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EUMETSAT

GERB calibration evolution – a cross-study with CERES

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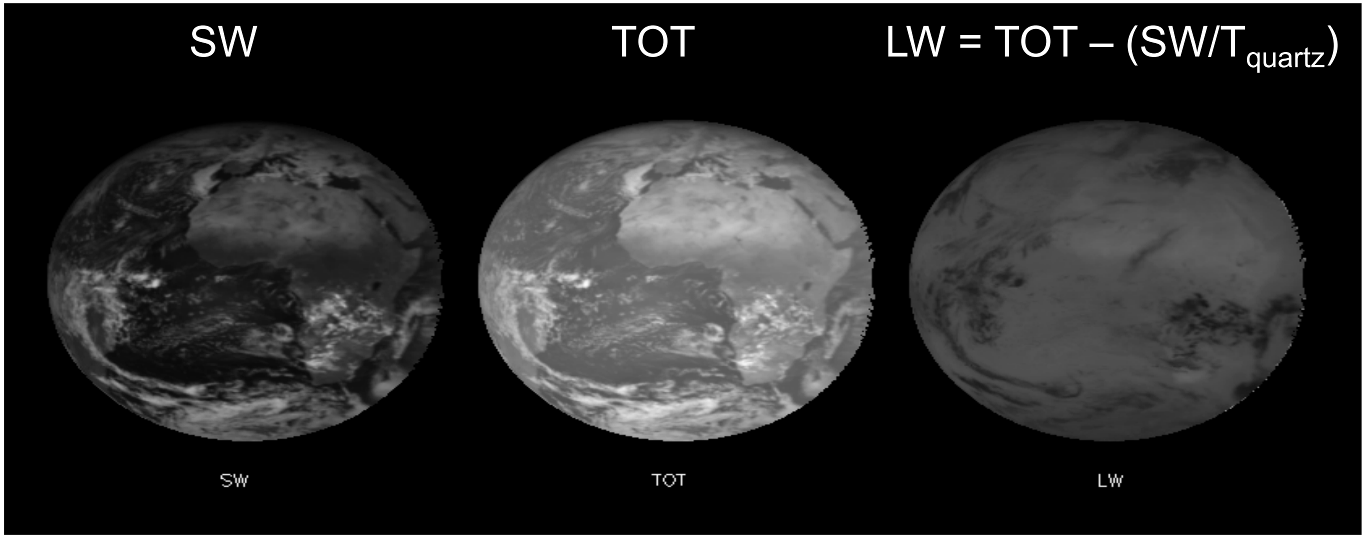
Introduction

GERB (Geostationary Earth Radiation Budget) are a series of broadband instruments:

TOTAL - (UV – Far Infrared) , (0.35μm to >150μm) ; SW - Quartz filter, (<4μm)
Nominal observation region - 60°N to 60°S, 60°E to 60°W
Linear array of 256 N-S detectors, taking 5½ minutes for a full scan



Raw pixel level radiance ---> Level 1.5 NANRG products
Processing, incl. higher res. METEOSAT imager SEVIRI, ---> Level 2 products
GERB-2 ----> METEOSAT-8 (April 2004-May 2007)
GERB-1 ----> METEOSAT-9 (April 2007-present)

Handover to GERB-3 planned in Feb 2013, but delayed due to GERB-3 despin mirror jam.

***UPDATE* 30th Apr 2015 GERB-3 resumed normal operation**

Aim of Study

TO DETERMINE CHANGES TO THE GERB CALIBRATION WHILST IN ORBIT

- Known change in spectral response across SW region

----> **CROSS COMPARISON OF GERB PRODUCTS WITH CERES SSF EDITION 3A (FM1, FM2, FM3, FM4)**

- Both use Denton UV enhanced silver-coated mirrors
- Both use a quartz filter in the SW
- Monitor GERB/CERES SW radiance ratio through time

Study compares all products with each CERES instrument for both LW and SW, however this talk will focus on the comparison between the **GERB-2 HR (9x9km) product** and the **CERES instrument FM2** for **June 04-06**.

Data Matching

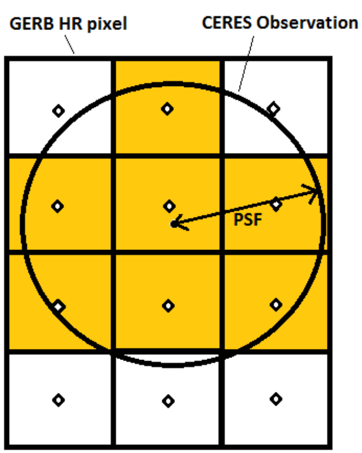
- **ANGULAR**

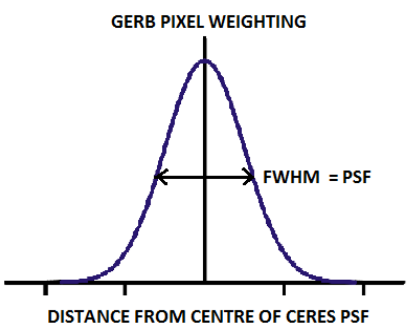
  -> Co-angular criteria - Observation angles must be < 8 °

- **TEMPORAL**

  -> Time of CERES observation must be within 7½ minutes

- **SPATIAL**





- GERB pixels with centres within a CERES PSF circle
- GERB radiance match as weighted Gaussian mean of these pixels

- **ADDITIONAL CRITERIA**

  -> Viewing zenith angle (VZA) < 60 °; Solar zenith angle (SZA) < 60 °;

  -> Ocean sun-glint angle > 25 °; GERB and CERES radiances > 0 W sr^{-1} m^{-2}

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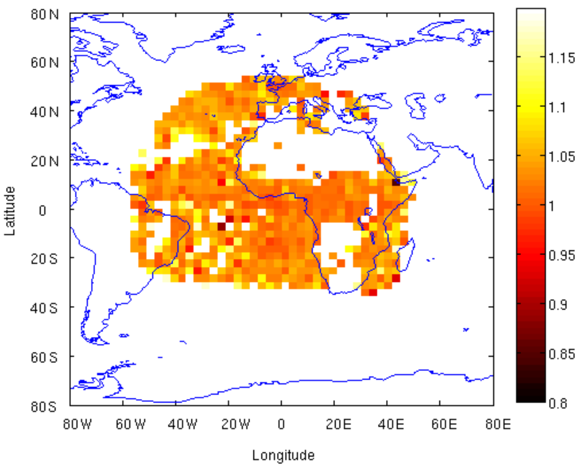
Some Initial Considerations

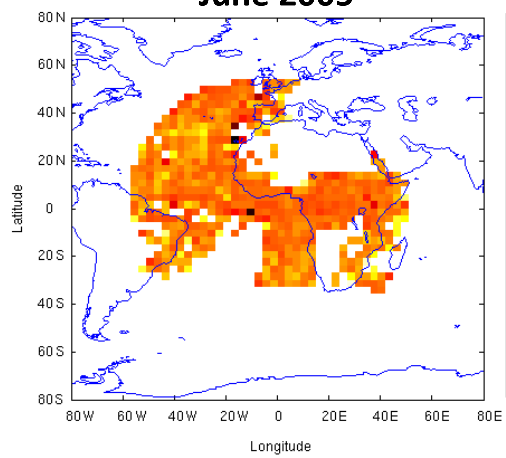
Earth split geographically into 3x3° regions. A GERB/CERES SW radiance ratio is calculated for each region as $\Sigma(\text{Radiance}_{\textbf{GERB,region}}) / \Sigma(\text{Radiance}_{\textbf{CERES,region}})$.

Completely Overcast Observations

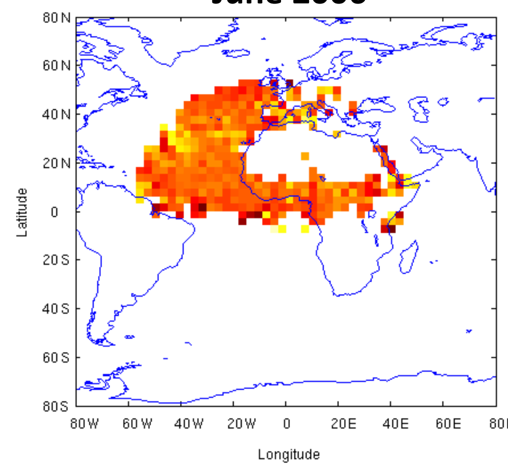
June 2004



June 2005

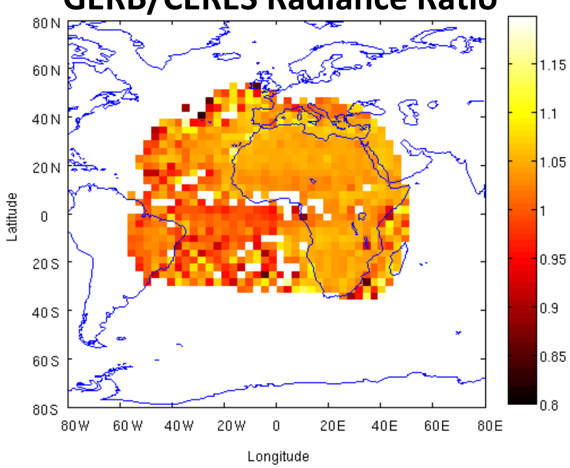


June 2006

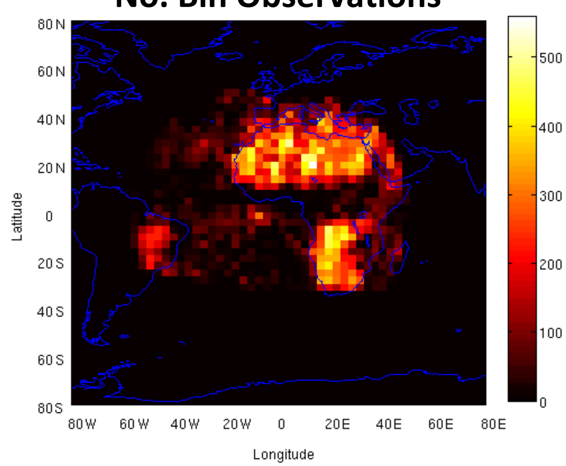


Completely Clear Sky Observations, June 2004

GERB/CERES Radiance Ratio



No. Bin Observations



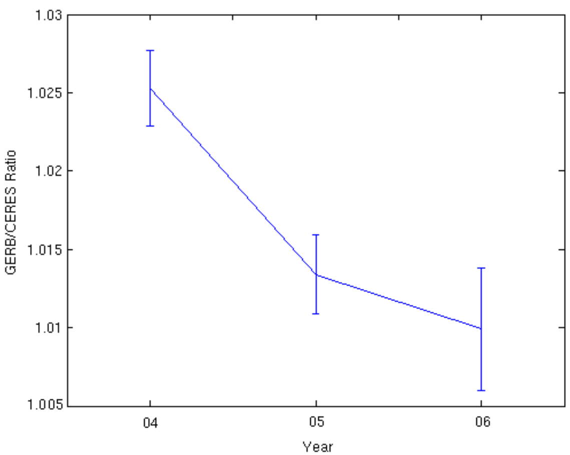
- **<u>Different areas of matching each year</u>**
- **Must be careful to <u>ensure sufficient matches for any sampling</u> so as not to calculate a representative ratio using samples of drastically different numbers**

Some Initial Considerations II

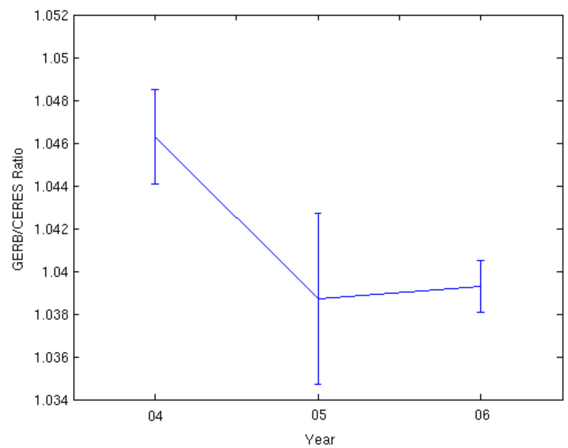
Ratios are calculated as $\Sigma(\text{Radiance}_{GERB,scene}) / \Sigma(\text{Radiance}_{CERES,scene})$

Errors are calculated as $2\sigma/\sqrt{(N-1)}$, where σ is the standard deviation of the average daily ratios, and N is the no. days.

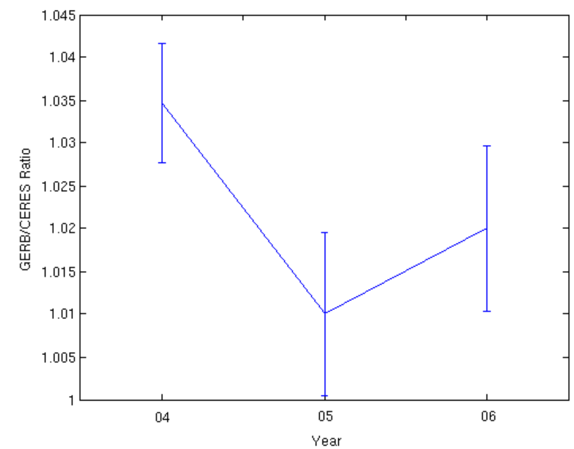
Completely Overcast



Clear-Sky Bright Desert



Clear-Sky Ocean

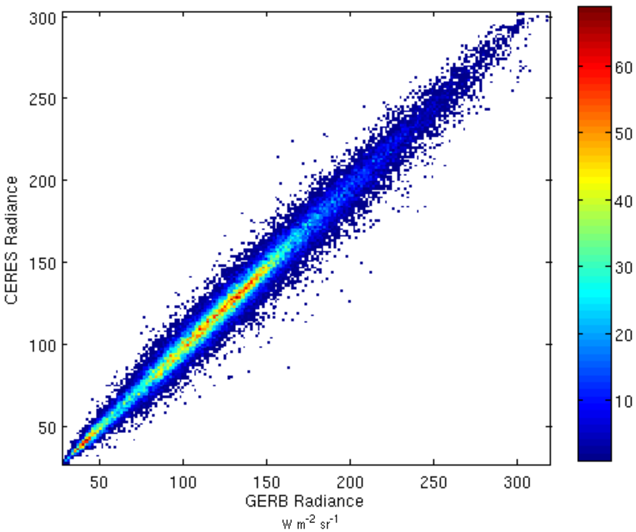


GERB/CERES radiance ratio and evolution expectedly **dependent on scene…**

…However, is separation by scene sufficient to apply a calibration update?

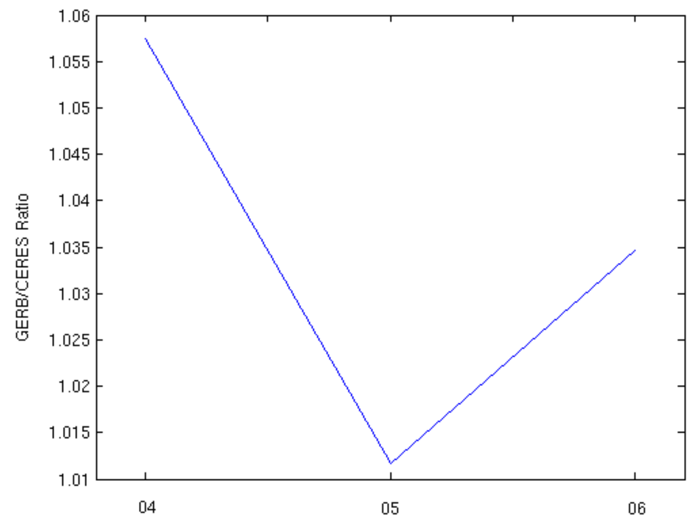
Some Initial Considerations III

2D Histrogram plot -
Completely Overcast June 2004



Same process for 05 and 06 →

GERB/CERES Radiance Ratio for June 04,05,06 calculated from linear regressions



Vastly different to that suggested by previous slide

Linear regression: $R^2 \approx 1$, Intercept < ± 0.1

Considering linear regressions performed on different ranges of GERB radiances above….

> 150 W sr^{-1} m^{-2} -> CERES = 1.187*GERB – 71.105

< 150 W sr^{-1} m^{-2} -> CERES = 1.430*GERB – 13.129

….illustrates that within a particular scene the GERB/CERES radiance ratio still has an **inherent dependence on the radiance**.

---> **Can a theoretical analysis help us find a good variable to separate by?**

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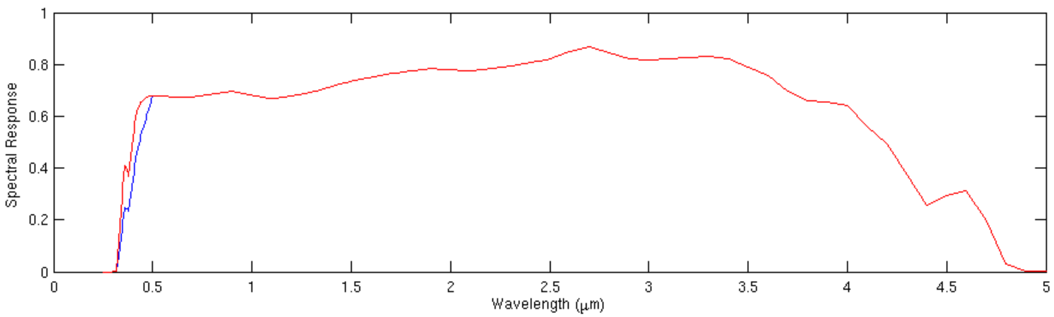
Theoretical Spectral Analysis

GERB assumed spectral response ϕ(λ) and changed response ϕ'(λ)



- Alter GERB spectral response at the shortest wavelengths
- Multiply **ϕ(λ)** by $e^{a(\lambda-0.5)}$, where a = -4ln(0.4), for $\lambda < 0.5\mu m$
  (following spectral response evolution study of CERES in Matthews et al. (2005))

Use a database of 750 simulated spectral radiance curves L(λ) using SBDART for a range of surface types (incl. use of the NASA ASTER spectral library) *(thanks to N. Clerbaux for access)*

For each scene, for each SZA 0:10:60, VZA 0:5:60, RAA (Relative Azimuth) 0:10:180, calculate:

Unfiltered radiance: $\int L(\lambda)d\lambda$
Assumed filtered radiance: $\int L(\lambda)\phi(\lambda)d\lambda$
Changed filtered radiance: $\int L(\lambda)\phi'(\lambda)d\lambda$
Unfiltering Factors $\alpha_{assumed}$, $\alpha_{changed}$ = Unfiltered Radiance/Filtered Radiance

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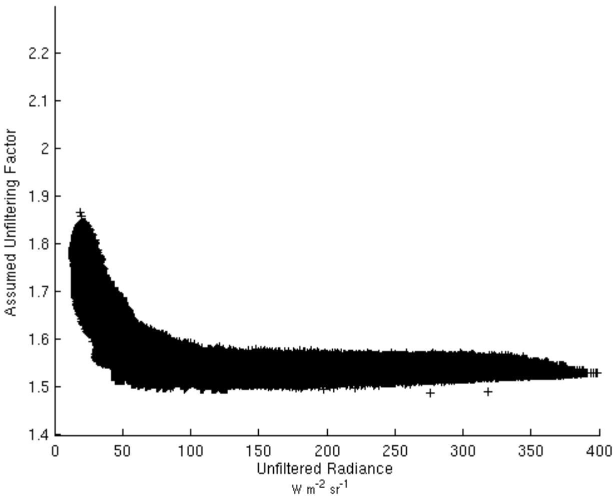
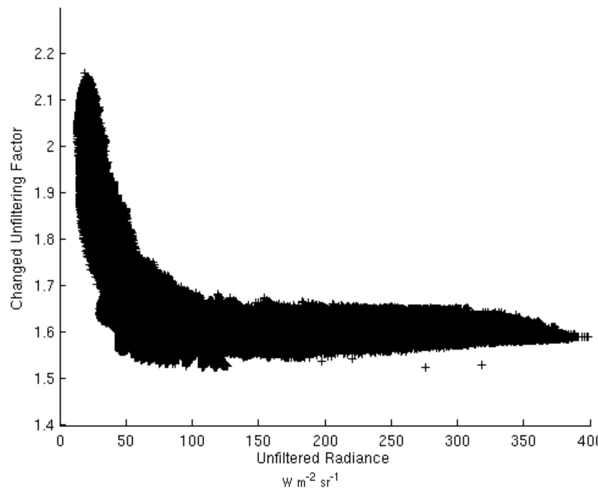
Predominantly Cloudy Scenes

THEORETICAL

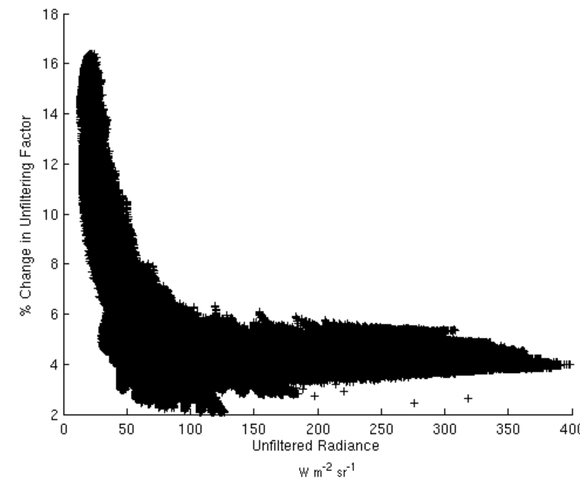
$\alpha_{assumed}$ vs. unfiltered radiance



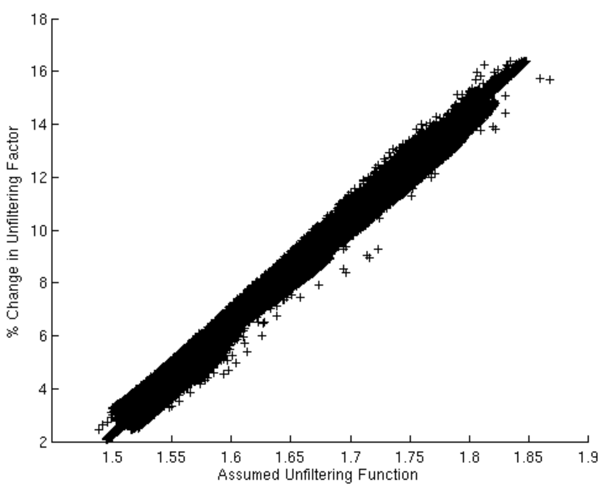
$\alpha_{changed}$ vs. unfiltered radiance



% change in α vs. unfiltered radiance



% change in α vs. $\alpha_{assumed}$



- Simulated change in GERB spectral response increases the associated unfiltering factor at all radiances
- **Percentage change in unfiltering factor appears to scale linearly with the assumed unfiltering function**
- Spread is due to variations in viewing geometry
- Does this linear relationship hold for all scenes plotted together?

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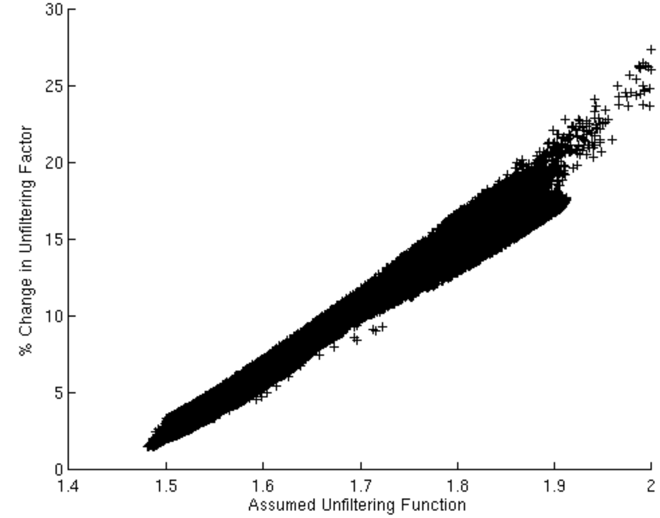
-> Linear relationship holds when all scenes are plotted together

All scenes, % change in α vs. $\alpha_{assumed}$



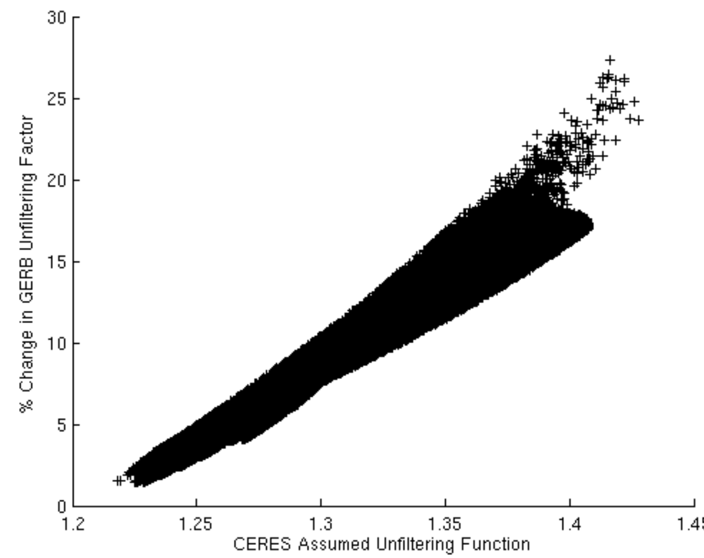
- However for use with real-world observations, only CERES unfiltered SW data is readily available currently.

- Perform same theoretical analysis with a CERES SW like response:

- **$\phi_{CERES}(\lambda) = \phi_{GERB}(\lambda)^{2/5}$ * Quartz Filter Transmission**

- Linear relationship holds for all scenes, however there is a larger spread due to a smaller range in $\alpha_{CERES,assumed}$.

All scenes, % change in α_{GERB} vs. $\alpha_{CERES,assumed}$



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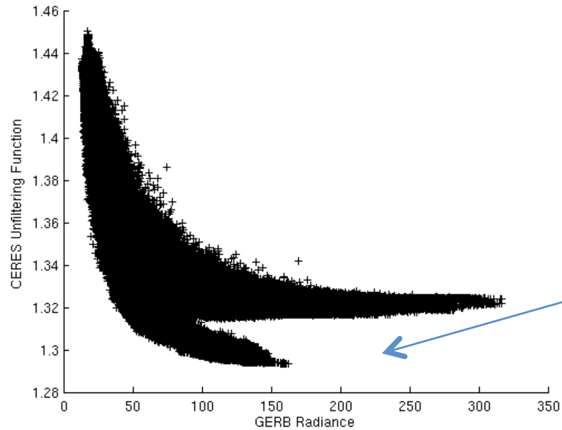
Application to Observations

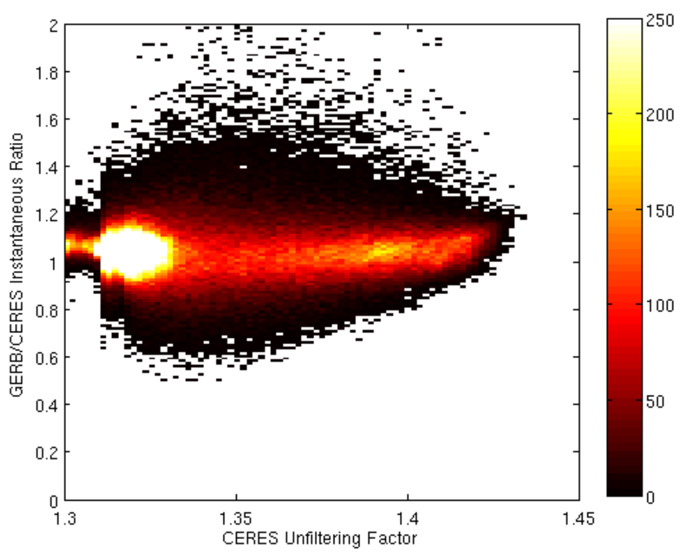
$\alpha_{\text{CERES, observed}}$ vs. GERB unfiltered radiance, June 2005



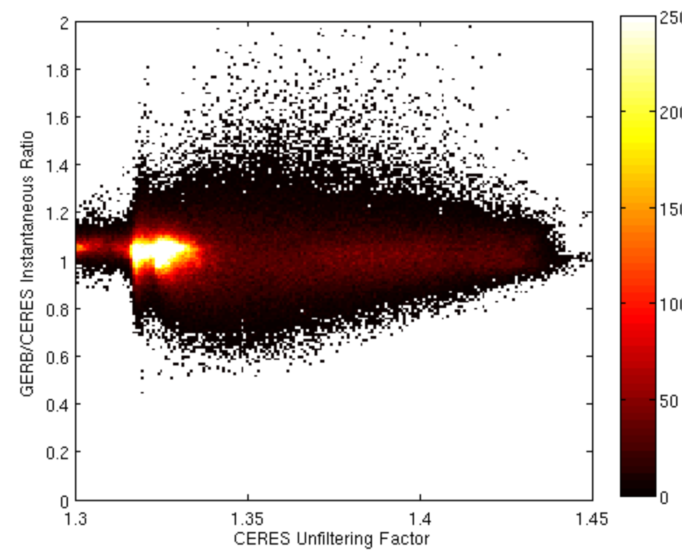
In the real data, there is a bifurcation at unfiltering factors below 1.32, that affects the analysis significantly, and is not present in any of the above theoretical simulations.

CERES unfiltering factor vs. GERB/CERES individual match ratios, plotted as a 2D histogram.

Jun 2004



Jun 2005



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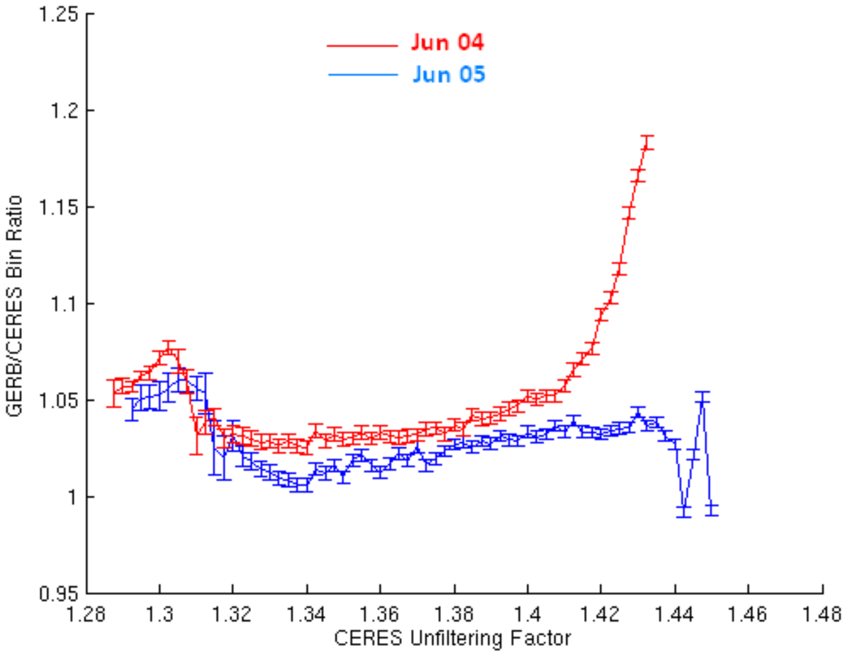
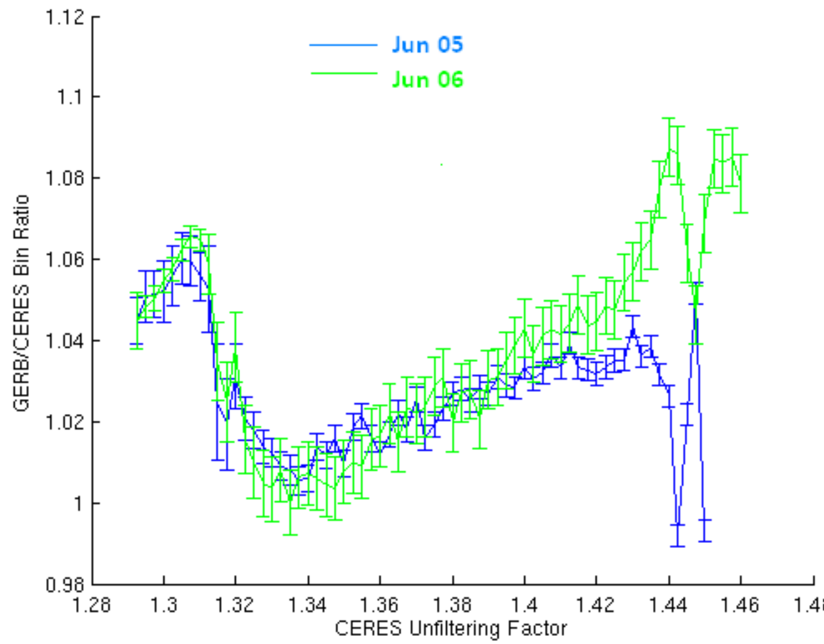
Application to Observations (cont.)

CERES unfiltering factor split into 71 bins 1.285:0.0025:1.46

GERB/CERES bin ratio calculated $\Sigma(\text{Radiance}_{\mathbf{GERB,bin}})/\ \Sigma(\text{Radiance}_{\mathbf{CERES,bin}})$

Error bars are calculated as a 2σ daily sample within each bin





- 1.32 < α_{CERES} < 1.42; Consistent 2% decrease of the ratio between Jun 04 and Jun 05. Between Jun 05 and Jun 06 there is little evidence of any significant shift in this region. Change does **not** scale with unfiltering factor, suggesting a **SW gain factor** rather than a spectral darkening.
- α_{CERES} < 1.32; Likely due to time-varying CERES unfiltering factor (not accounted at present)
- α_{CERES} > 1.42; Region consisting of very **dark** scenes requires further work.

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Conclusions/Discussion

- Theoretical study confirms that unfiltering factor is a better variable than either radiance or scene for quantifying the effect on the data of an evolving instrument spectral response

- Initial results show that application of this technique to study real data is promising and has highlighted several interesting features for further investigations

- To put these changes in context, and distinguish trends due to instrument changing response from comparison noise, this study will be extended across the full GERB record utilizing matched radiances from FM1, FM2 and FM3. Studies are also planned for limited periods to compare the GERB and CERES unfiltering factors.

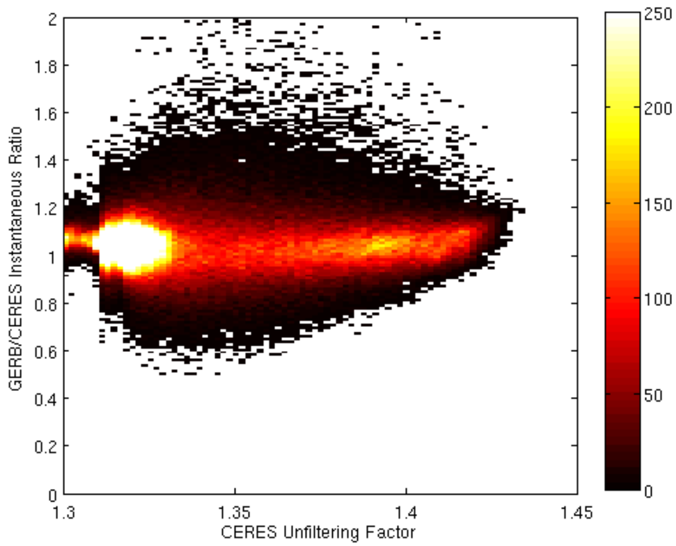
- Plan to use these comparisons to derive a correction to the unfiltered GERB radiance as a function of the GERB unfiltering factor.

END

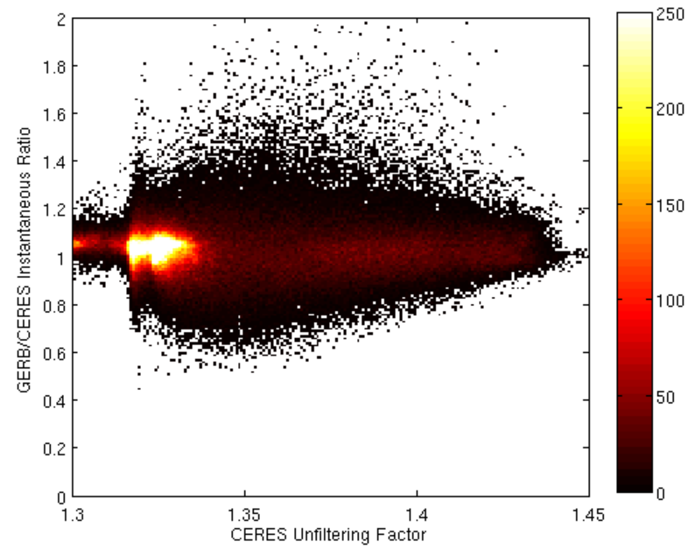
Application to Observations (cont.)

CERES unfiltering factor vs. GERB/CERES individual match ratios, plotted as a 2D histogram. The colour indicates the number of matches in each bin, and the colour bar is (significantly) saturated at 250.

Jun 2004



Jun 2005

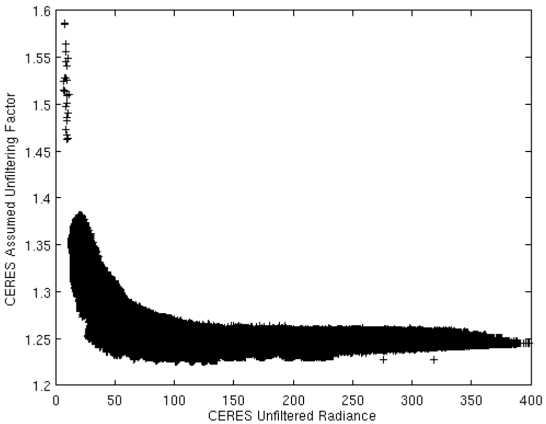


- Can notice the bifurcation point
- Numbers highly concentrated into a small fraction of the CERES unfiltering factor range
- Similar numbers of matches in both years, so there is a noticeable effect of the different viewing regions between the two years

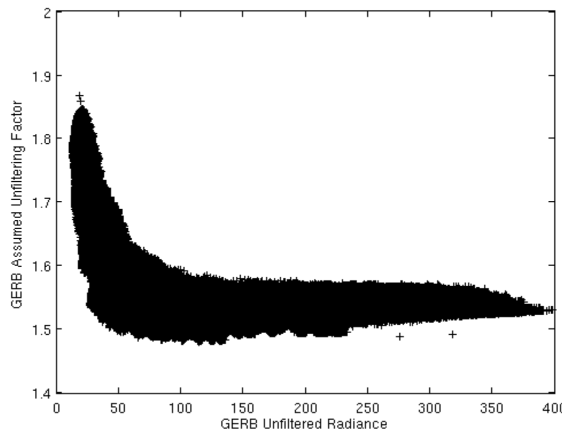
Application to Observations

ALL SCENES, *THEORETICAL*

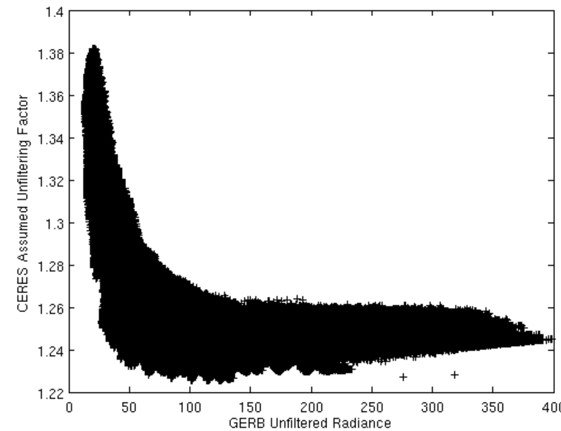
$\alpha_{CERES,assumed}$ vs. CERES unfiltered radiance



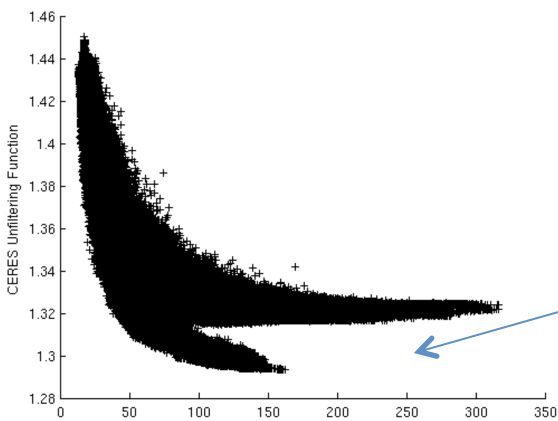
$\alpha_{GERB,assumed}$ vs. GERB unfiltered radiance



$\alpha_{CERES,assumed}$ vs. GERB unfiltered radiance

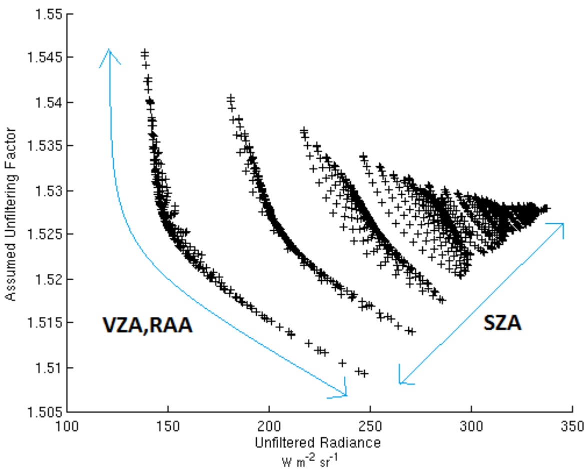


$\alpha_{CERES, observed}$ vs. GERB unfiltered radiance, June 2005



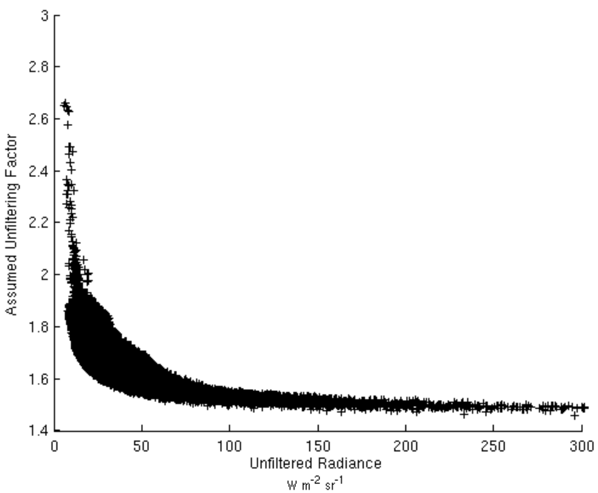
In the real data, there is a bifurcation at unfiltering factors below 1.32, that affects the analysis significantly, and is not present in any of the above theoretical simulations.

Variation with viewing geometry for one cloud scene



- The thickness to the curves of α vs. radiance on the previous slide is due to variation of α with viewing geometry
- This variation is small compares to the variation of α with radiance

$\alpha_{assumed}$ vs. unfiltered radiance for ocean scenes



- Axes restricted
- $\alpha_{assumed}$ > 2 and unfiltered radiances > 300 W m^{-2} sr^{-1} can be removed by increasing the threshold on the ocean sun glint angle
- Similar structure to cloudy scenes – do we recover a similar linear relationship between the percentage change in the unfiltering factor and the assumed unfiltering factor for all scenes?

GERB 3 status

Successfully commissioned and running well but suffered a mirror stopping event 27th April 2013 soon after starting operational life.

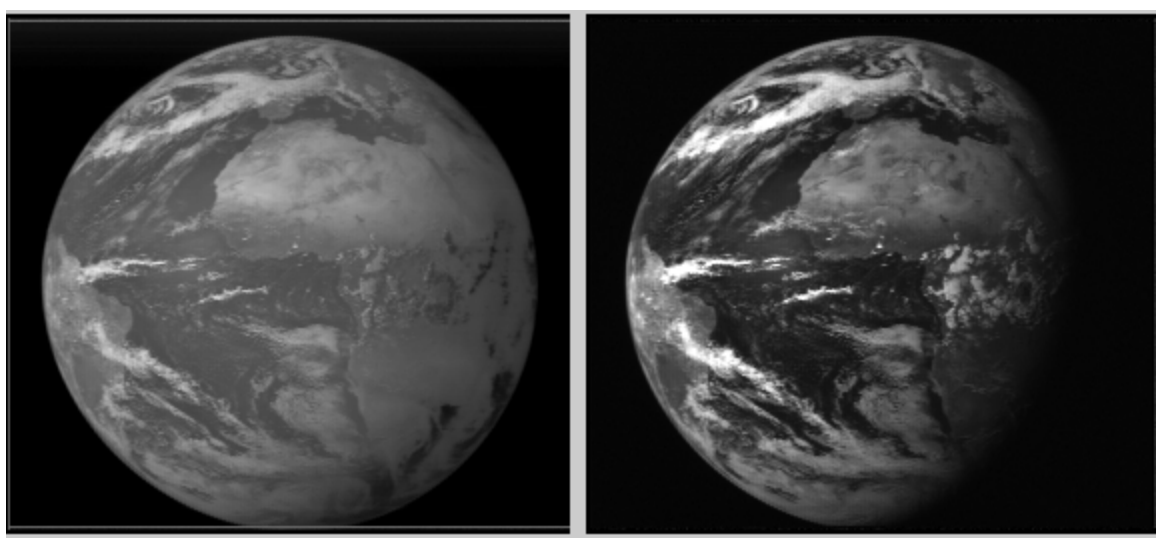
Numerous restart attempts and recovery operations performed over the next 2 years all failed to produce any discernible movement in the mirror.

The mirror was finally restarted on 11th February 2015 and normal operations resumed 30th April 2015 (after eclipse season).

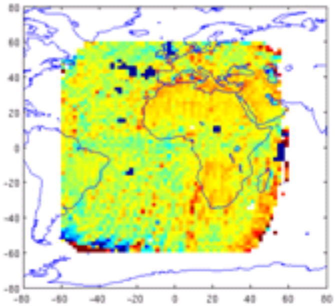
- Probable root cause: bearing debris coupled with a weakness in the 'upgraded and improved' GERB 3 mirror control system on start-up after a power cycle. Possible additional contributor of non-optimal control circuit tuning resulting in reduced available maximum torque for GERB 3 or particuarly bad bearing condition considered possible but not confirmed.
- GERB 3 operating procedures altered to minimise future risk, but further running experience required to determine optimal response to future events.
- GERB 4 modified to address startup weakness of upgraded mirror control system.

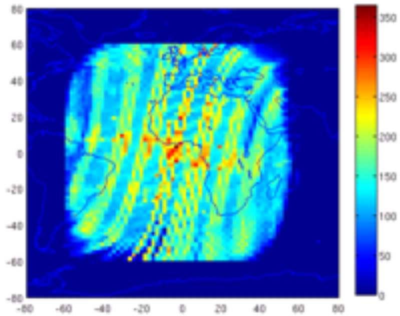
GERB 3 Normal mode data

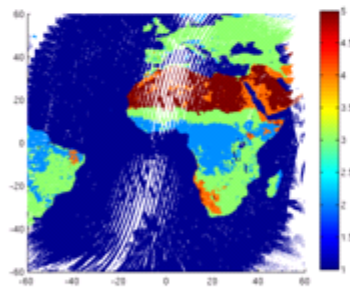
- Raw data TOTAL and FILTER from resumption of NORMAL operations on 30/04/2015
- Lunar and CALMON scans performed pending assessment



June 2004

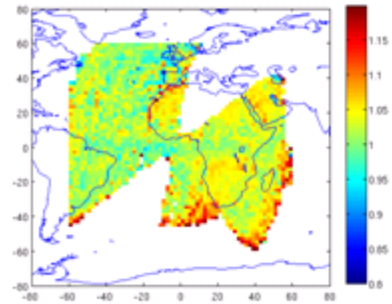


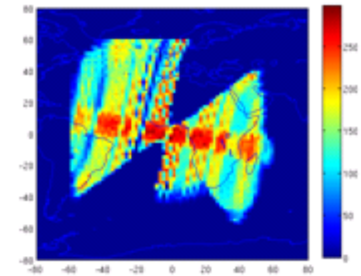




Ocean = 310178
Dark vegetation = 37819
Bright vegetation = 77327
Dark desert = 14372
Bright desert = 37483

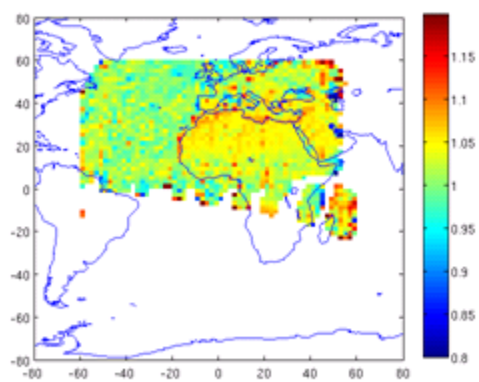
June 2005

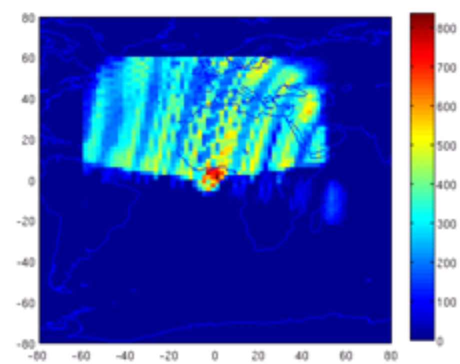




Ocean = 213422
Dark vegetation = 38769
Bright vegetation = 52758
Dark desert = 12959
Bright desert = 19248

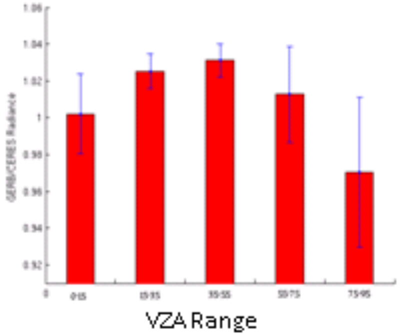
June 2006



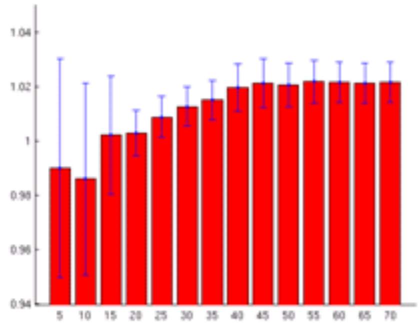


Might be worth redoing analysis only for boxes where there are a minimum amount of points within-

Or remove point from analysis if point falls within a box with outside 0.8-1.2…

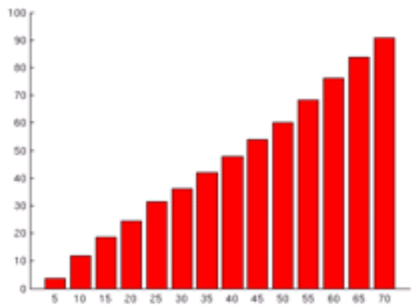


Cumulative VZA plot, i.e. ratios when considering 0-5, 0-10, 0-15 VZA etc.

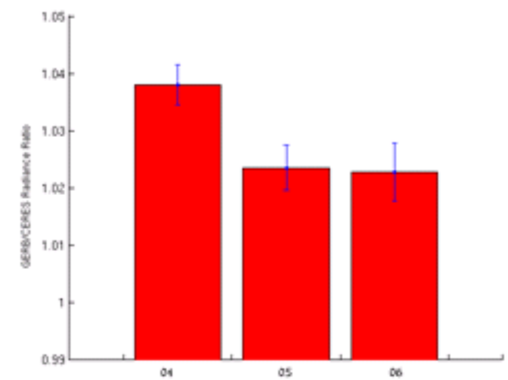


Although there is a noticeable darkening with VZA, the cumulative effect of adding observations up from 0 stays consistent from roughly 40 degrees upwards

Cumulative distribution (%), i.e. when considering 0-5,0-10,0-15 VZA etc.
---> roughly even spread of observations in each 5 degree VZA bin



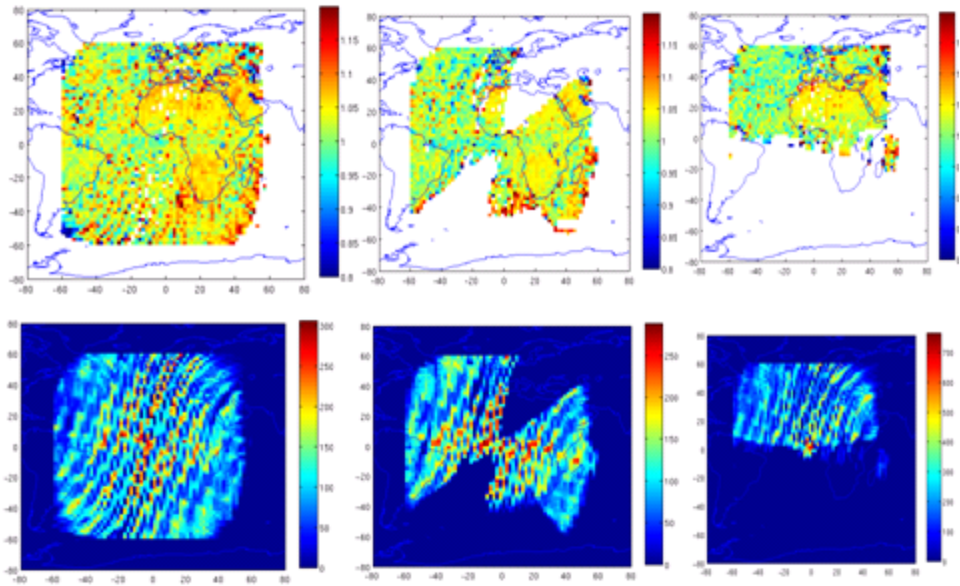
FM2 radiance ratios calculated as <all gerb observations>/<all ceres observations>
Standard deviations calculated from the daily radiance ratios, as before



04	05	06
1.0380±0.0035	1.0235±0.0039	1.0227±0.0051

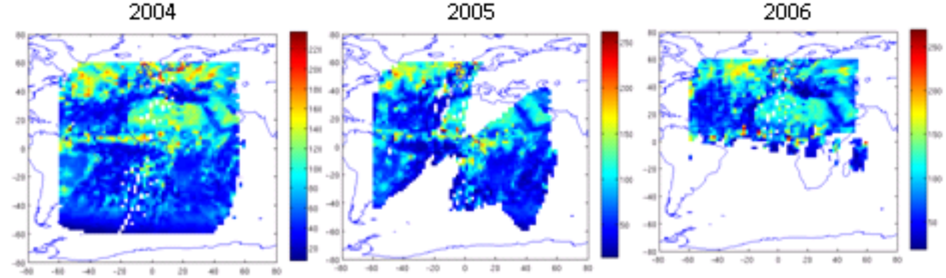
2 degree plots (0.8-1.2 scale), <all gerb in bin>/<all ceres in bin>

2004 2005 2006

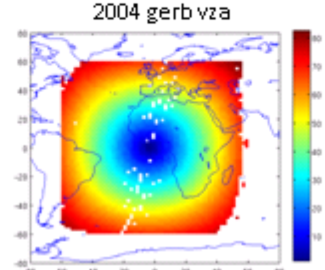


2 degree plots (0.8-1.2 scale), ceres radiance

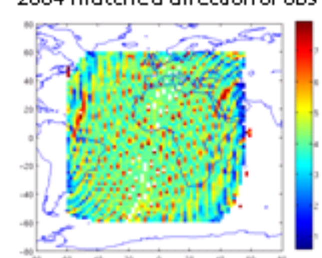
2004 2005 2006



2004 gerb vza



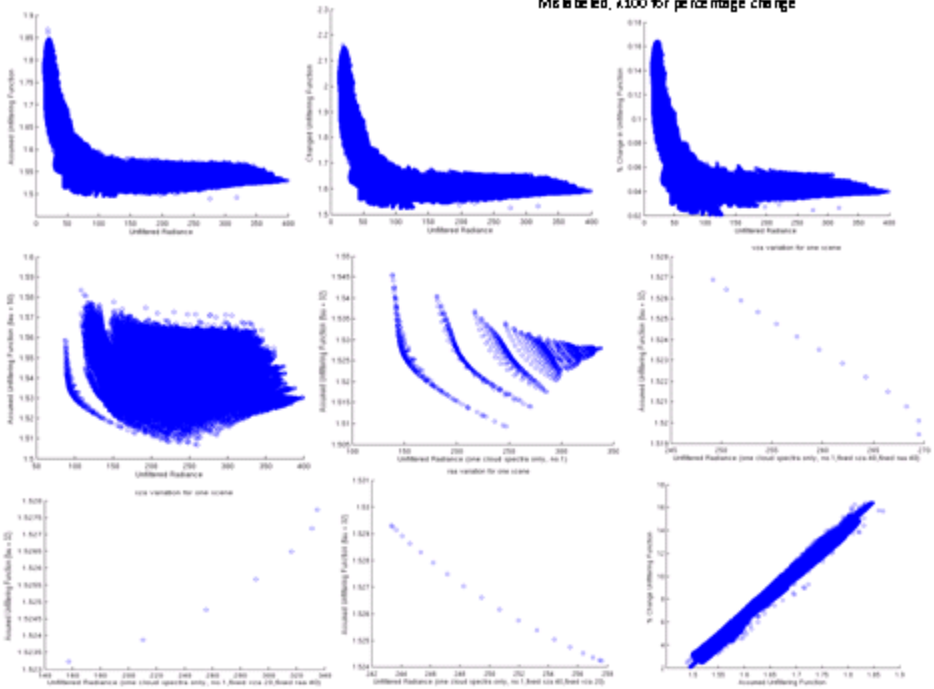
2004 matched direction of obs



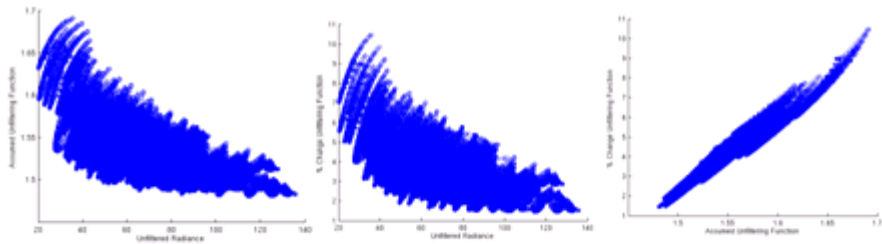
Smaller criteria biases towards the edges of the matched domain – possible cause for increase in SD

Cloud

Mislabeled, x100 for percentage change



Desert



Vege