EOSense

Automated Monitoring of Radiometric Calibration and Data Quality

An alternative for optical sensors

IDEAS+ WP3520 Calibration and Data Quality Toolbox

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PRINCIPLES

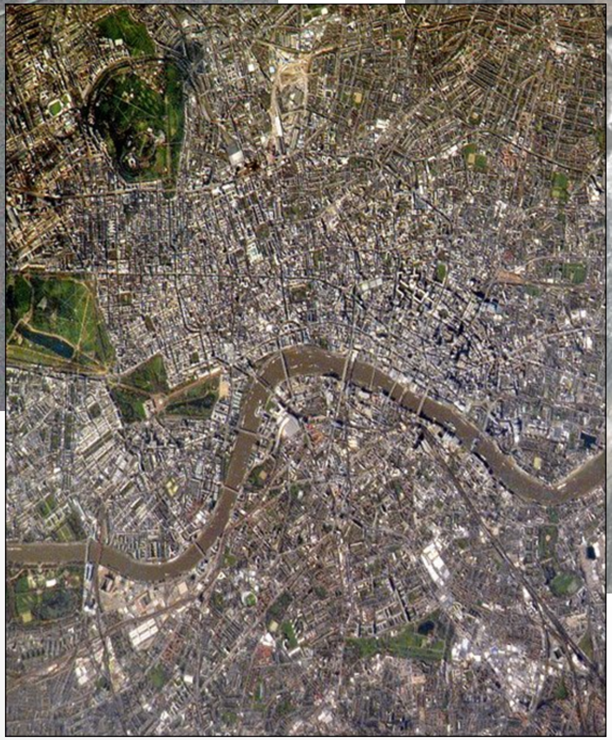
Basic principles

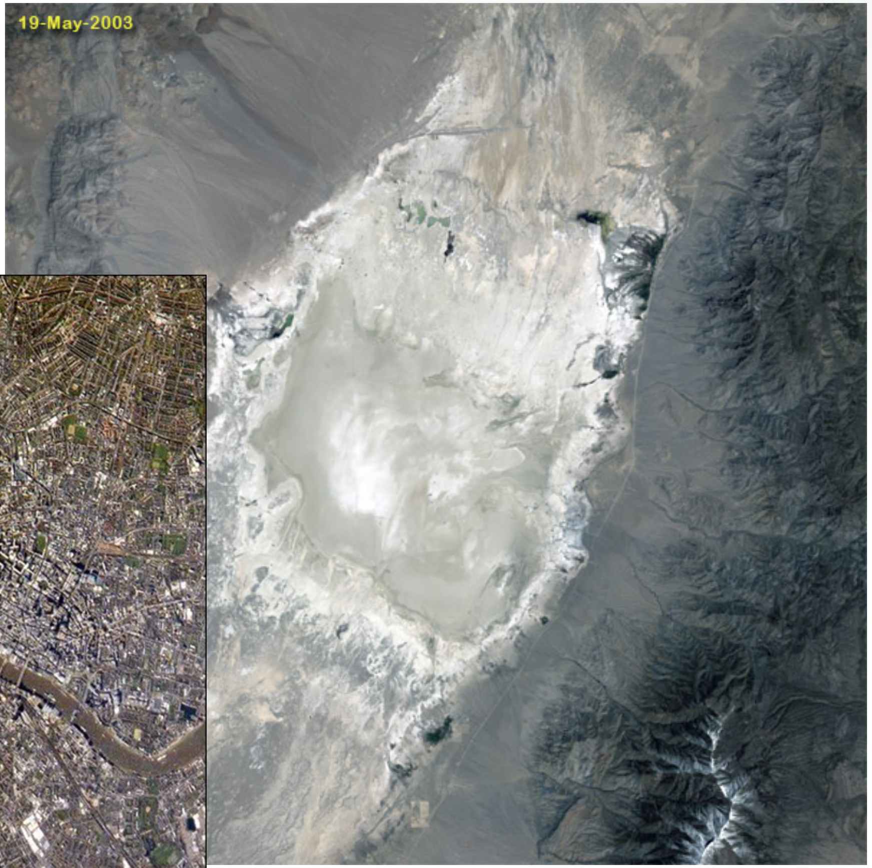
- Currently radiometric calibration and data quality relies largely on infrequently acquired on-board data (Sentinel-2 has a calibration cycle every month) or through vicarious calibration using specific sites that may have environmental limitations (Dome-C during its winter, cloud cover over Libya 4). So opportunities are limited.

OUR APPROACH

- All images collected contain useful information for assessing changes in radiometry and data quality, this provides very high temporal sampling of parameters of interest.

Types of images we use, essentially everything





How much data do we need?

- For some analyses we need many images, absolute calibration drift for example uses the whole earth as a reference, which means we use billions of individual measurements, all normal images processed in the standard processing chains.
- For others we need a single image (snapshot of relative gains) which provides unprecedented detail on changes happening almost real time on the spacecraft.
- The data used can be at different levels for different tasks, using bias subtracted Level 0 and radiometrically corrected Level 1B data <u>without</u> any geometric correction or resampling.

Advantages of using normal images

- By using normal images, we have a much higher sampling interval, every 41 seconds for Sentinel-2 rather than every month using on-board devices.
- We can therefore monitor and update our results with a much higher frequency than many on-board devices and vicarious methods which use specific sites, that can only be accessed infrequently.
- By using normal images, in theory we can update coefficients automatically as soon as an issue is encountered (detector non-uniformity, where a single detector responsivity changes dramatically in a short period of time)
- We also avoid "dead" periods where a specific site cannot be used, such as the polar sites in Antarctica and Greenland that for precision work can only be used effectively for one to two months per year.

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AREAS BEING INVESTIGATED

Areas being investigated (all in-orbit) using normal images

- Absolute Calibration drift (earlier phase)
- Signal to Noise Ratio assessment (earlier phase)
- Focus assessment (still in progress)
- *Relative gain determination (still in progress)*
- *Non-linearity assessment (still in progress)*

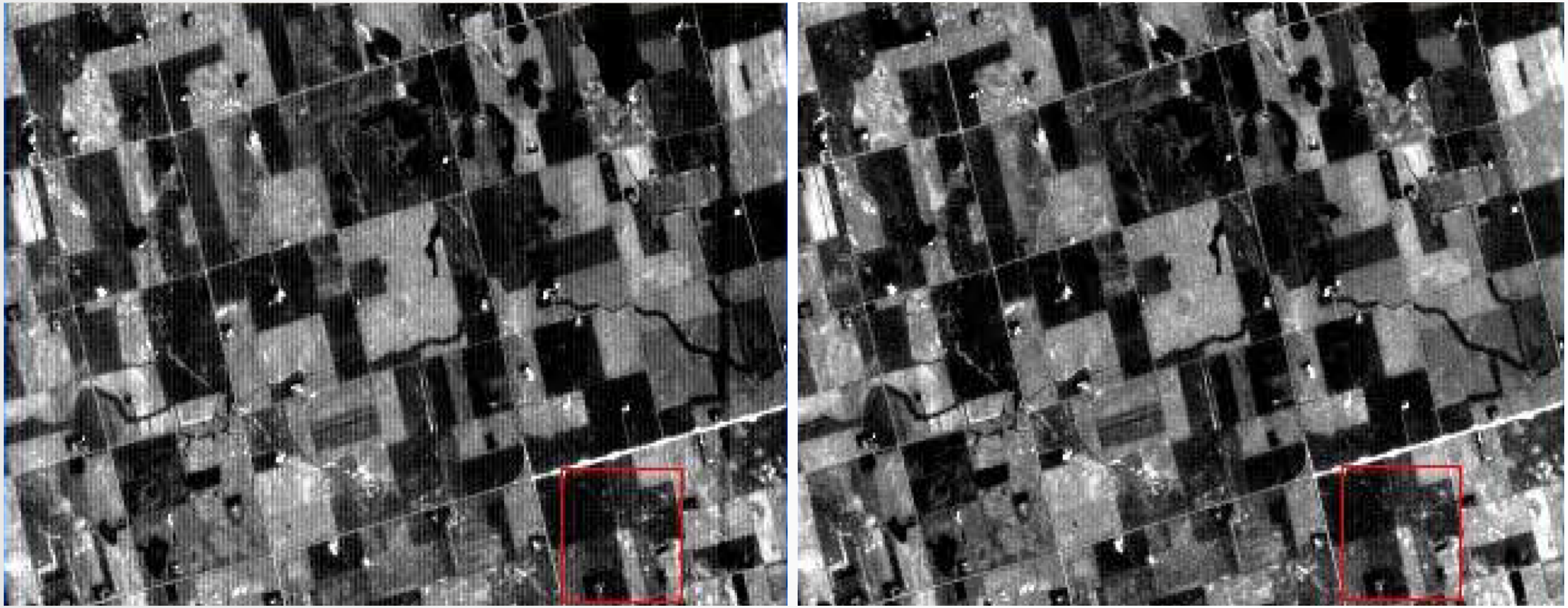
RELATIVE GAIN

- What is relative gain
  - When a detector array is manufactured each detector in the (let us assume) silicon substrate has slightly different behaviour, including
    - Different bias values when there is no signal
    - Some non-linearity in response
    - Different overall response to the same signal level (gain values)

So to get a stripe free image from a group of detectors in a linear array we need to equalise all the detectors, so we get the same response to the same radiant energy on the detector surface.

<u>This is the relative gain correction</u>.

RELATIVE GAIN STRIPING



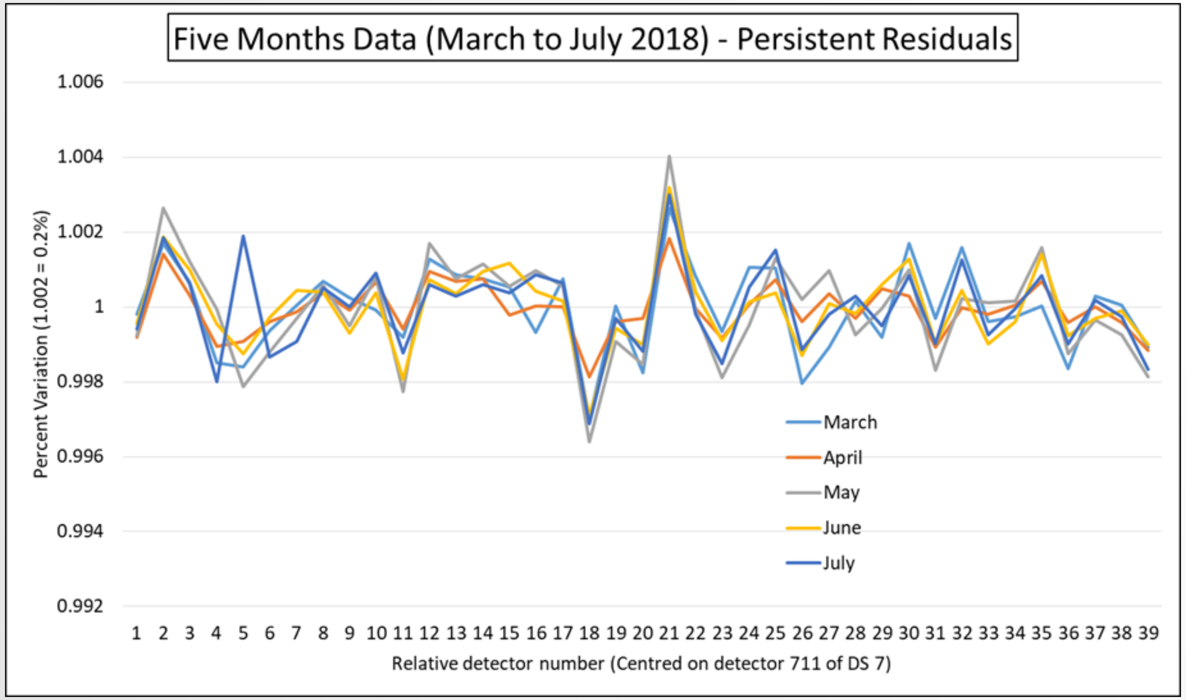
With a poor calibration (equalisation) of the image, we can still see the residuals (right). These will be persistent in all images.

RELATIVE GAIN – SENTINEL 2

- For the Sentinel-2 analysis we have been using radiometrically corrected (L1B) data. As it is radiometrically corrected, the detectors have already been equalised and we should see no residual calibration errors between detectors when we apply our relative gain algorithm.
- The MPC (responsible for the calibration) states that the residual errors are at the 0.01% level based on the monthly diffuser analyses, much better than the 0.2% initial requirements for the sensor.
- However, when we started to use normal images using our relative gain algorithm, instead of finding negligible residuals stated by the MPC, <u>we found large (larger than requirements) persistent residuals</u>.

PERSISTENT RESIDUALS

- A persistent residual is a calibration residual found in radiometrically corrected and equalised imagery. In theory, in a perfectly calibrated image there should be no residuals.



X-axis is a relative detector number, 39 detectors centred on detector 711 for the Blue band detector set 7 (there are 12 detector sets that make up the swath)

Y-axis is percentage variation observed, where 1.002 = 0.2%.

Each month is the average of five random images.

CORRELATED PERSISTENT RESIDUALS

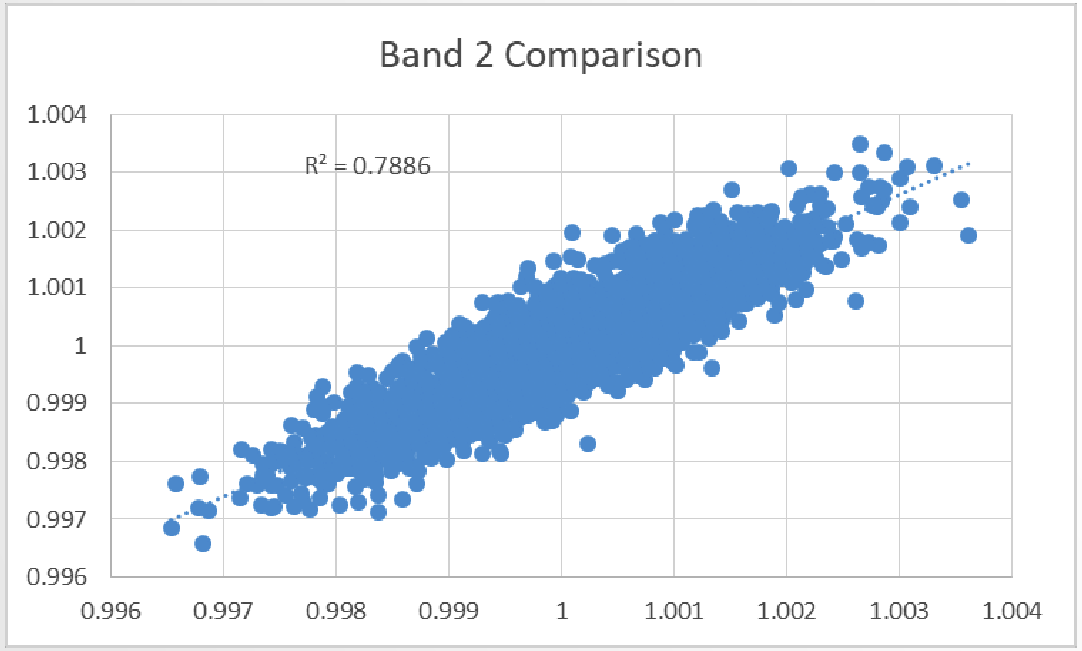
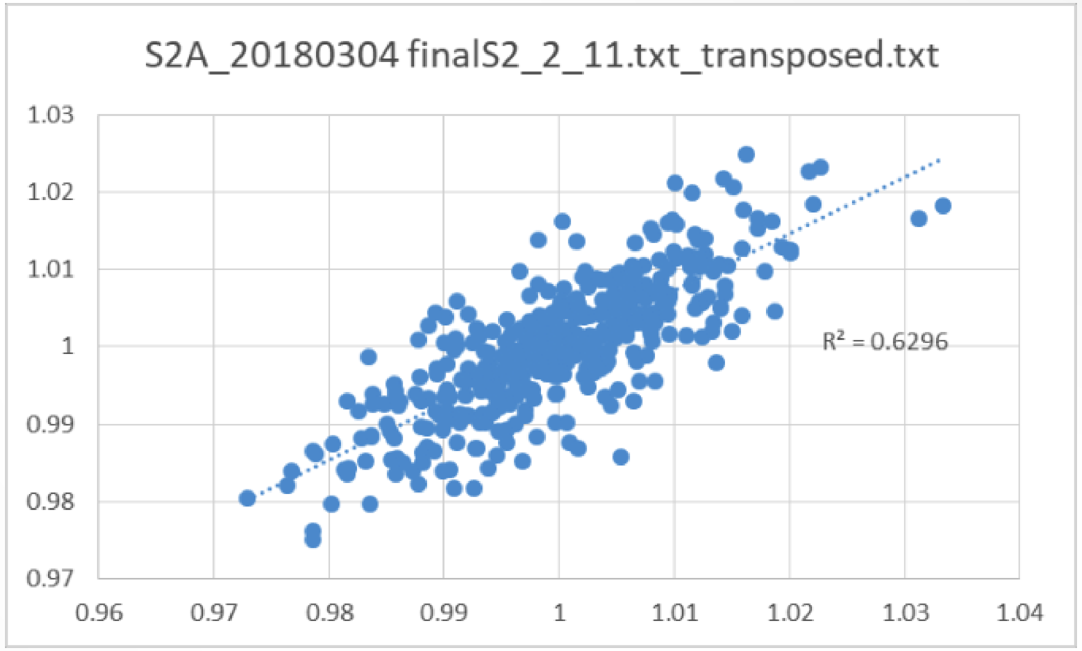


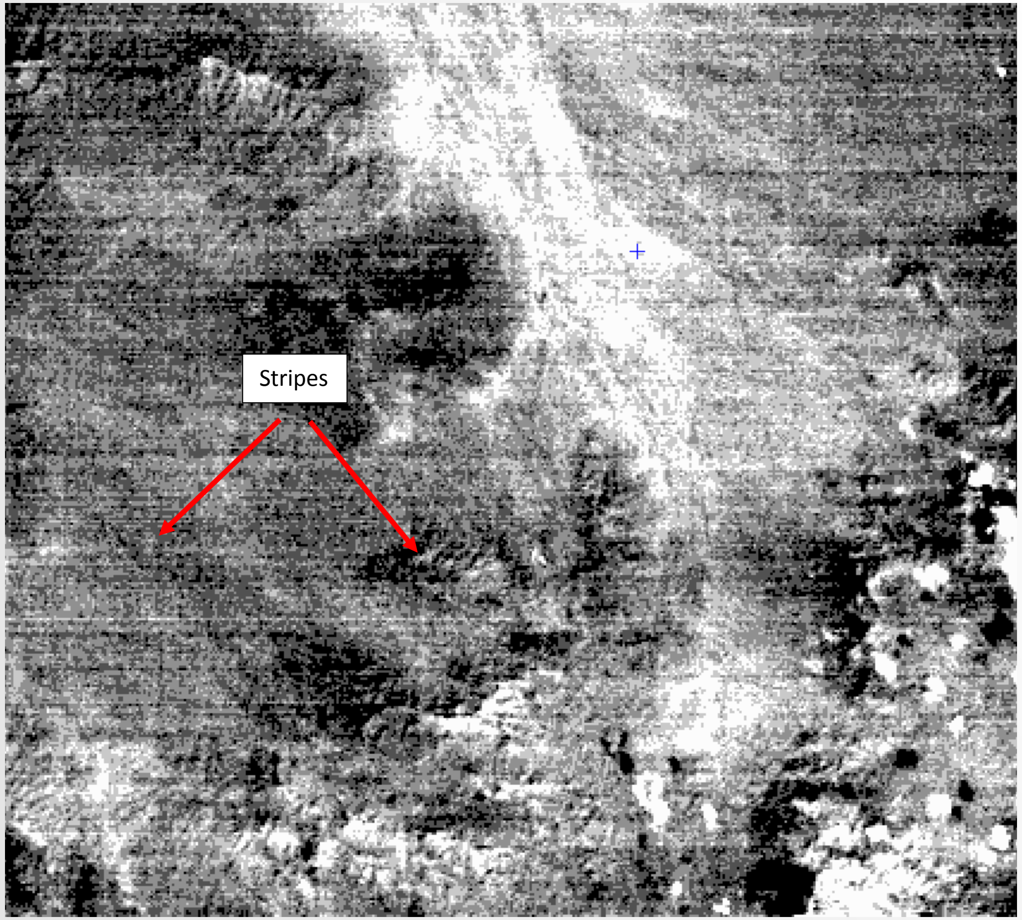
Figure 2: Comparison between the Africa (x) and Argentina (y) showing strong correlation



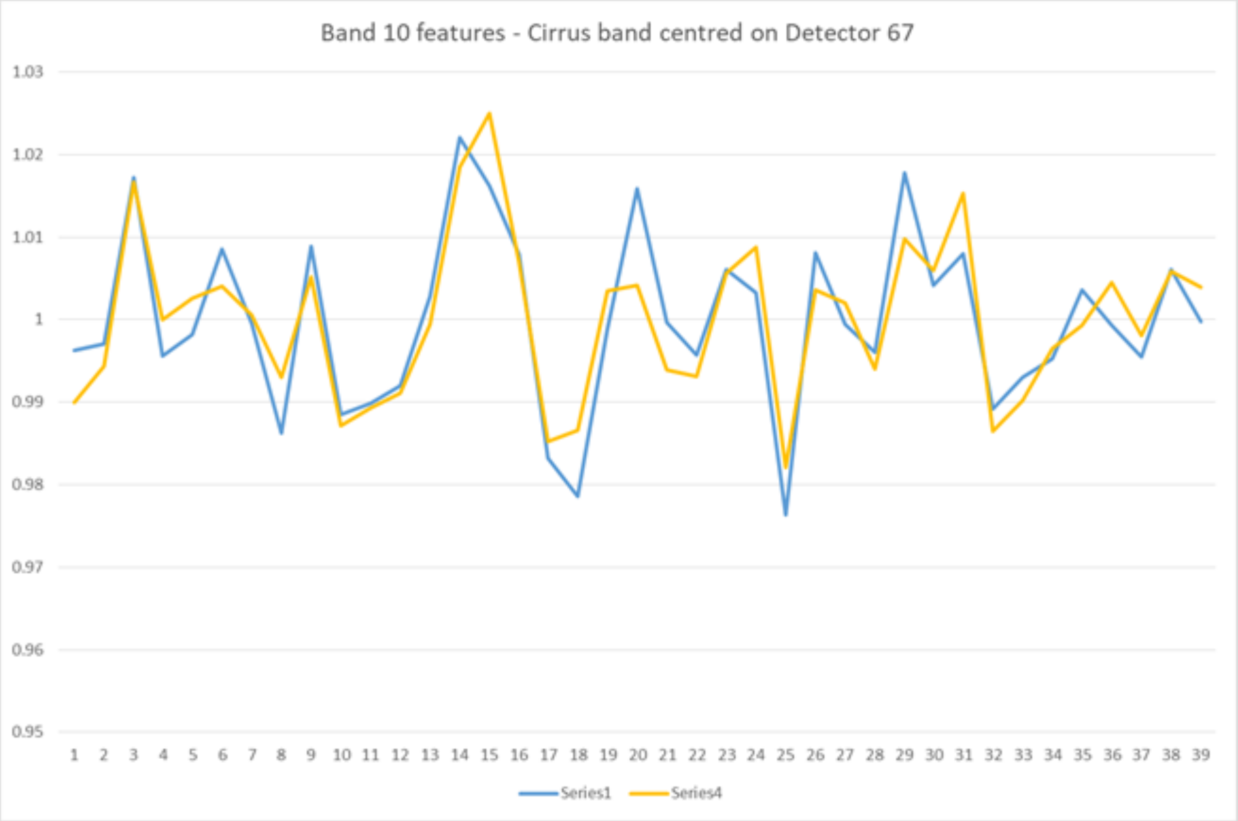
Band 10 - Argentina (x) and California (y)

If we get any two images and plot the calibration residuals determined by our relative gain algorithm in a scattergram we see very high correlations in the imagery (blue band left, cirrus band right). The blue band values exceeding 0.3%, the cirrus band values exceeding 2% a huge discrepancy.

CIRRUS BAND STRIPING EFFECTS



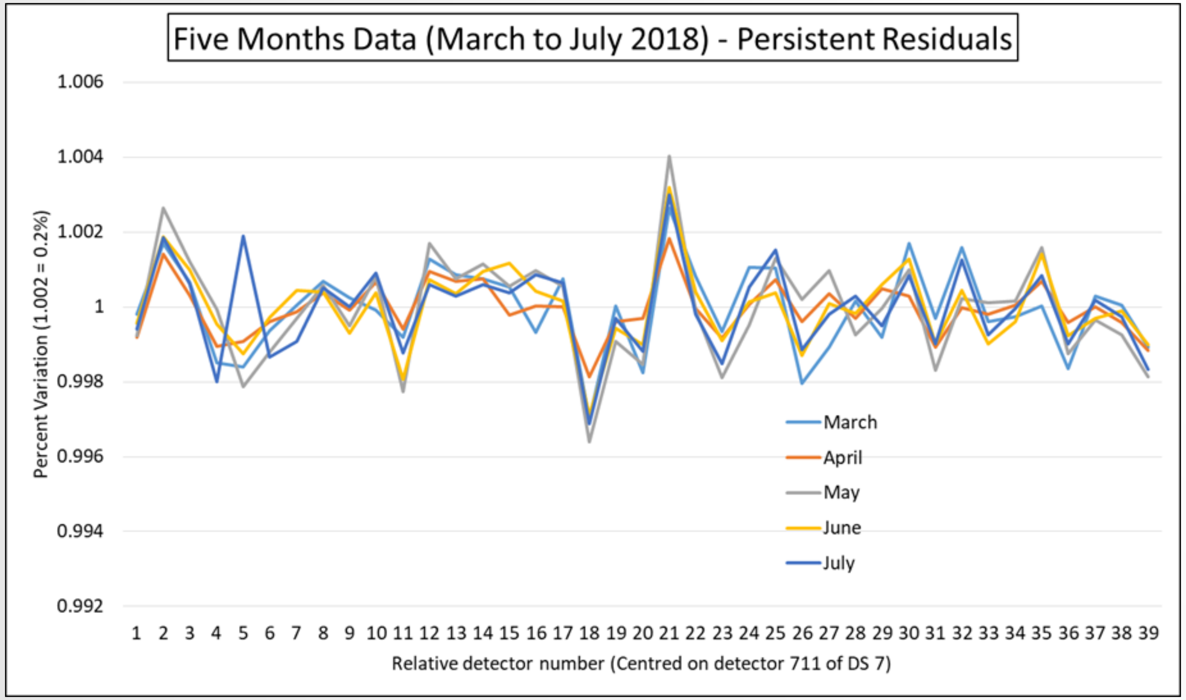
Cirrus band showing extensive vertical and horizontal banding effects



Band 10 features from the Argentina and California images Detector Set 2

PERSISTENT RESIDUALS – VARIABLE DEPTHS

- Finding persistent residuals means we have to ask the question…

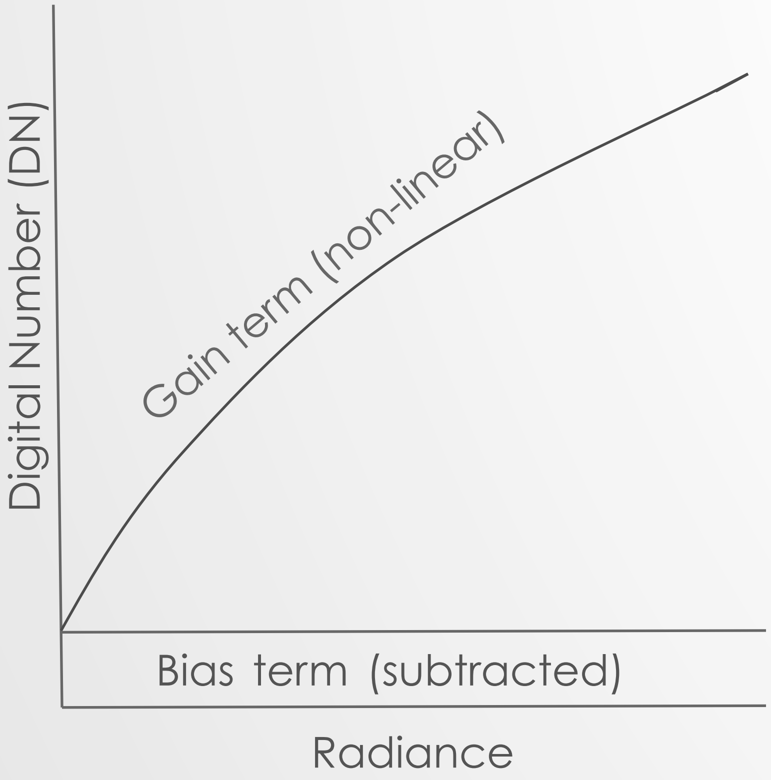


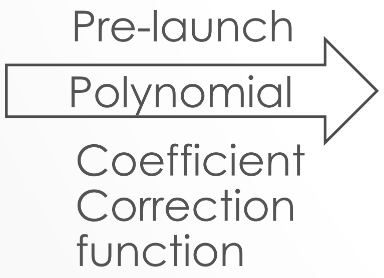
Why can we see these features in normal images but the MPC can not see them in diffuser images?

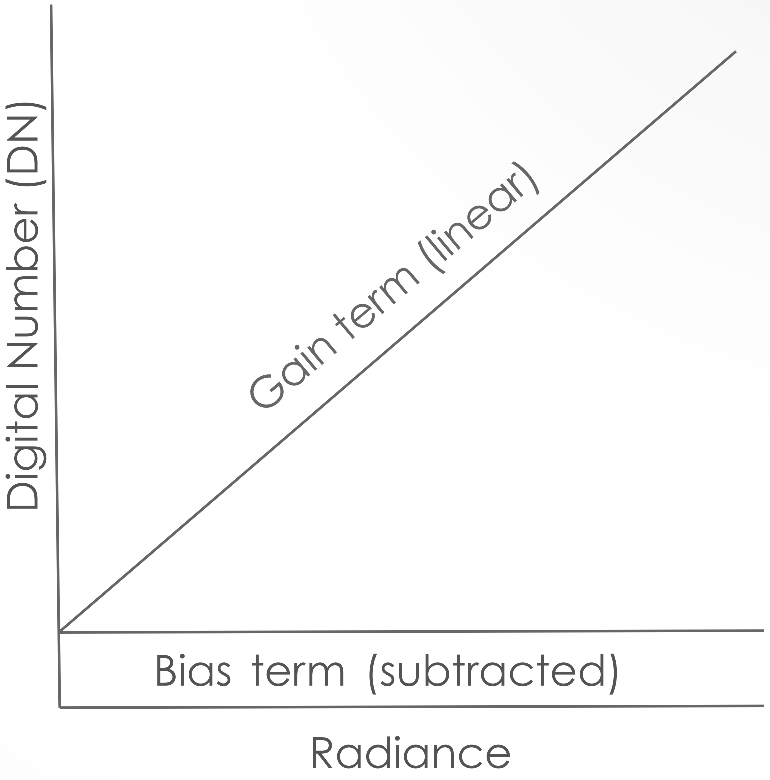
A clue to why could be what we see in the plot (left). Note that the grey line extremes are greater than the orange line extremes with the dark blue line extremes in-between.

We considered that this sort of behaviour, along with the fact that the MPC saw nothing could be related to a non-linearity error.

NON-LINEARITY PRE-LAUNCH

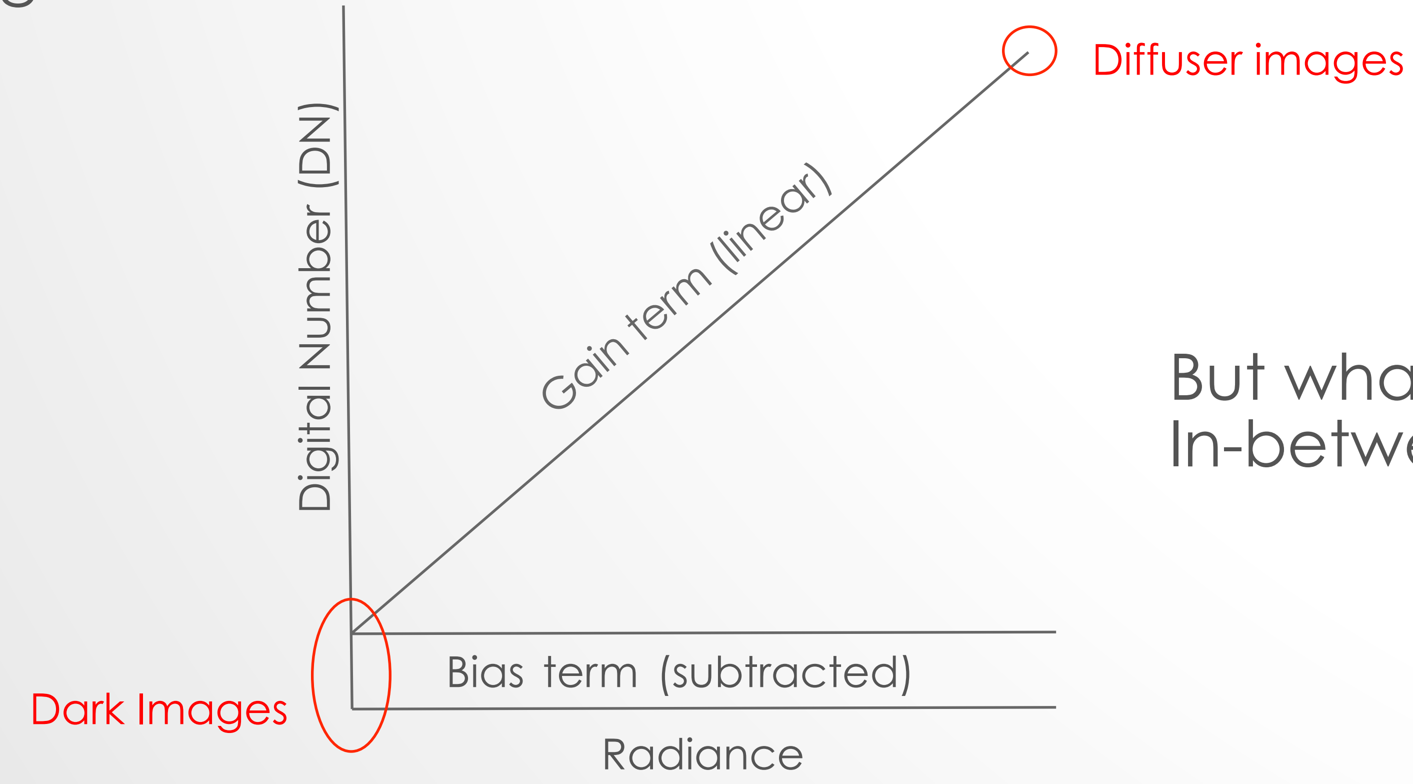






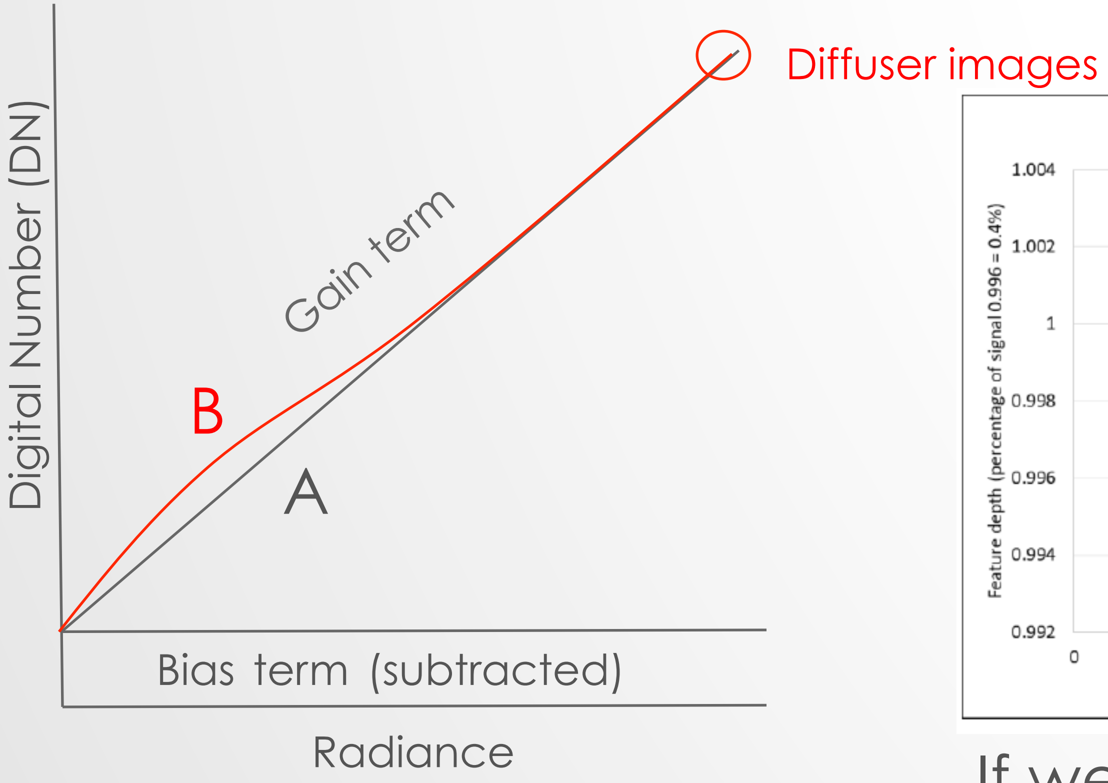
NON-LINEARITY

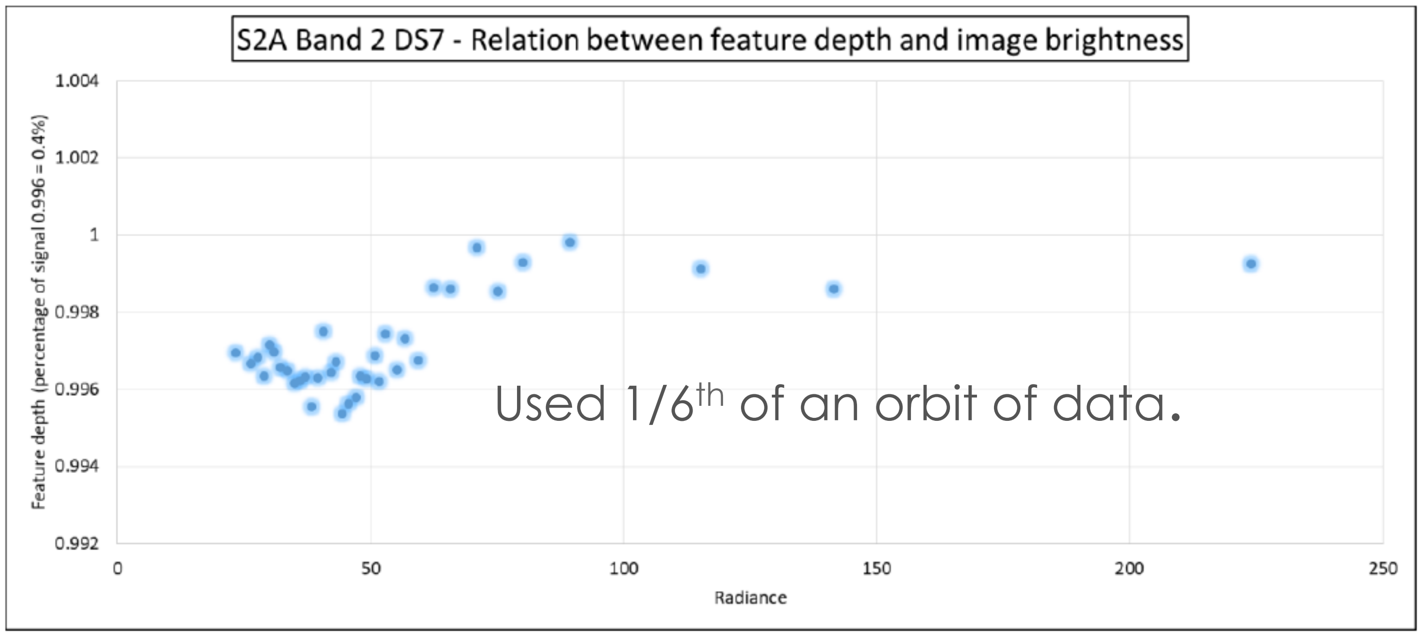
- Not easily validated in space, we can get the bias term from dark images and we can get the upper bound from diffuser images.



But what happens
In-between?

EXAMPLE OF NON-LINEARITY IN S2A?

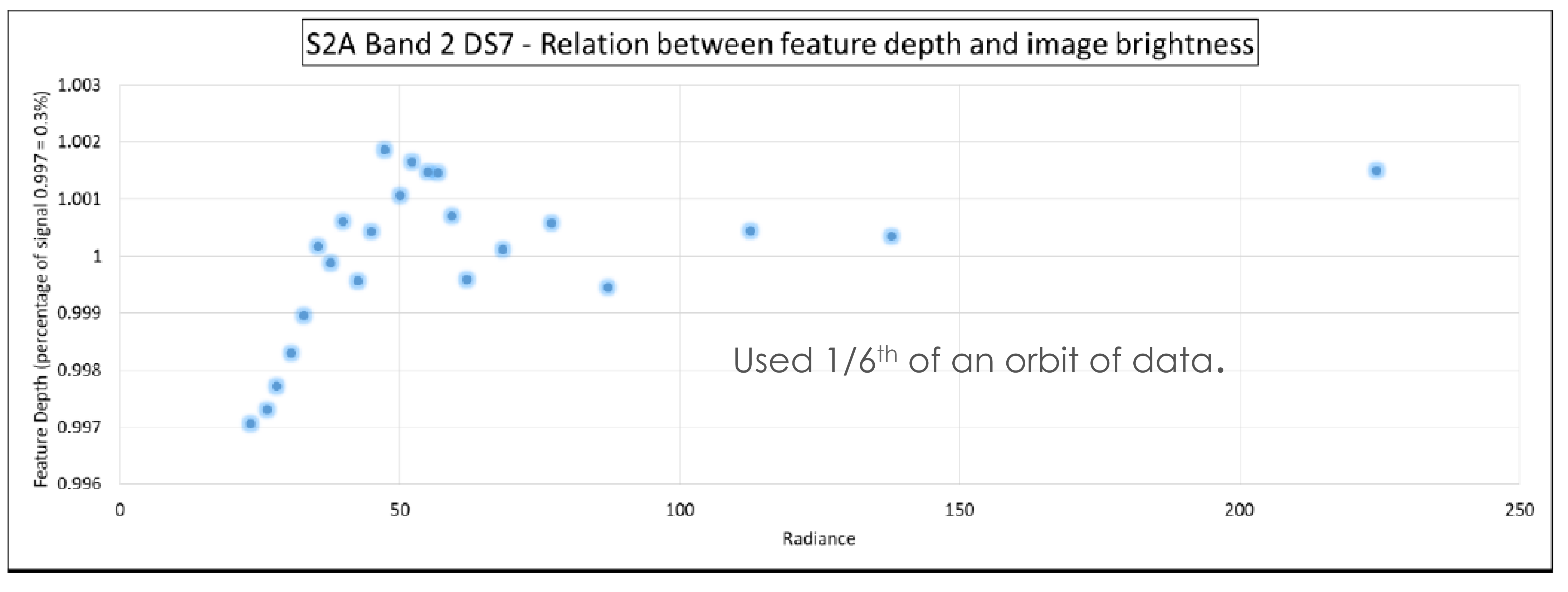




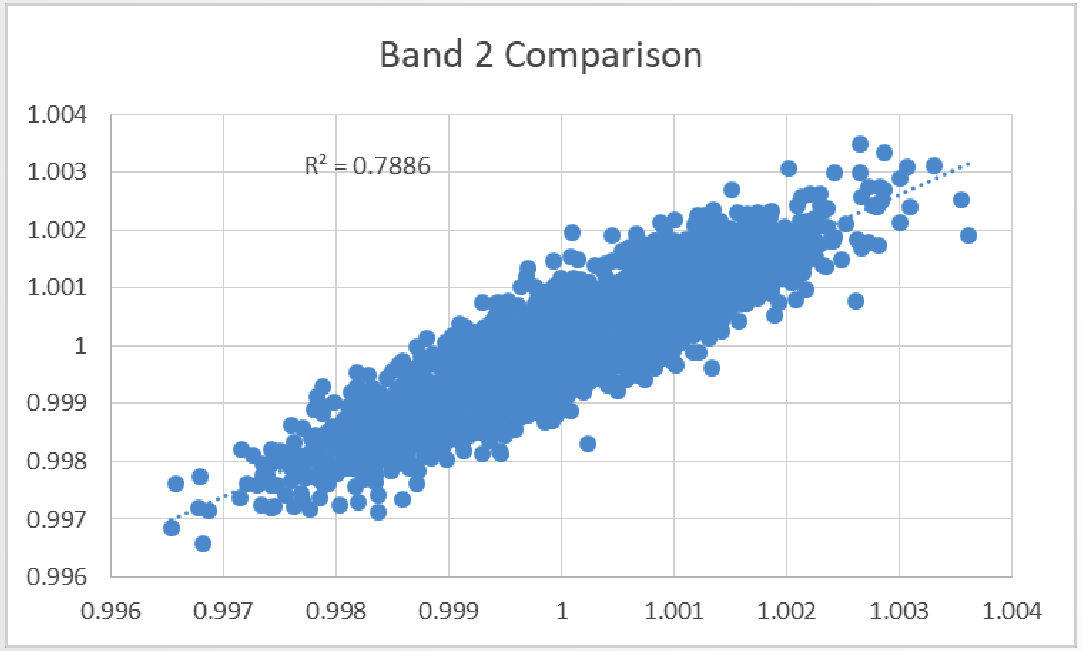
Assuming our non-linearity correction is not perfect (B)

If we ratio the values A/B we get a distinct pattern of behaviour which shows the correction required to remove the persistent residuals

ANOTHER EXAMPLE



CORRELATED PERSISTENT RESIDUALS



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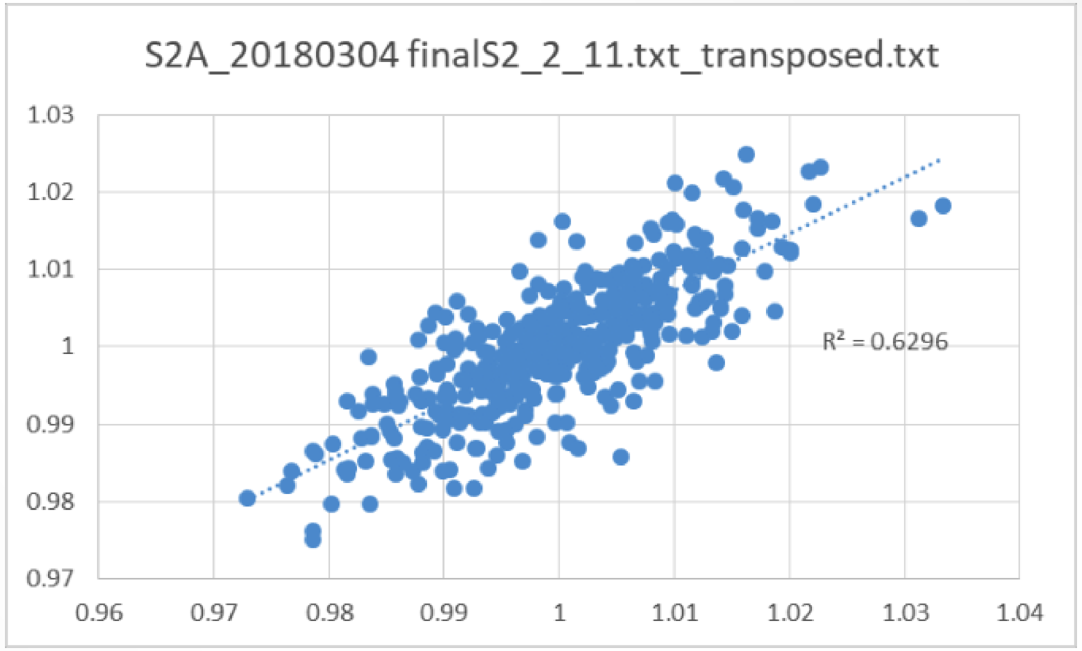

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CONCLUSIONS

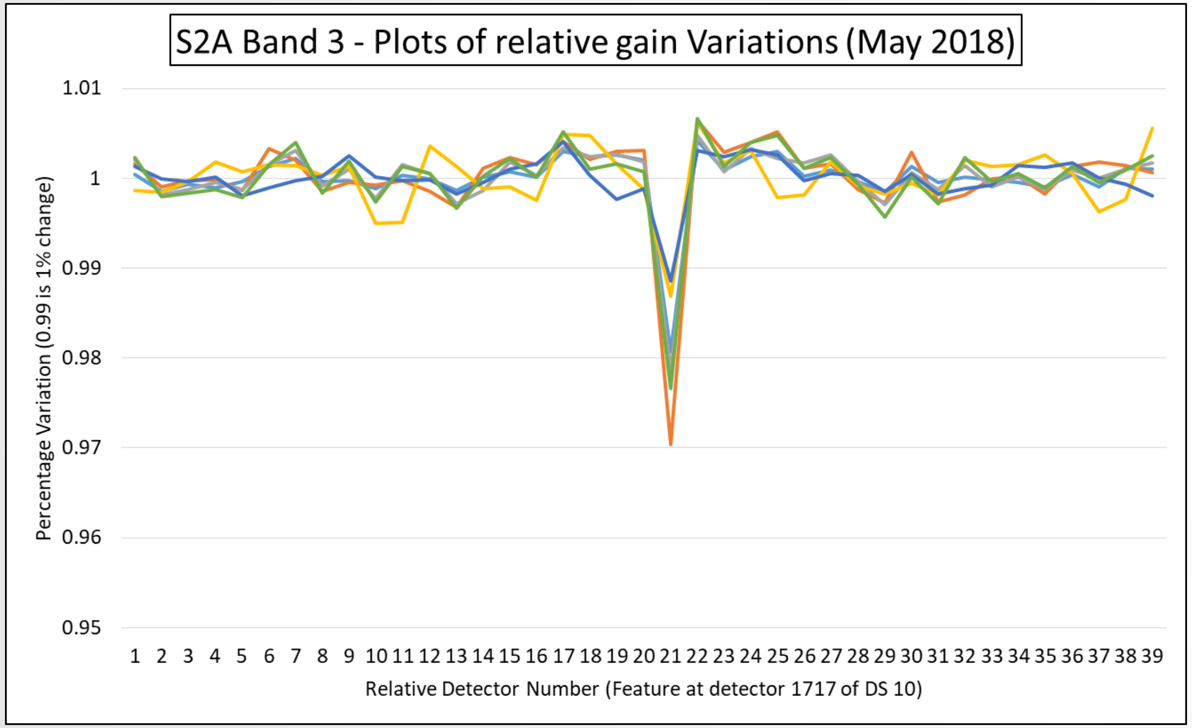
- We can see persistent residuals of the same average magnitude over an extended time period, producing artefacts that exceed requirements by over 100% in some cases. This was determined using <u>only one sixth of an orbit </u>of normal randomly chosen data.
- We believe they can not be seen in diffuser images as at the diffuser brightness there is no discrepancy, they are caused by poor non-linearity correction in the brightness range of normal images.

<u>Recommendation</u>

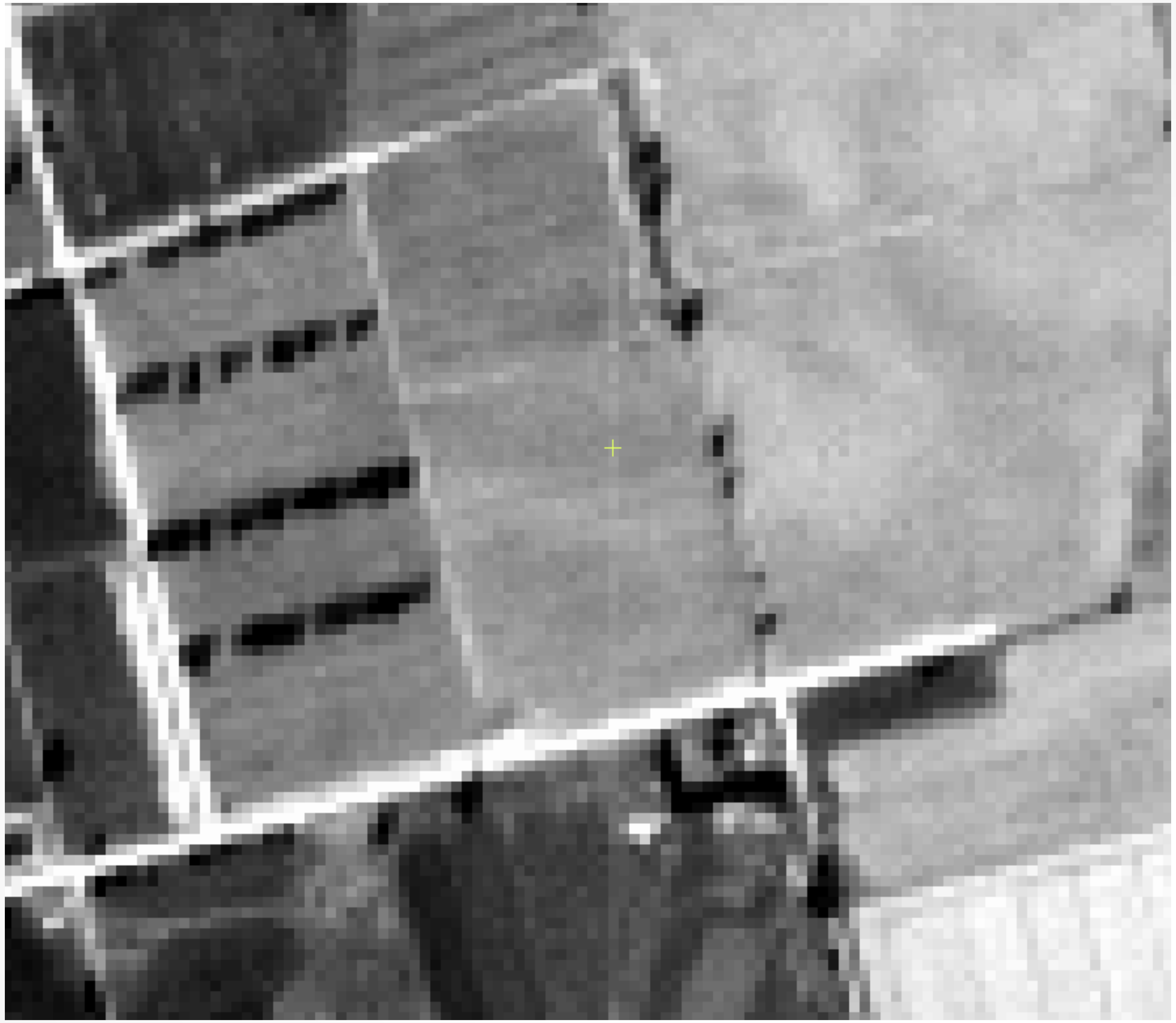
- A whole days worth of data (14 orbits), bright snow and clouds to dark terminator data should give a good range to fully define non-linearity and produce correction terms to be applied to Sentinel-2 to avoid this issue in future. This can be automated and updated as needed with one days notice.

WHAT ELSE CAN WE SEE?

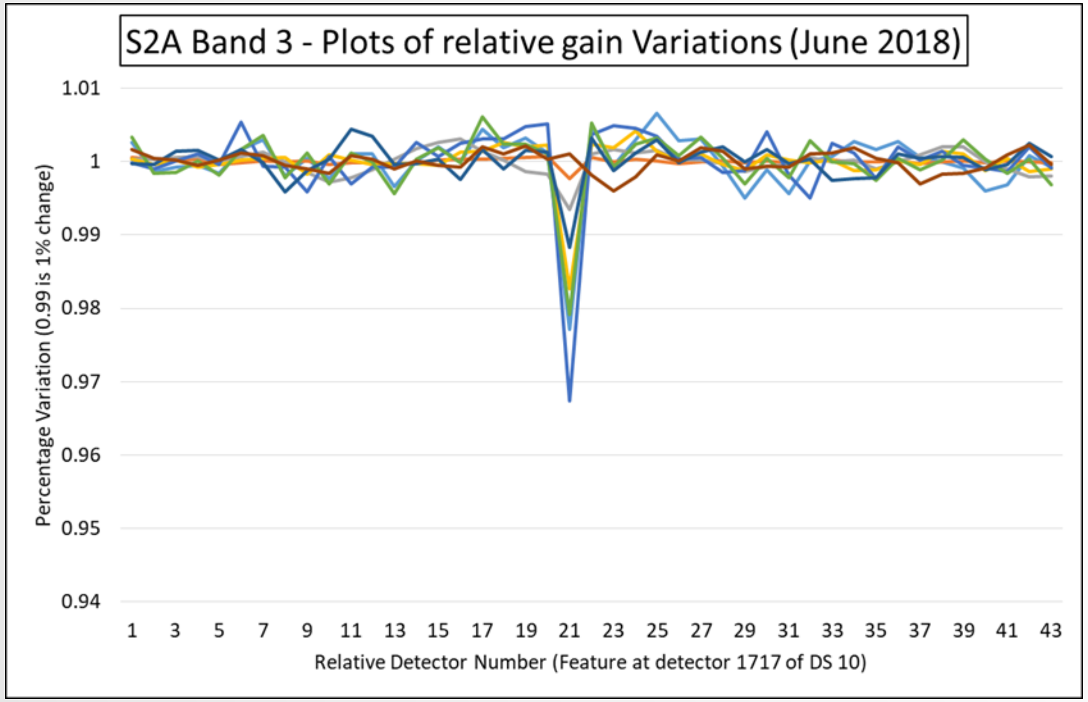
LARGE ERROR SEEN IN MAY 2018

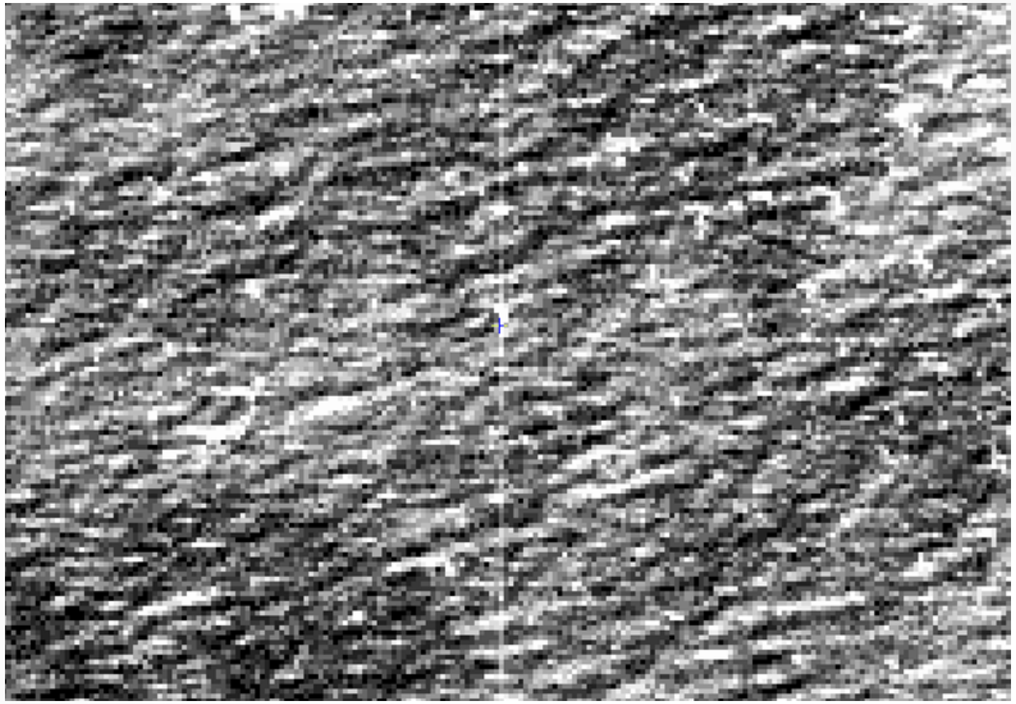


A 2-3% error residual seen in all images processed in May, producing visible artefacts. Green band DS 10.



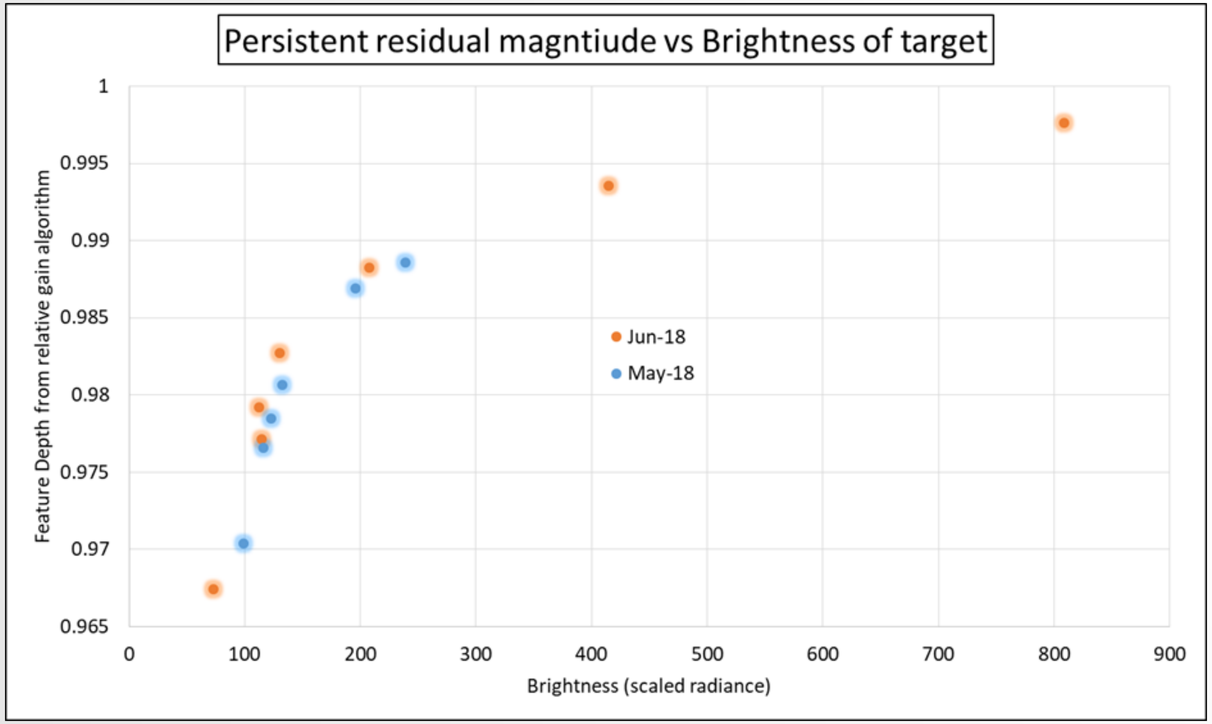
STILL THERE IN JUNE !

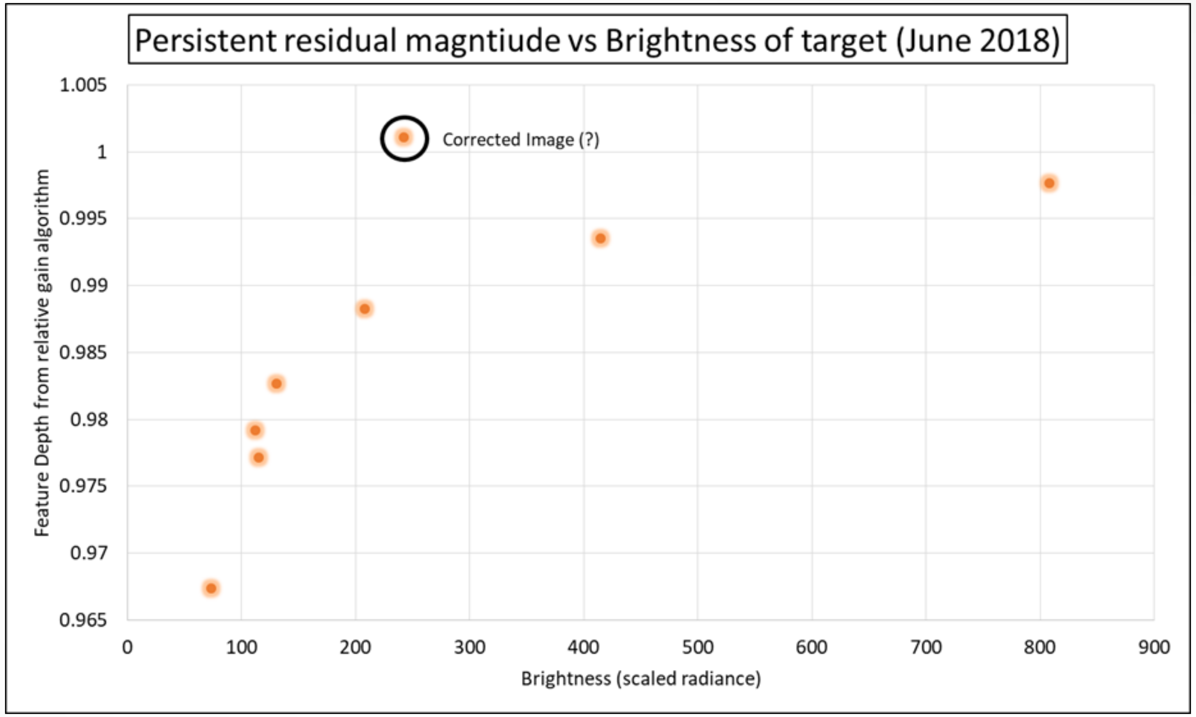




The same feature persists throughout June, until the 21st June, then it disappears. Note the variation in the depth of the feature, are the changes related to brightness variations?

PLOTTED FEATURE DEPTH AGAINST SCALED RADIANCE

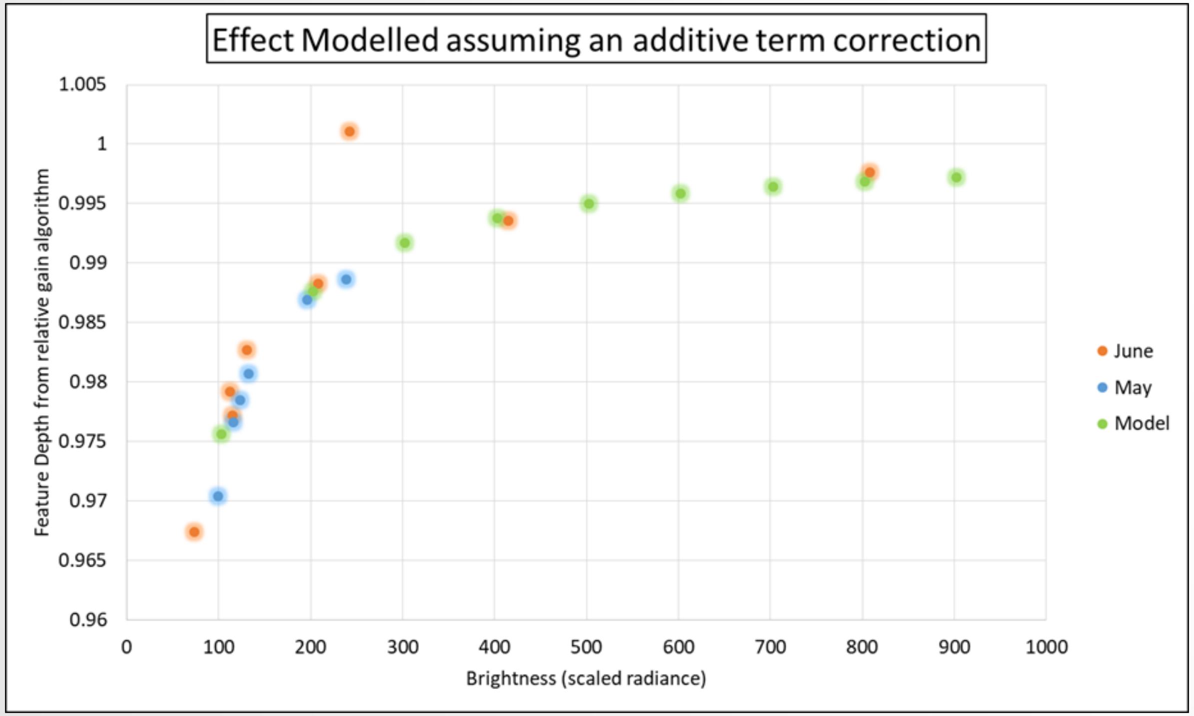




May and June data shows a very consistent feature depth with brightness, converging towards a value of one.

The last image we have (June 21st) no longer fits the profile, we assume a correction was made.

MODELLED ADDITIVE EFFECT



We created a very simple model assuming an additive term of 2.5 scaled radiance units (green dots) which accounted for almost all the variation seen.

Therefore we can distinguish quite clearly between additive terms where the model converges towards one, and multiplicative effects shown previously.

FEATURE BACK IN JULY

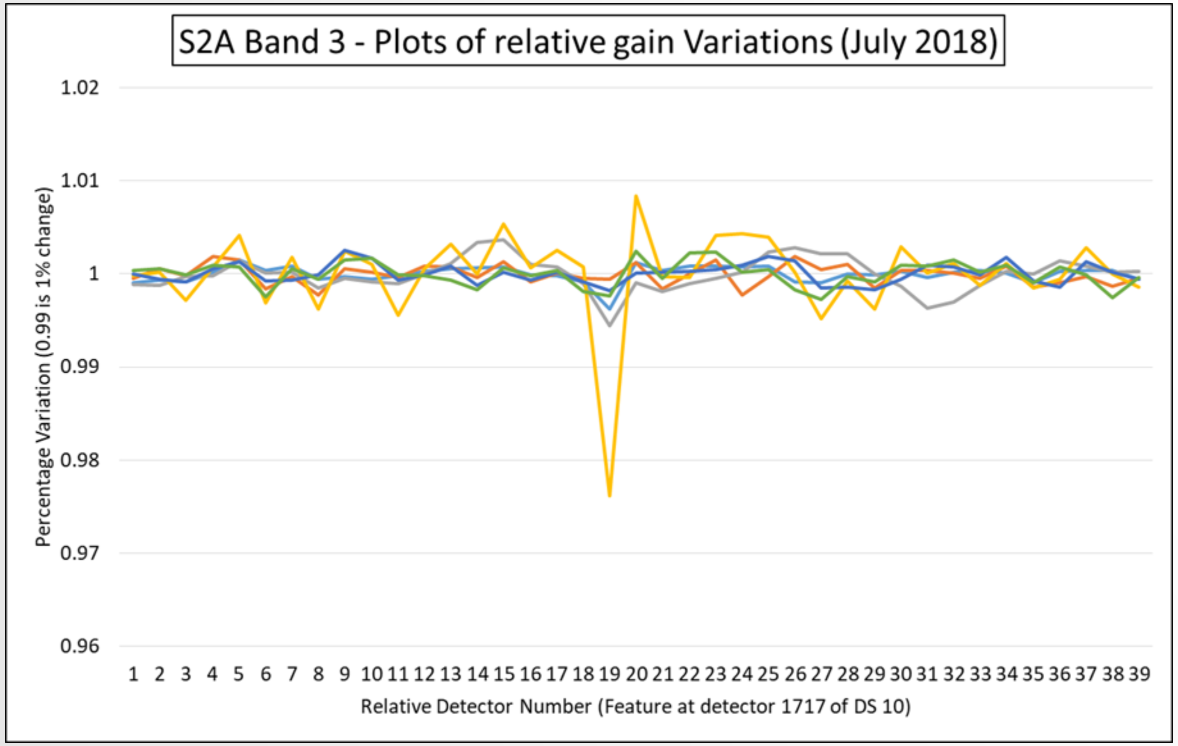
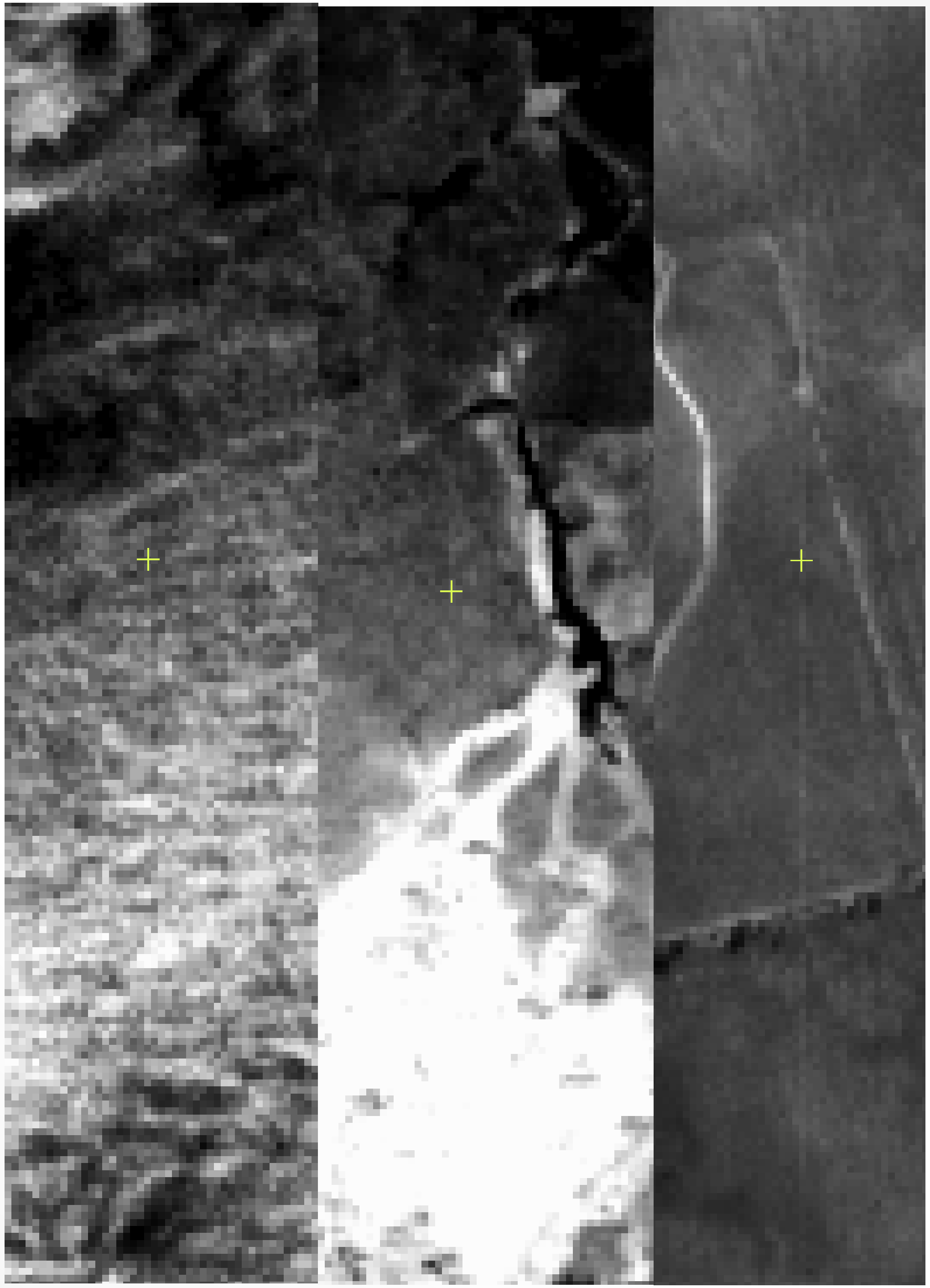
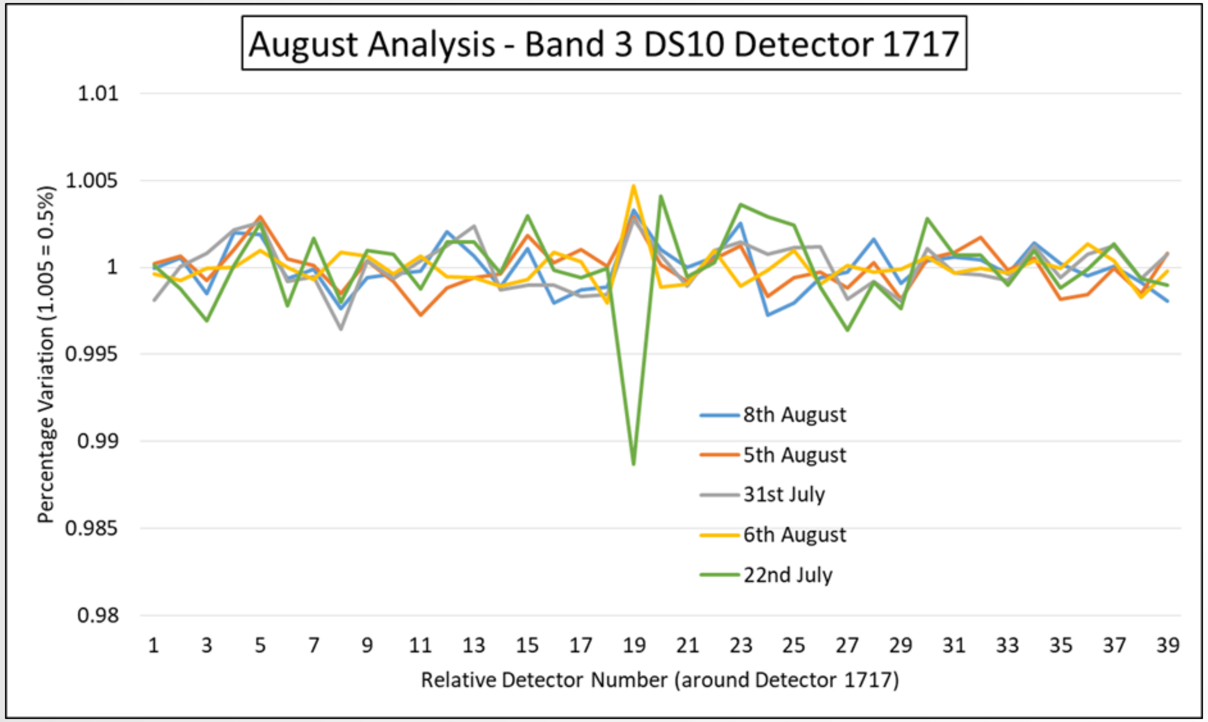


Image	Date	Magnitude
North America	3rd July 2018	No noticeable feature
Europe	3rd July 2018	No noticeable feature
South America	3rd July 2018	No noticeable feature
Africa	8th July 2018	0.38% feature
Australia	8th July 2018	2.4% feature
Asia	12th July 2018	0.55% feature



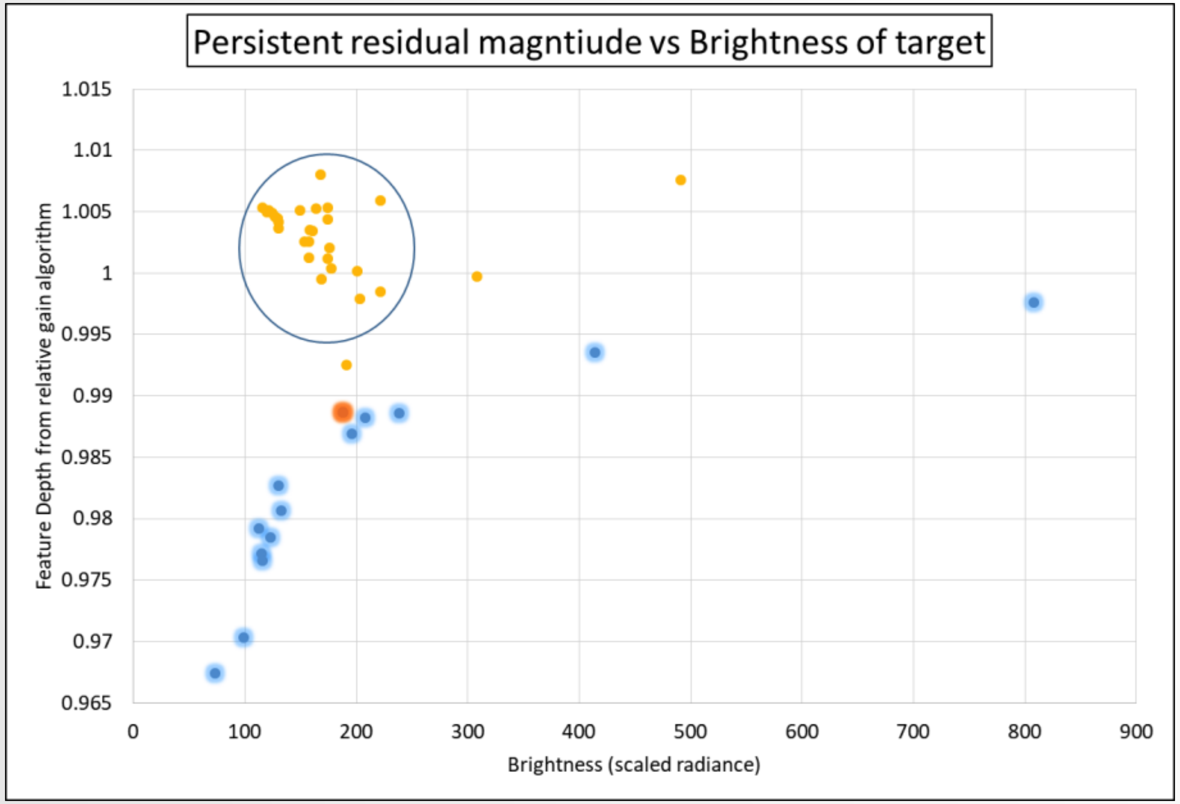
FINALLY FEATURE DISAPPEARS IN AUGUST !



After three months finally on the 22nd July the feature disappeared (at least until the 8th August), but we saw a small inverse feature in its place.

Breaking good news for ESA…
A quick look at the 17th and 18th August showed that the large feature had not returned, the small inverse is, however, still present.

RESIDUALS NOW LOOK DIFFERENT



The original May and June data is shown in blue, the 22nd July image is shown in orange.

The later images with the inverse feature are shown in yellow. The feature straddles the one line, it has structure.

Probably a multiplicative persistent residual.

CONCLUSIONS ON THIS FEATURE

- It was a large feature, present for more or less three months and ten times larger than requirements. It was corrected at least once and returned.
- We identified it as a bias term error, which should be detectable in the dark images collected monthly.
- The high temporal sampling of using normal images means we can identify the presence of these features as they occur within a single orbit and not wait for a month and either flag or correct them.

SUMMARY AND CONCLUSIONS

- Using the diffuser alone as a reference, being so bright, is far removed from the expected surface brightness, any errors in the non-linearity curve will produce persistent residuals whose depth will vary with the surface brightness
- Using single normal images its possible to recover the persistent residuals.
- We can separate bias term and multiplicative errors based on their behaviour over different brightness targets.
- Using single images we can see effects appear and disappear and provide alerts and even automated corrections to remove striping induced by these effects with a sampling frequency that exceeds on-board and alternative vicarious methods.

RECOMMENDATIONS

- A single orbit of data should be provided as a minimum, this should give sufficient information to map all the non-linearity differences we can find, a whole day (14 orbits) might give enough to provide definitive corrections for non-linearity effects. This would also be useful for focus estimation.
- It would help to work alongside the MPC to determine if they can confirm the effects we see in the imagery (where possible) and that we can perhaps trial correction methodologies that can be implemented to avoid the issues demonstrated in this presentation. Currently communication with the MPC is non-existent and slows the development work considerably.

EOSense – Conservation and outreach with Virtual Reality

Thank you for your attention

FOCUS QUICKIE

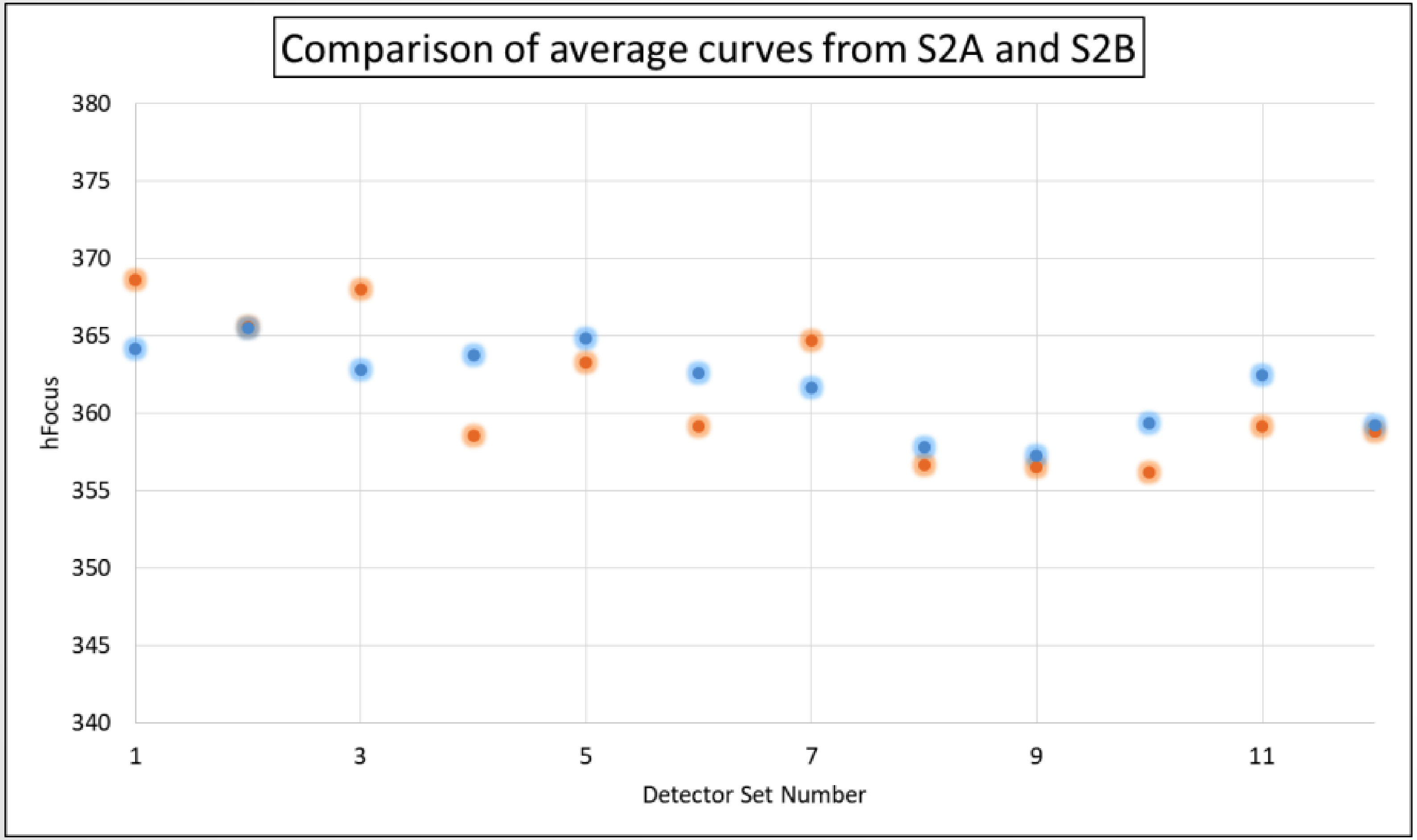


Figure 4: Average curves generated using 27 S2A images and 21 S2B images

Using the same one sixth of an orbits worth of data we were also able to assess the across-track focus variation across the twelve detector sets

Some asymmetry can be seen, higher on the left (S2A blue, S2B orange).

Ideal would be a whole days worth of data from each sensor.

Possibility of trending focus change with time.