Use of Deep Convective Clouds

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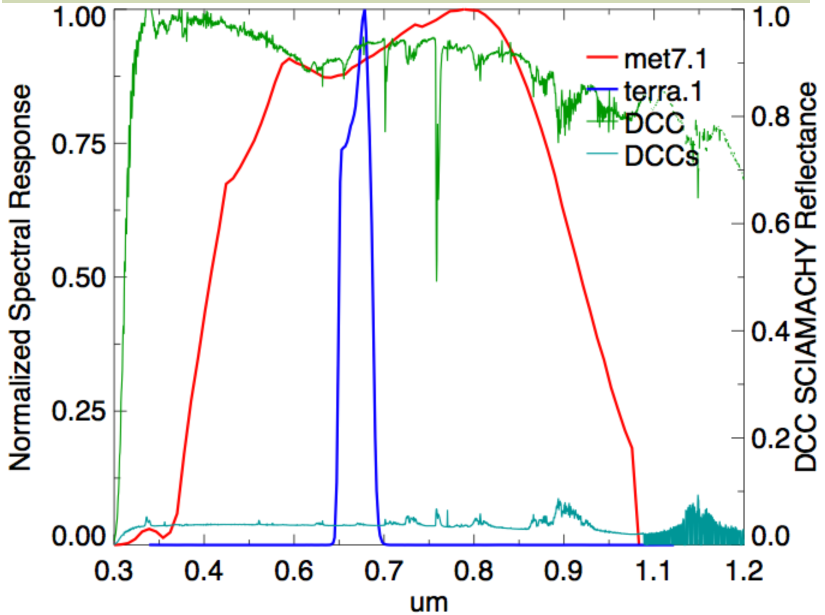
Motivation

- Deep Convective Clouds (DCC) are cold, bright, stable, TOA level, and nearly-isotropic targets located near the equator
  - DCC are used as solar diffusers to monitor visible calibration
  - Are observed by all GEO and LEO satellites
  - DCC angular variability is predictable
- DCC are easily identified by a simple IR threshold
  - The IR calibration is based onboard blackbodies
  - Need good visible and IR pixel co-registration not navigation
- Can DCC be used as an invariant target for calibration?
  - To help calibrate historical geostationary and AVHRR sensors to provide a 25 year record of well calibrate visible radiances
  - Are DCC invariant geographically?

SCIAMACHY Spectra

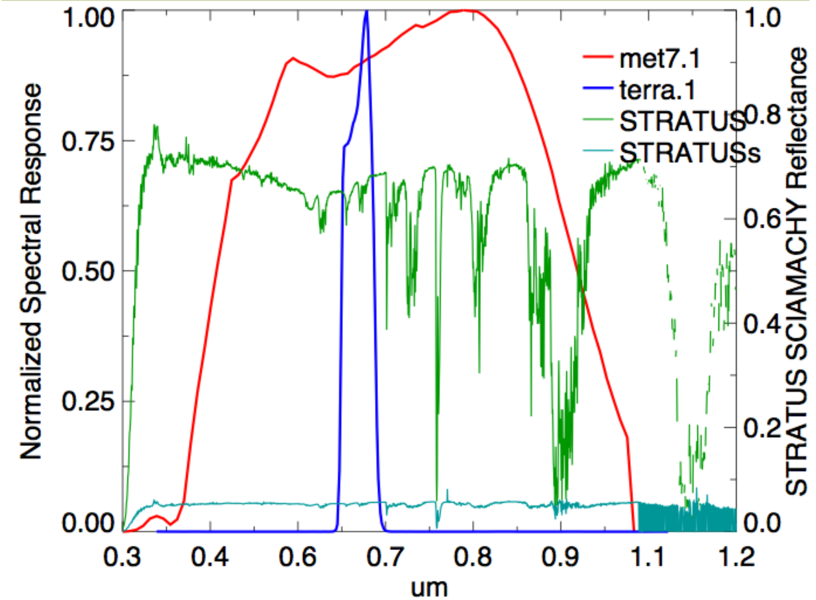
Courtesy of SCIAMACHY

DCC spectra at TOA



SAT	Cum	SCs	SCt	Rads	Radt	Ref
met7.1	0.7090	1356.4	1379.9	396.1	403.2	0.9181
terra.1	0.6466	1543.4	1575.3	452.7	462.2	0.9218
RATIO		0.8789	0.8760	0.8750	0.8724	0.9960

Bright stratus spectra near surface



SAT	Cum	SCs	SCt	Rads	Radt	Ref
met7.1	0.7090	1357.3	1379.9	271.8	276.7	0.6301
terra.1	0.6466	1544.4	1575.3	322.4	329.1	0.6564
RATIO		0.8789	0.8760	0.8432	0.8408	0.9599

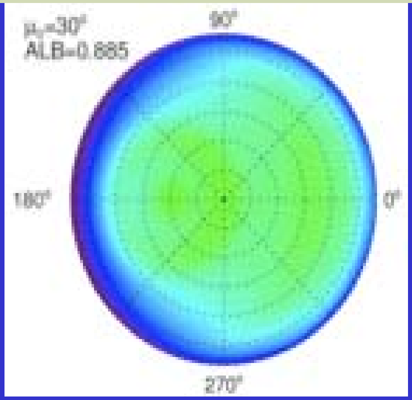
- At the TOA only oxygen and ozone bands are apparent, where as in the lower atmosphere there is water vapor absorption in the near IR
- The reflectance ratio over DCC between Terra-MODIS and Meteosat-7 is 0.9960, predicted to be nearly 1.0 for most visible channels, whereas bright stratus is 0.9599
- DCC angular dependence model should be independent of wavelength for most operational visible satellite channels

DCC MODIS 0.65µm modeled dependencies

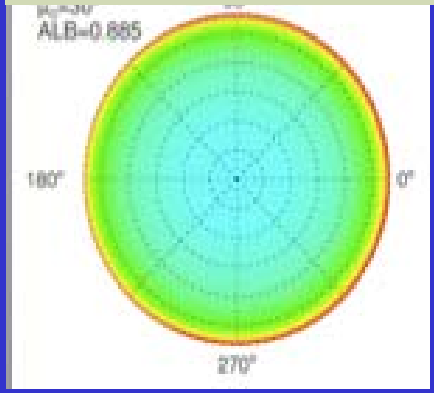
- DISORT scatter, correlated-K absorption
- Hexagonal column ice crystal model

SZA=30°

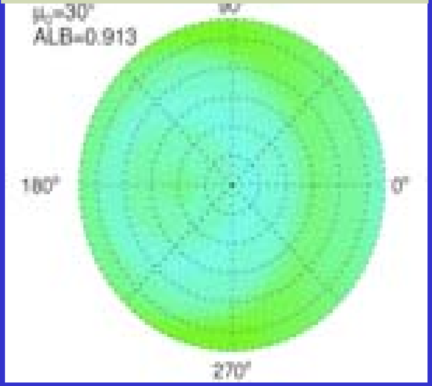
DCC ADM



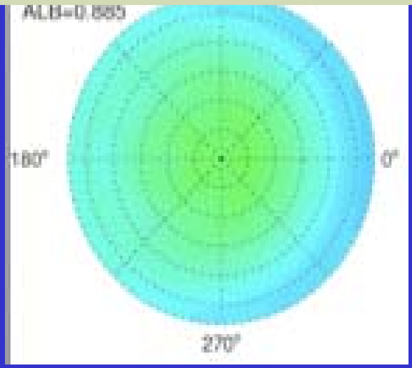
Ozone 300-200 DU

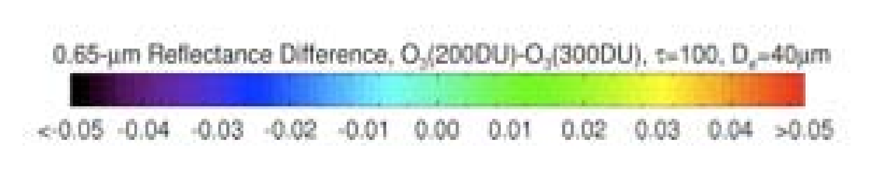


De 30-50 µm



τ 200-100





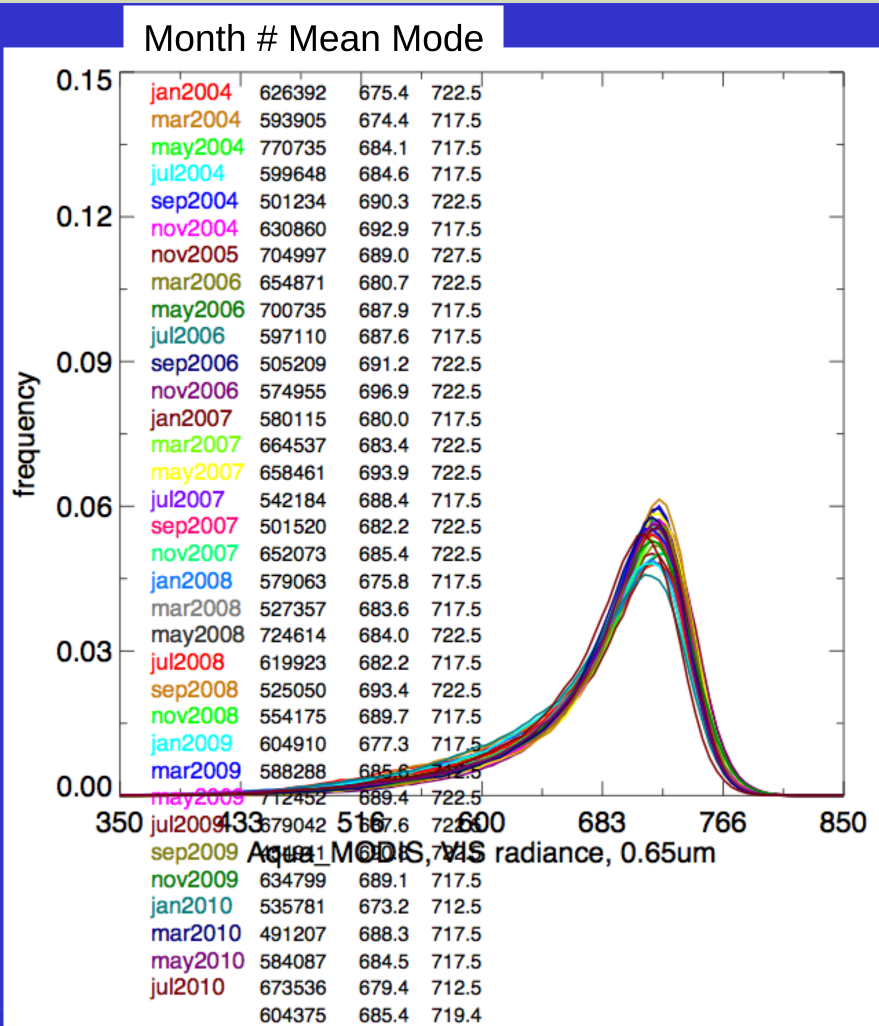
- DCC are uniform within 40° VZA and SZA
- <1% predicted impact due to optical, particle size and, 0³

DCC Calibration Procedure

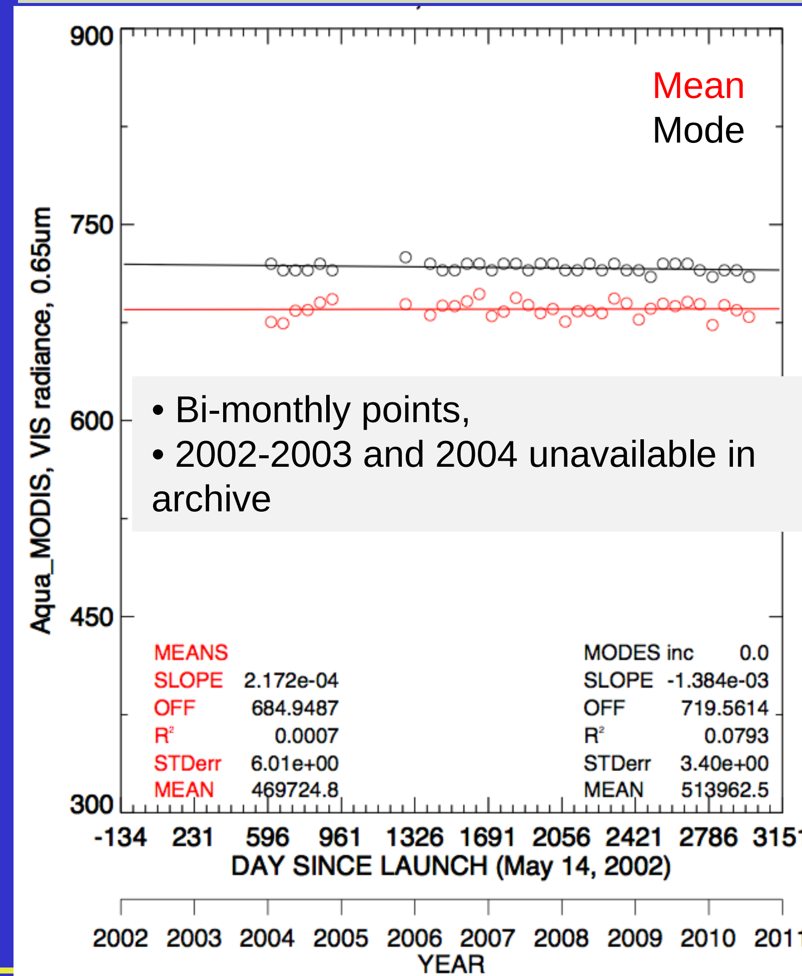
- Identify DCC MODIS pixels,
  - T(11µm) < 205°K
  - ±30° latitude, all longitudes
  - Limit the σ 0.65µm <3% and σ 11µm<1°K of surrounding pixels to help identify DCC
  - ~ 0.5% of all tropical pixels
- Convert DCC pixel radiances to overhead sun
  - Use CERES ADM and directional models
  - Limit VZA<40°, where the DCC is more isotropic
  - Terra/Aqua orbit limits the SZA<40° in the tropics
- Construct monthly PDFs over lifetime of satellite
- Plot the mode and mean of the monthly DCC radiances
  - Normalize the radiances to evaluate stability of sensor

Aqua Monthly PDFs

Monthly DCC Radiance PDFs

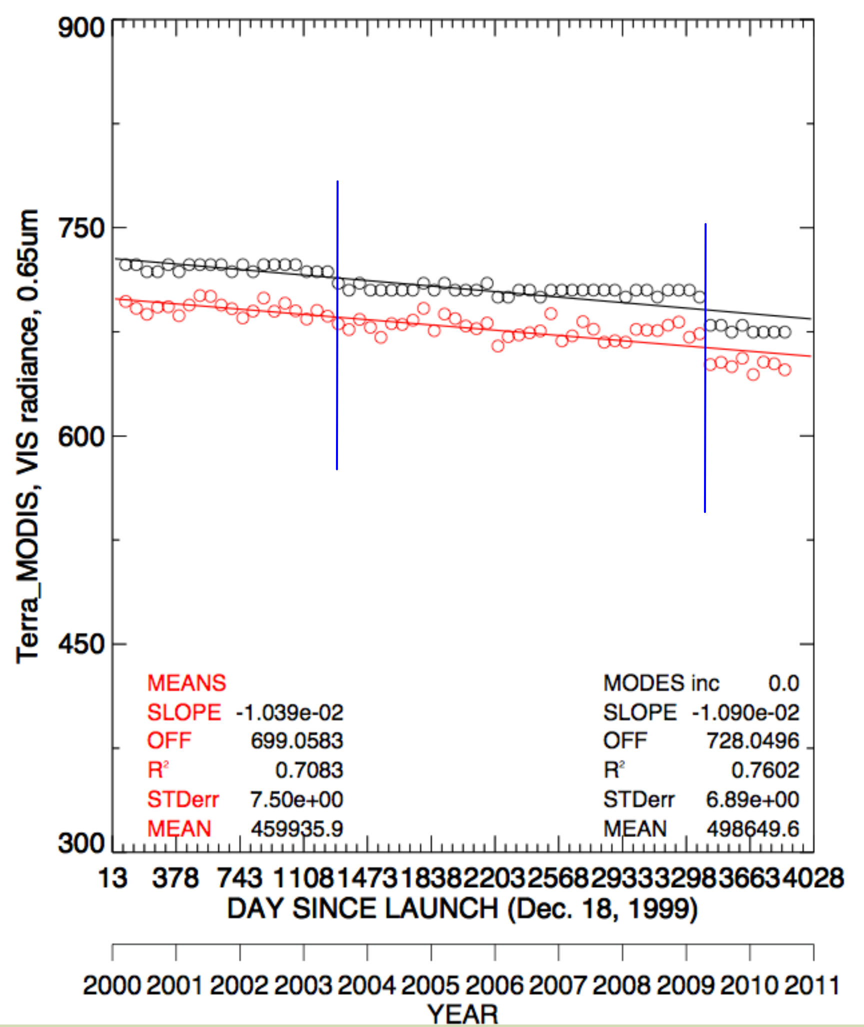


Monthly DCC Radiances



- Note how the monthly PDFs are very similar in shape, indicating robustness of method
- Use both Mode and Mean of the monthly radiances to track over time

Terra Monthly PDFs

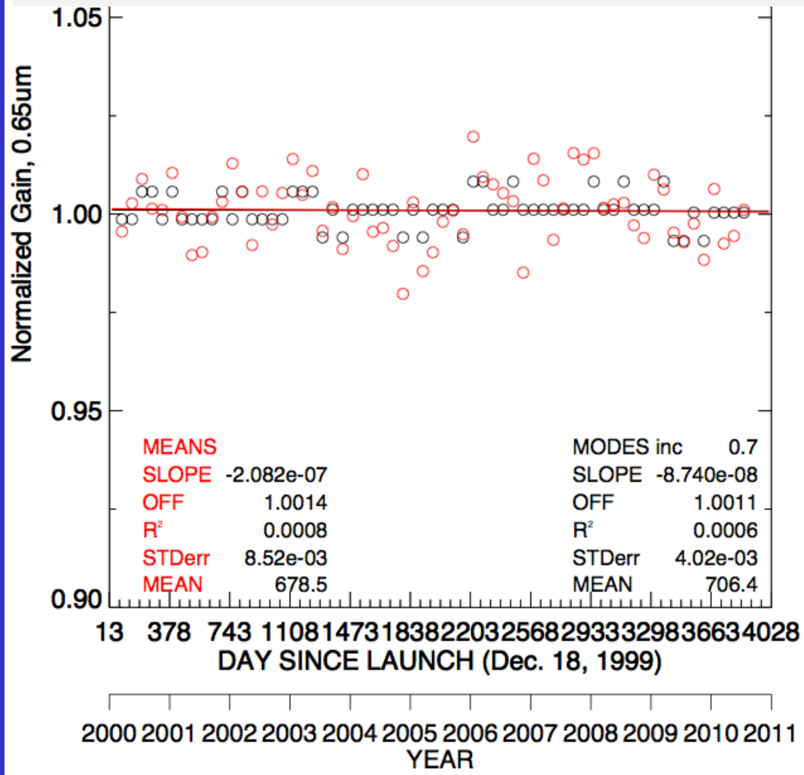


- Note the discontinuities at Nov 2003 and April 2009 identified by DCC calibration
- Collection 5 MODIS had calibration coefficient jumps, which will be corrected in Collection 6 due out shortly, on order of 1-2%

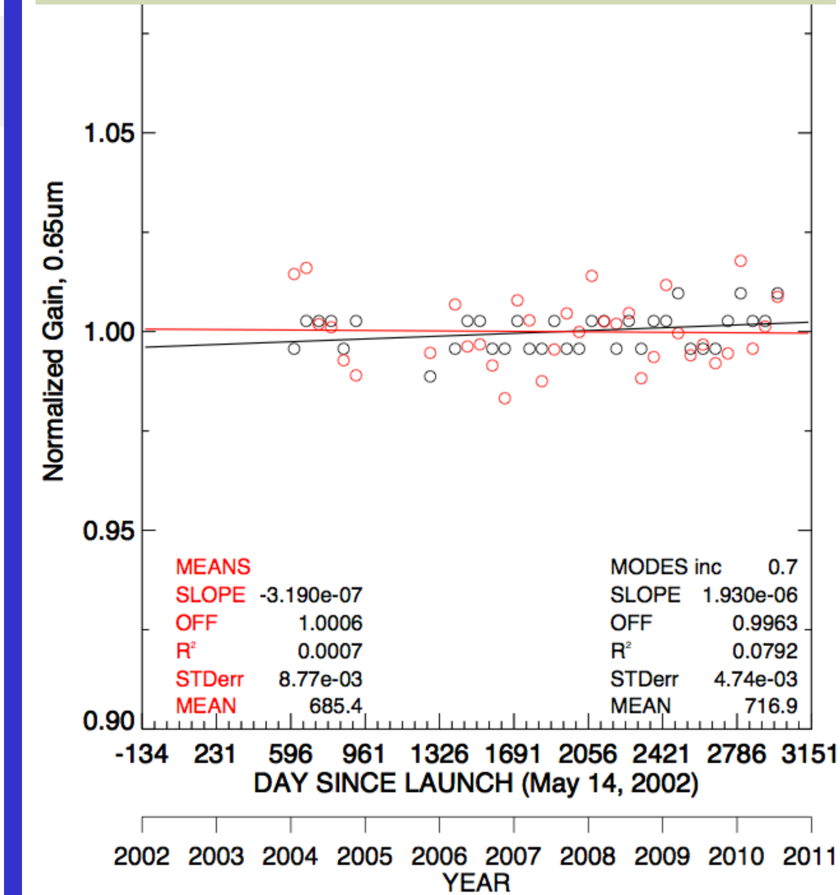
Normalized DCC radiance trend

Terra

• After accounting for known calibration jumps in Nov 2003 and April 2009



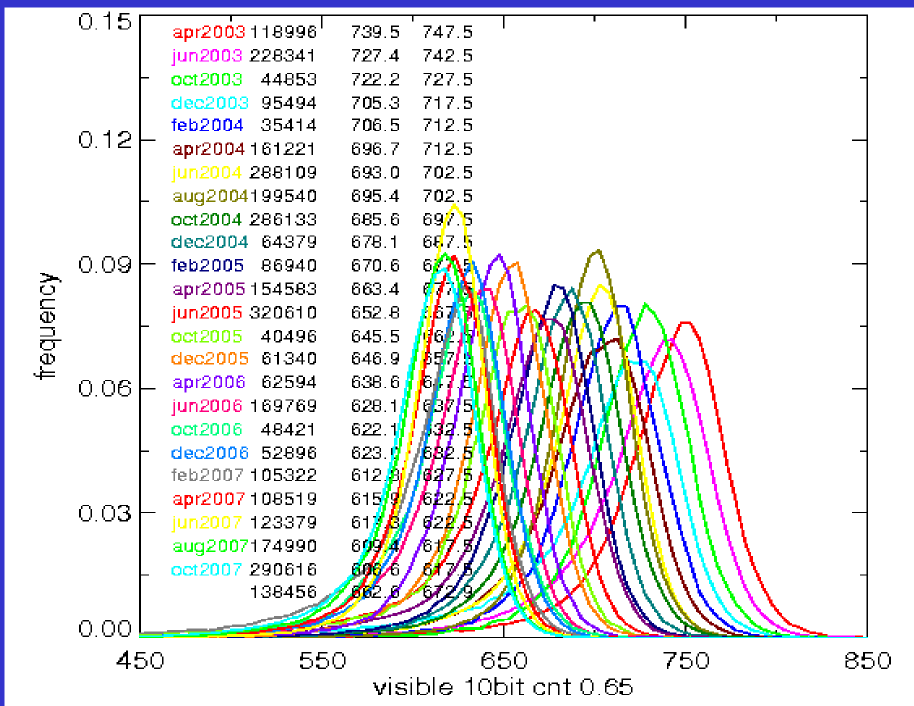
Aqua



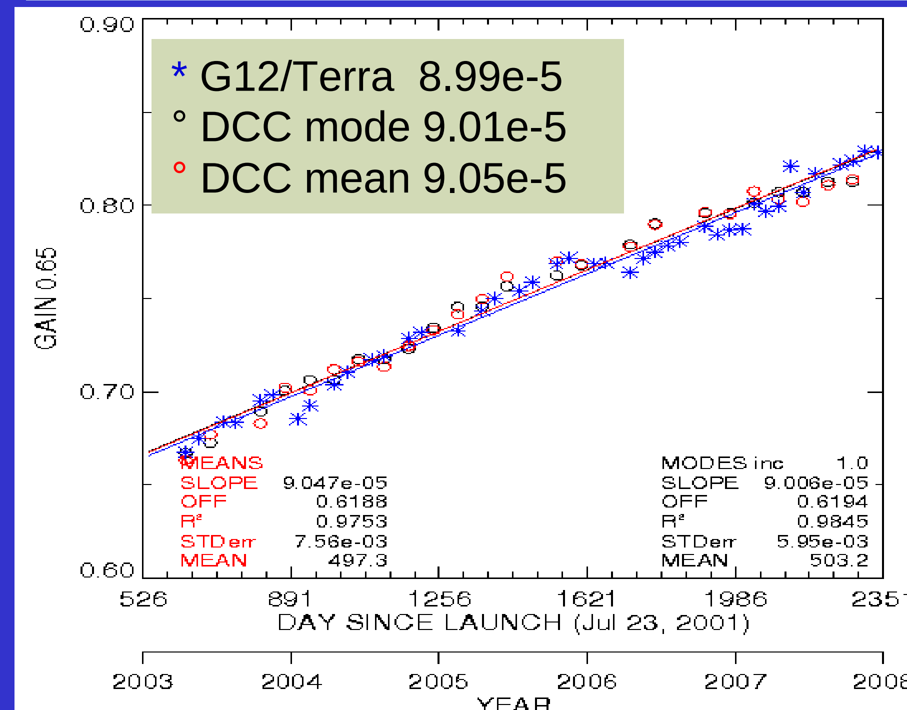
- Terra MODIS stability within 0.1%/decade for both mean and mode
- Aqua MODIS stability within 0.7 and 0.1%/decade for mode and mean respectively
- The mode standard error is half of the mean method standard error
- The Aqua MODIS DCC are ~ 1% brighter than the Terra

GOES-12 DCC stability calibration

GOES-12 Monthly DCC PDFs



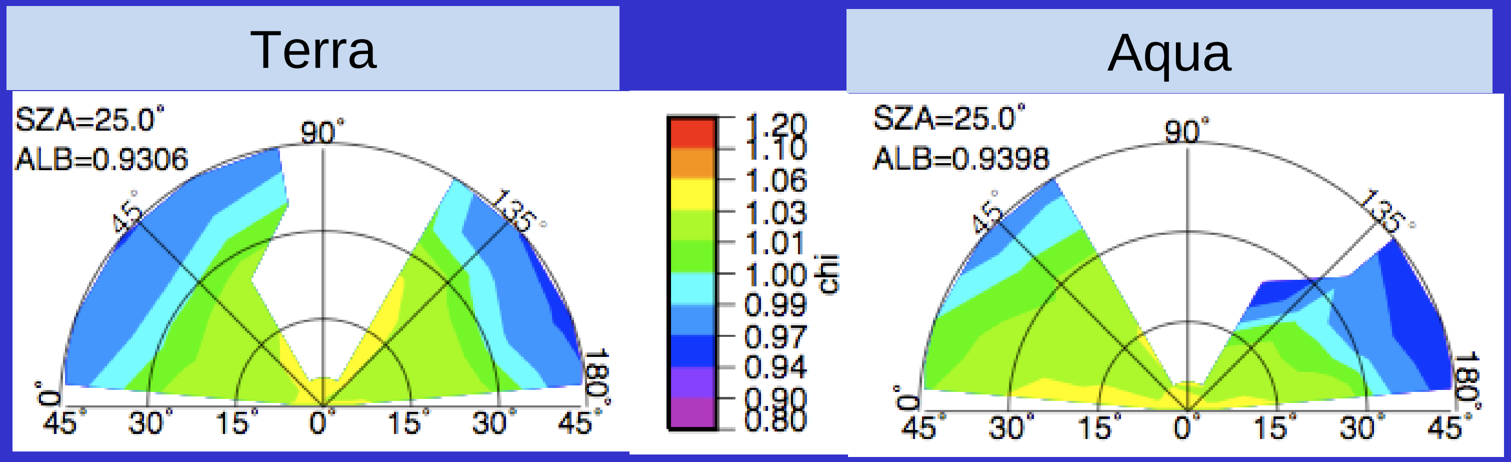
GOES-12 DCC gain(day^{-1}) trend



- Normalize the DCC count relative count trend onto the GOES-12 calibration derived from MODIS
- It is remarkable the gain trends are within 0.7%

DCC characterization with MODIS

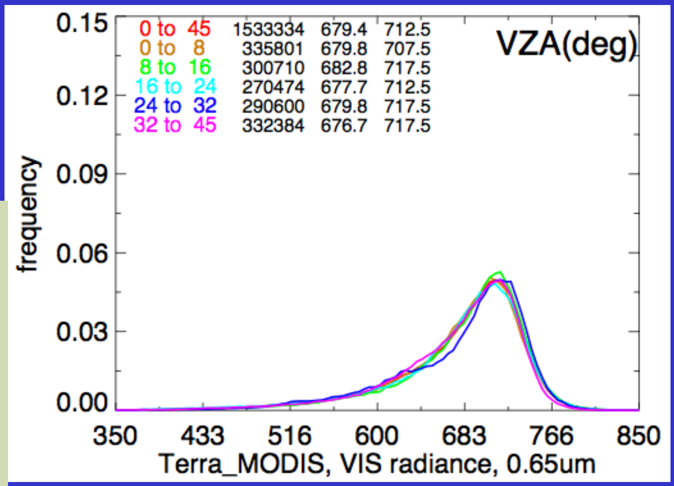
- MODIS is a well calibrated instrument, well suited to characterize DCC radiances
  - which uses a solar diffuser and monitor for stability
  - Absolute calibration of MODIS is 2%
- MODIS DCC bidirectional model from observations
  - CERES ADM not applied

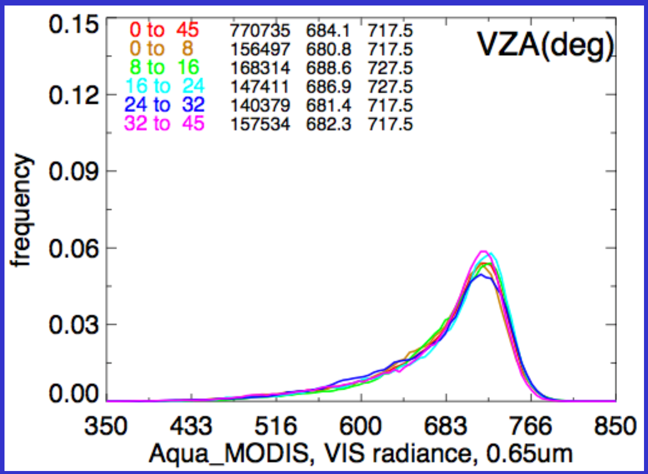


- Similar magnitude to theory and CERES ADM
- ±3% relative radiance angular dependence inside 40° VZA

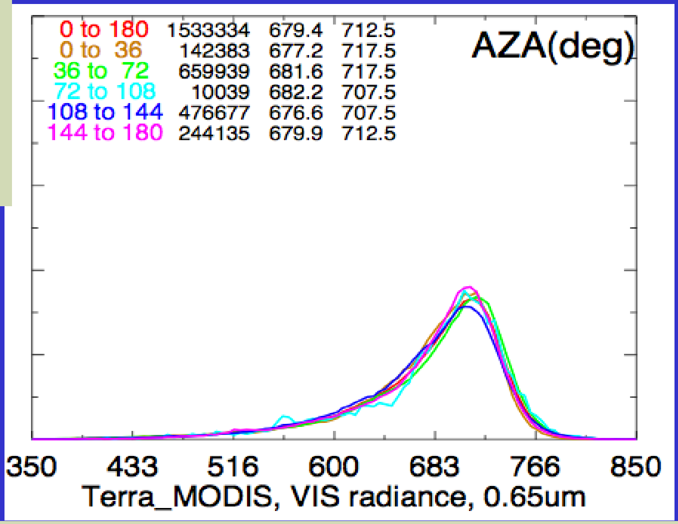
Validation of CERES bidirectional model

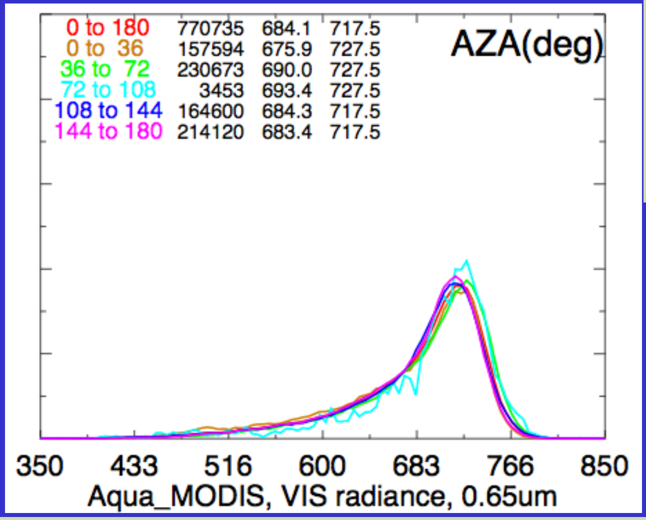
Terra, Nov 2000





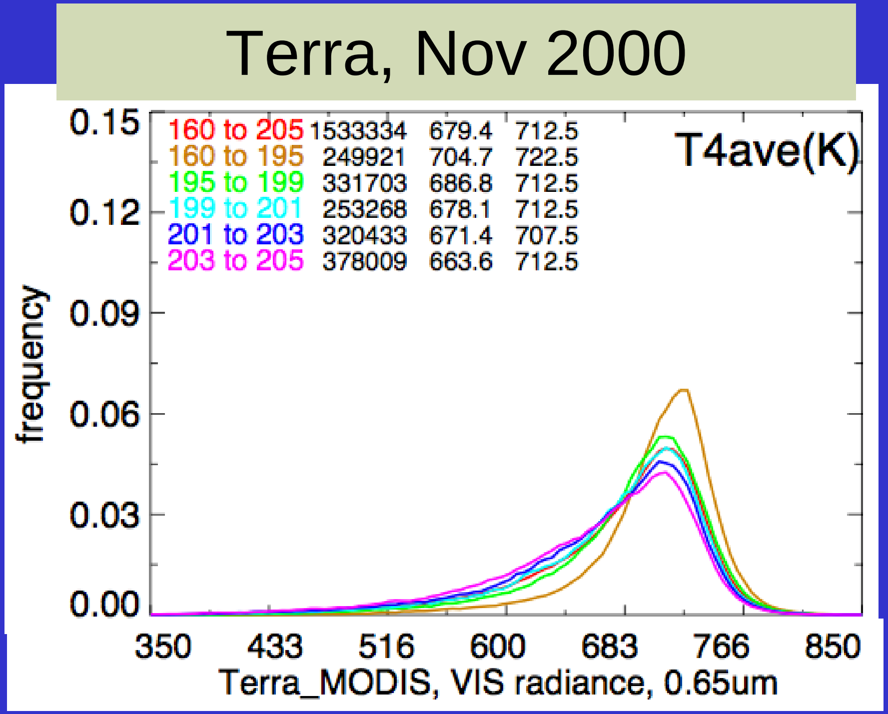
Aqua, May 2004

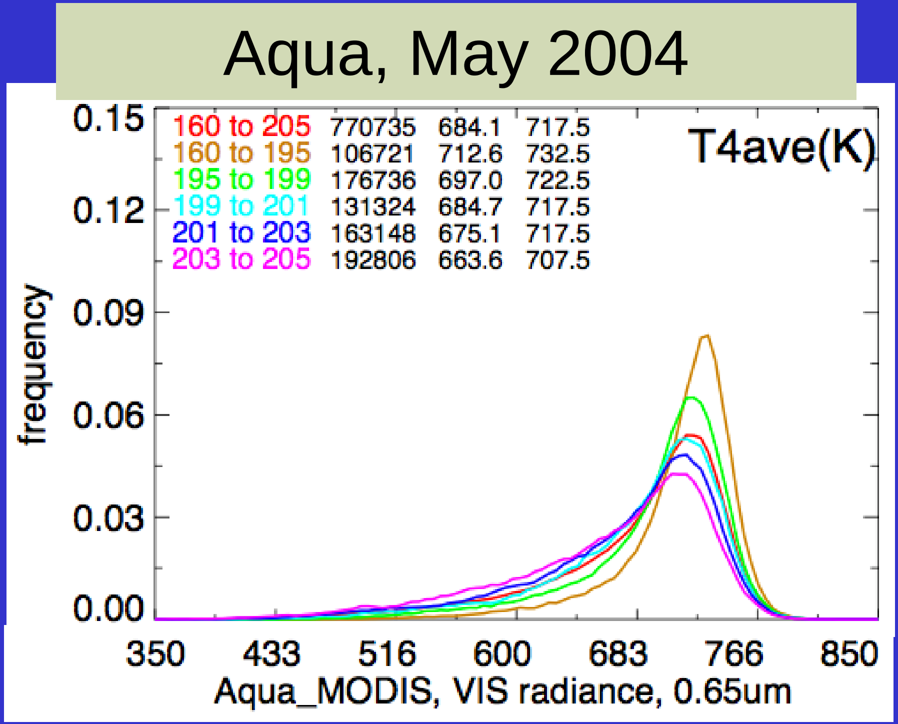




- Stratify the monthly PDFs by VZA and AZA angle,
- The bidirectional model is robust if the VZA and AZA PDFs are identical
- No apparent functionality with SZA, σ 0.65µm, σ 11µm, or day of month

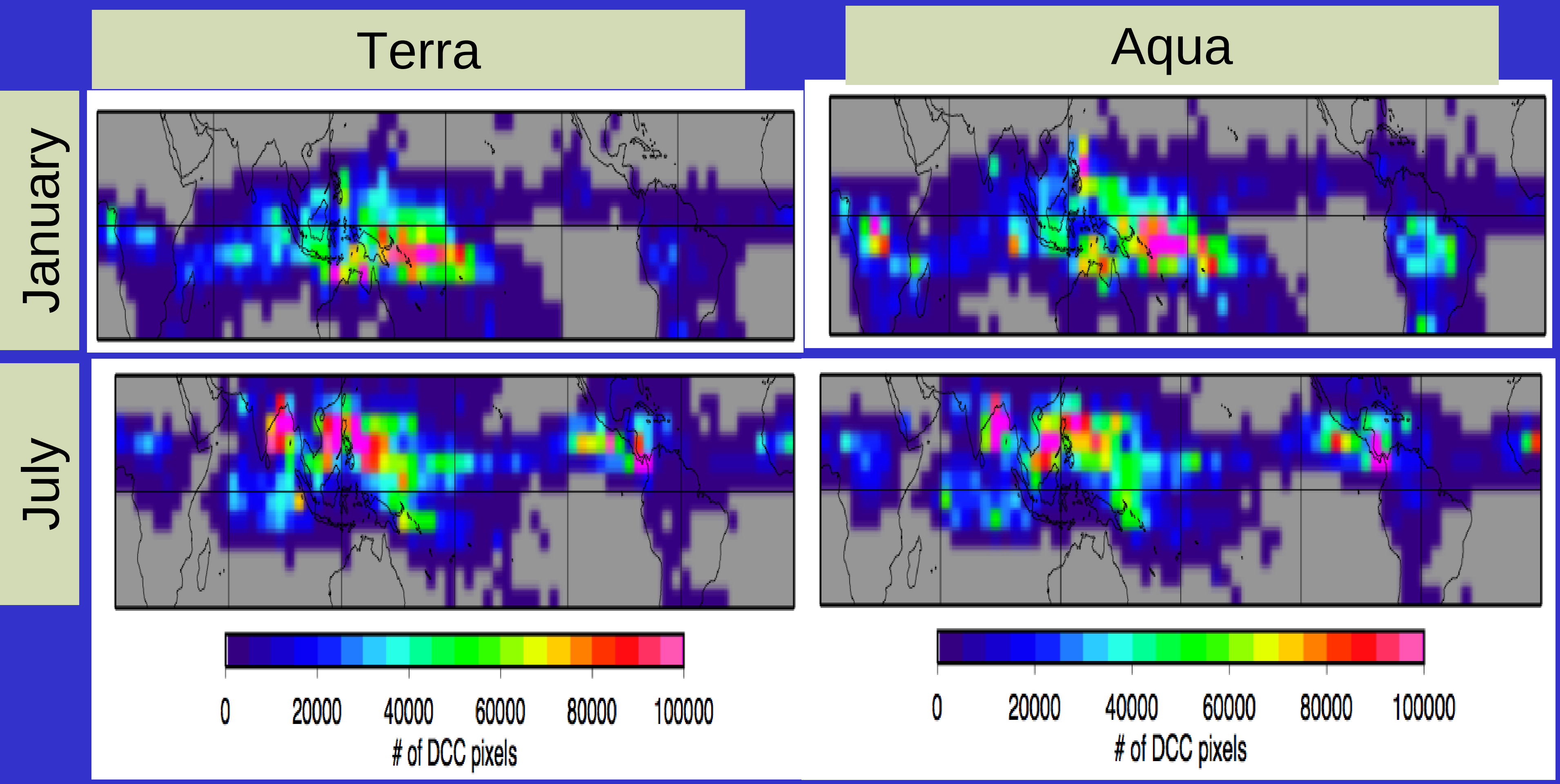
Stratification of 11µm T(K°) threshold





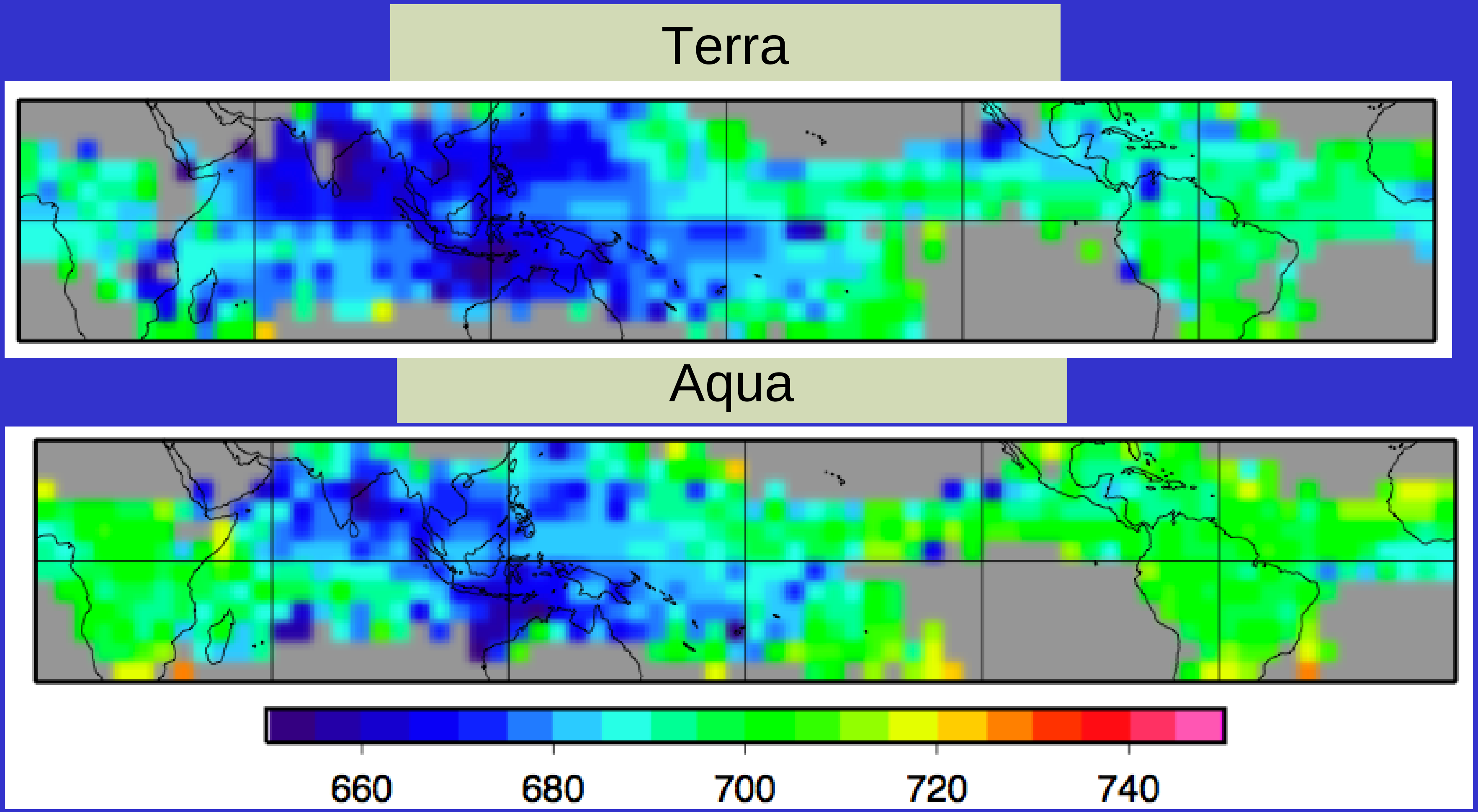
- Colder IR Temperature threshold identifies only the brightest DCC as seen by the more pronounced PDF peak, but reduces the DCC population by 85%
- The DCC radiance dependency on the IR temperature between 205° and 190° is ~ 5% for both Terra and Aqua and for mode or mean methodology

Geographical distribution of DCC



- Most DCC occur in the Tropical Western Pacific
- DCC clouds move with the sun
- DCC over land occur in the afternoon and are mostly identified by Aqua over Brazil and Africa in January

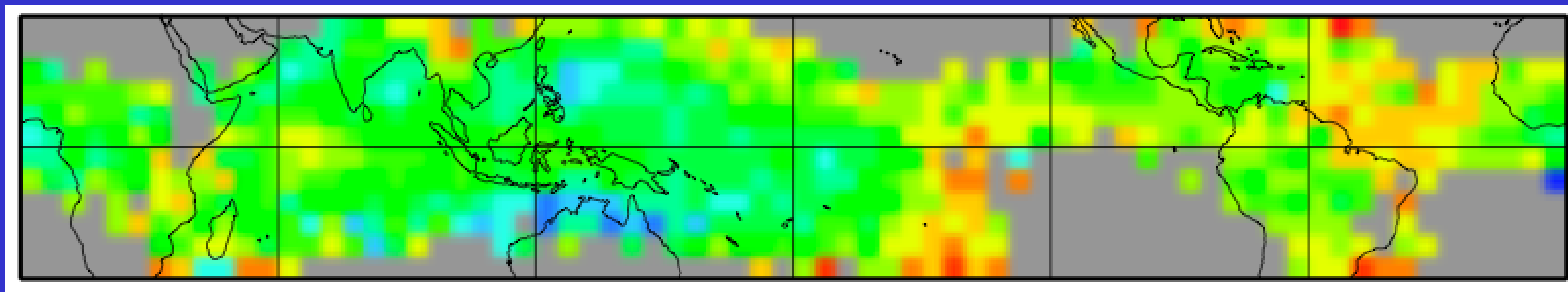
DCC nadir radiance



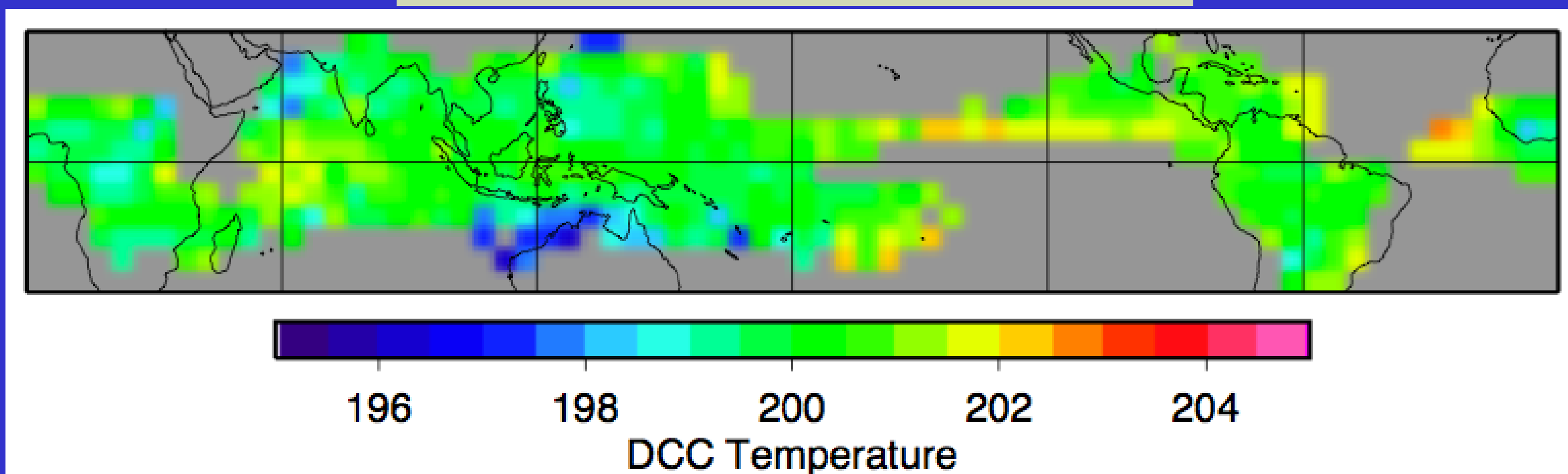
- Aqua brighter than Terra, probably calibration difference
- The Tropical Western Pacific has the darkest DCC
- Land regions have brighter DCC, ~ 5%>TWP
- Is it a function of cloud top temperature?

DCC nadir radiance

Terra

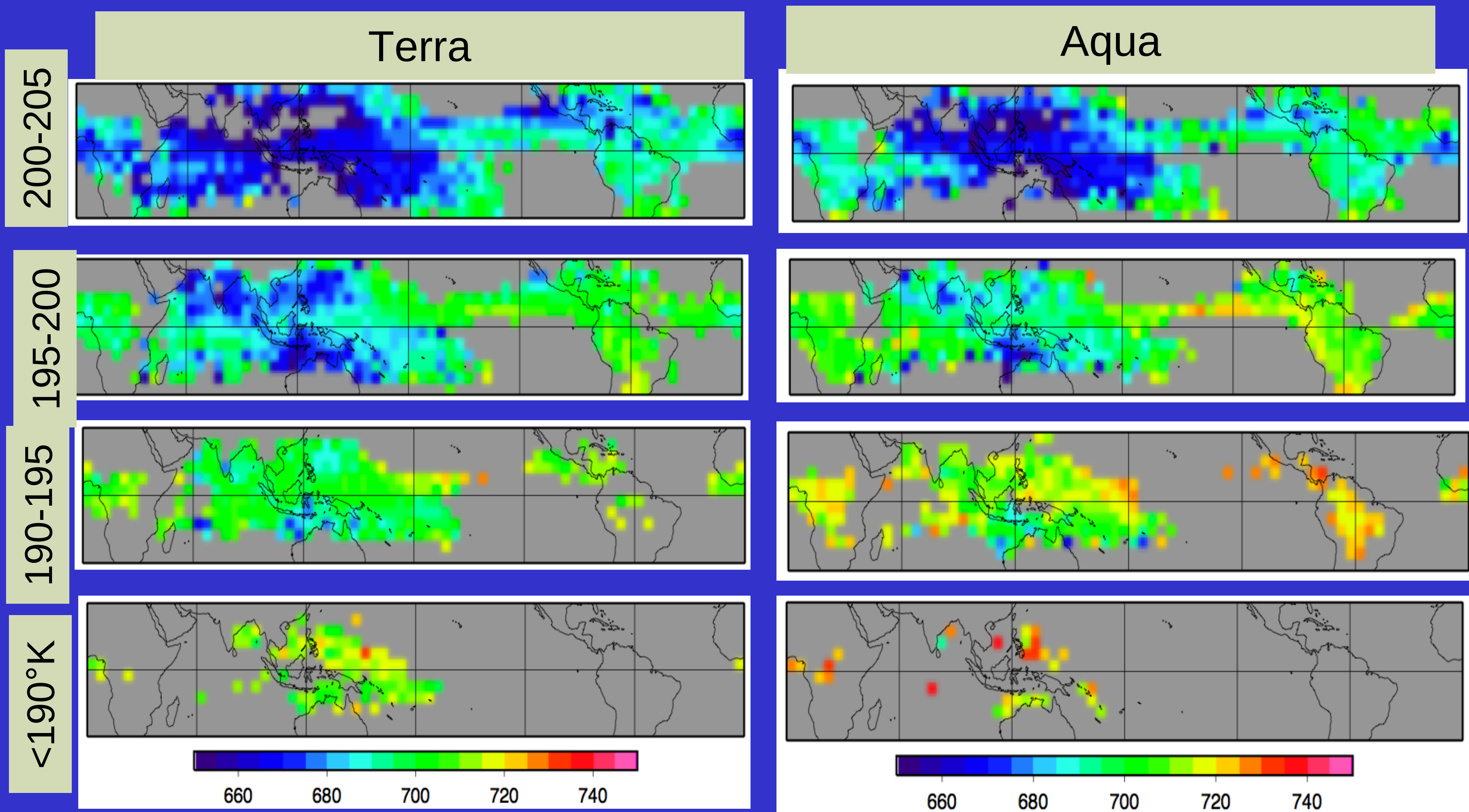


Aqua



- Temperature seems to be geographically independent

DCC nadir radiance



- After stratifying by cloud top temperature, the TWP DCC radiance is less than over land regions in all cloud top temperature categories
- Possible ice particle habit differences, check particle size
- Note the occurrence of DCC is reduced with colder temperature thresholds

Conclusions

- DCC calibration can provide relative calibration trends
  - Extensive tropical targets seen by all geostationary and polar orbiting satellites
- DCC calibration show that MODIS calibration is stable
  - Able to find jumps in the calibration coefficients
  - Indicates that Aqua is brighter than Terra by ~1%
  - bidirectional models can account for most angular dependencies
- DCC issues that need to be resolved for use in absolute calibration
  - There is a increase of DCC radiance with decrease of the temperature threshold to identify DCC, ~ 5% between 204° and 192°
  - Tropical Western Pacific DCC are darker independent of temperature threshold as compared with land based convection