NASA-Langley satellite cross-calibration, deep convective cloud calibration, and MTSAT case study

D. R. Doelling L. Nguyen, P. Minnis
NASA Langley Research Center

L. A. Avey, D. A. Spangenberg
SSAI

3rd Conference of GSICS Research Working Group (GRWG-III)
Camp Springs, Maryland, 19-21 February 2008,

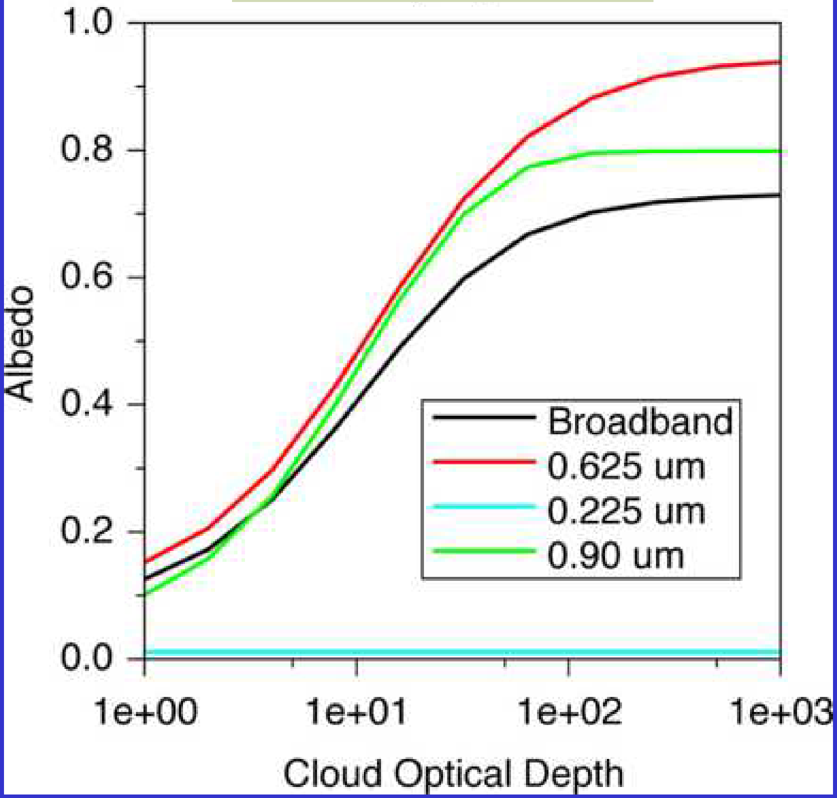
OUTLINE

- Deep Convective Clouds
  - G12 Case study
  - G12,G10,G08 DCC trends
  - Terra-MODIS, Aqua-MODIS, TRMM-VIRS
  - G07 Pinatubo
- LEO/GEO cross-calibration monthly regressions
  - standard error improvements
- MTSAT - case study
- Conclusions

Deep Convective Cloud Technique (DCCT)

- Cold bright tropopause targets located at the equator
  - ~ 80% albedos at low solar zenith angle (SZA) ensuring very bright targets
  - Stable reflectivity is achieved when the reflection and absorption are in equilibrium
  - Identified with simple IR threshold, no navigation needed
- Monitors gain degradation over time, but does not provide absolute calibration

Fu-Liou albedos



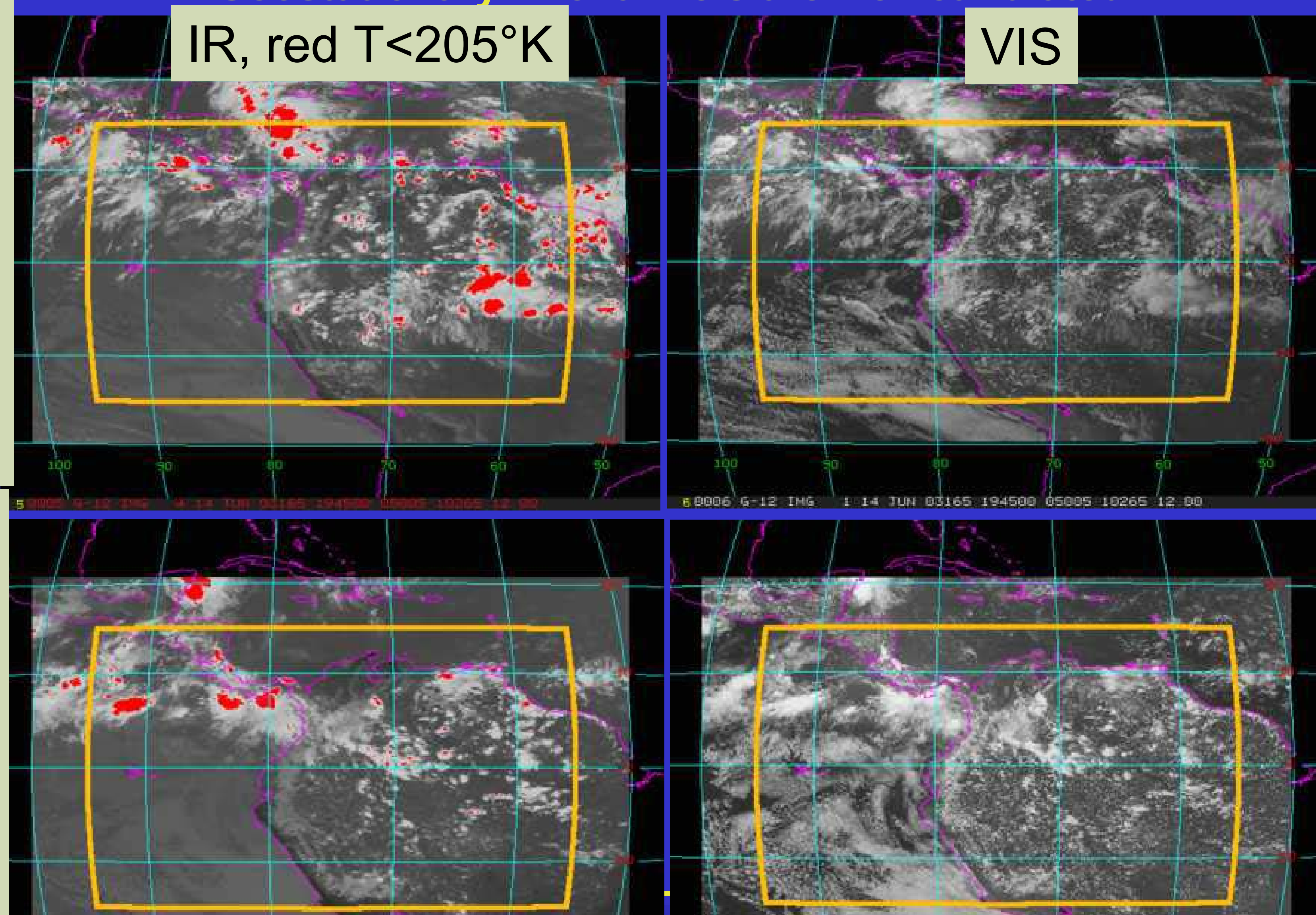
- Fu-Liou radiative transfer code
  - McClatchey Tropical Profile
  - 10km thick ice cloud over ocean
  - 60μm particle size
  - Vary cloud optical depth from 1 to 1000
  - Cos(sza) = 0.9

Identify DCC pixels by IR (11µm) threshold of T<205°K

Geostationary IR channels are well calibrated

Jun 14 2003 19:45 GMT

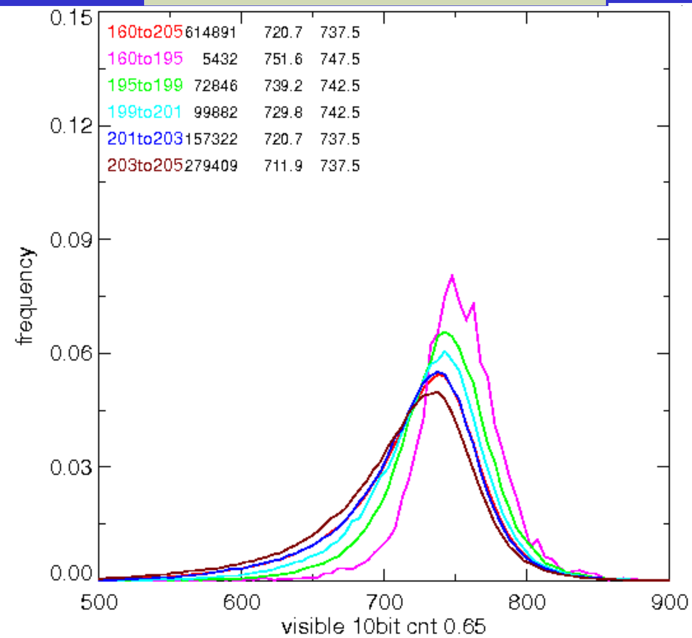
June 28 2003, 17:45 GMT



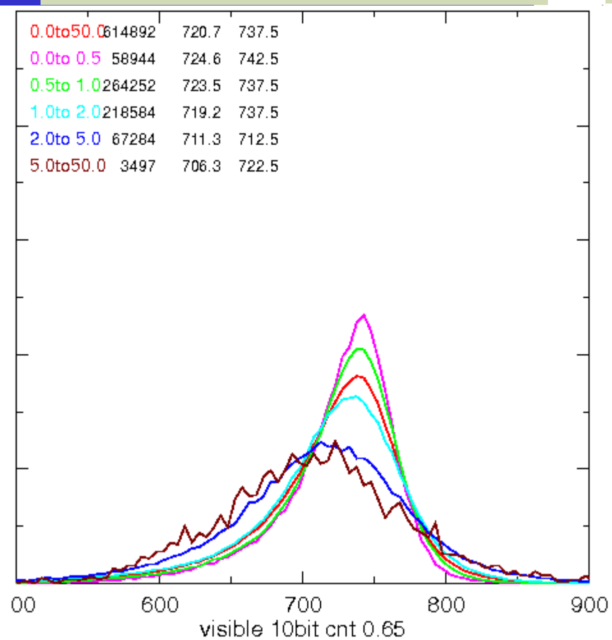
- Limit GEO search area to ± 15° latitude and ± 20 in longitude from subsat point
- Use 5 daily 1-hourly images centered at the subsat local noon

GOES-12 June 2003 DCC monthly PDFs

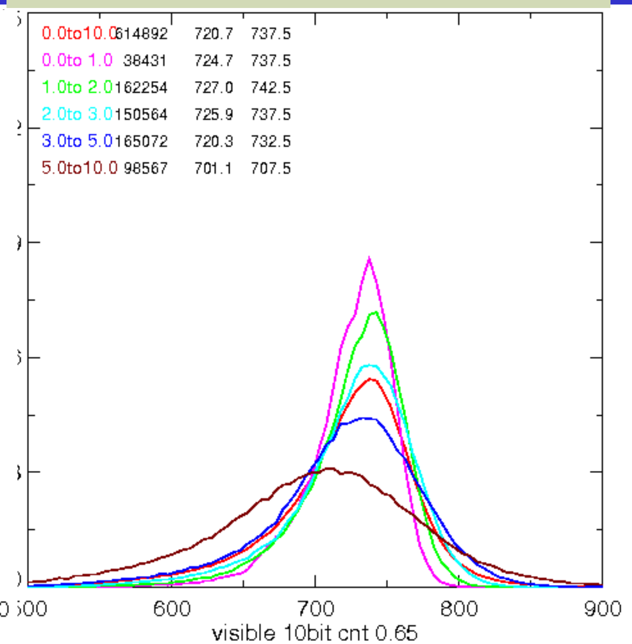
IR (11µm,°K) bins



IR (11µm,°K) σ bins



VIS (0.65µm,DC) σ bins



- Draw monthly PDFs from ~ 100000 DCC identified pixels
- Note that reducing the IR threshold increases the PDF peak
- Sharpen PDF peak by only using pixels that have a IR standard deviation < 1°K and visible < 3%, based on the 8 surrounding pixels

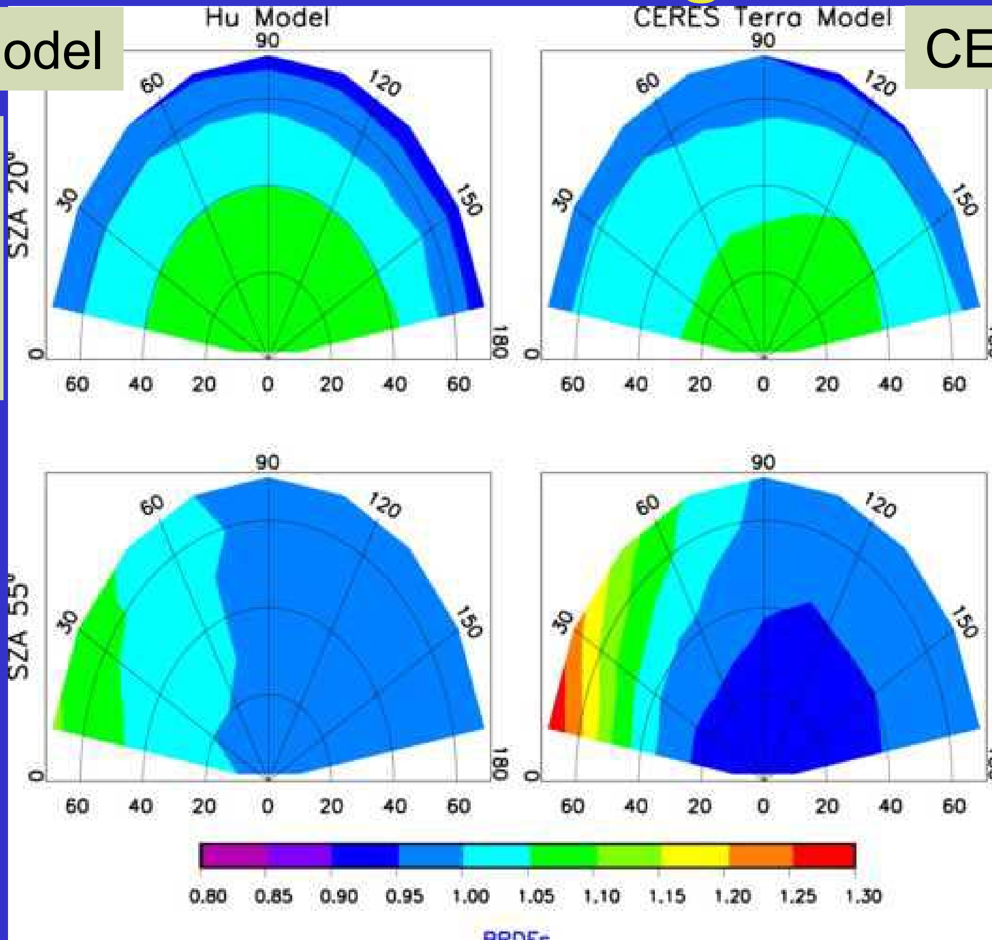
Use DCC ADMs to remove angular sampling biases

Hu Model

CERES Model

SZA = 20°

SZA = 55°

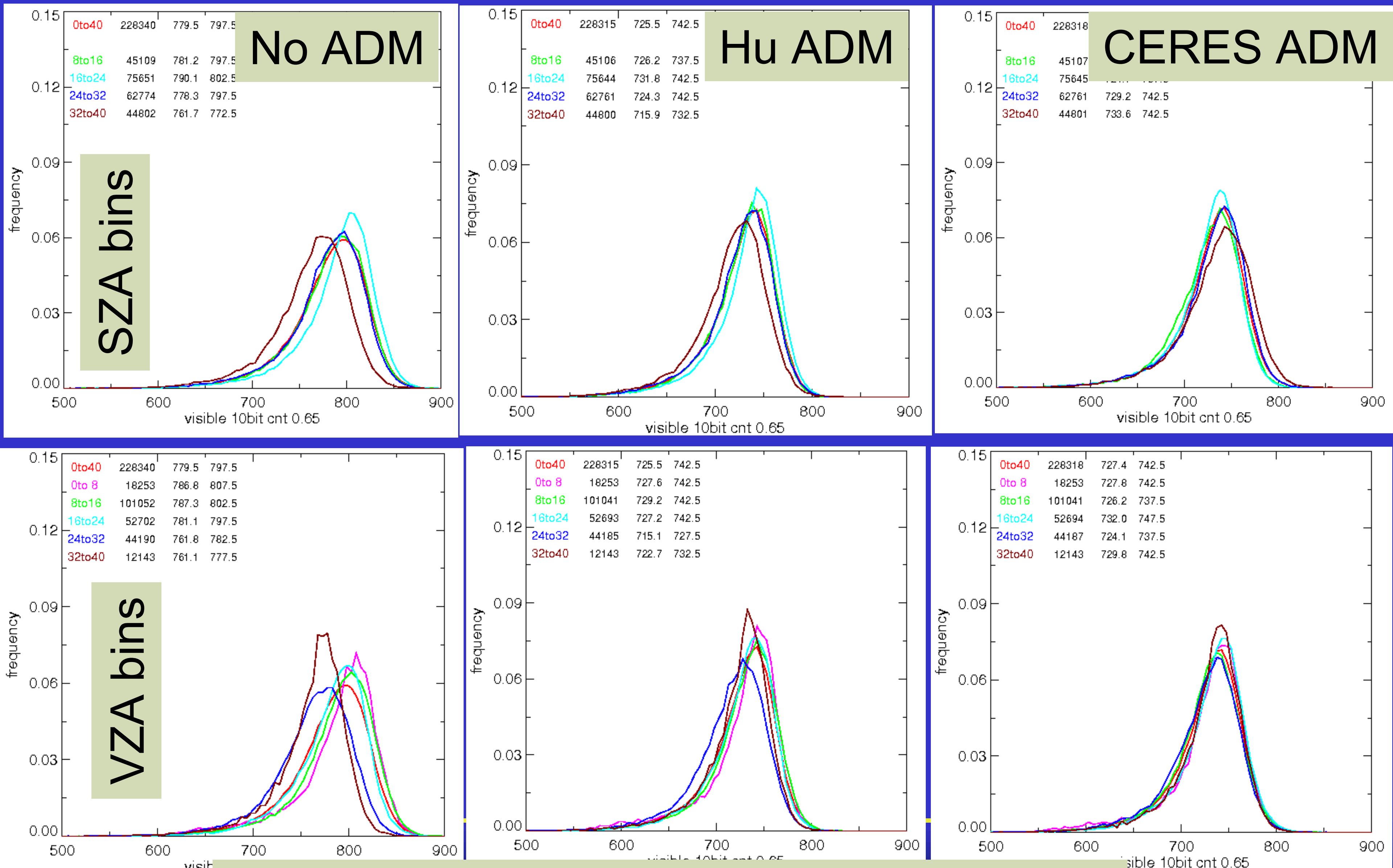


- **Hu Model**
  - –MODTRAN absorption
  - –DISORT scattering
  - –Ice cloud at 120 optical depth
  - –Broadband model

- **CERES Model**
  - –Angular binned CERES radiances
  - –Optical Depth >50 bin
  - –Overcast Ice cloud bin
  - –Broadband model

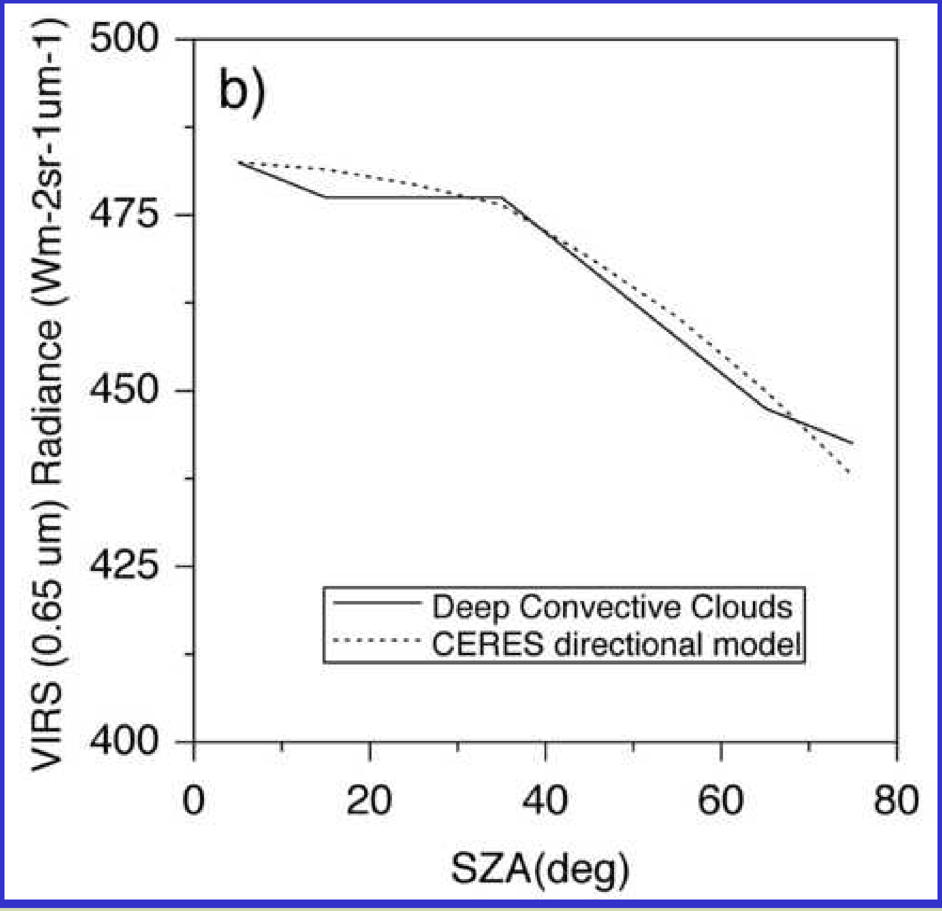
- Hu Model is a DCC Theoretical based bidirectional model (*Hu et al. 2004*)
- CERES model is the CERES bidirectional model (Ice, 50 τ)
- Limit viewing geometry where there is near Isotropic reflection at low sun angles < 40° and view angles < 40°
- Normalize radiance (counts) to overhead sun

GOES-12 June 2003 DCC monthly PDFs



- Note that the CERES ADM has the most uniform PDF structure
- Use CERES ADM to remove angular sampling variations

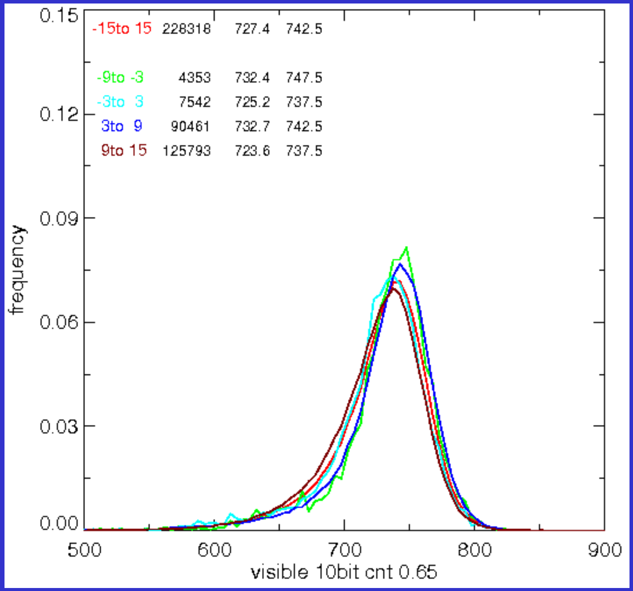
Comparison of VIRS DCC radiances and the CERES DCC directional model



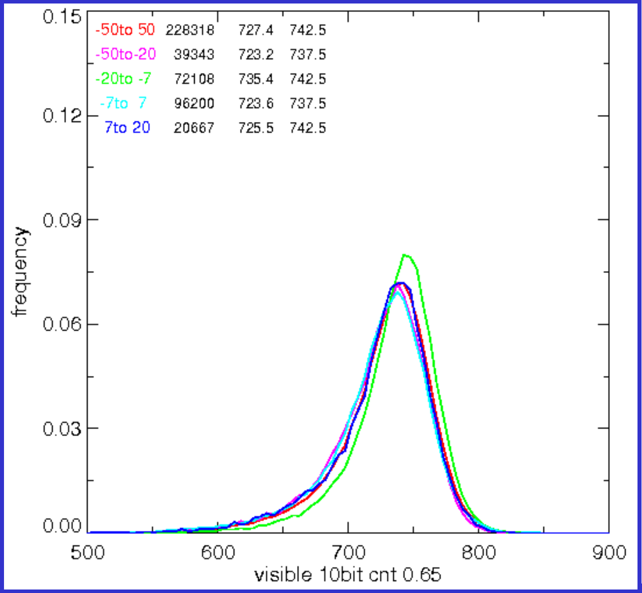
- Validate CERES directional model by stratifying VIRS DCC radiances by SZA
- VIRS precesses every 46 days thereby observes all SZA
- VIRS has onboard visible calibration, employing a solar diffuser
- 9.2% reduction in radiance between 5° and 75° SZA

GOES-12 June 2003 DCC monthly PDFs

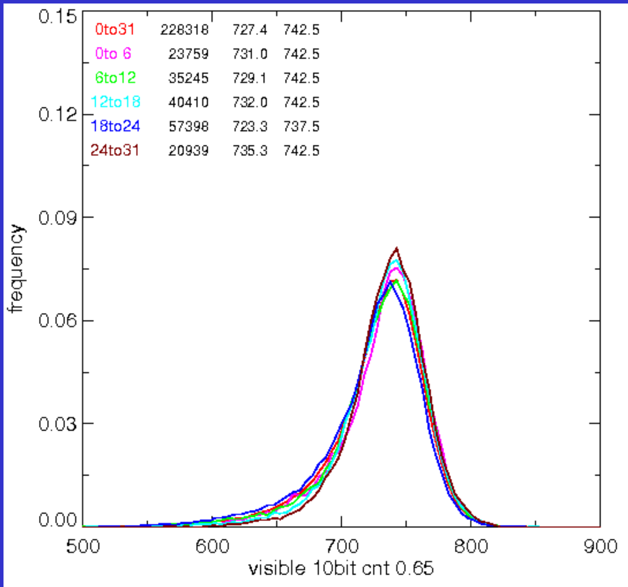
Latitude bins



Longitude bins



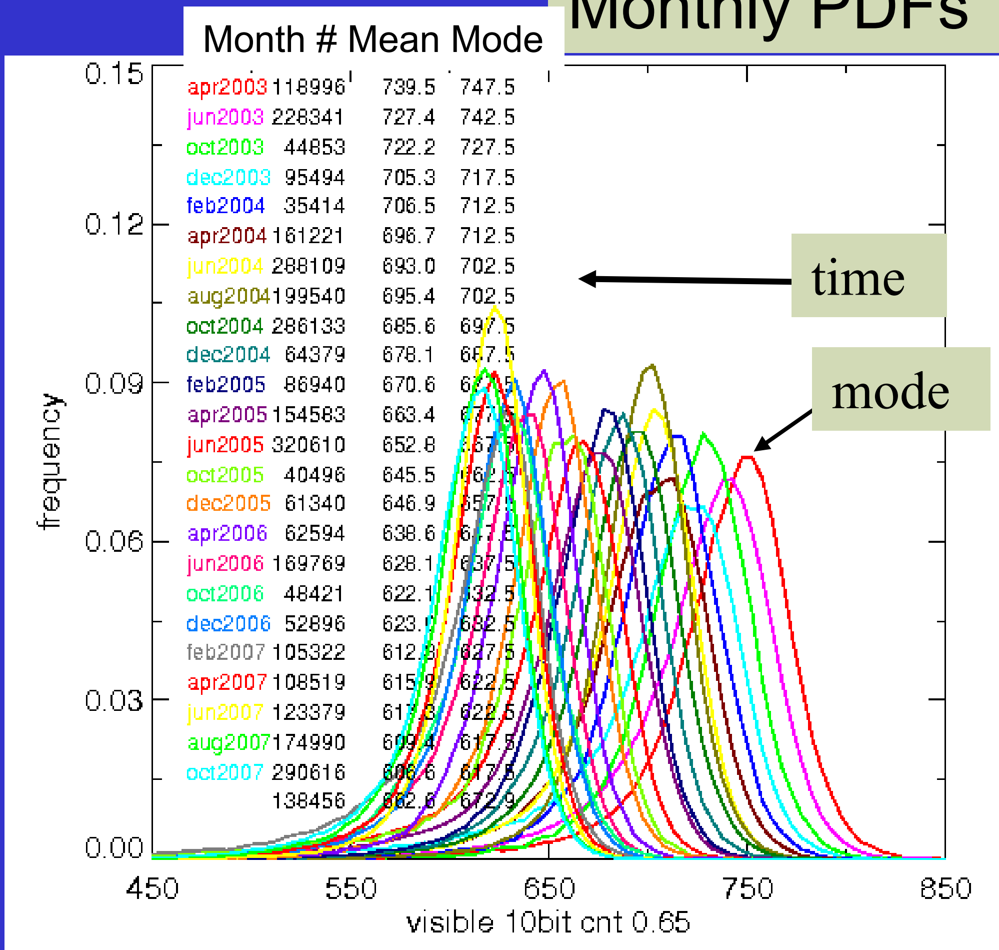
Week bins



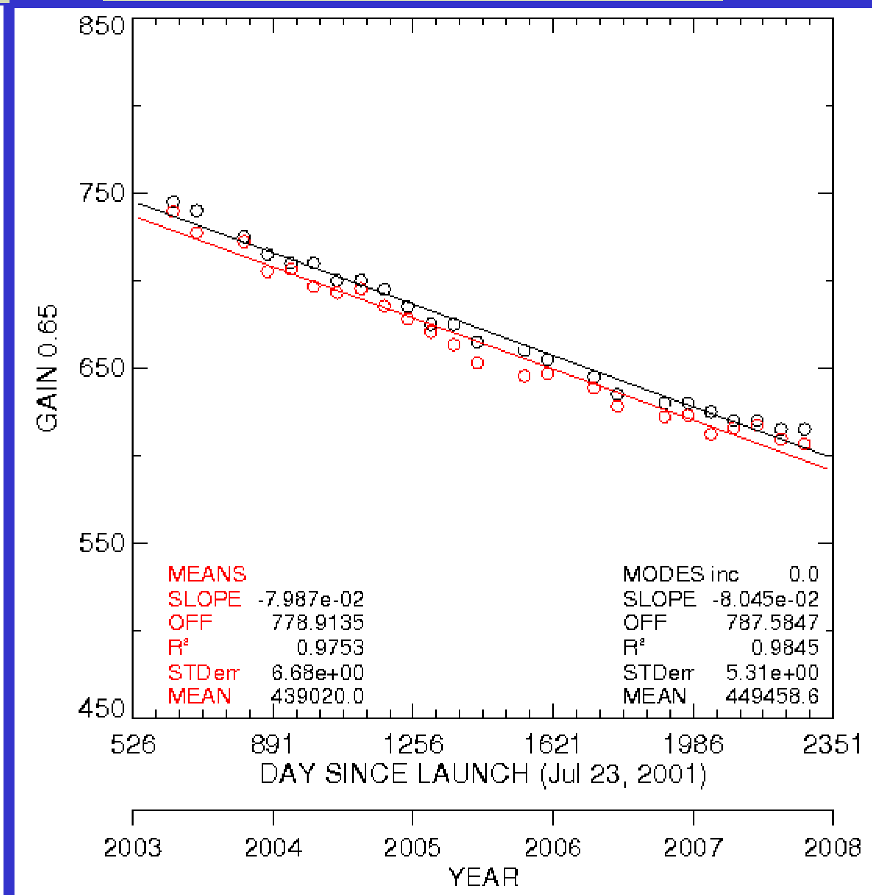
- DCC reflectances are spatially and temporally consistent
- DCC formed over land and water generate the same PDF shape

2003-2007 GOES-12 DCC monthly PDF counts

Monthly PDFs



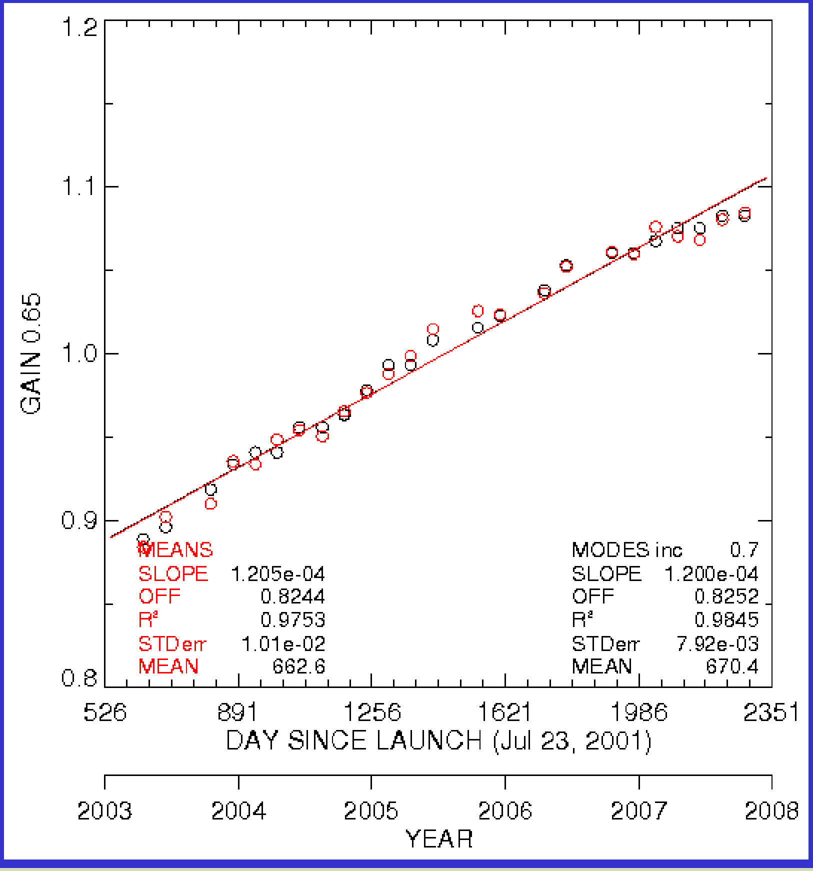
Monthly PDF counts



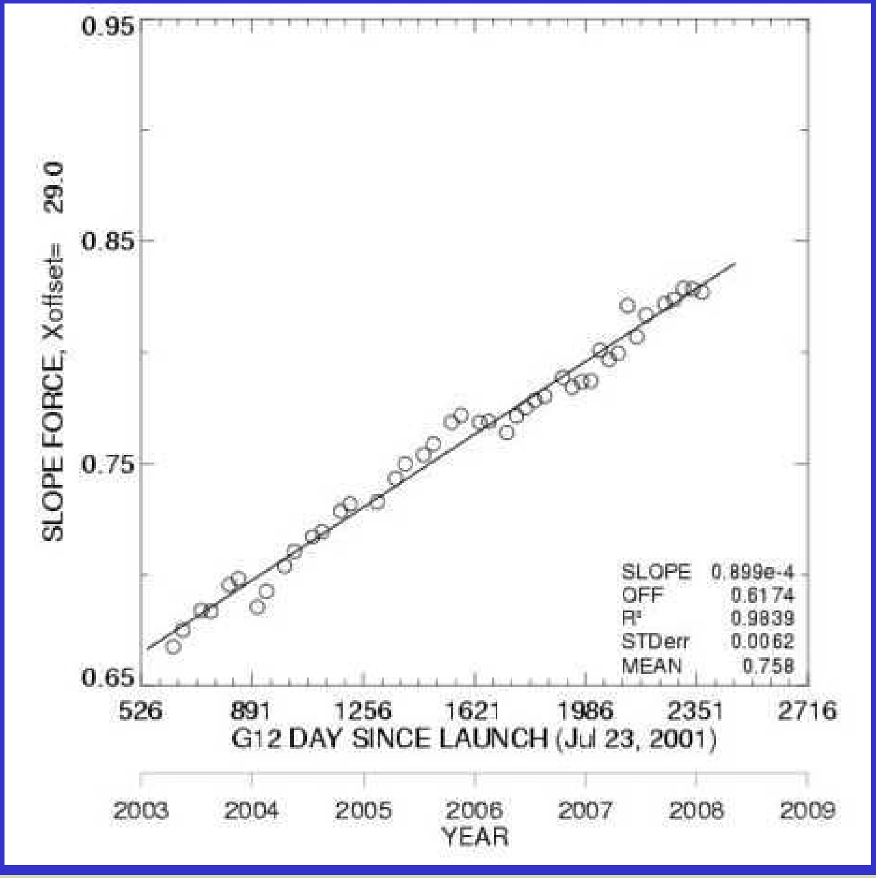
- Plot the monthly visible DC as a function of time
- Compute the monthly mean and mode in terms of visible DC

Comparison of GOES-12 visible gain degradation

GOES 12 using DCC

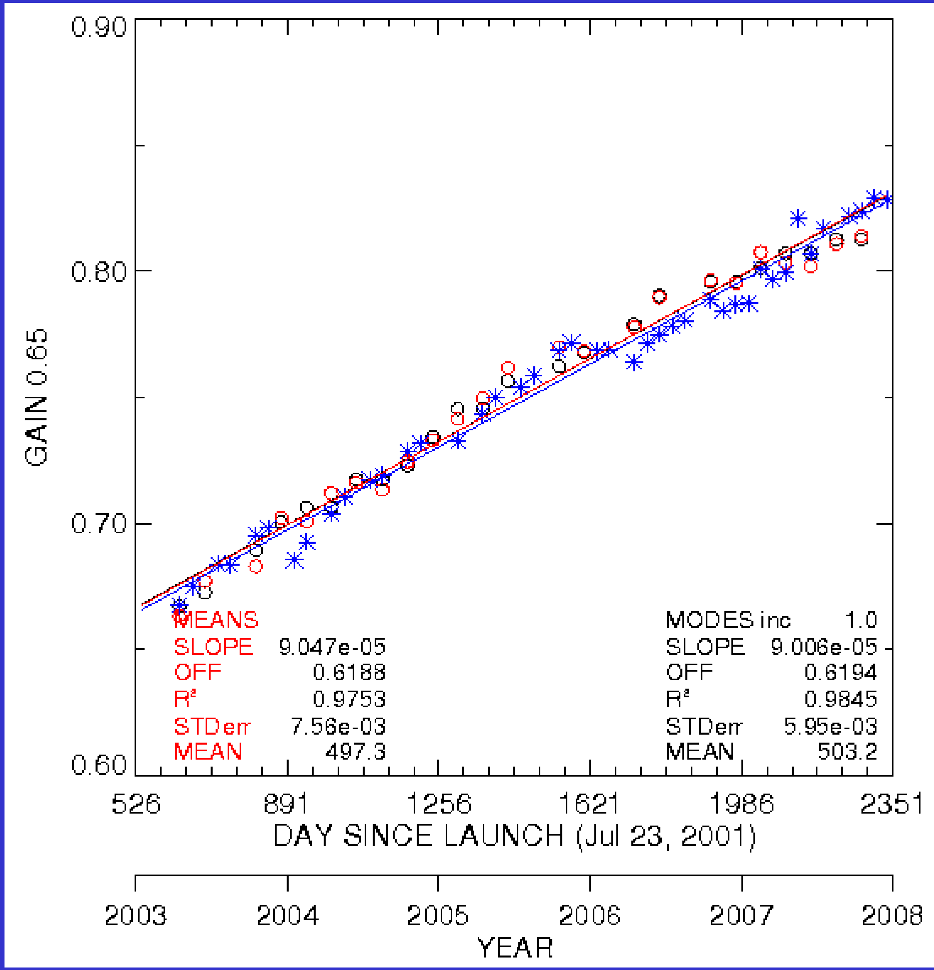


GOES 12 using Terra-MODIS



- normalize the DCC counts with the 5-year mean and invert
- apply the mid-timeline G12/Terra-MODIS gain to the DCC monthly gain ratios to place the DCC gains ontop of the G12/Terra gains

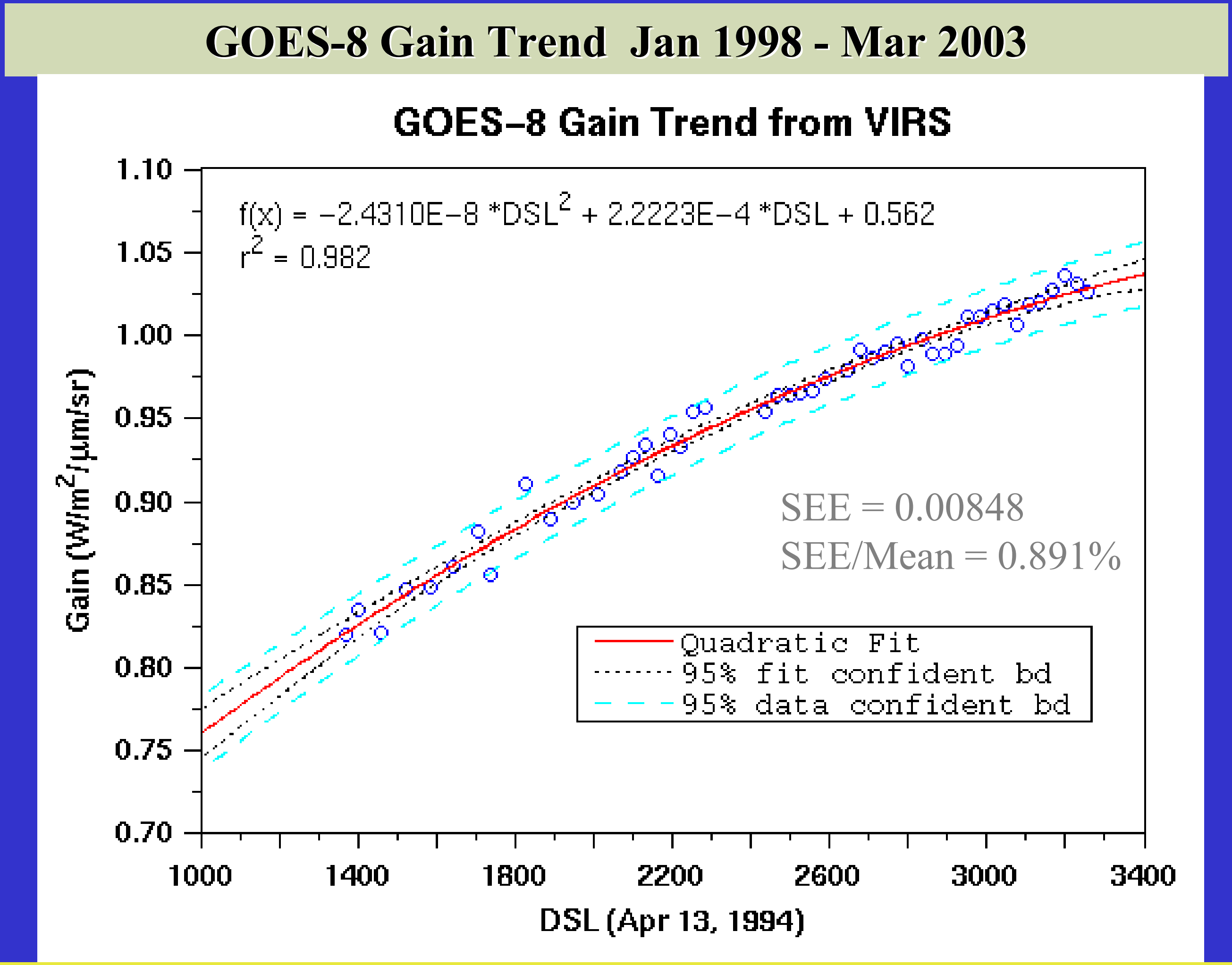
Comparison of GOES-12 visible gain degradation



* G12/Terra 8.99e-5
° DCC mode 9.01e-5
° DCC mean 9.05e-5

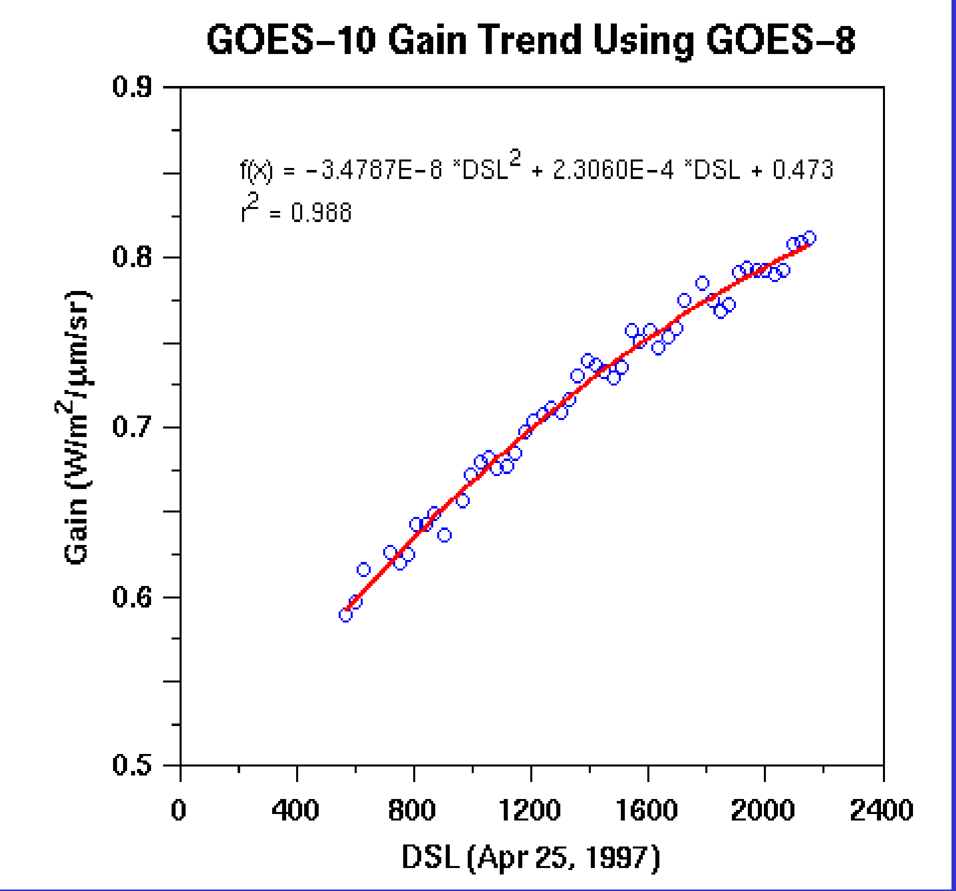
- It is remarkable the gain trends are within 0.7%

Time Series of GOES-8 Slope Trend

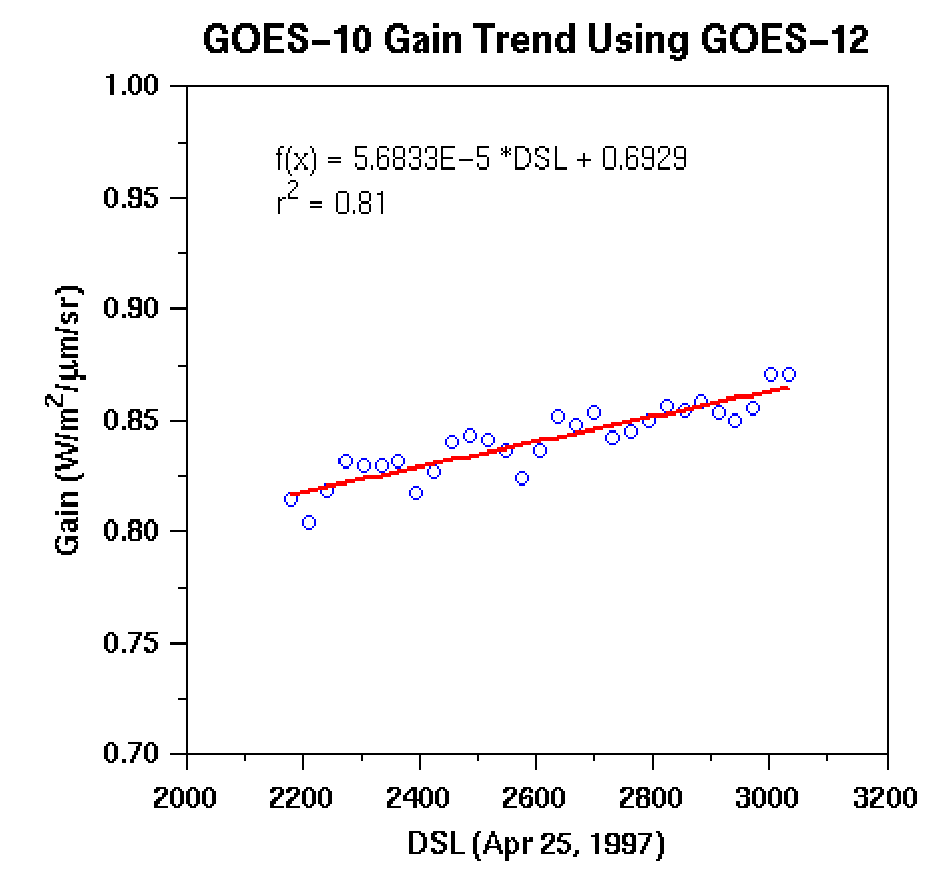


GOES-10 Calibration Using G8/VIRS & G12/VIRS

Nov 1998 - Mar 2003

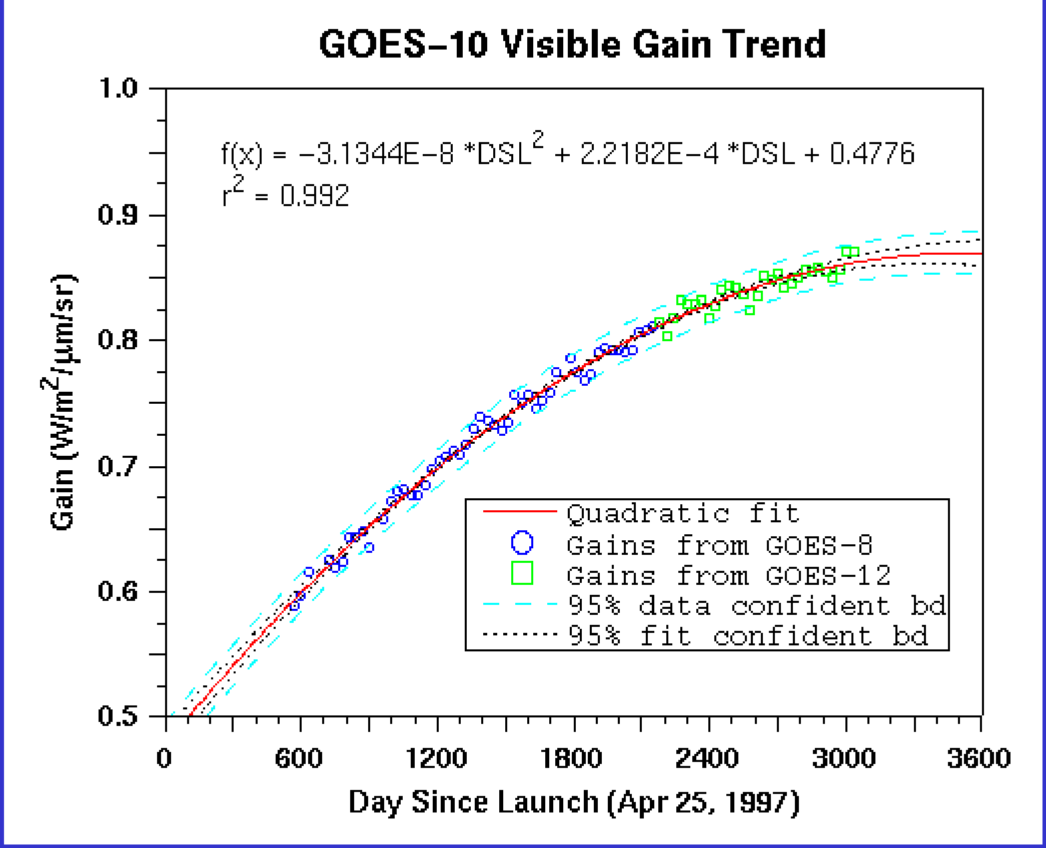


Apr 2003 - Aug 2005

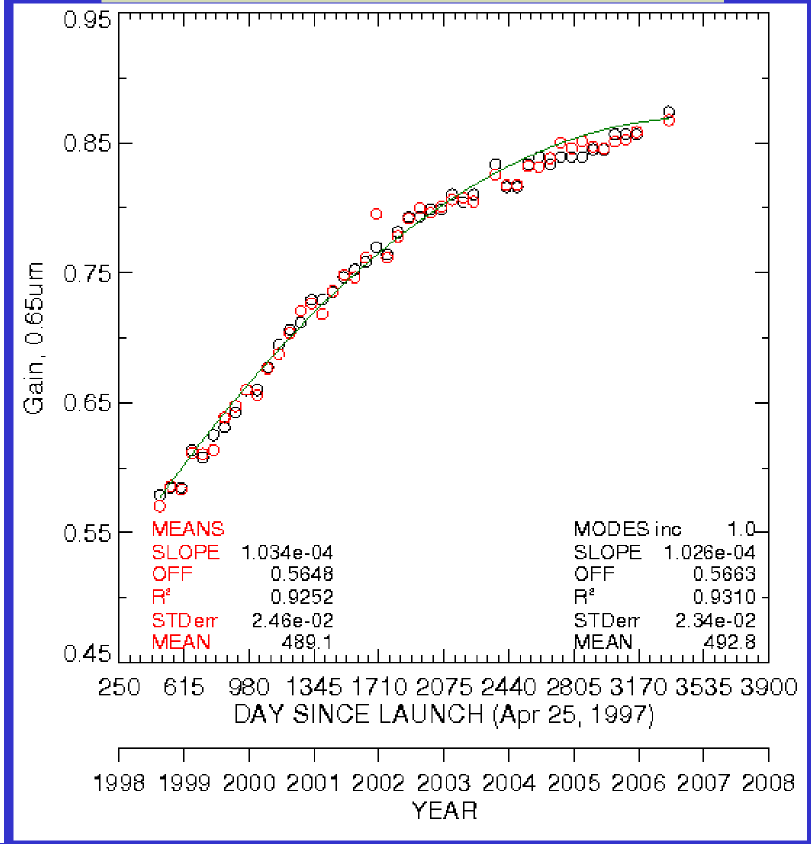


Comparison of GOES-10 visible gain degradation

GOES 10 based on G8&G12/VIRS

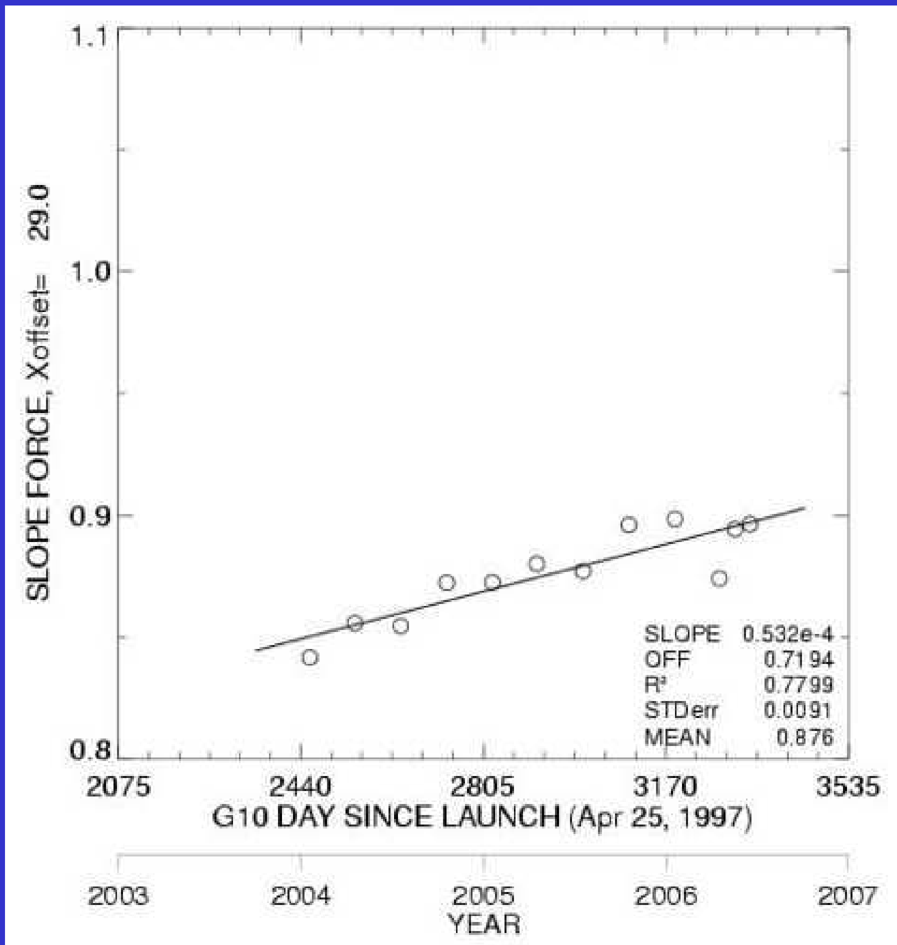


GOES10 using DCC

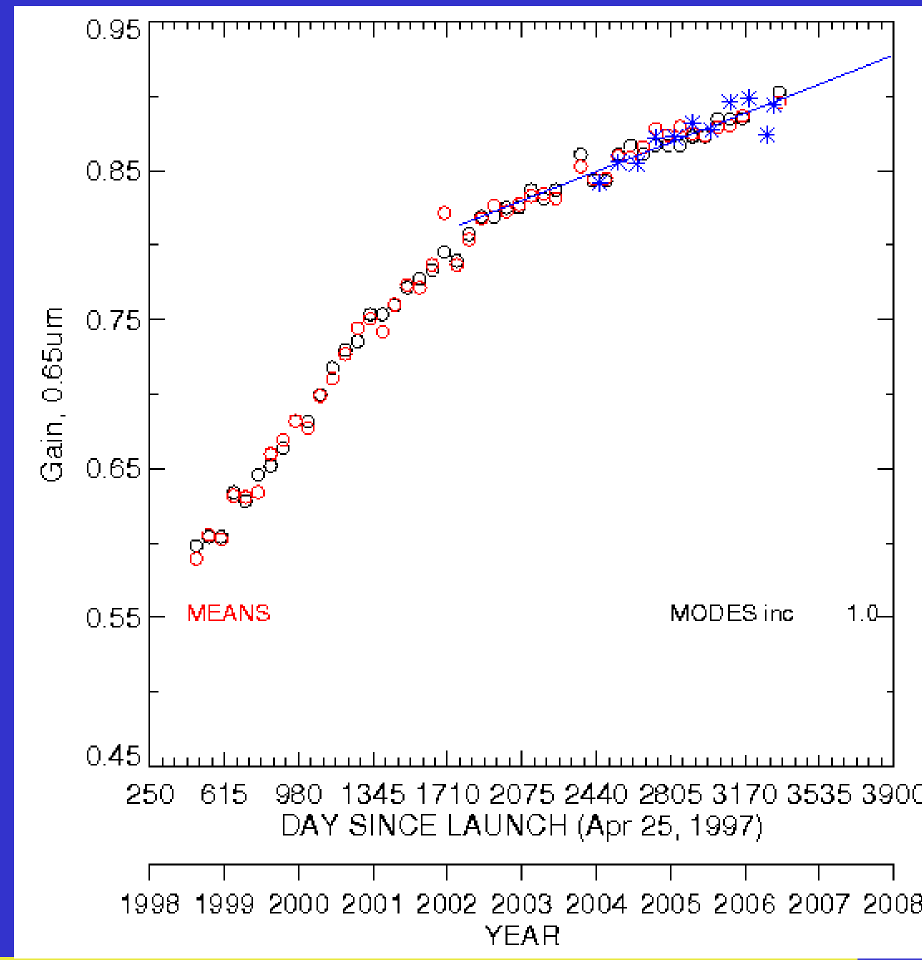


Comparison of GOES-10 visible gain degradation

GOES10 using Terra-MODIS

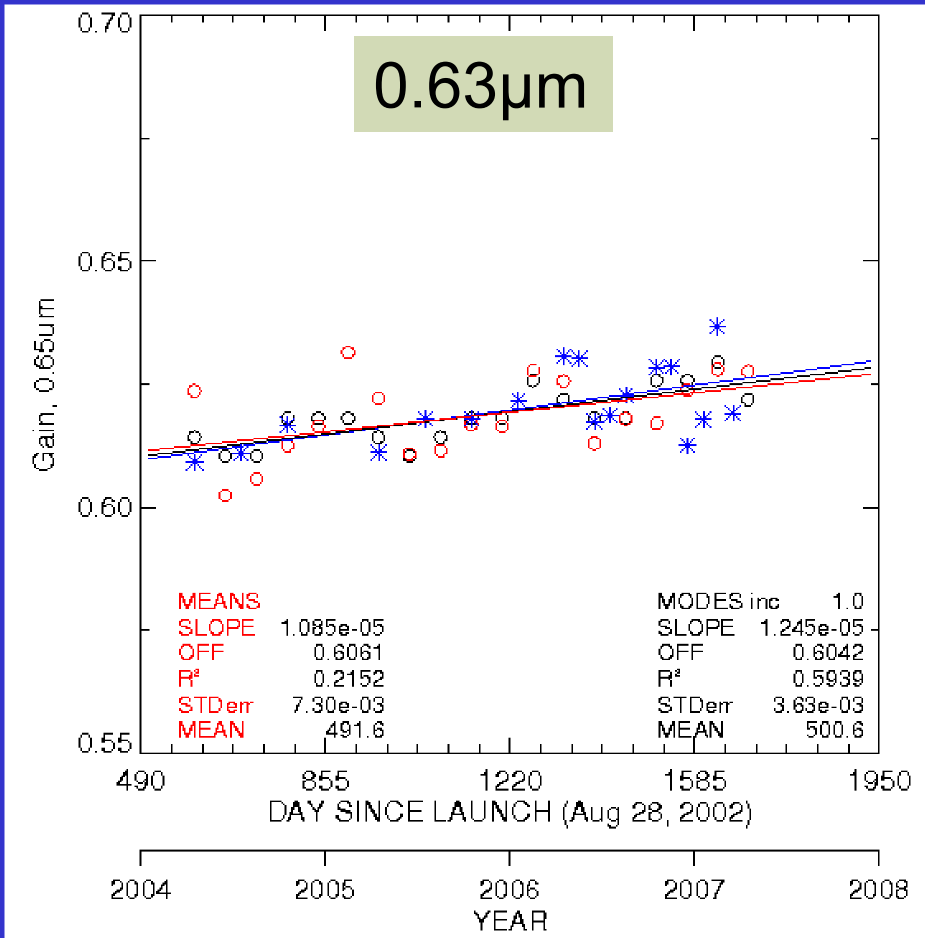


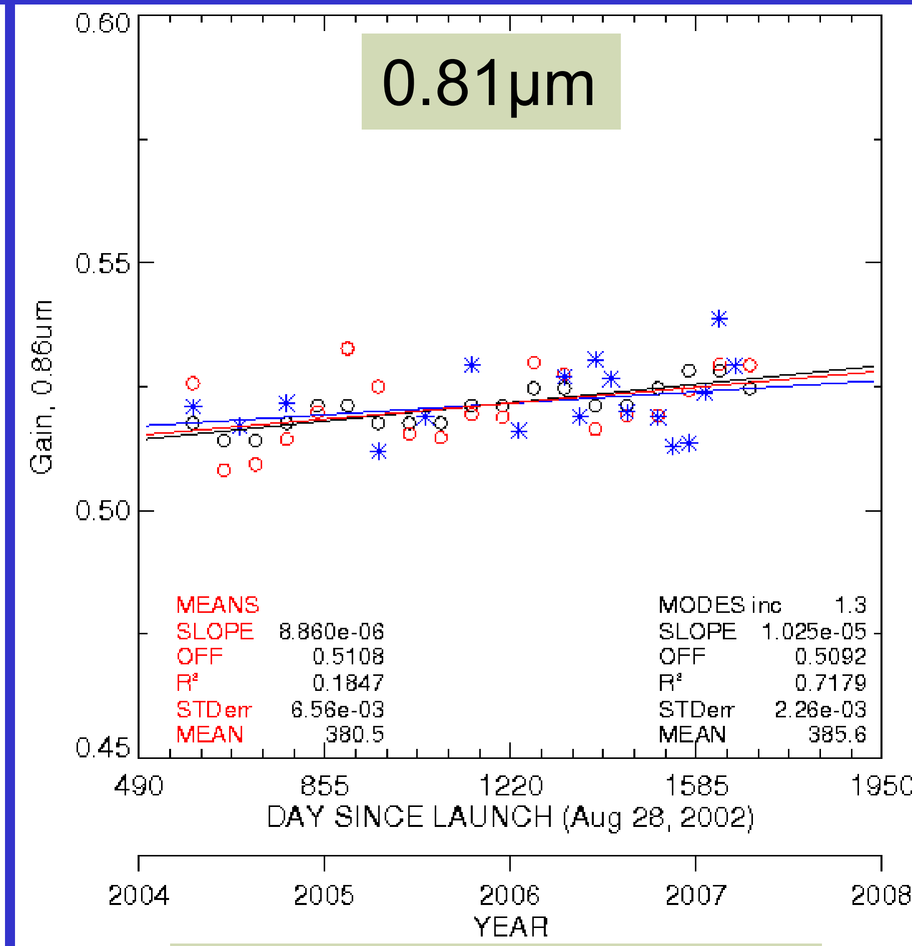
GOES10 using DCC



- Terra-MODIS/VIRS gain ratio = 1.03

Comparison of MET8 visible gain degradation





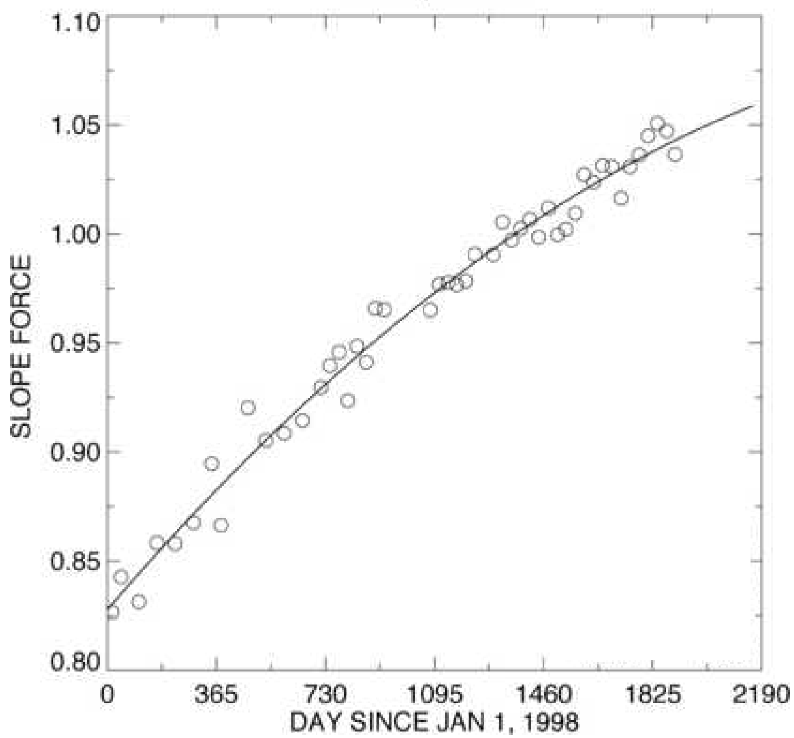
* MET8/Terra1.29e-5
° DCC mode 1.25e-5
° DCC mean 1.09e-5

*MET8/Terra 0.72e-5
- Terra-MODIS saturates

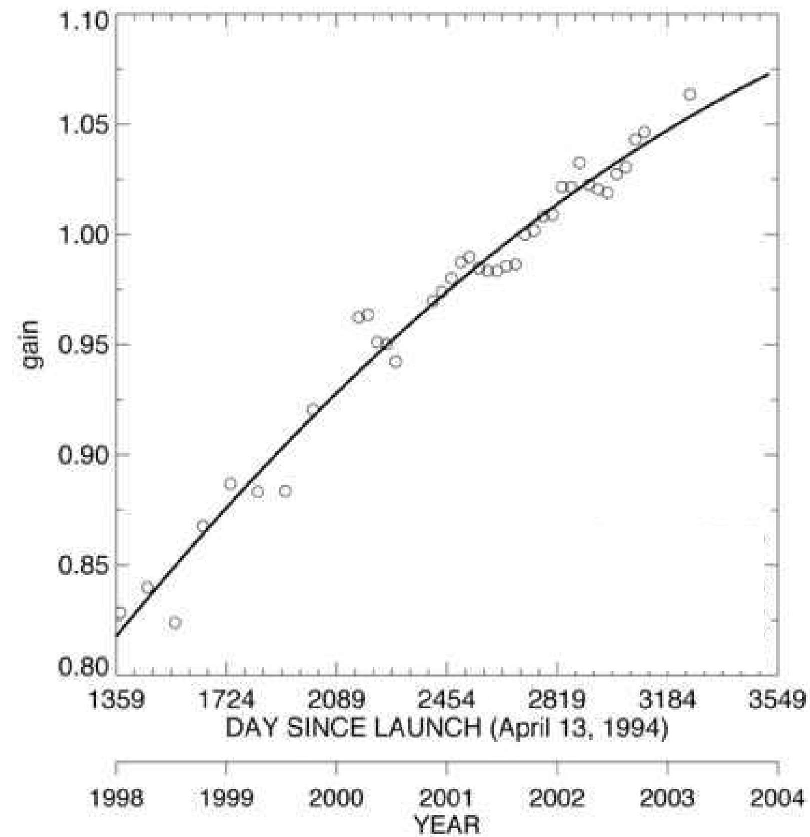
° DCC mode 1.03e-5
° DCC mean 0.88e-5

Comparison of GOES-8 gains based on VIRS and DCC

GOES-8 based on VIRS

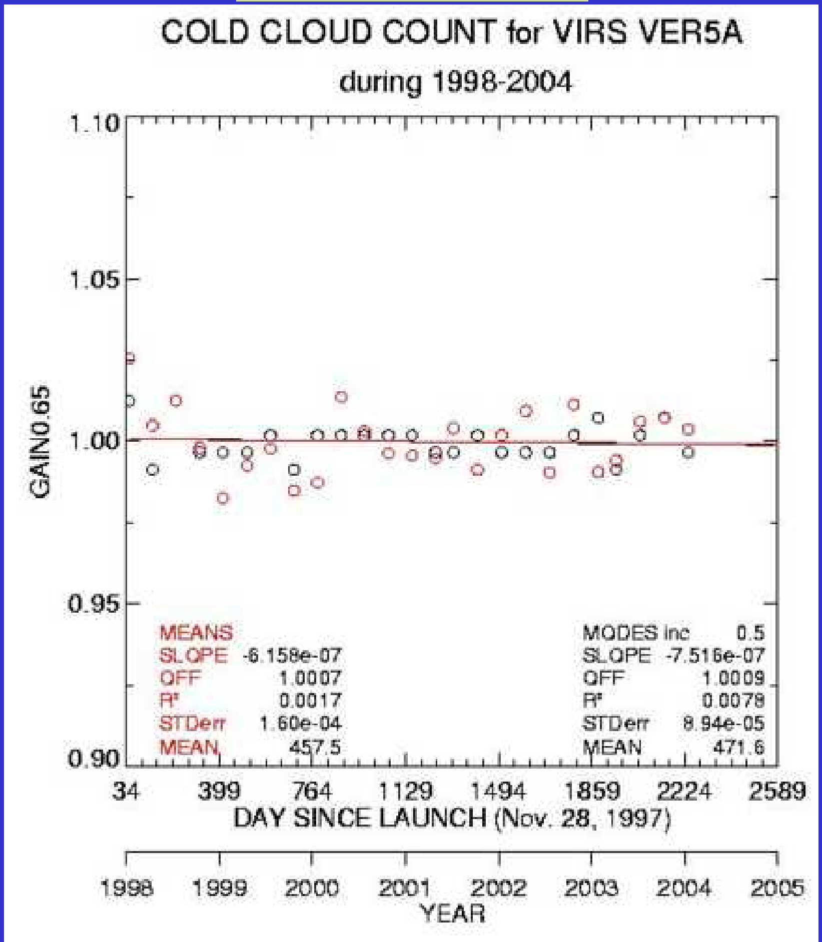


GOES-8 based on DCCT

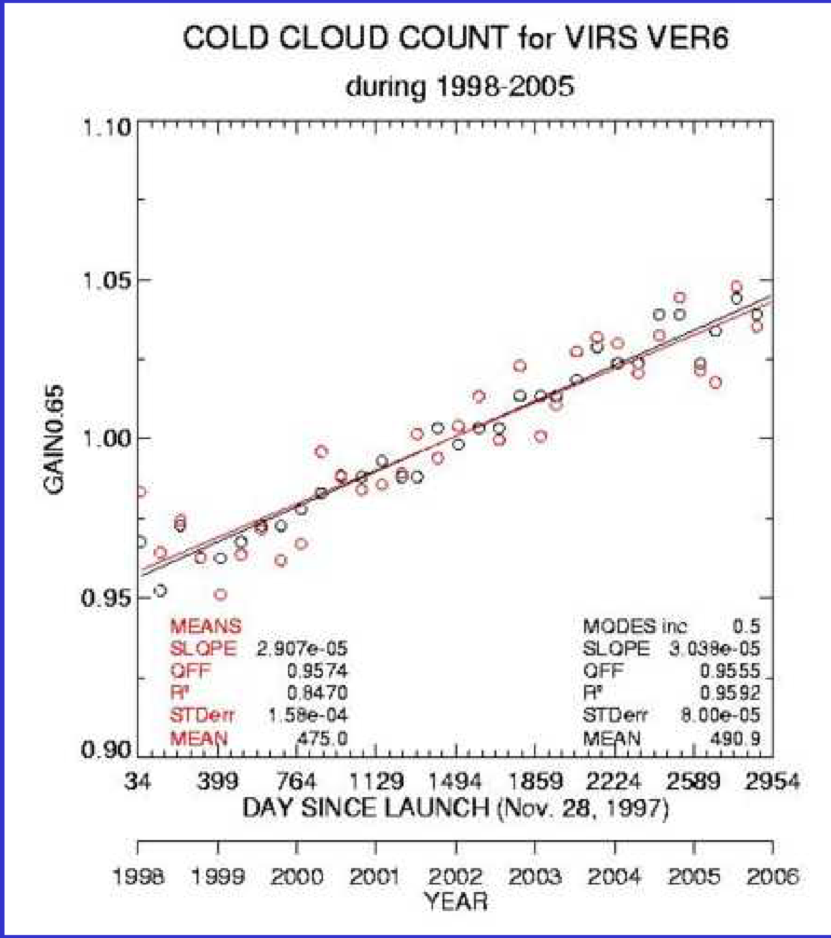


VIRS DCC degradation

Version 5A

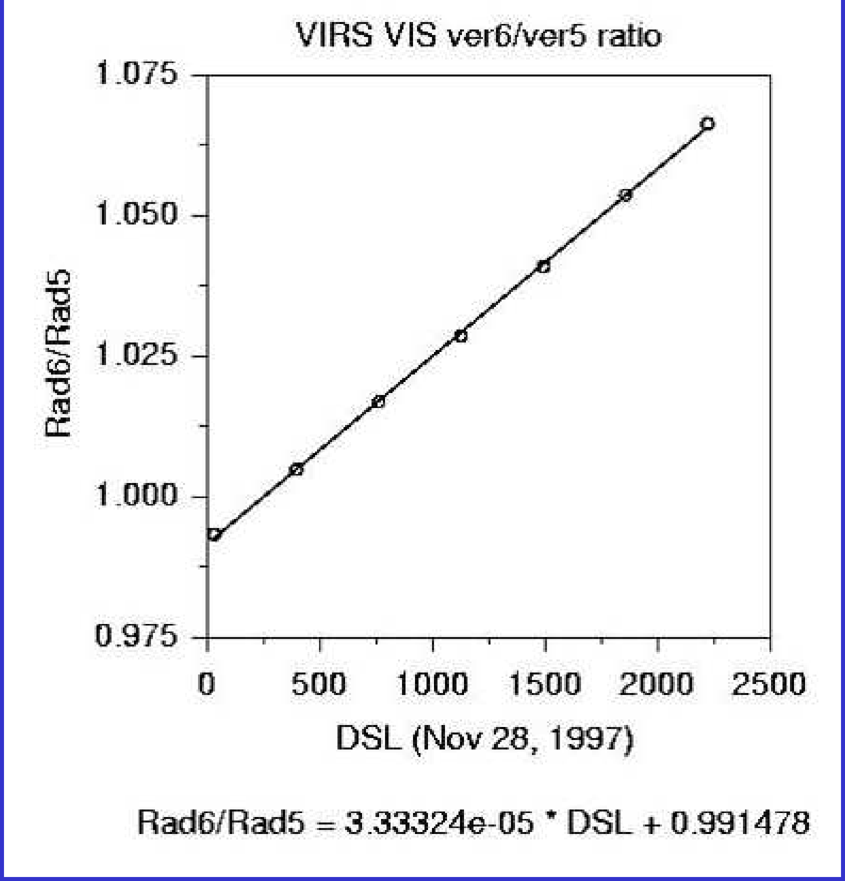


Version 6

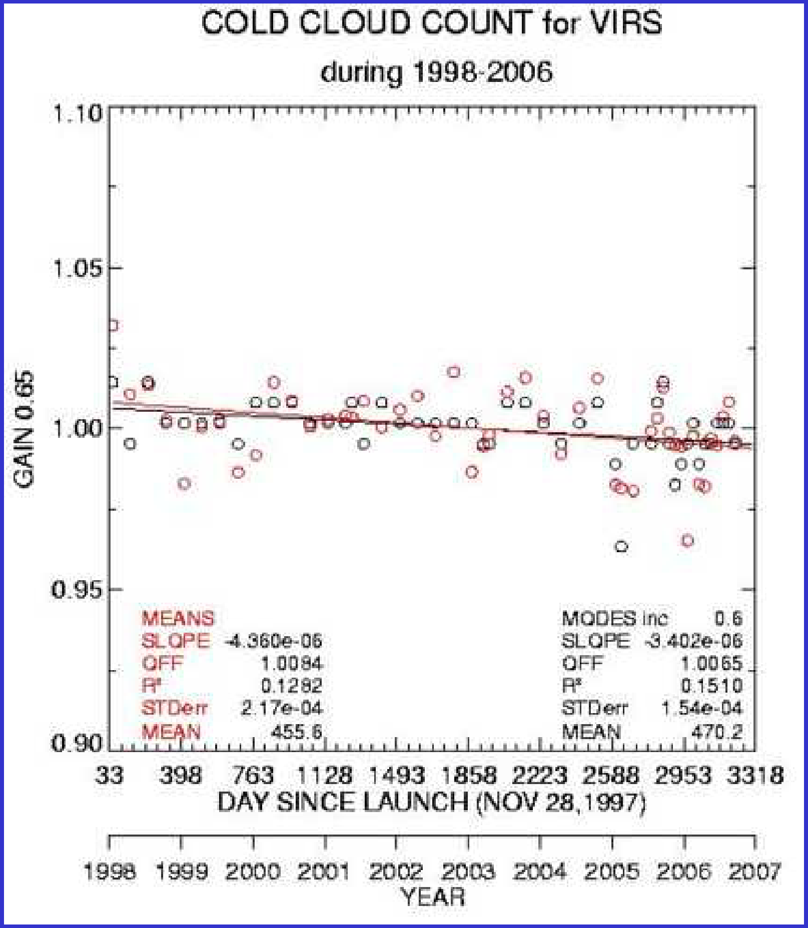


VIRS DCCT degradation

VIRS Ver6/Ver5A correction

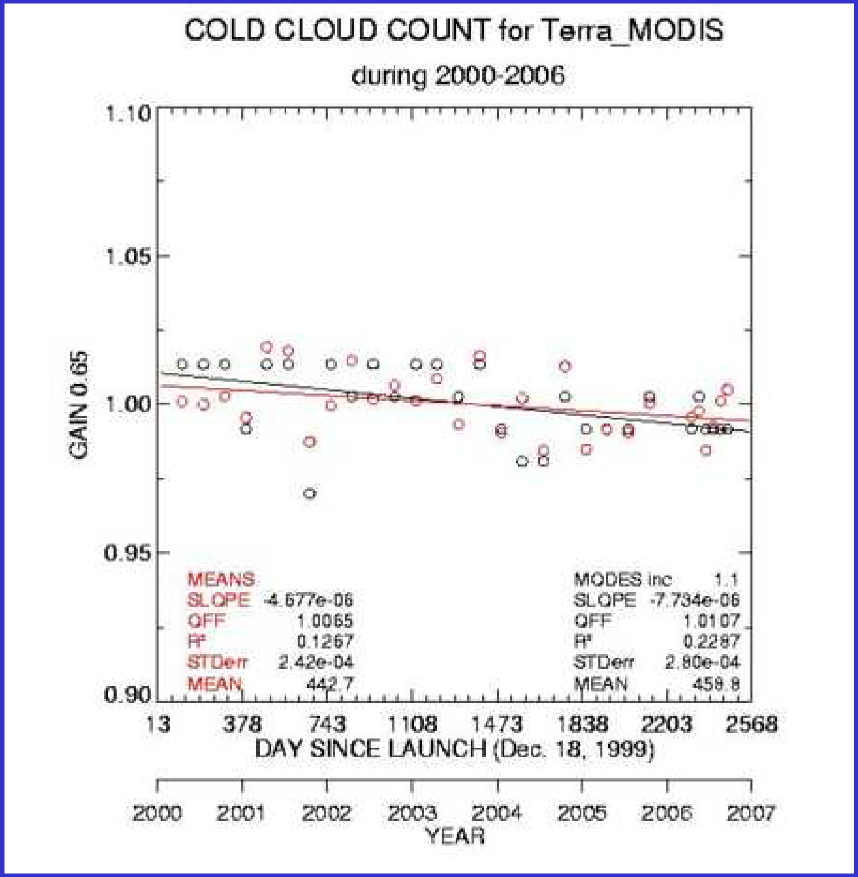


VIRS Ver6 corrected



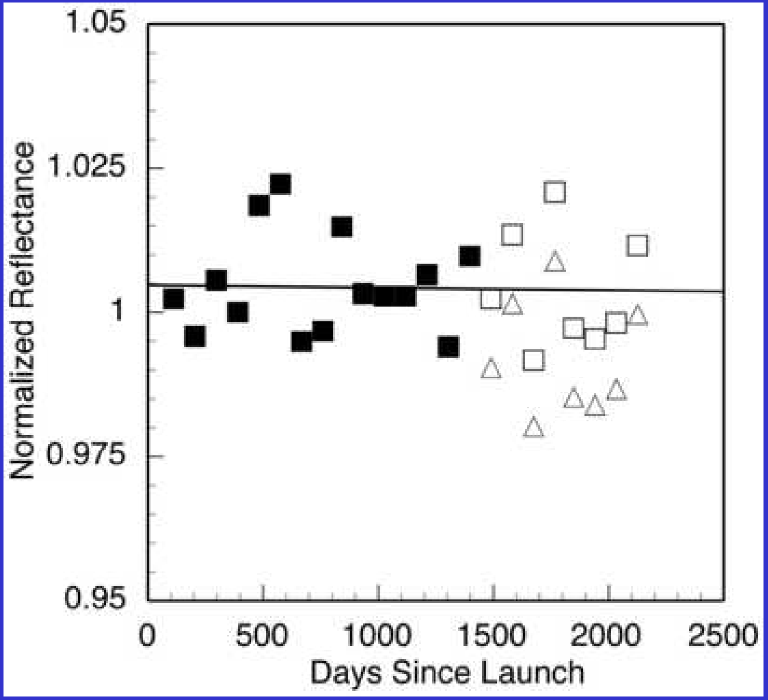
- VIRS DCC trend = 0.12%/yr-1

Terra-MODIS DCC degradation

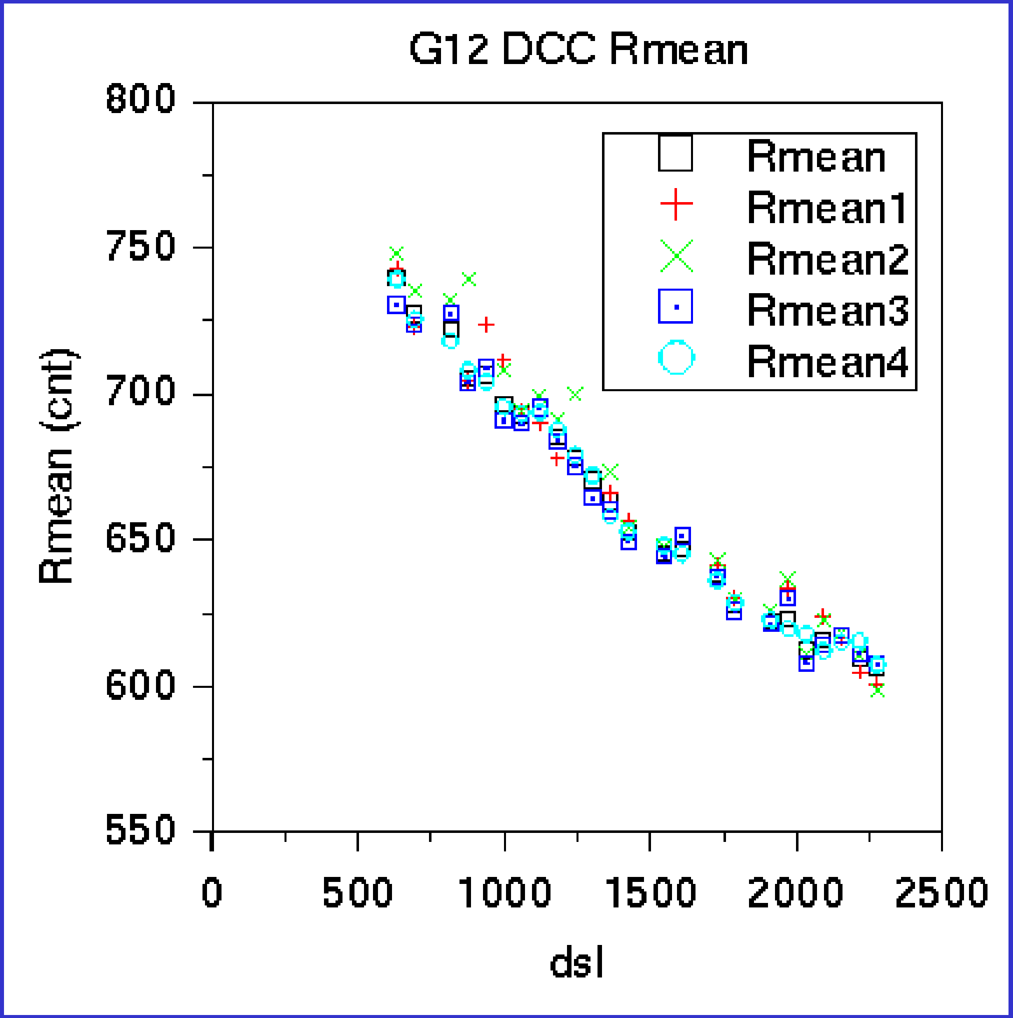


- Apparent trend due to gain jump in late 2003
- Correction needed after

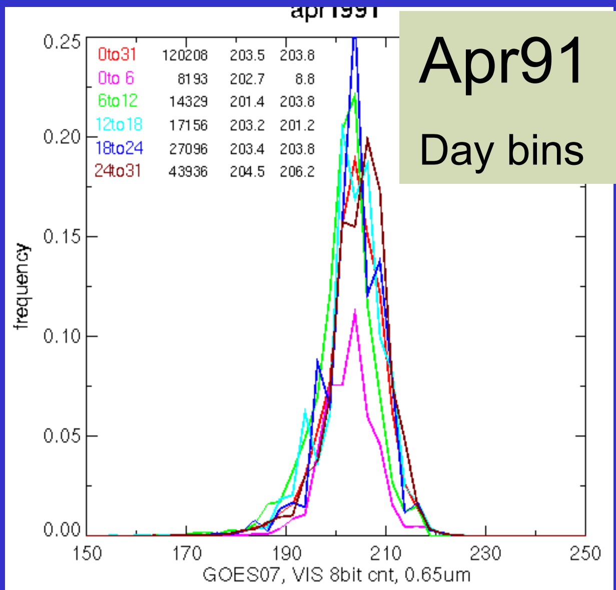
Open squares corrected for gain change

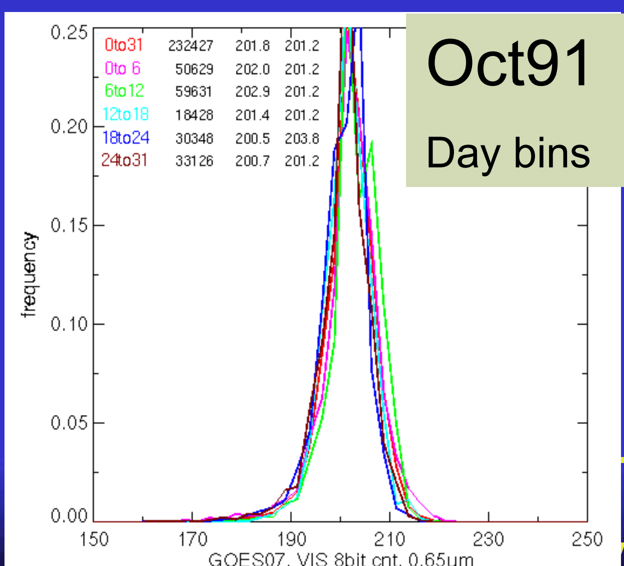


G12 as a function of longitude

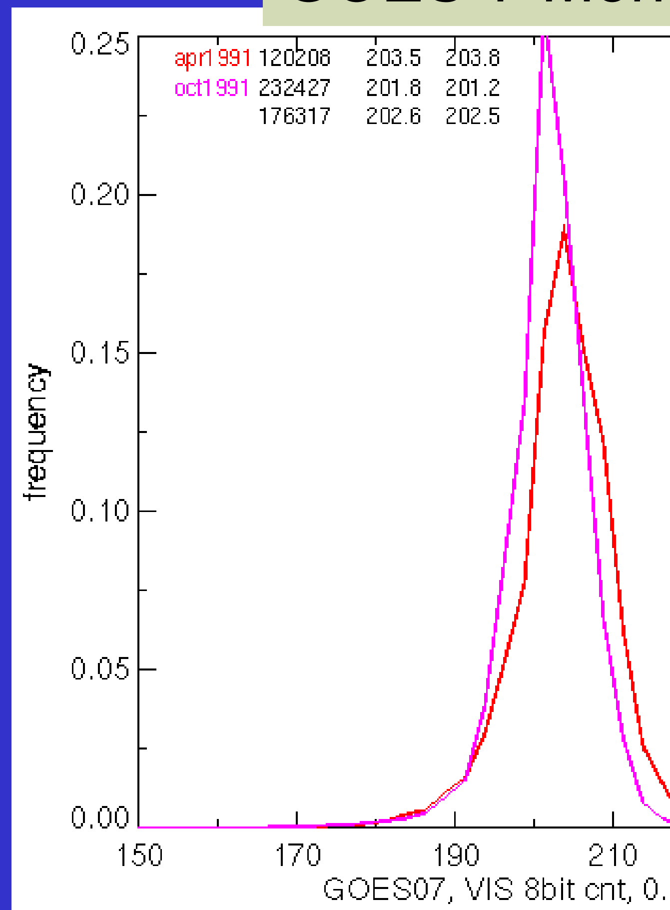


Mt Pinatubo stratospheric aerosol effects





GOES-7 Monthly PDF



- Eruption was June 12, 1991

Goestationary Visible Calibration Approach

1. Determine stability of reference LEO imagers
   a. Use ATSR, VIRS, *Terra* & *Aqua* MODIS, VIIRS, CLARREO
   b. Validate with LEO/LEO and DCC
2. Cross-calibrate every 1-3 months
   a. Use LEO/GEO using "well-calibrated" reference LEO imagers
   b. Use GEO/GEO to confirm calibration, 3-way calibration
   c. Use DCC to validate calibration stability
3. Derive degradation equations for each GEO sensor
4. Account for spectral differences in channels theoretically
   a. CLAREREO is a solar hyperspectral instrument and will provide absolute calibration relying on instrument spectral response

- Use many approaches and samples to stabilize the statistics!

LEO-to-GEO/LEO Cross-Calibration Method

- Match data & compute average radiance *L* , brightness temperature *T*, or Count *C* within a 0.5° region using selection constraints

  - ΔSZA < 5°, ΔVZA < 10°, ΔRAA < 15°, Δt < 15 min, no sunglint

- Normalize all solar channels to common solar constants
- Normalize each radiance to a common SZA
- Perform linear regression

$$X_{ref} = a\, Y_{sat} + b$$

$X = L$ or T; $Y = L$, T, or C

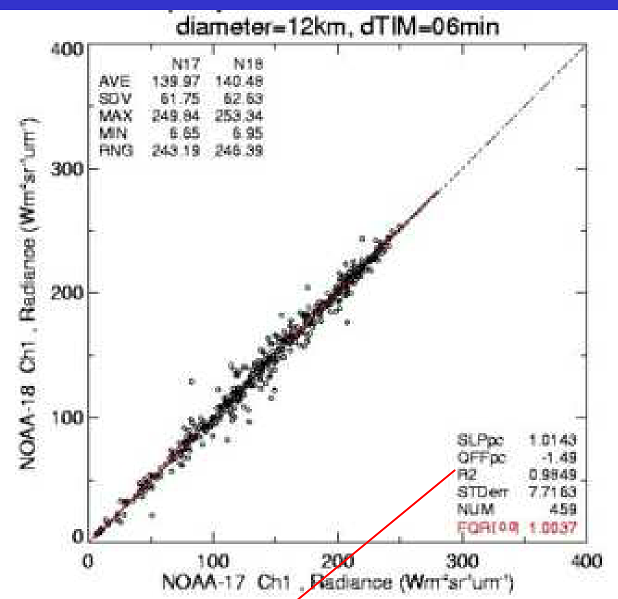
- Compute trends in $a(t)$ and $b(t)$ from sets of coefficients

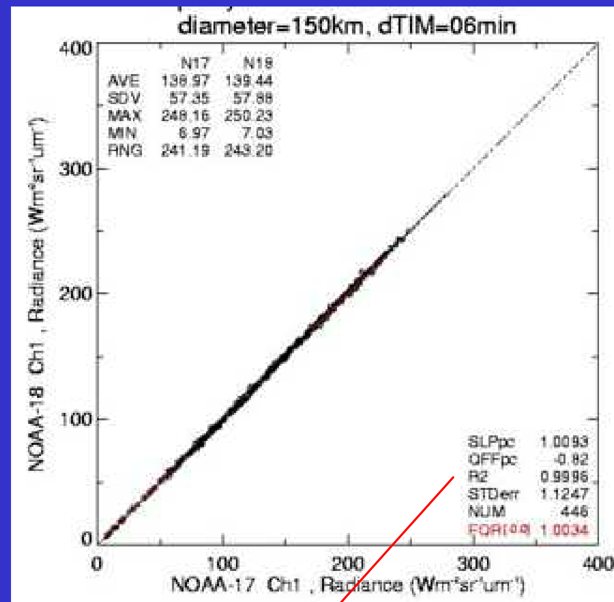
$$a = c_o + c_1\, DSR + c_2\, DSR^2; \qquad b = d_o + d_1\, DSR + d_2\, DSR^2$$

DSR = days since reference date

Minnis et al., JTech, 2002

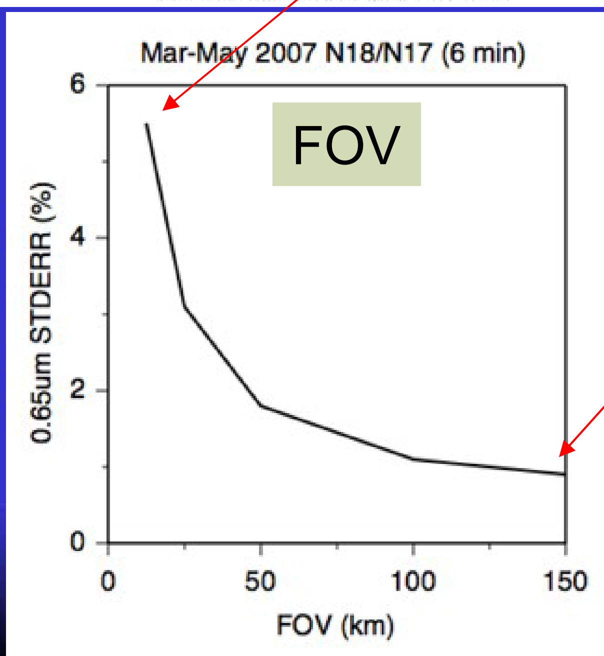
AVHRR N18/N17 Visible standard error (%)

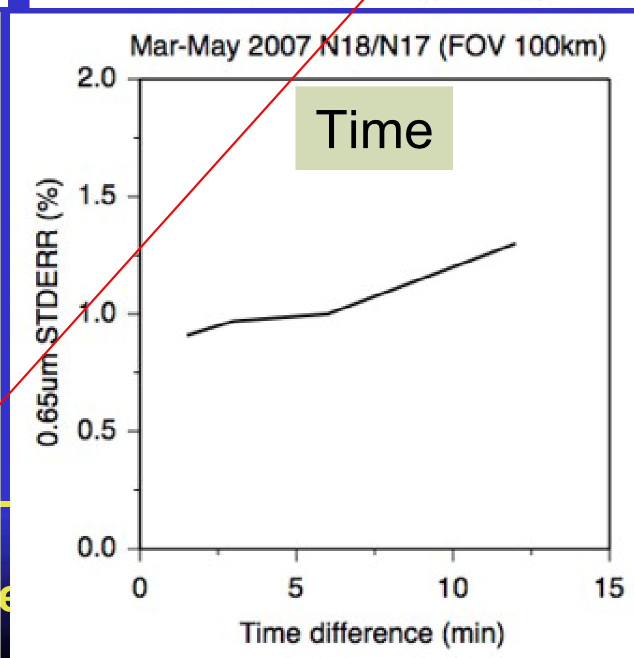


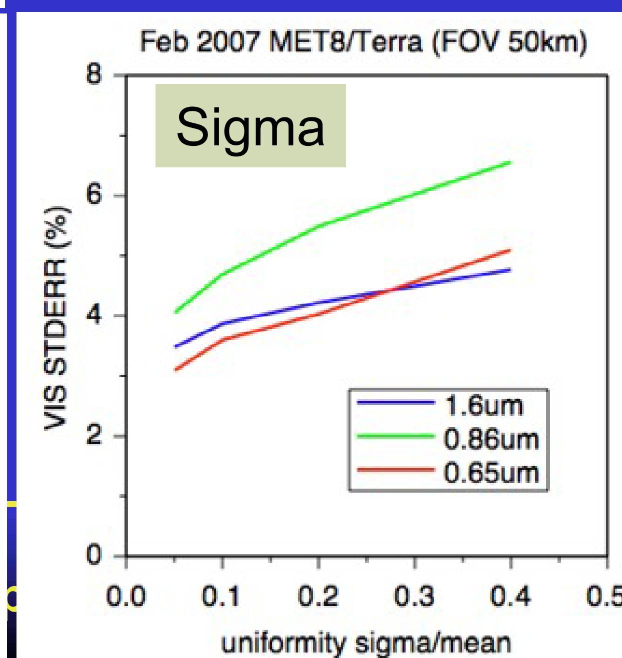


- Visible stderr < 1% by
  - -Increasing FOV
  - -Decreasing time difference
  - -Decreasing spatial sigma

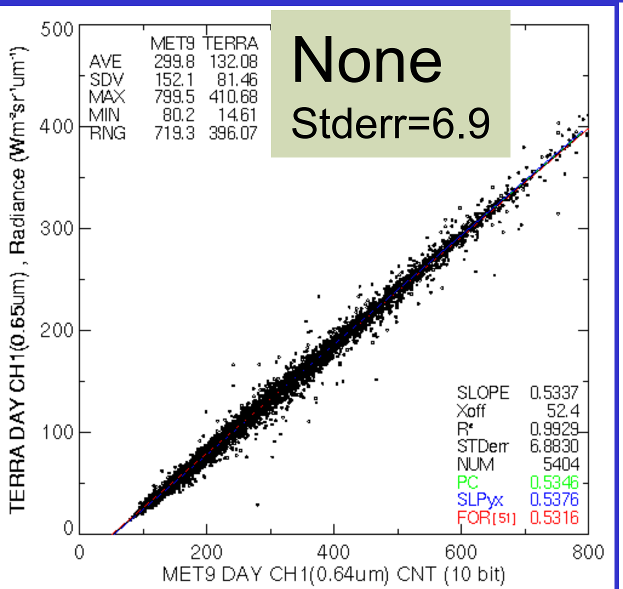
When response functions are identical

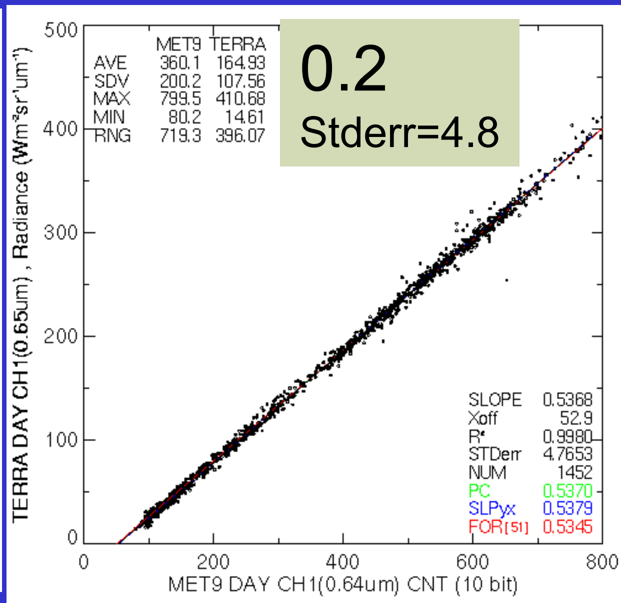


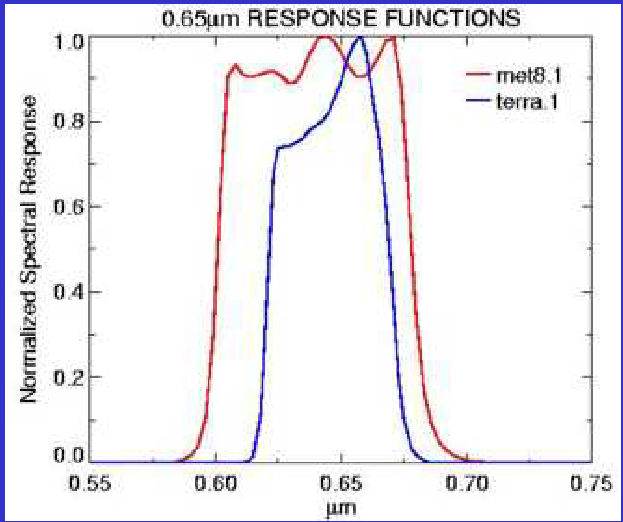


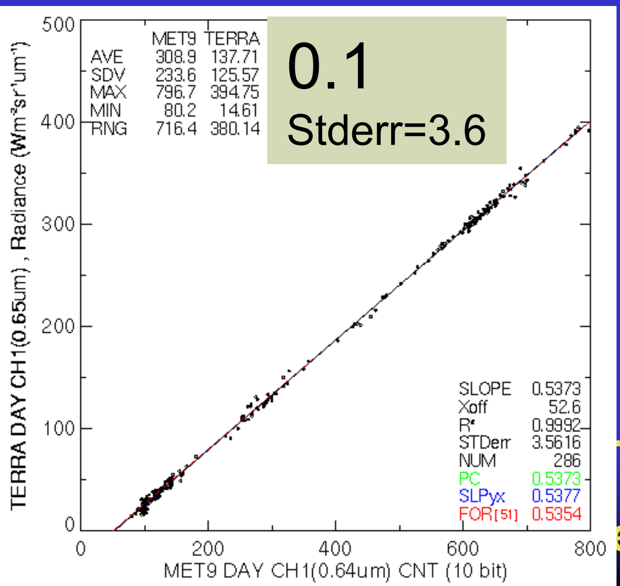


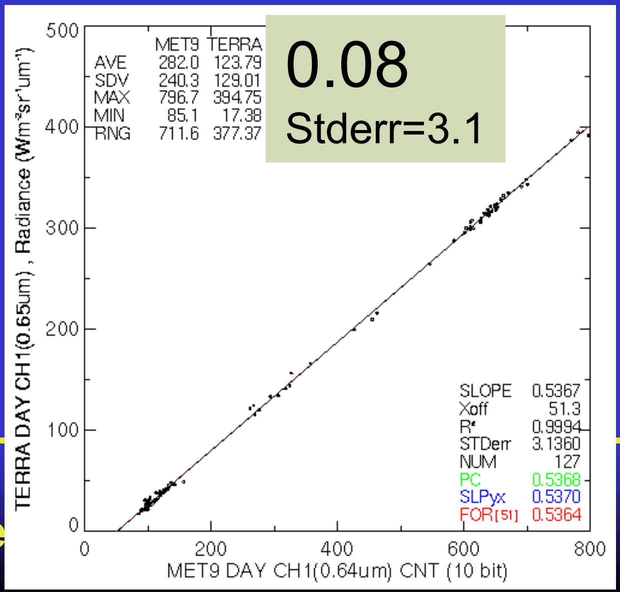
MET8/Terra VIS spatial sigma limits

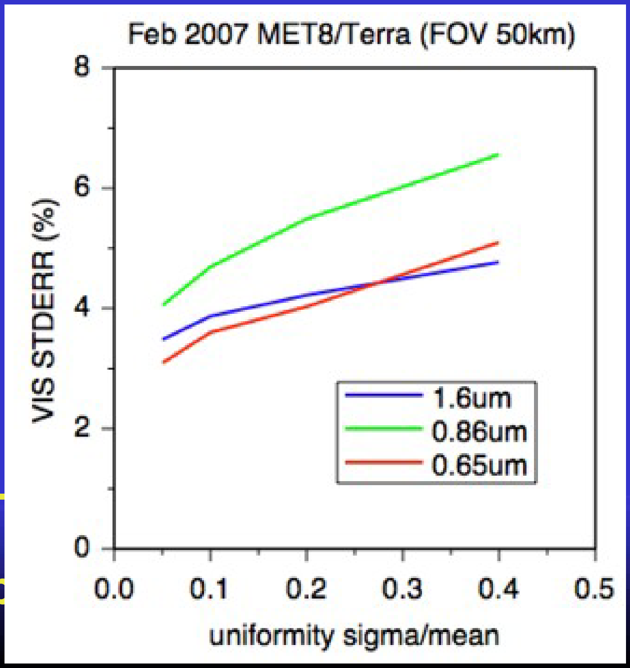






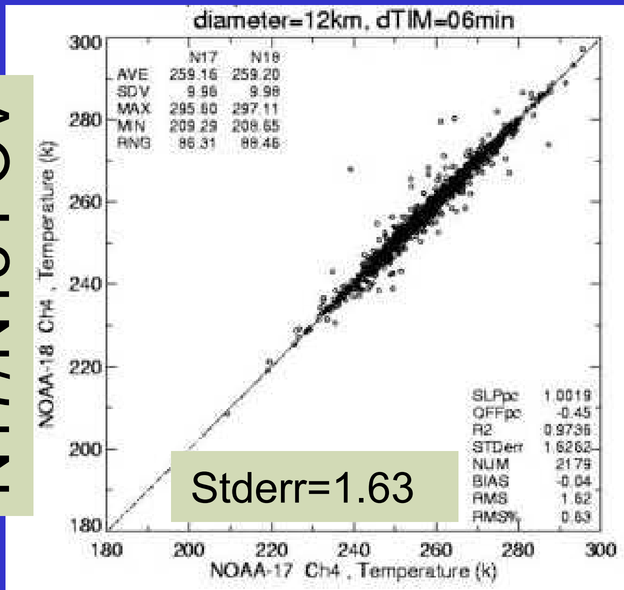




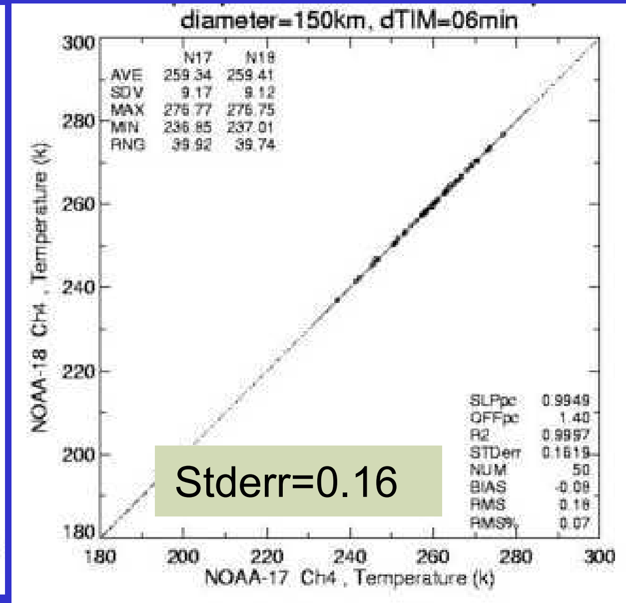


N17/N18 FOV and MET/Terra IR sigma limits

N17/N18 FOV



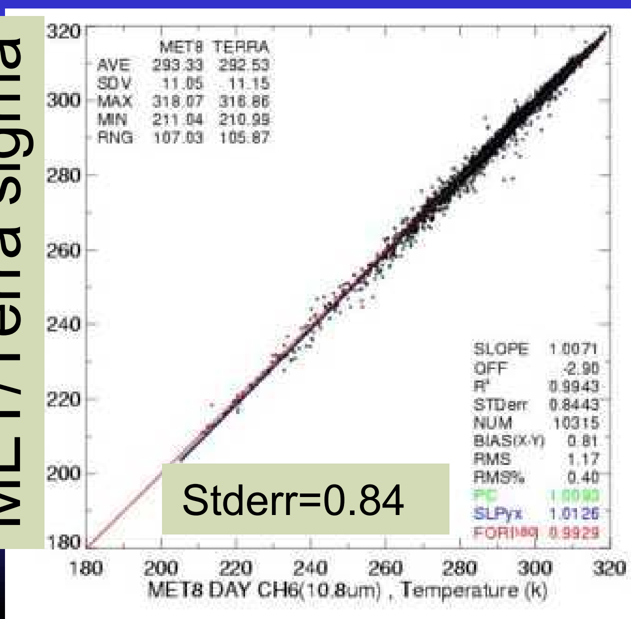
Stderr=1.63



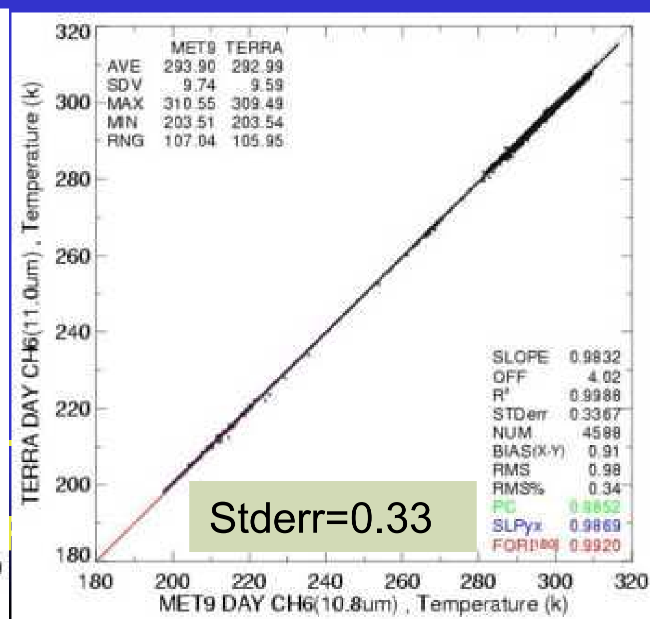
Stderr=0.16

Reduce IR stderr<0.1%

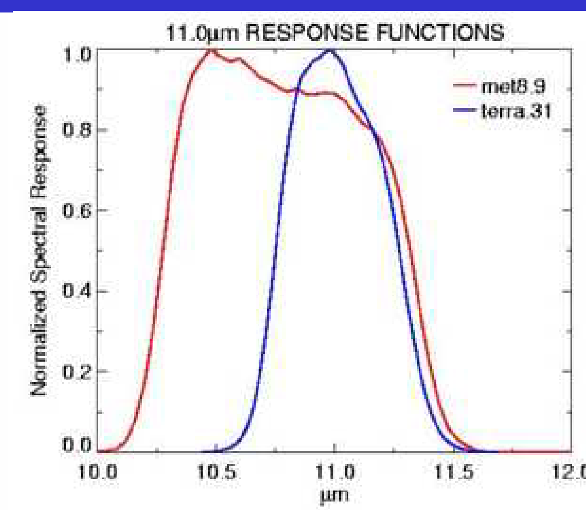
MET/Terra sigma



Stderr=0.84



Stderr=0.33

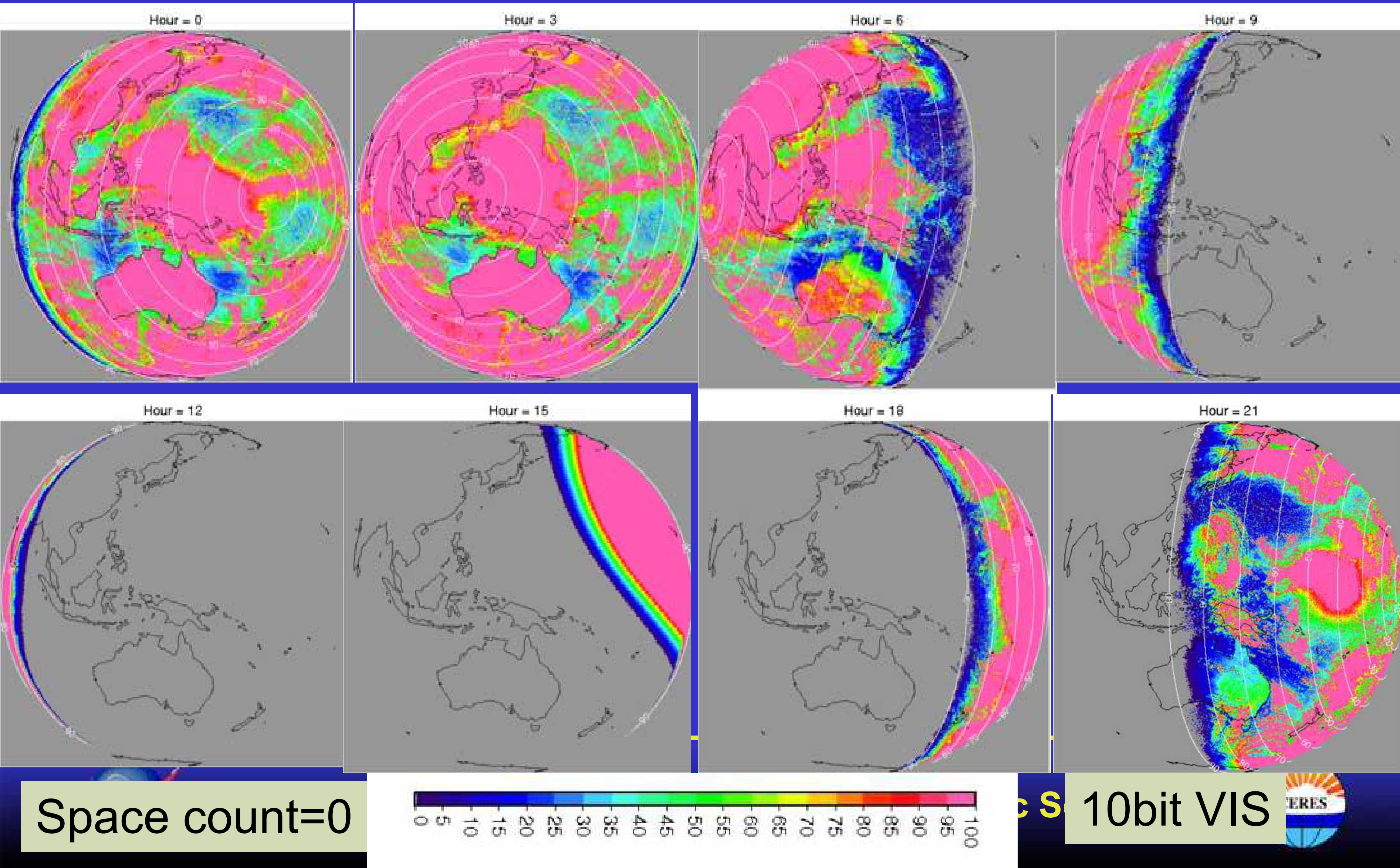


MTSAT case study

- Space count
- Visible nonlinearity gain
- Daily gain fluctuations

• Note that many terminator MTSAT pixels have counts of 0 when the SZA<90°

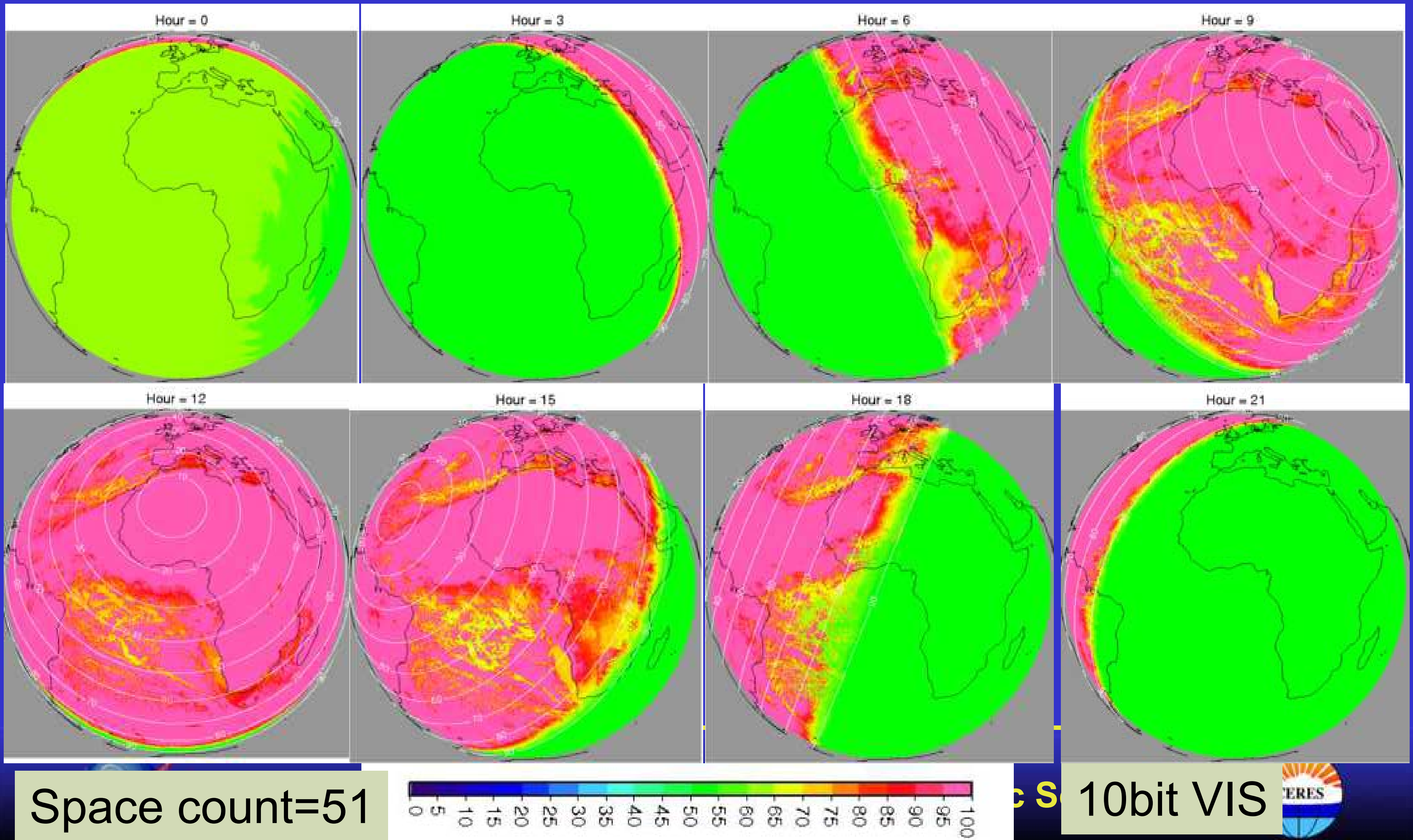
MTSAT VIS, Sept 17, 2007



Space count=0

10bit VIS

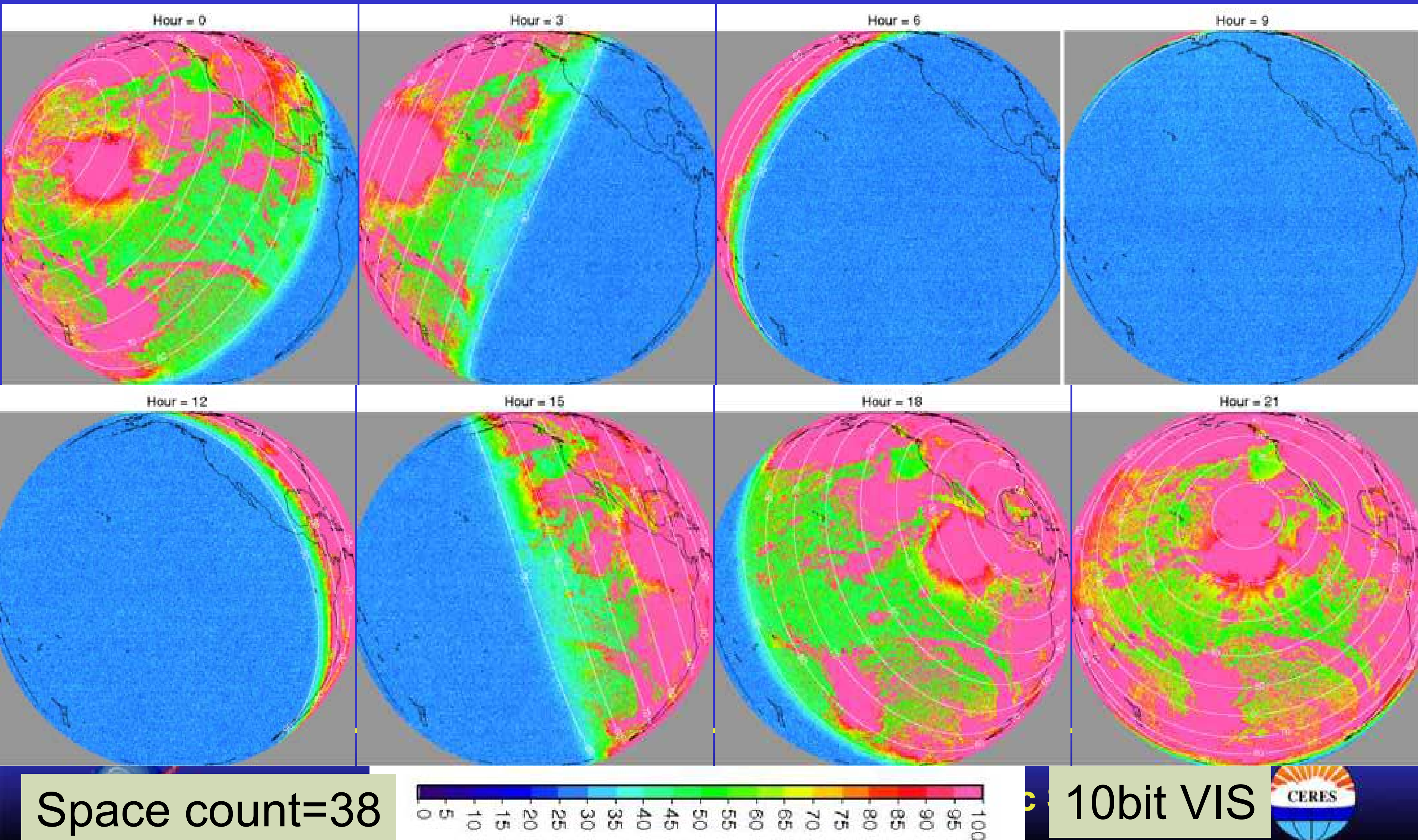
MET8 VIS, July 1, 2006



Space count=51

10bit VIS

GOES11 VIS, July 18, 2006

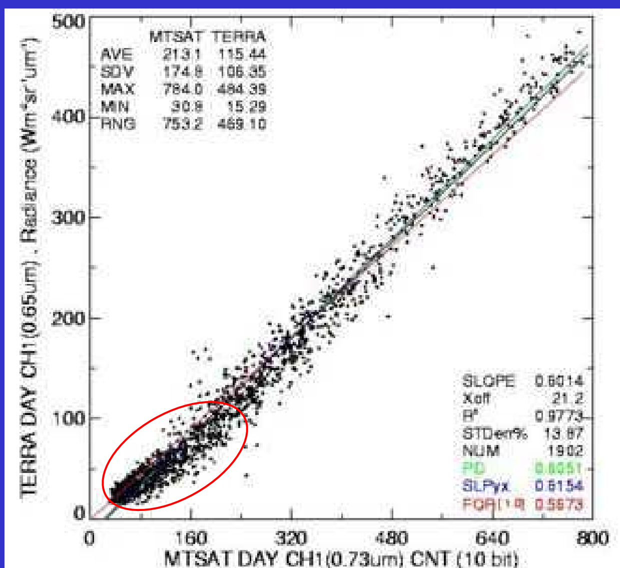


Space count=38

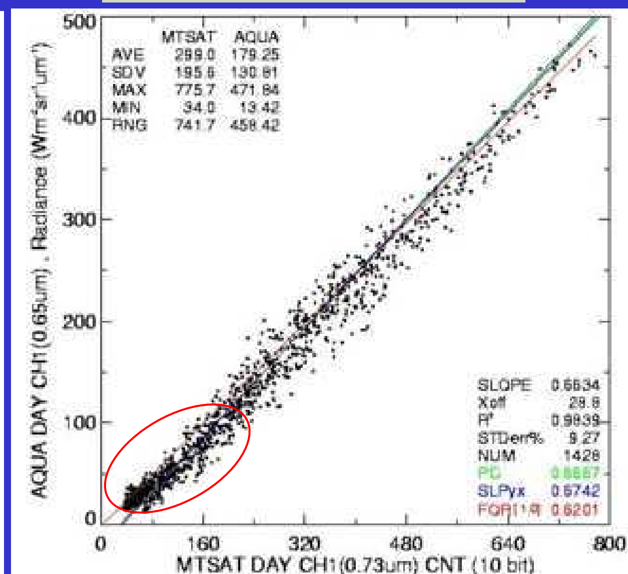
10bit VIS

MTSAT 10bit visible calibration, Sep 2007

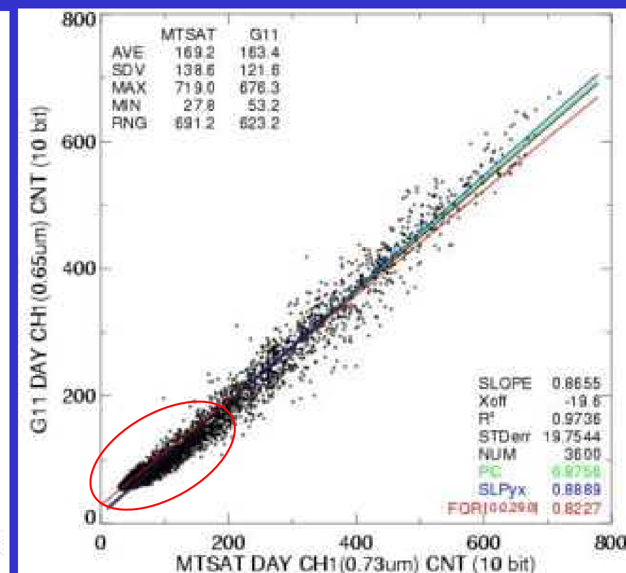
MTSAT/Terra



MTSAT/Aqua



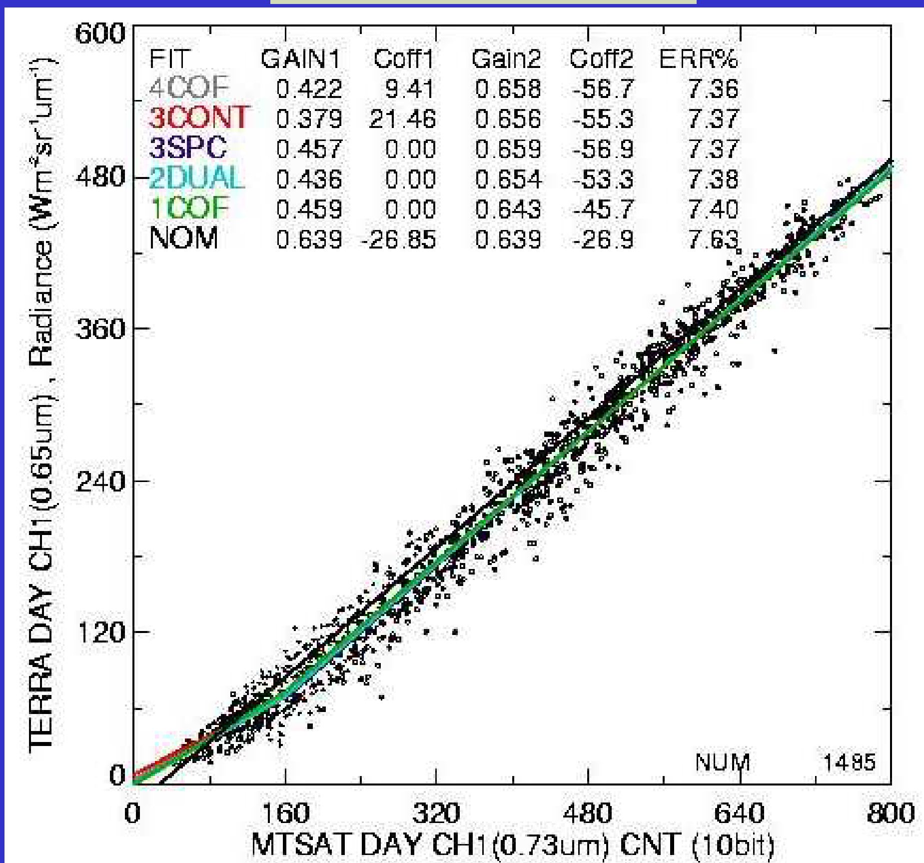
MTSAT/GOES11



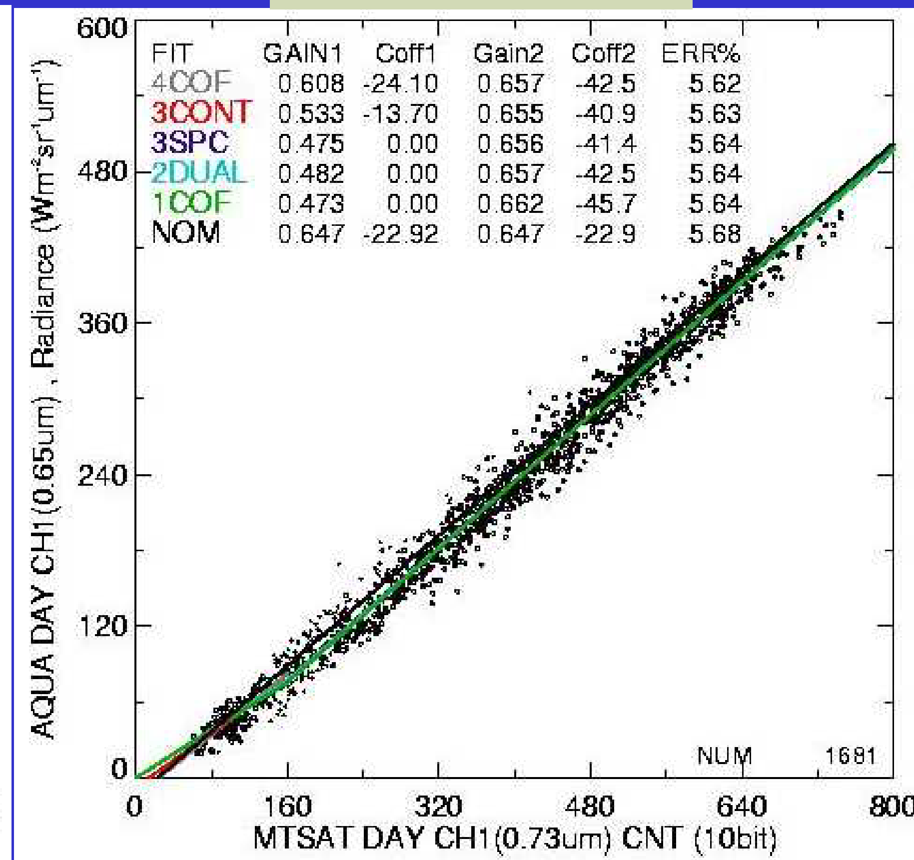
- Use dual gain approach, breakpoint at 160, fix space count at 0
- Difficult to detect nonlinearity using stable reflective targets (DCC)
- Note the MODIS cross-calibration occurs near noon

MTSAT dual fit calibration, Nov 2007

MTSAT/Terra



MTSAT/Aqua

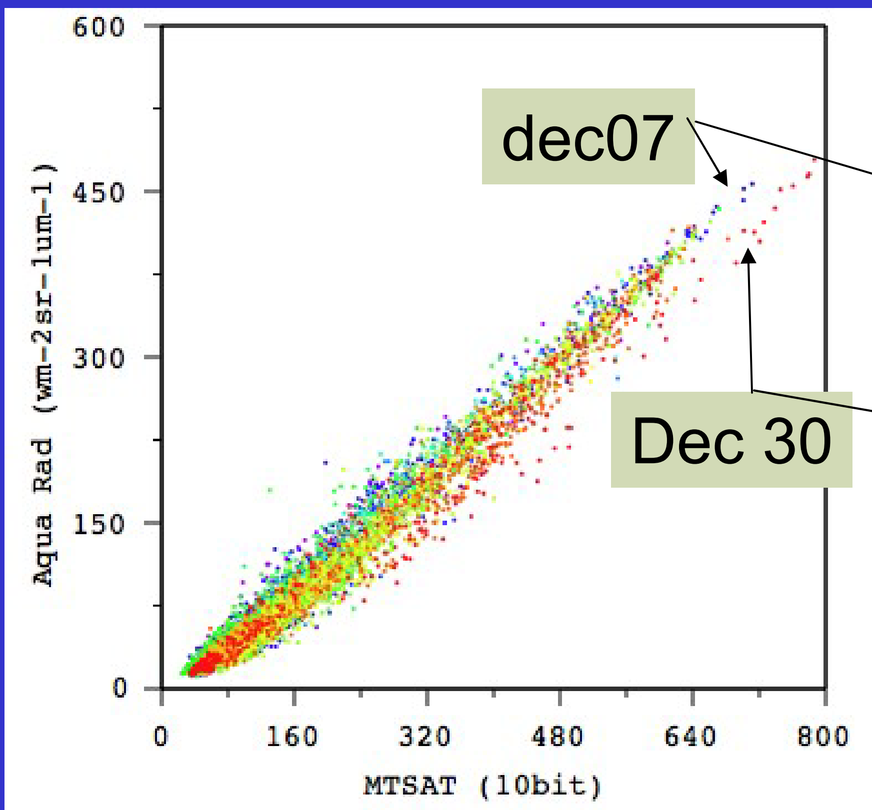


- 2DUAL, force spc=0, breakpoint=160, both gains = breakpoint
- Note very consistent high gains
- Spatial visible standard deviation threshold at 40%

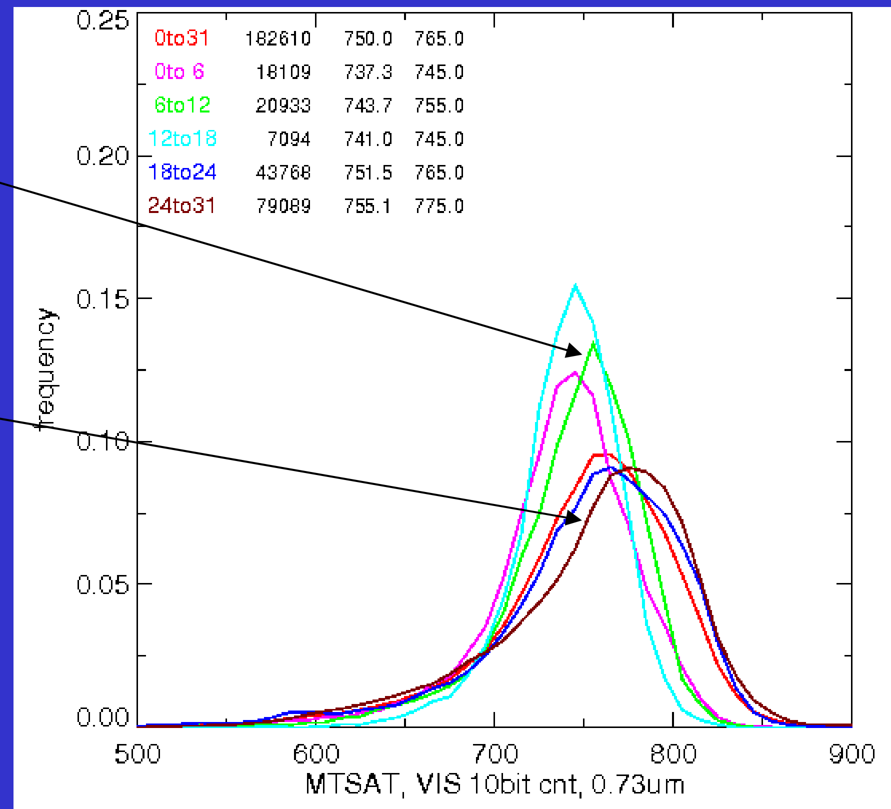
es

The use of DCC to detect sudden gain shifts Dec 2007

Aqua/MTSAT color by day



DCC MTSAT day bins



- Seems to be shift in the visible calibration ~ Dec 18, 2007

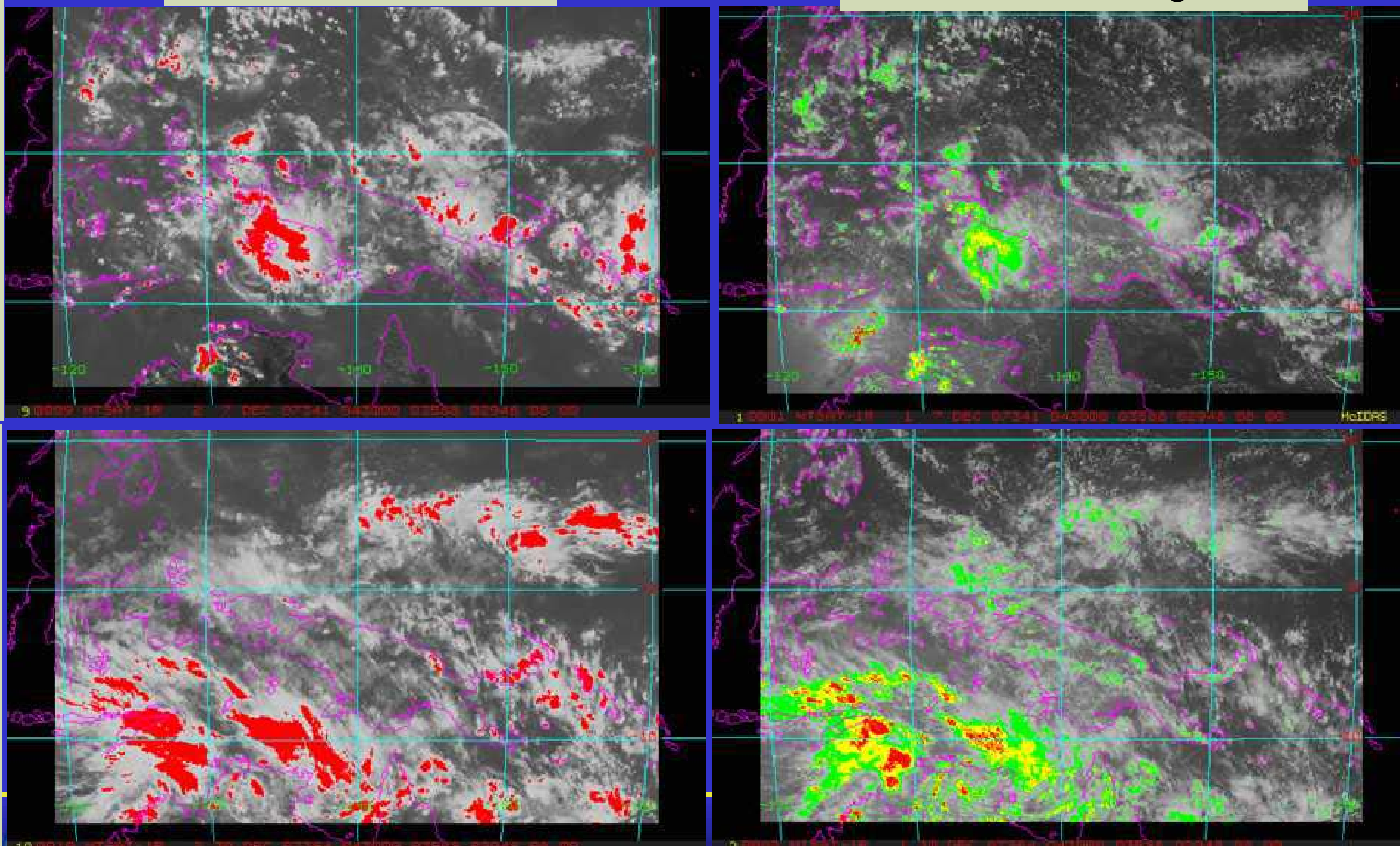
Comparison of MTSAT DCC for Dec 2007

IR, red T<205°K

VIS, DC>650 green

Dec 7 2007, 04:30 GMT

Dec 30 2007, 04:30 GMT



Conclusions

•Well-calibrated GEO & LEO radiances necessary to produce accurate & cross-platform consistent cloud properties and fluxes

- **Reference imager radiances necessary**
- **Cross-platform normalization can provide accurate calibrations**
- **Deep Convective Clouds can be used to monitor stability**

• NASA-Langley has developed a prototype end-to-end system linking the calibration of relevant channels on a host of satellites

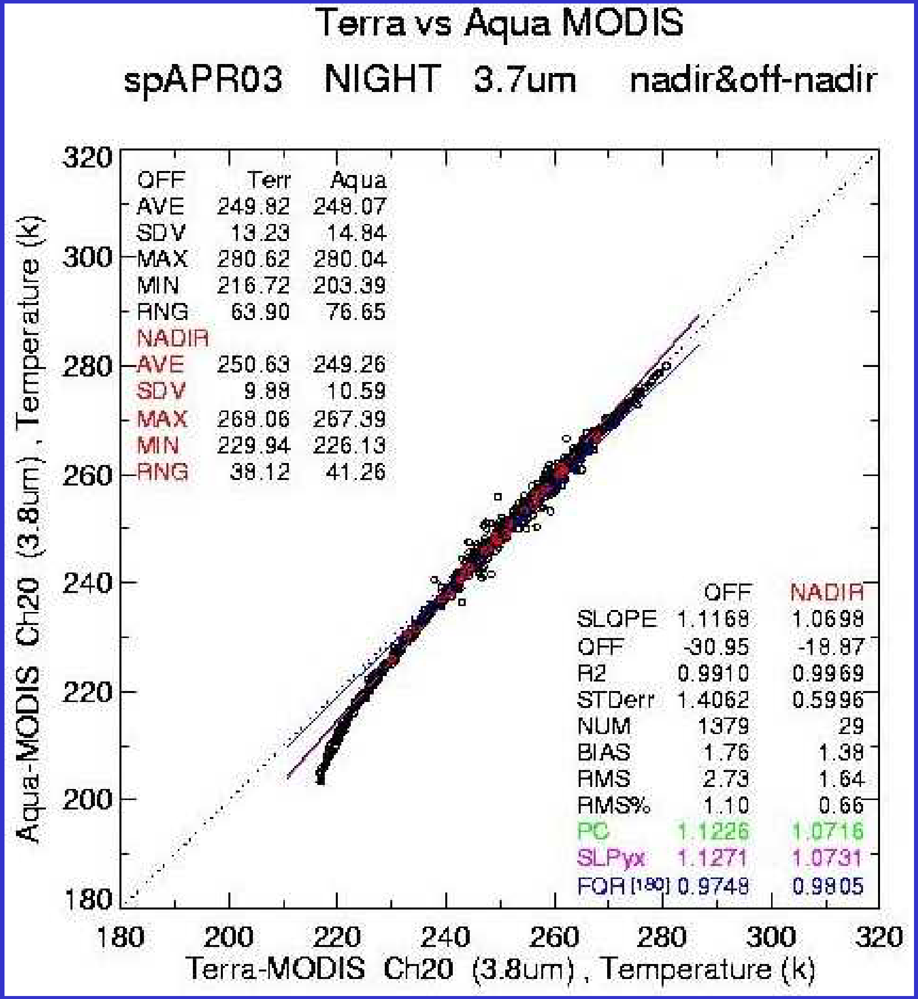
- **MODIS serves as reference**
- **Multiple approaches ensure redundancy & error checking**
- **Radiative transfer methods used to adjust normalized results**
- **Automated data ingestion and web based analysis - L. Nguyen**

Visible Calibration Summary

	ADVANTAGES	DISADVANTAGES
REFERENCE SATELLITE CROSS-CALIBRATION	Resolve entire dynamic range	Continuous satellites measurements needed
Hyperspectral visible CLARREO SCHIAMACHY	The ideal calibration transfer which takes into account the spectral response function	Multi-spectral footprints are are large. SCHIAMACHY is 30x60km and CLARREO is ~100x100km
SNO method	No ADMs needed Many LEO/LEO matches	Critical pixel to pixel matching. Pixels must be same size. Few LEO/GEO matches
Ray-matching	Uses gridded pixel matching, more matches than SNO	Noise from time, angular and spectral mismatches
STABLE REFLECTIVE TARGETS	No satellite instruments needed	Cannot resolve entire visible dynamic range
Deep convective clouds	Abundent tropical targets. Identified by IR threshold No apriori information	Longterm stratospheric and microphysics unknown
Stable desert sites	Deserts are near the GEO subsat point. Large stable desert areas can monitored daily	Limited geographically Unknown longterm albedo stability. Needs apriori surface BDRF and atmospheric profiles. Needs accurate clear-sky detection
Bright playas	Designed for absolute calibration by resolving the calibration spectrally. Surface albedo, BDRF and atmospheric profile are measured for every match	Limited sites. Very small footprint, requiring accurate navigation to locate pixcls over the site. Sites need to be actively maintained. Limited sampling
Lunar calibration	The Moon's reflectance is very stable both spectrally and temporally	Reflectance is only 15% of brightest earth targets. Observed once a month

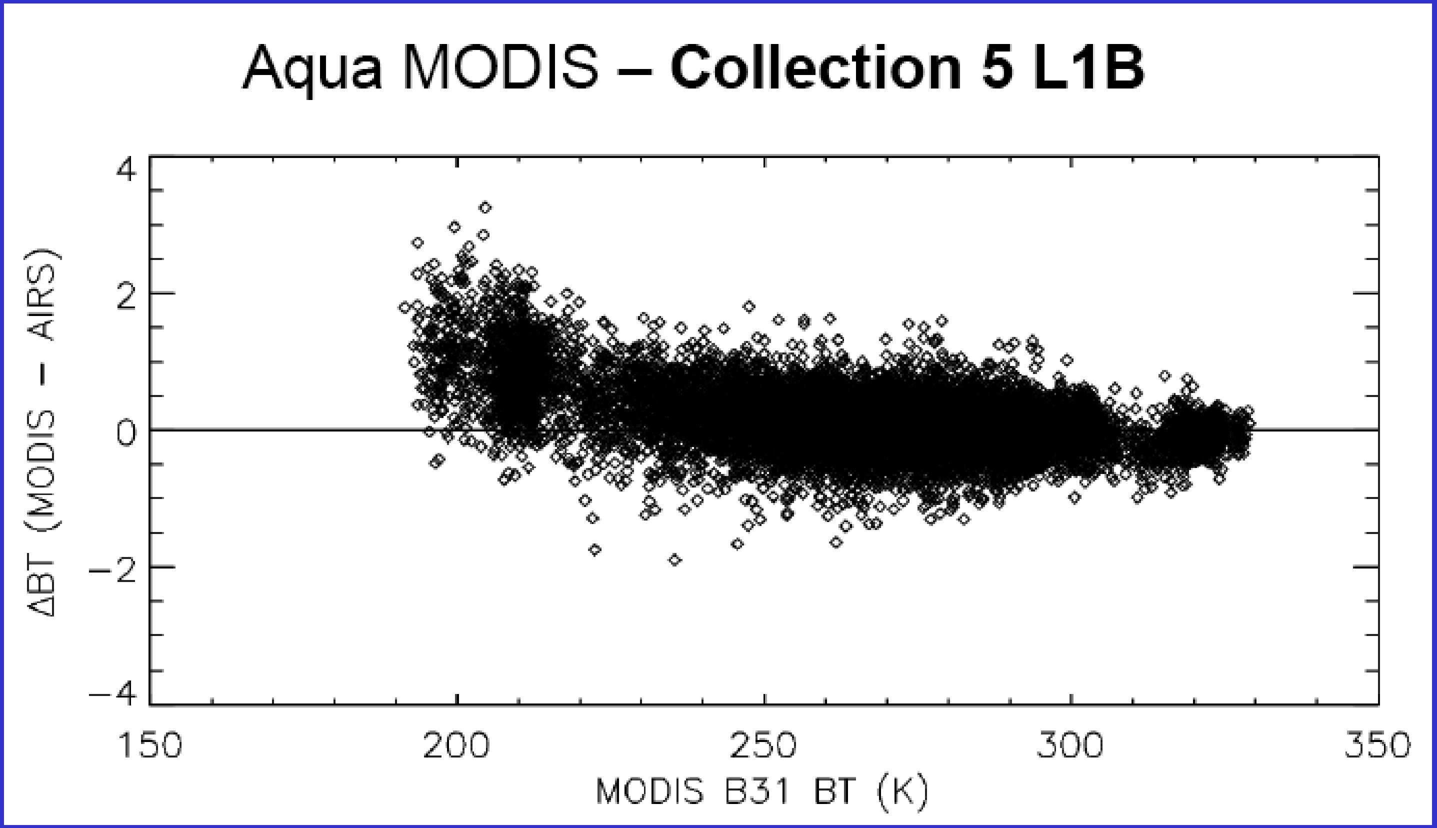
Backup slides

Comparison of Terra/Aqua MODIS 3.7µm channel

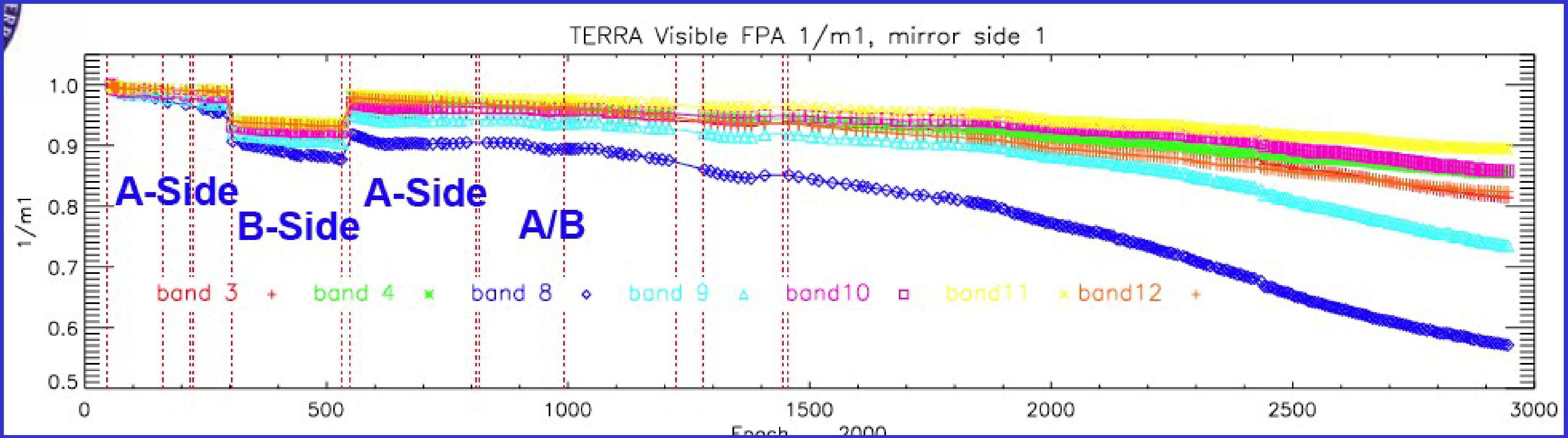


- Will be corrected in Collection 6
- Not enough resolution in the Terra DC at low temperatures

Comparison of AIRS and Aqua-MODIS 11µm temperature, 1 orbit, June 20, 2006



Terra-MODIS RSB Response Trending



- ~45% decrease in band 8 (0.4µm) response
- shorter wavelengths degrade faster over time

Theoretical Spectral Correction

- **Spectral filter functions vary from imager to imager**
  - Atmospheric scatter and absorption vary with wavelength
  - Surface and cloud reflectance vary with wavelength
  - Need to correct intercalibrated radiances

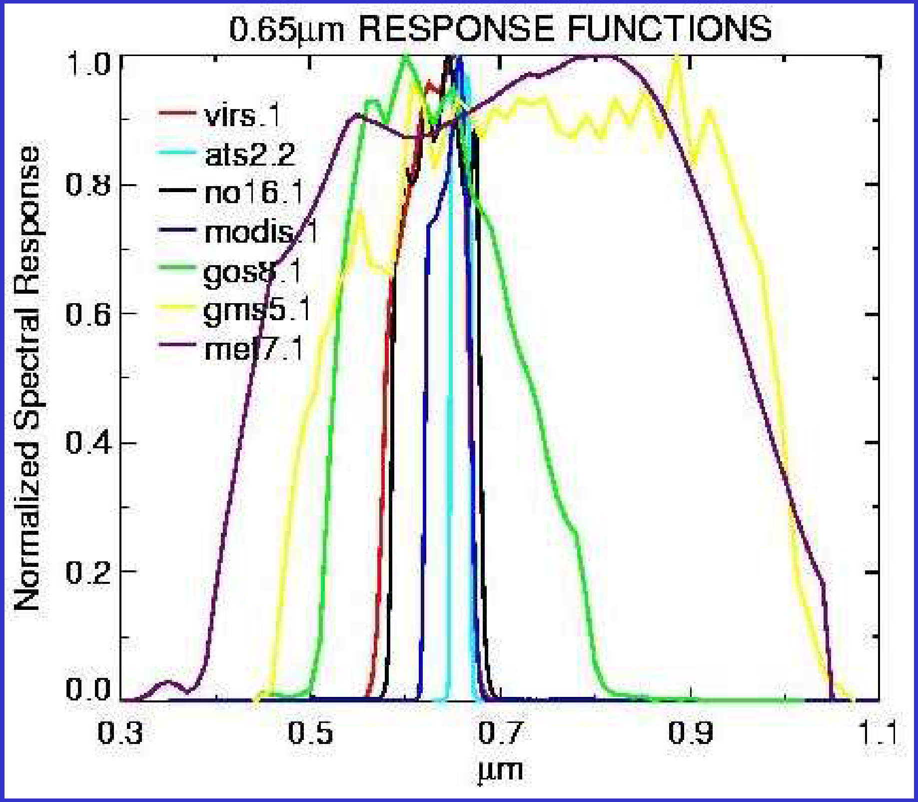
- **Approach**
  - Use radiative transfer models to compute $L_{sat}[L_{ref}(K)]$, K = sfc type

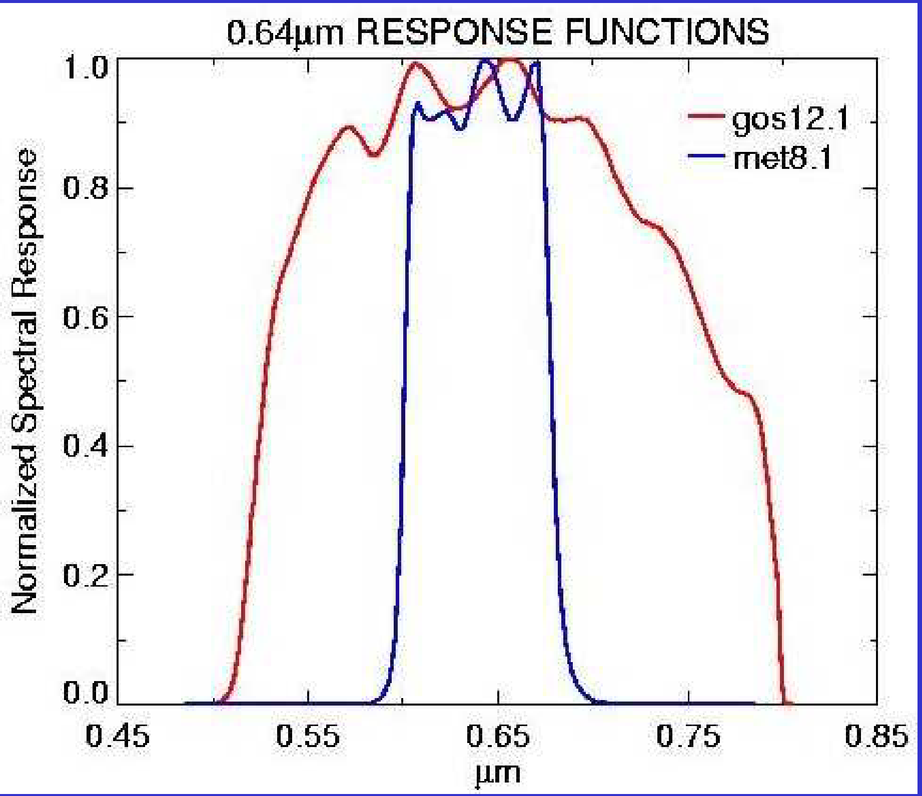
    Compute L_x for range of atmospheres, clouds, & aerosols for all imagers x

    $$L_{sat}(K) = \mathrm{f}(L_{ref}(K)) \qquad (1)$$

  - Use SBDART, 3 SZAs, albedo not L, 3 sfc types: ocean, vegetation, sand
  - Given normalized value of L'_{sat} from intercalibration, compute final value as $L_{sat}(K) = \mathrm{f}(L'_{sat}(K))$

Visible Channel Spectral Response Functions

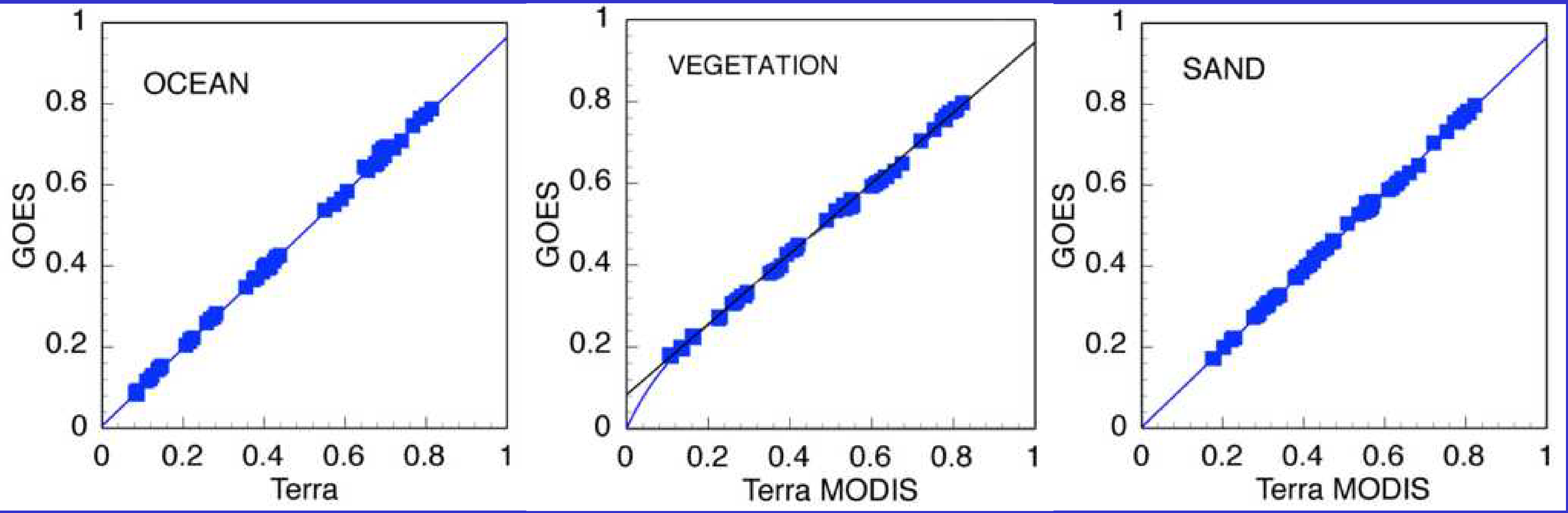




Similar variations seen in other channels!

Examples of Spectral Corrections, MODIS to GOES

0.65 µm



Ocean and sand are very similar, vegetation brighter for GOES

Spectral Corrections to *Terra* MODIS, Ocean only

Satellite	a	b
GOES	0.9584	0.0056
Meteosat-7	$A(\mu_o)$	$B(\mu_o)$
Meteosat-8	0.9741	0.0036
MTSAT-1R	$C(\mu_o)$	$D(\mu_o)$
VIRS	0.9540	0.0109
N14	0.9484	0.0030

- Broadbands have SZA dependence
- SEVIRI closest to MODIS