CHARACTERIZING DEEP CONVECTIVE CLOUDS (DCC) AS AN INVARIANT CALIBRATION TARGET

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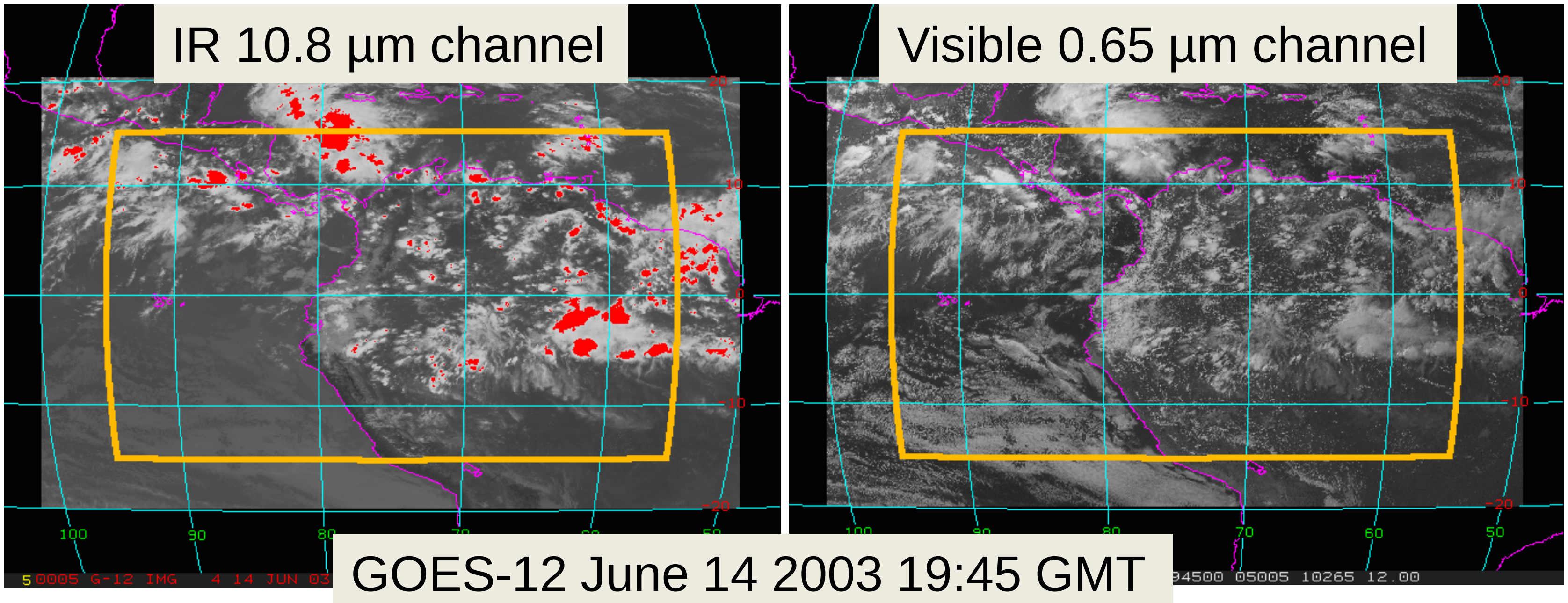
DCC as Earth Invariant Targets

- DCC are bright tropical at tropopause level clouds offering the brightest Earth invariant targets
  - Found over all GEO and LEO satellite domains
  - Optically thick clouds found over both land and water with no surface radiation contribution at cloud top
  - Easily identifiable using an IR window channel temperatures threshold, good visible and IR co-registration required
  - DCC are dynamic targets and occur ~0.5% over the tropics, unlike desert targets, good navigation is not required.
- Small spectral band adjustments to account for spectral band differences
  - Little water vapor and atmospheric absorption above the tropopause
  - DCC are spectrally flat for wavelengths less than 1 µm
- DCC calibration is a large ensemble statistical approach
  - Near Lambertian solar diffusers
  - Slight regional (land/ocean), diurnal, seasonal and inter-annual DCC reflectance variations

DCC Invariant target methodology (stability monitoring)

- Identify monthly all DCC pixels over the GEO domain
  - Assume that the GEO and MODIS window channel IR temperatures are stable
  - Use an IR and visible spatial homogeneity thresholds to capture the core rather than the anvil
- Convert the DCC radiance to an overhead sun radiance using a DCC BRDF model
- Apply a spectral band adjustment factor (SBAF) to the Aqua-MODIS sensor radiance to convert the radiance to an equivalent GEO sensor radiance using SCIAMACHY hyper-spectral radiances.
  - very small adjustment for DCC $<1\mu m$
- Histogram all of the pixel level DCC overhead sun radiances and determine the PDF mode radiance.
- Monitor the drift of the monthly GEO PDF mode radiances, which represents the visible degradation of the sensor

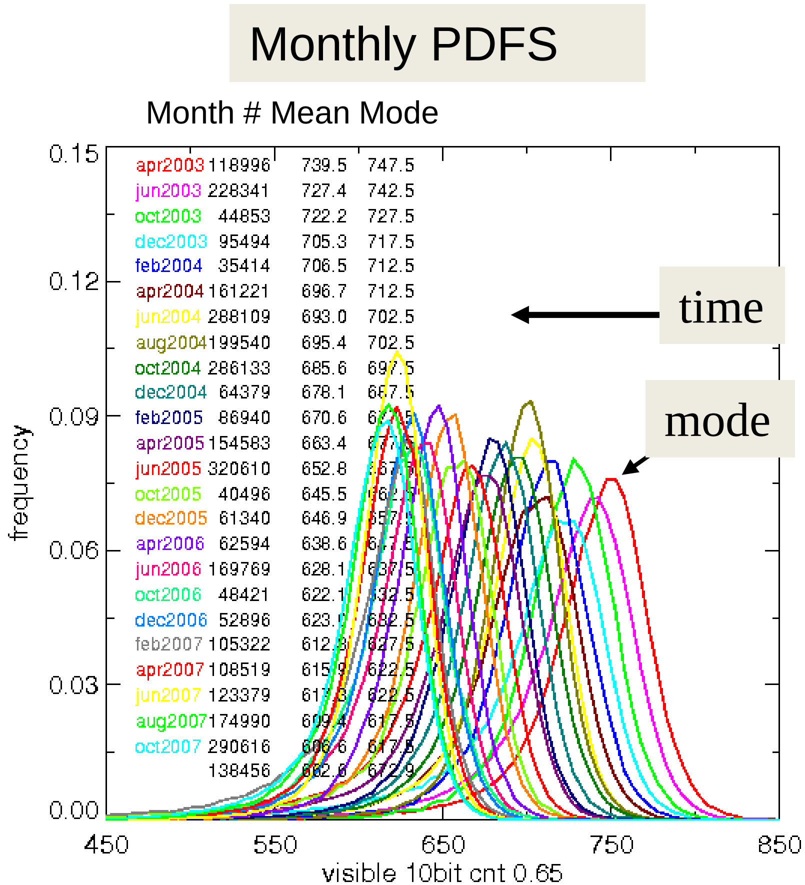
DCC identification

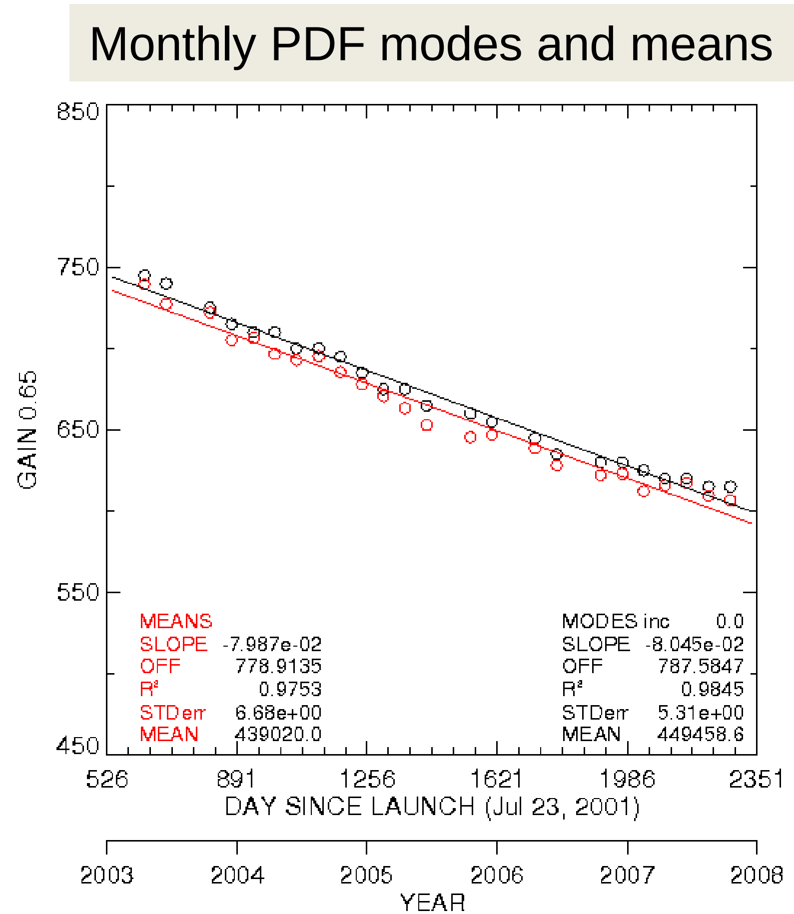


- Between 40k and 250K GOES-12 pixels are identified monthly

Doelling et al. 2011 (GSICS)

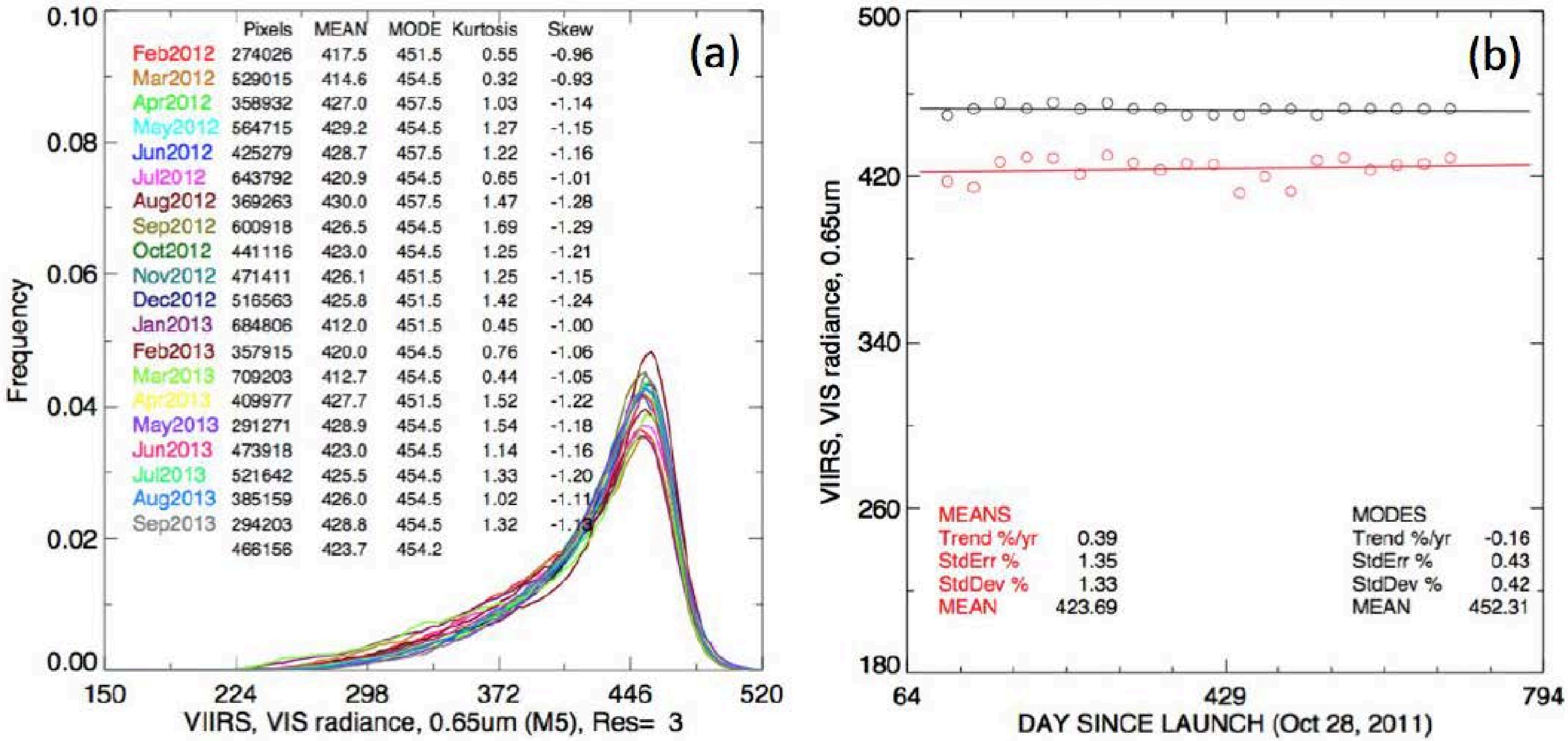
GOES-12 (0.65µm) DCC monthly PDFs





- Monthly PDF modes and means show a decrease, which indicates that GOES-12 is degrading over time

VIIRS I1 (0.65μm) DCC mode radiances



- The VIIRS I1 NASA LandPeate calibrated radiances appear stable over time
- The PDF mode has a smaller standard error than the mean in this case

DCC Invariant target methodology (absolute calibration)

- Assume that the GEO (monitored) sensor and Aqua-MODIS (reference calibration) sensor have the same DCC PDF mode radiance
  - Both MODIS and GEO observe the same DCC over the GEO domain at the time of the Aqua-MODIS overpass
  - Bu using the same local time period and GEO domain, reduces the calibration transfer uncertainty due to the slight regional and diurnal DCC reflectance variations
  - This method does not need any contemporary Aqua-MODIS observations making it possible to calibrate historical GEOs referenced to the MODIS calibration, by assuming small inter-annual DCC reflectance variations
- Validate with GEO/Aqua-MODIS ray-matched calibration
  - Ray-match over both all-sky tropical ocean and DCC cores.
  - Consistency among all independent methods validates all methods

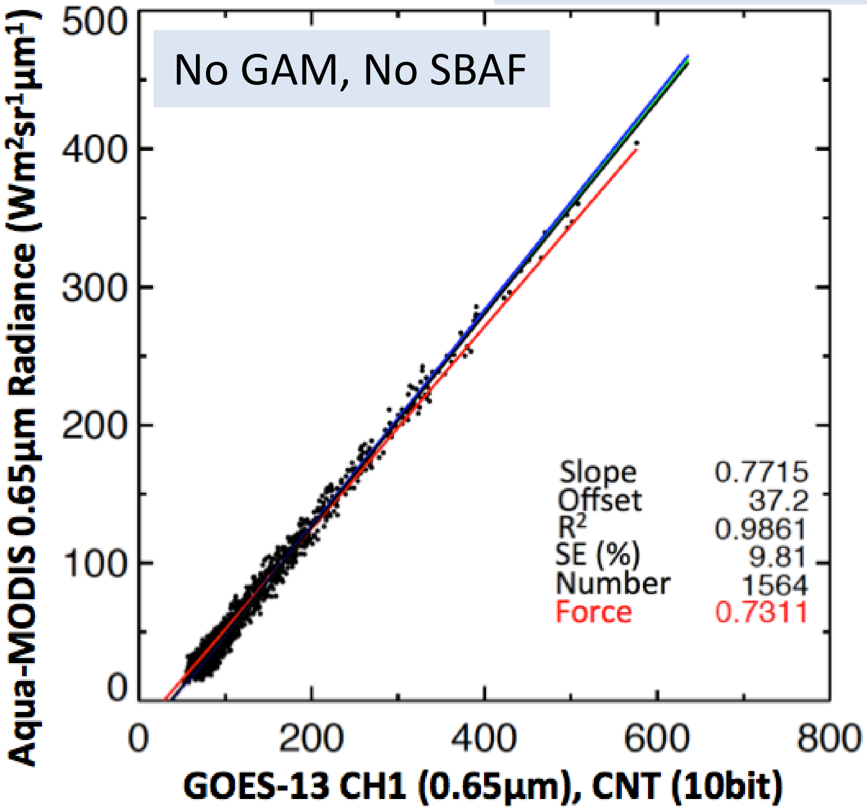
All-sky Tropical Ocean Ray-match Calibration

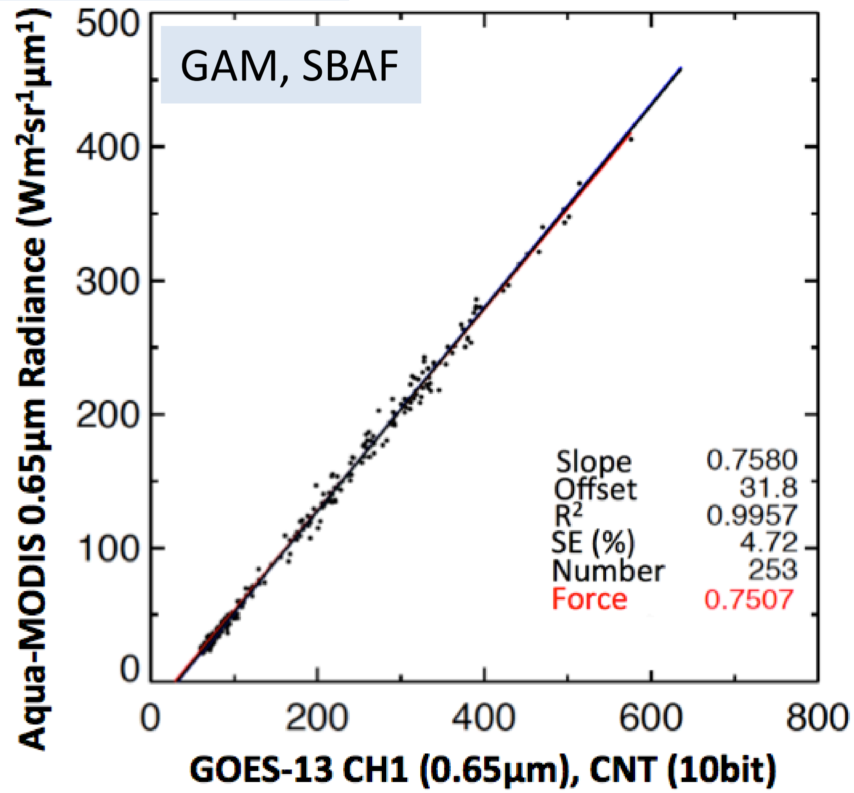
- Grid MODIS and GEO pixel-level radiances into 0.5° latitude by 0.5° longitude grid over the GEO domain
  - If within 15 minutes
- Gradual Angular Match (GAM) the MODIS and GEO radiance pairs, begin with 5° view and azimuthal angle differences for clear-sky conditions and gradually increase the tolerance to 15° for bright clouds
  - Clear-sky is more anisotropic and requires strict angle matching, whereas bright clouds are more Lambertian and can allow for more tolerant angle matching
  - Most of the sampling is over clear-sky, least over bright clouds
- Apply an SCIAMACHY hyper-spectral based spectral band adjustment factor (SBAF) to account for spectral band difference
- Apply a visible spatial Homogeneity Filter (HF) to account for miss-navigation, parallax error, and time induced radiance field mismatch errors due to advection

Doelling et al. 2016, submitted

All-sky Tropical Ocean Ray-match calibration

GOES-13/Aqua-MODIS for April 2011





Red line = linear regression through the space clamp offset (force fit)
Black line = linear regression
Under perfect ray-matching conditions, the force fit and the linear regression should be equal

- Lax angular matching and not accounting for spectral band differences, introduces a bias = 2.6%

Doelling et al. 2016, submitted

All-sky Tropical Ocean Ray-match calibration

Satellite		GOES-13	GOES-15	Met-7	Met-9	MTSAT-2
Linear – Space Offset (counts)	Ed3	6.4	4.6	1.2	2.7	-2.6
	add GAM	4.1	4.4	1.1	2.8	-4.3
	add SBAF	1.5	1.4	-0.1	1.1	-0.9
	add HF (Ed4)	1.4	1.1	0.0	1.1	-0.3
Linear - Force Fit Gain (%)	Ed3	4.2	3.0	2.0	1.0	-0.6
	add GAM	1.6	1.7	1.1	0.5	-1.3
	add SBAF	0.4	0.4	-0.5	0.5	-0.5
	add HF (Ed4)	0.3	0.0	-0.4	0.2	-0.4

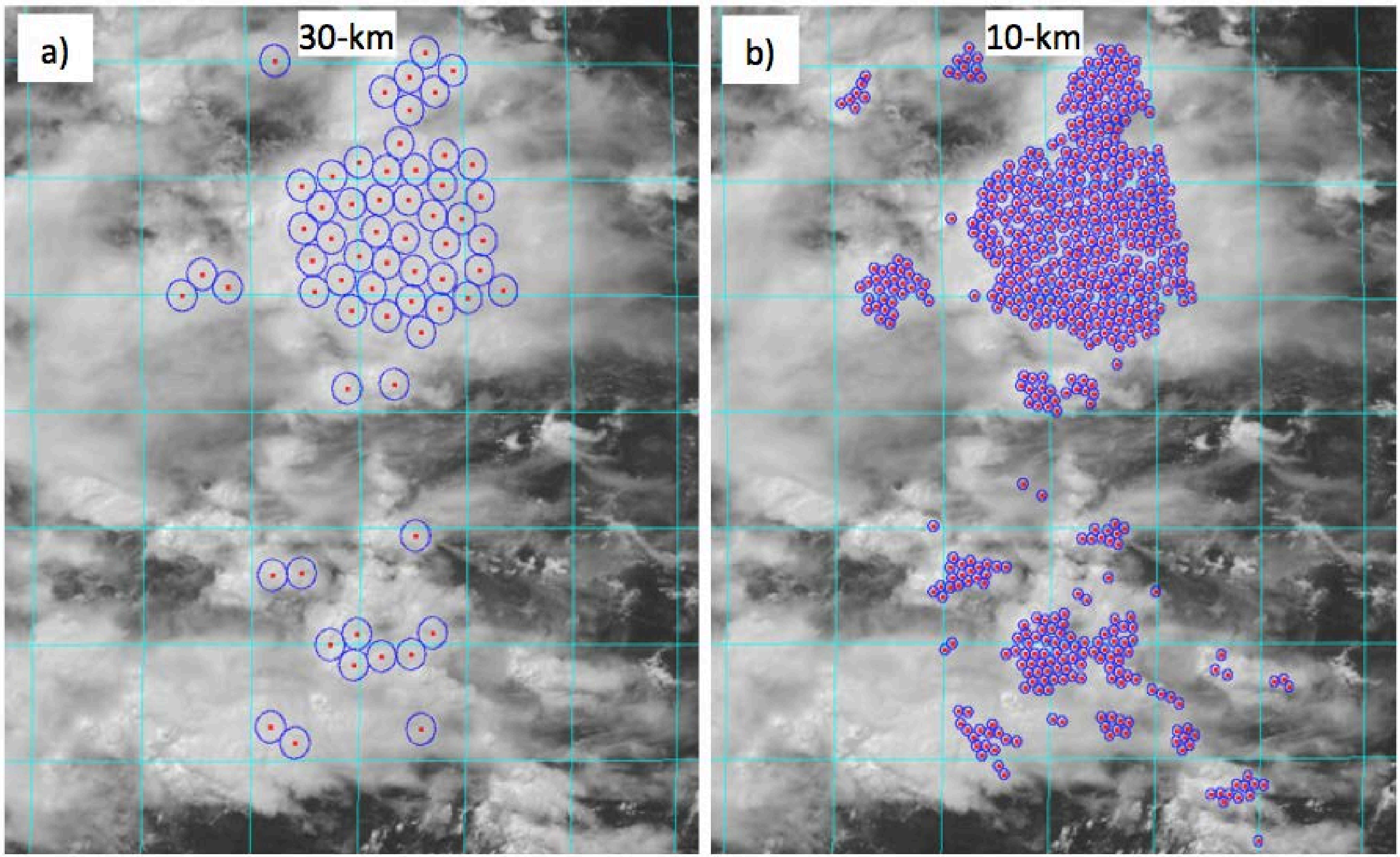
- GAM+SBAF+HF, the force fit and linear regression gains are within 0.4%
  (No GAM, no SBAF, no HF 4.2%)
- The GAM+SBAF+HF, the linear fit and the space clamp offset are within 1.4 counts
  (No GAM, no SBAF, no HF 6.4 counts)
- In order to get calibration coefficients within 1%, precise angle matching and spectral band adjustment factors must be taken into account.

DCC ray-match calibration

- Find DCC core centers by finding the coldest pixel temperature and averaging all pixel visible radiances within either a 10-km or 30-km diameter core in the MODIS image
  - The mean core temperature < 220K
- Use MODIS DCC core center locations to compute the the corresponding GEO radiance mean
  - The scattering angle must be within 15°
  - GEO must be within 15 minutes of MODIS
- Apply an SCIAMACHY hyper-spectral based spectral band adjustment factor (SBAF) to account for spectral band difference
  - Same as the the DCC invariant target calibration

Doelling et al. 2016, submitted

MTSAT-2, July 20, 2011, 2:32 GMT, 1-km visible image

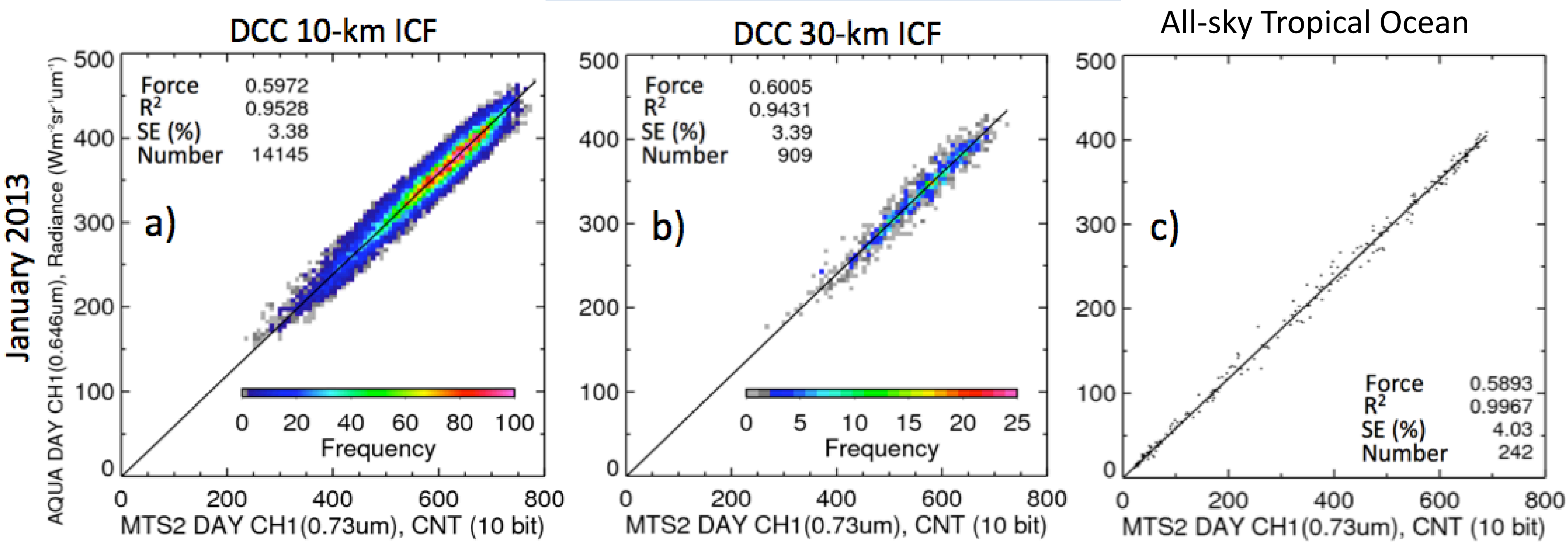


- The cyan lines indicate a 1° latitude by 1° longitude grid

Doelling et al. 2016, submitted

Ray-matched monthly force fit regression pairs for DCC and ATO methods

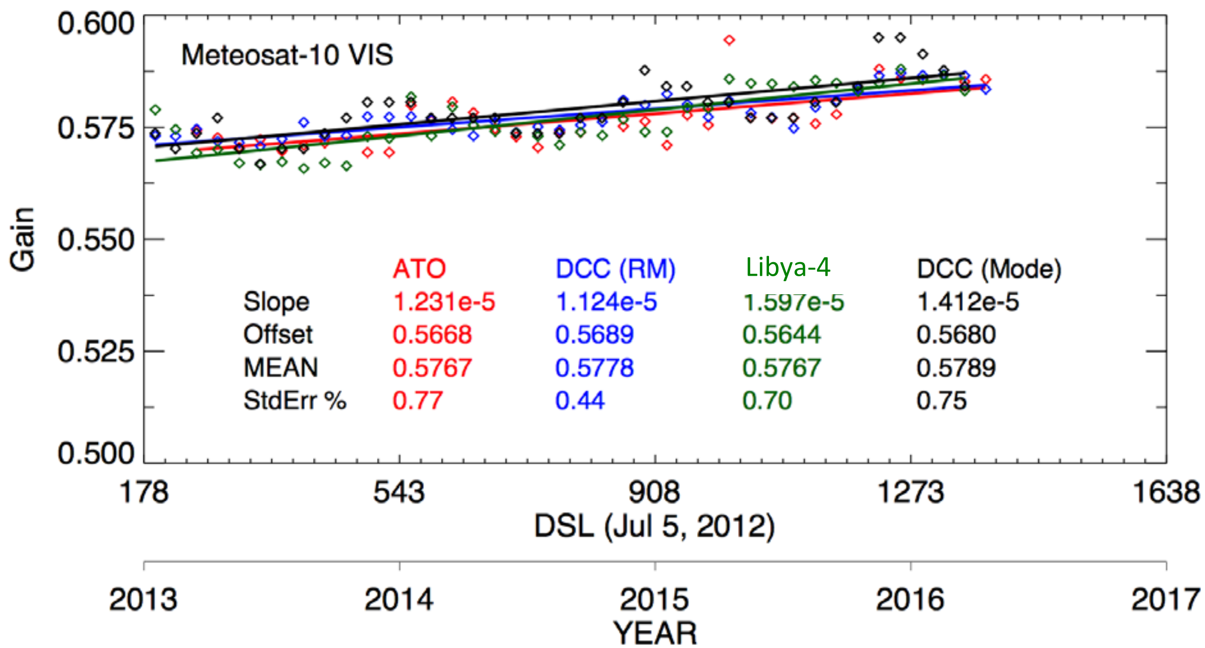
MTSAT-2/Aqua-MODIS, Jan. 2013



- Most of DCC radiance pairs fall along the force fit line
- Both the 30-km and 10-km DCC core diameters force fit gains are very consistent

Comparison of Met-10 VIS/NIR calibration methods

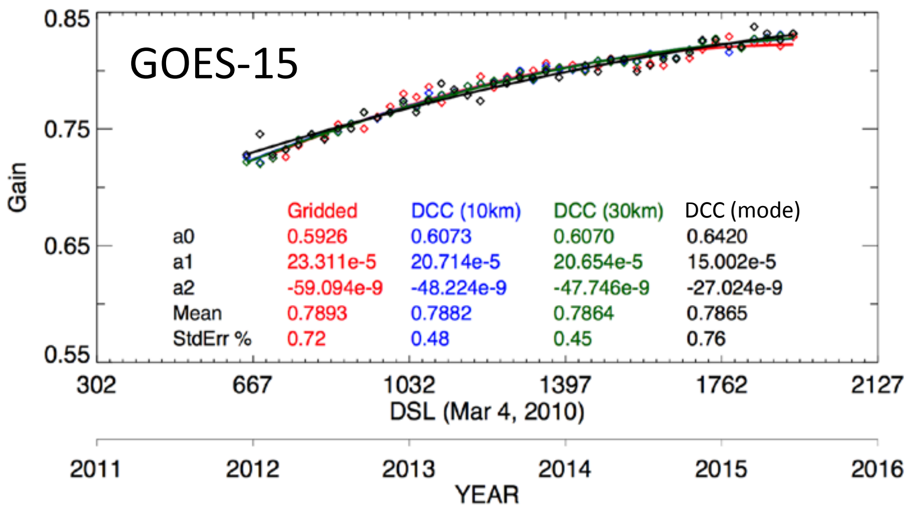
- Validate that the Aqua-MODIS DCC mode radiance equals the Meteosat-10 DCC mode radiance over the Met-10 domain
  - thereby validating that the DCC mode algorithm properly transferred the calibration reference
- All calibration methods are within 0.4%, DCC RM and mode within 0.2%

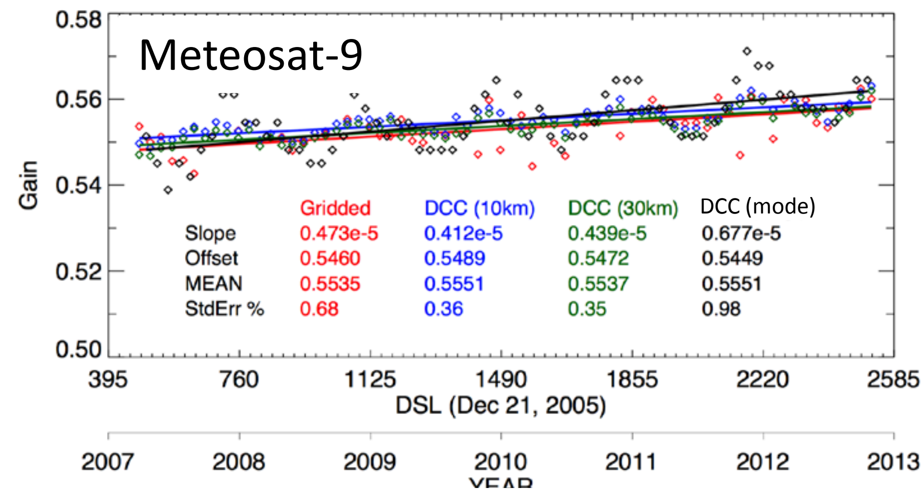


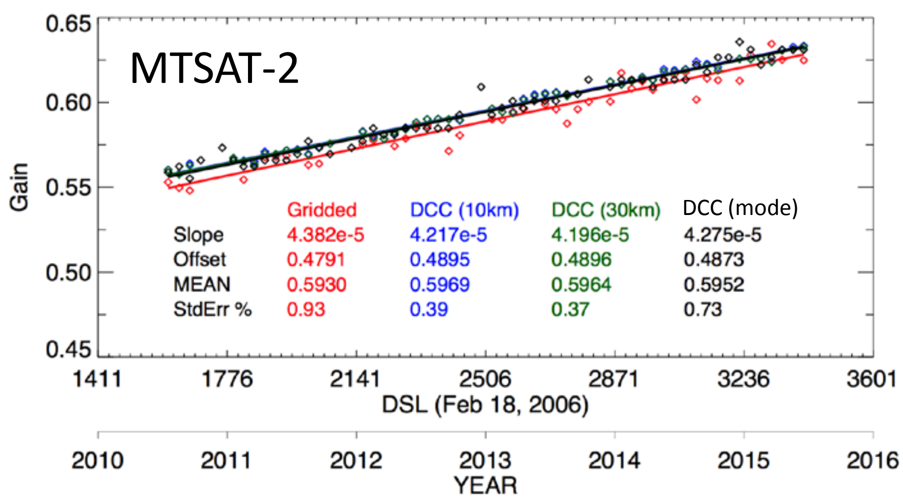
ATO: All-Sky Ocean Ray Matching
DCC (RM): DCC ray-matching
Libya-4: Based on Met-9 Libya-4 model
DCC (Mode): DCC mode radiance method (GSICS)

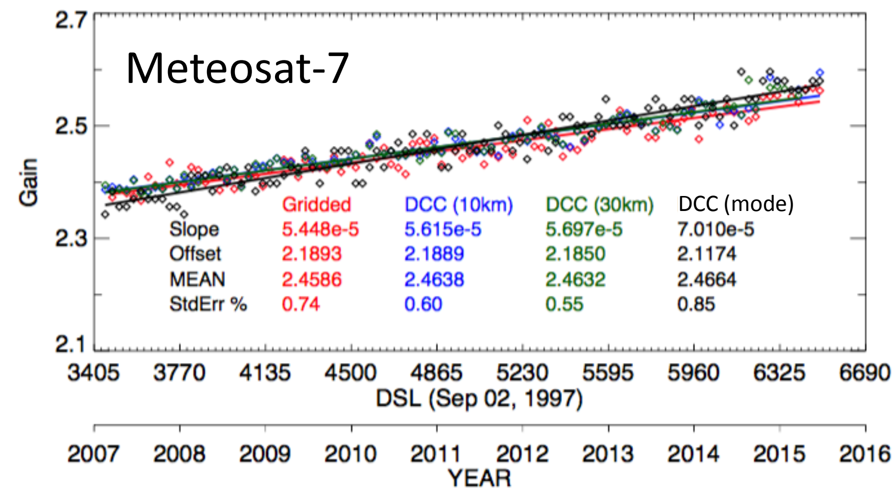
Doelling et al. 2016, in preparation

Comparison of all-sky tropical ocean ray-matching, DCC ray-matching and DCC invariant target approaches







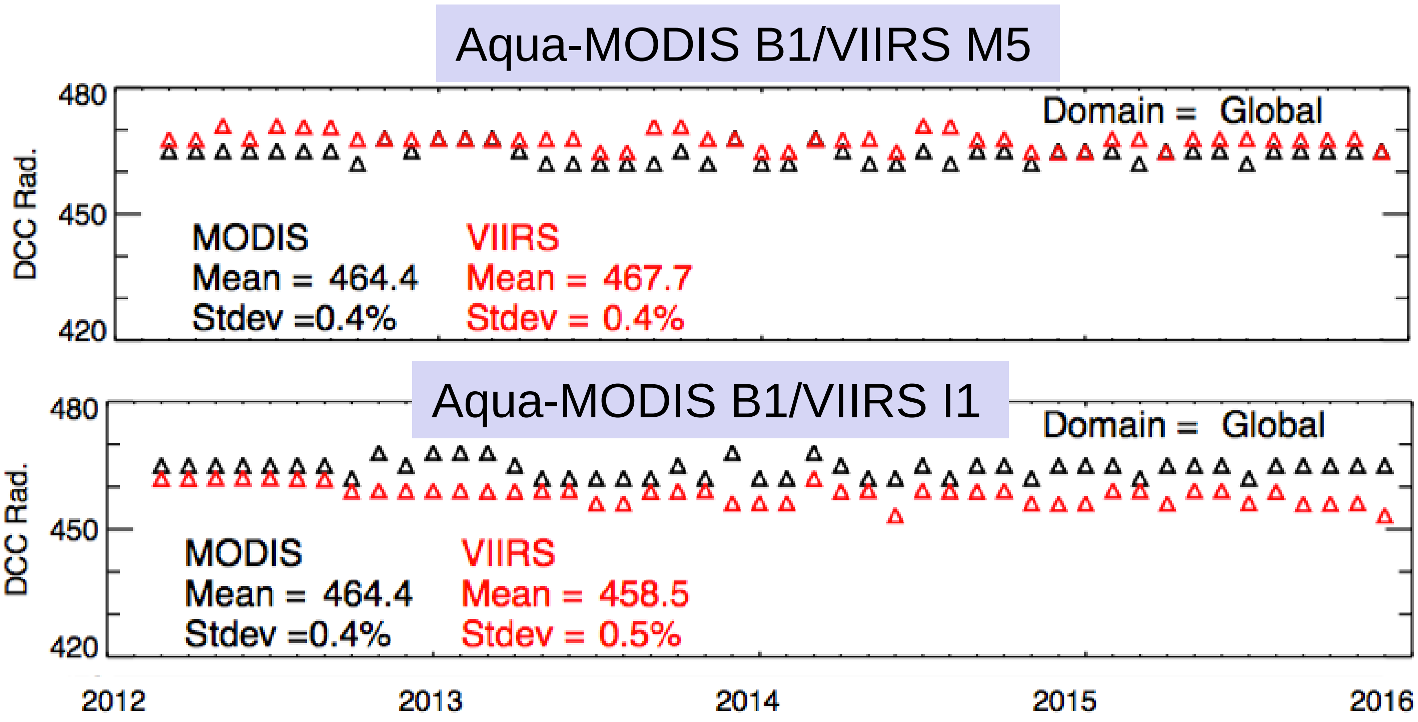


- All calibration methods are within 0.4%, except for MTSAT-2 at 0.7%
- All DCC calibration methods are within 0.3%

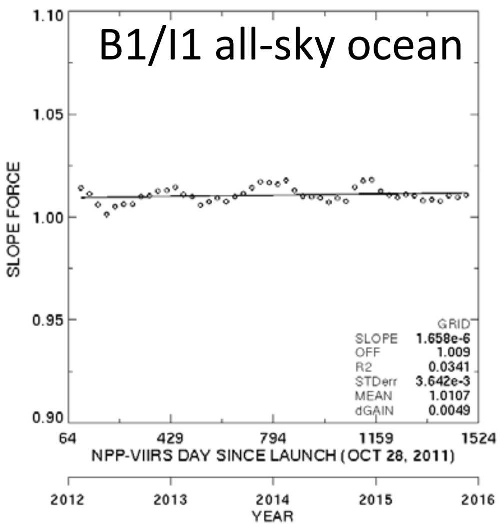
DCC mode absolute calibration verification

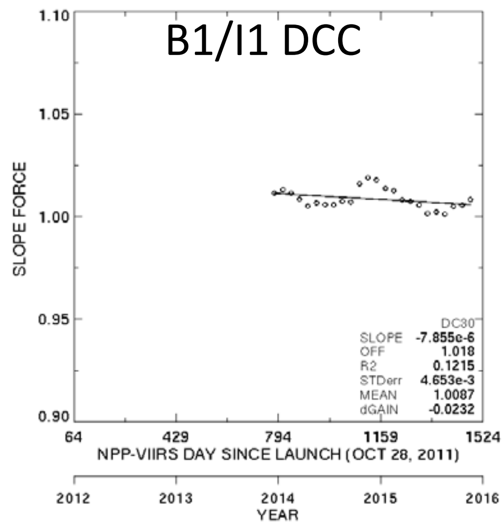
- Use both MODIS B1, VIIRS M5, and VIIRS I1 as calibration references
- Does the DCC mode radiance ratio of the calibration references equal the all-sky and DCC ray-matching ratios?
- Do each of the calibration references show the same GEO domain/global DCC mode ratio?

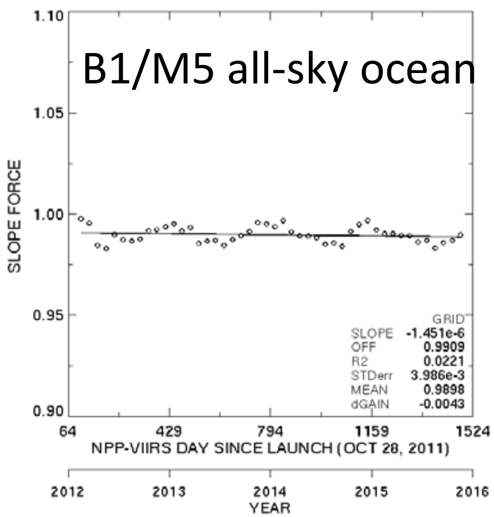
MODIS and VIIRS DCC mode radiance comparison

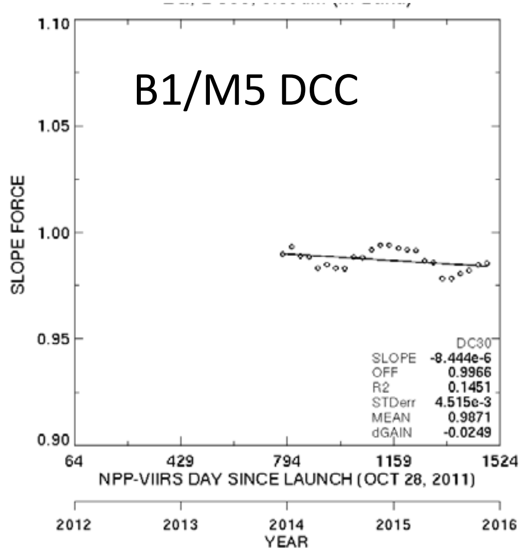


MODIS/VIIRS band ratio comparisons









%	MODIS-VIIRS M5	MODIS-VIIRS I1
DCC mode	-0.7±0.5	1.3±0.4
DCC RM	-1.3±0.5	0.9±0.5
All-sky Ocean RM	-1.0±0.3	1.1±0.3

- The DCC mode radiance and RM are consistent within 0.6%
  - -Need to get more DCC ray-matched data
  - - The DCC mode radiance and all-sky RM are consistent within 0.3%

- This allows the DCC mode to transfer the reference calibration (~0.5%) to other sensors and need not be contemporary and can be applied historically

MODIS and VIIRS DCC mode radiance GEO domain differences

%	MODIS B1	VIIRS I1	VIIRS M5
Global	464.4	458.5	467.7
GOES-W 135° W	+0.5±1.1	+0.1±1.0	-0.1±1.0
GOES-E 75° W	+0.4±0.5	+0.1±0.6	+0.1±0.5
Met-10 0° E	+0.6±0.7	+0.6±0.8	+0.6±0.7
Met-7 60° E	+0.1±0.9	-0.0±1.2	+0.1±0.9
FY2E 86° E	-0.6±0.8	-0.3±0.8	-0.3±0.7
MTSAT-2 1	-0.6±0.8	-0.3±1.0	-0.4±1.0

- The GEO domain minus the global DCC mode radiance is consistent within 0.3% between MODIS B1, VIIRS I1, and VIIRS M5, except for GOES-W
- This allows the DCC mode to transfer the reference calibration to other sensors and need not be contemporary and can be applied historically

Conclusions

- DCC invariant target calibration has been extensively used to verify satellite sensor stabilities
  - DCC provide the greatest Earth target signal to noise ratio and the with the least water vapor absorption, that behave as near Lambertian solar diffusers
- DCC invariant target calibration can also successfully transfer the calibration of one sensor to another sensor
  - This assumes that both sensors have the same DCC PDF mode radiance over the same local time and spatial domain
    - Does not require coincident or ray-matched DCC
  - This allows the DCC invariant target calibration method to be applied to historical sensors
    - Assume small inter-annual variability
    - Similar to the deserts and polar ice approach