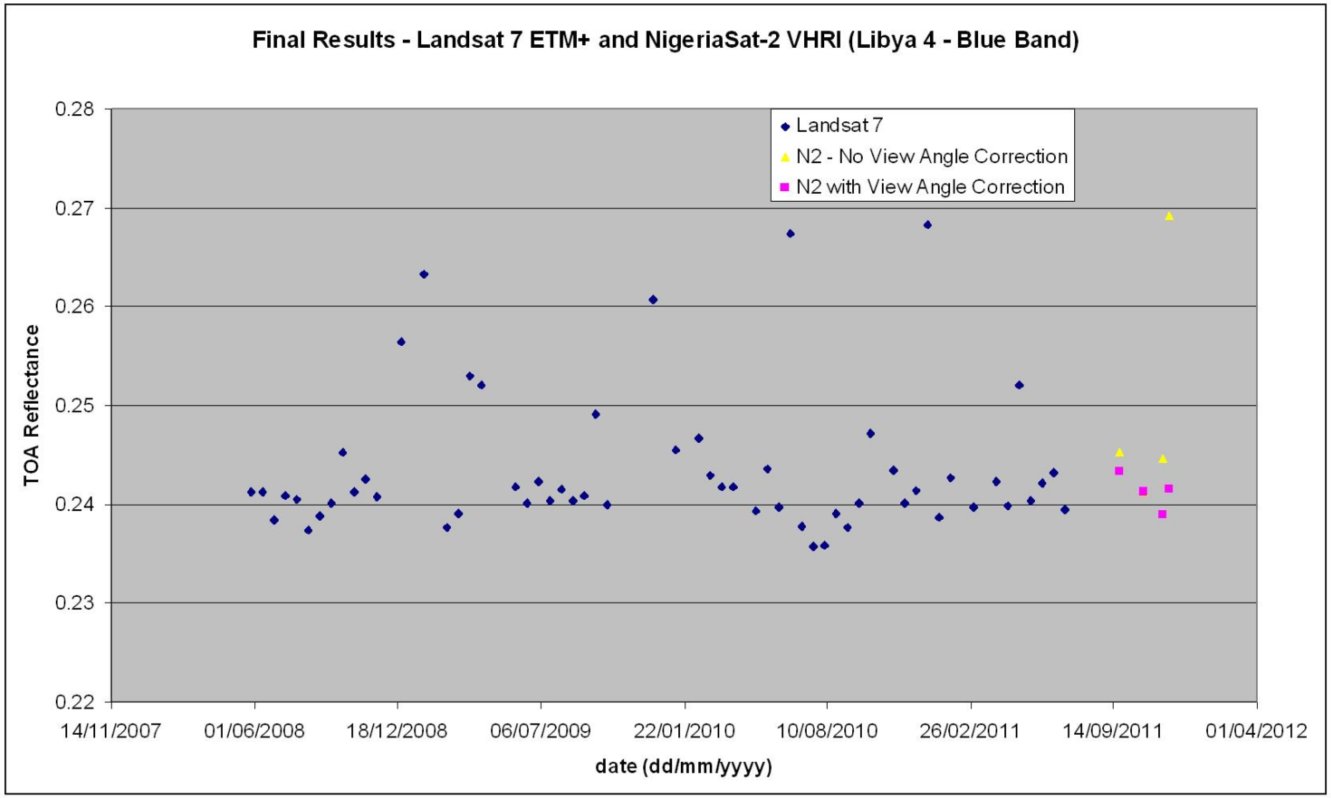
Cross-Calibration Libya 4 – View Angle Effects



- View Angle profile (after removal of the seasonal element) generated using UK-DMC-2 data.
- N2 data points (only four) fit pattern. Many more needed.

Final Calibration results N2 – Libya 4

- Data corrected iteratively
  - Removal of seasonal trend
  - Removal of view angle effects
  - Calculation of differences when compared to Landsat 7 data
  - Adjustment of coefficients to approach Landsat 7 more closely



Conclusions

- View angle effects are the most significant effects to deal with, especially when trying to collect large numbers of images.
- The variability across the site becomes important for higher resolution sensors.
- Using a simple set of corrections, it is possible to reduce the uncertainties in the cross-calibration process to approximately 2.0% of the mean TOA reflectance.

Recommendations

- Improved modelling of the surface and atmosphere are necessary to reduce the uncertainties in the cross-calibration process to below 1.5% with the aim of better than 1.0%.

- Further work is necessary to estimate uncertainties related to the small band differences between the different sensors we cross-calibrate.

- Care should be taken to correct for site variability especially for higher resolution sensors that view only part of a site.