TISA Working Group Update

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37th CERES Joint Science Team Meeting

Virtual Meeting, April 26-28, 2022

TISA (Time/Space Averaging) objectives

- Spatially average the instantaneous CERES footprint fluxes and imager clouds and hourly GEO (geostationary imager) pixel radiances and clouds into 1 deg regions
- Temporally interpolate and average the CERES observed and GEO derived fluxes and clouds into daily/monthly averages
  - SSF1deg use constant meteorology diurnal models using only CERES observations to compute the daily fluxes and clouds
  - SYN1deg use geostationary derived hourly fluxes to infer the fluxes between CERES measurements
    - Rely on SW and LW GEO narrowband to broadband relationships and carefully normalize the GEO fluxes with CERES regionally to anchor the GEO fluxes to the CERES instrument calibration standard
    - Need to calibrate the GEO channel radiances to the MODIS reference for consistent fluxes and clouds
- Responsible to forward process monthly the EBAF-TOA product within 2-months of real time
- FluxByCloudType (FBCT) stratifies the CERES flux by cloud-type with the addition of MODIS cloud-type derived fluxes within partly cloudy footprints
- Calibrate the GEO, VIIRS, and MODIS imager channel radiances to the MODIS C5 calibration reference to enable consistent cloud retrievals
  - Verify the stability of the GEO, MODIS and VIIRS imagers using Earth invariant targets

Outline

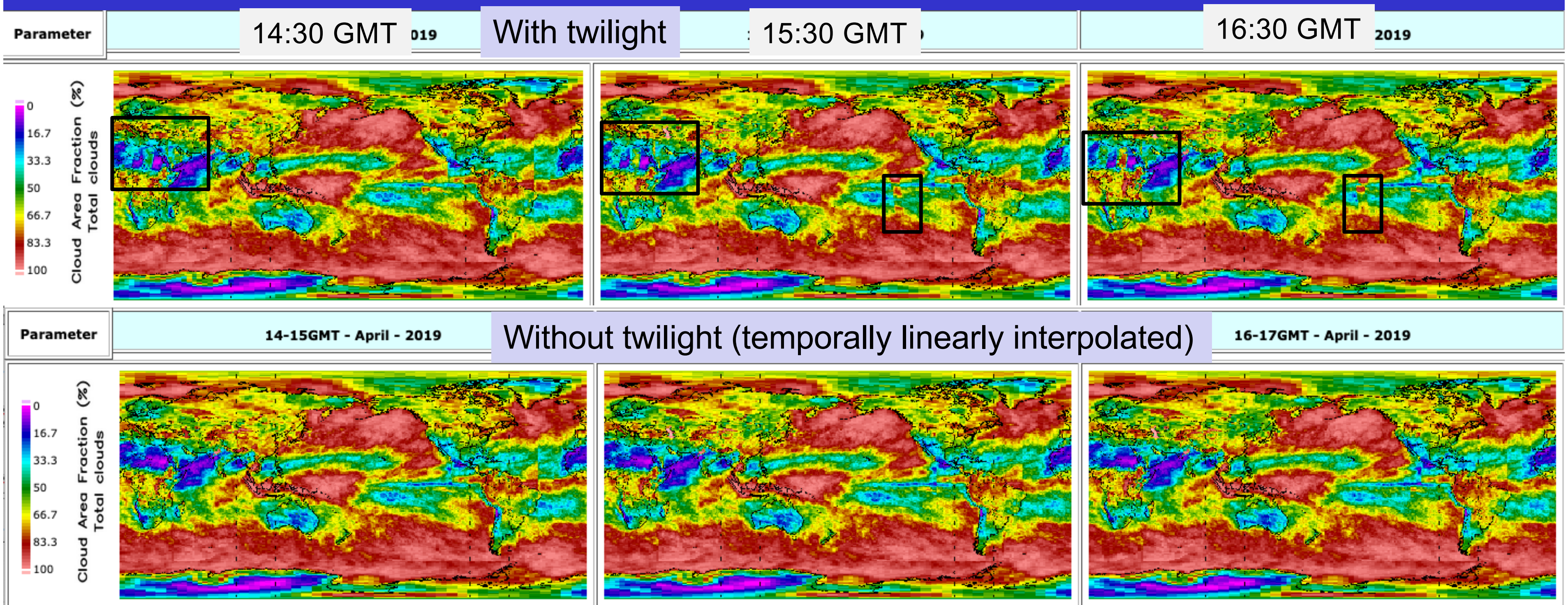
- SYN1deg – Ed4.2
- FBCT Ed5 improvements
- GEO Ed5 SW NB to BB progress – Land application
- MODIS/VIIRS imager radiometric scaling and stability analysis

SYN1deg Ed4B

SYN1deg Ed4b product

- GEO twilight cloud retrievals cause spurious cloud properties (cloud fraction striping), which impacted LW surface fluxes
  - Linearly interpolate the cloud properties across twilight hourboxes (SZA>60)
- Consistent GEO boundaries across the record
- Reprocess the Meteosat 8-10 satellite cloud retrievals with consistent Met-11 code
  - Met-10 Feb 2013 to Feb 2018 (finished), Met-8 April 2004 to April 2007 (finished)
  - Met-9 April 2007 to Jan 2013, Met-8 Indian Ocean Feb 2017 to Feb 2018
- Incorporate improved 2-channel GEO cloud retrievals
  - Cloud working group is improving the 2-channel code by comparing against multi-channel GEO retrievals
  - GMS-5 Mar 2000 to April 2003, Met-7 Mar 2000 to April 2004
  - Met-5 over Indian Ocean March 2000 to Jan 2017
  - Replaced binary output with hourly GEO pixel level clouds and radiances netCDF files
- SYNI (computed fluxes) to start processing in July 2022 and finish by end of 2022
  - Release early 2023

SYN1deg, April 2019 Monthly hourly cloud fraction



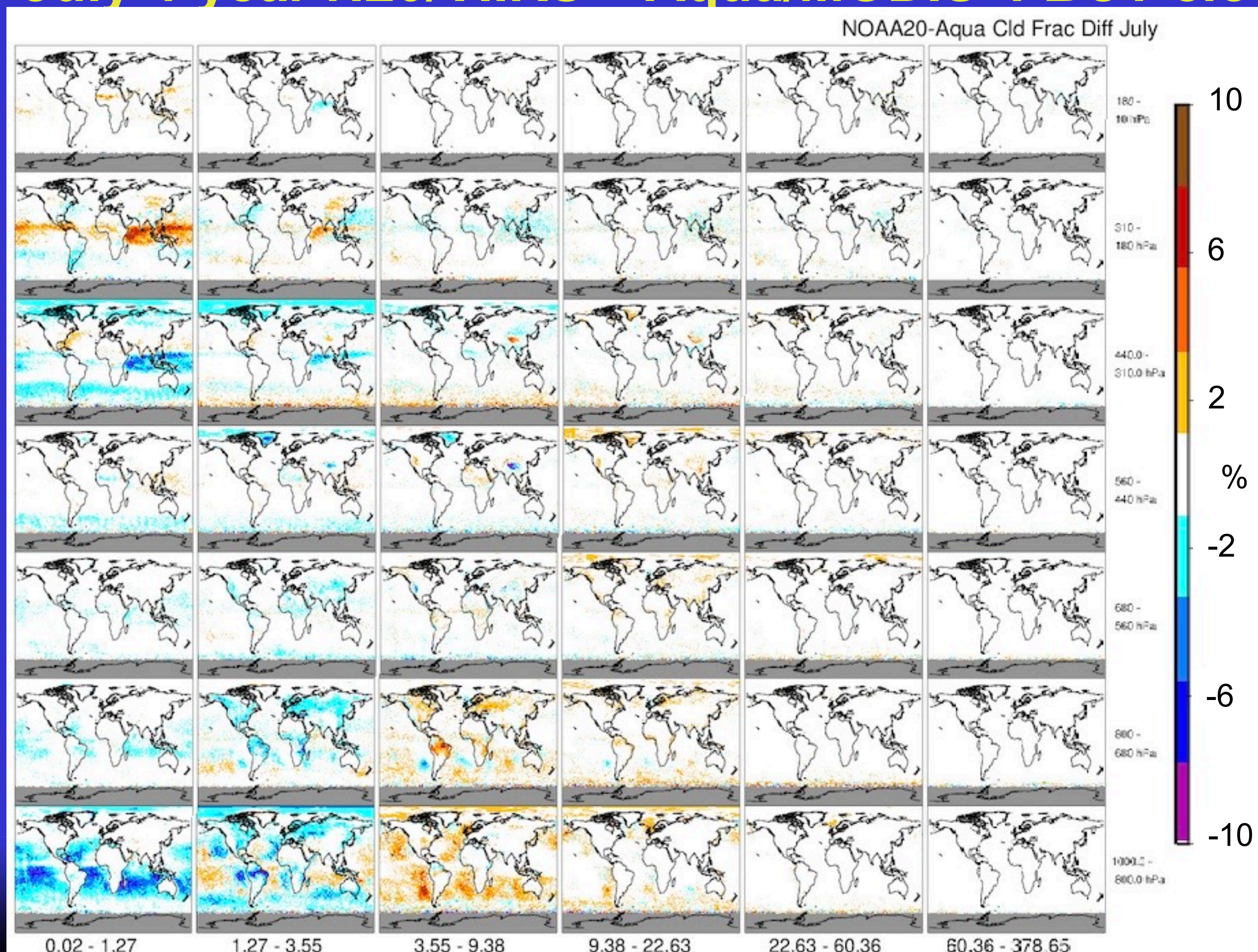
- GEO twilight cloud retrievals cause spurious cloud properties (cloud fraction striping), which impact LW surface fluxes
- Similar to the GEO SW TOA flux, which are temporally interpolated for hourboxes with SZA >60 deg, linearly interpolate cloud properties across the twilight hourboxes

FBCT

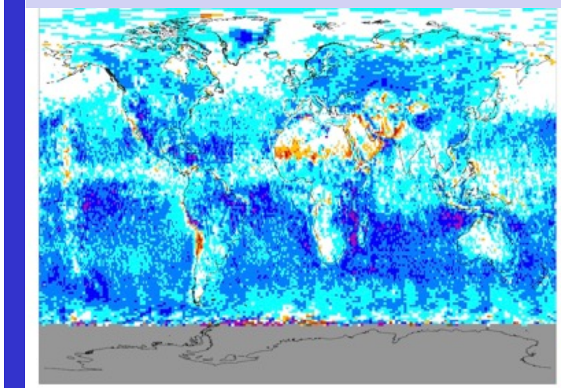
FluxByCloudType (FBCT)

- FBCT Ed4 paper is published:
  - Sun, M., Doelling, D. R., Loeb, N. G., Scott, R. C., Wilkins, J., Nguyen, L. T., & Mlynczak, P. (2022). Clouds and the Earth's Radiant Energy System (CERES) FluxByCldTyp Edition 4 Data Product, *Journal of Atmospheric and Oceanic Technology*, *39*(3), 303-318. Retrieved Mar 17, 2022, from https://journals.ametsoc.org/view/journals/atot/39/3/JTECH-D-21-0029.1.xml
- An error in the daily FBCT cloud type albedo was discovered by a user
  - The bug was fixed in the code
  - The whole FBCT record rerun and released in Feb 2022
- Working on a consistent FBCT Terra&Aqua and NOAA-20 only record
  - processed the 4-year NOAA-20 overlap record (2018-2021)
  - Looked at FBCT, cloud fraction, cloud optical depth, SW and LW flux climatologies differences between Terra&Aqua and NOAA-20
  - Tried simple climatological adjustments, need to have consistent clouds

July 4-year N20/VIIRS – Aqua/MODIS FBCT cloud fraction difference



July total cloud fraction difference

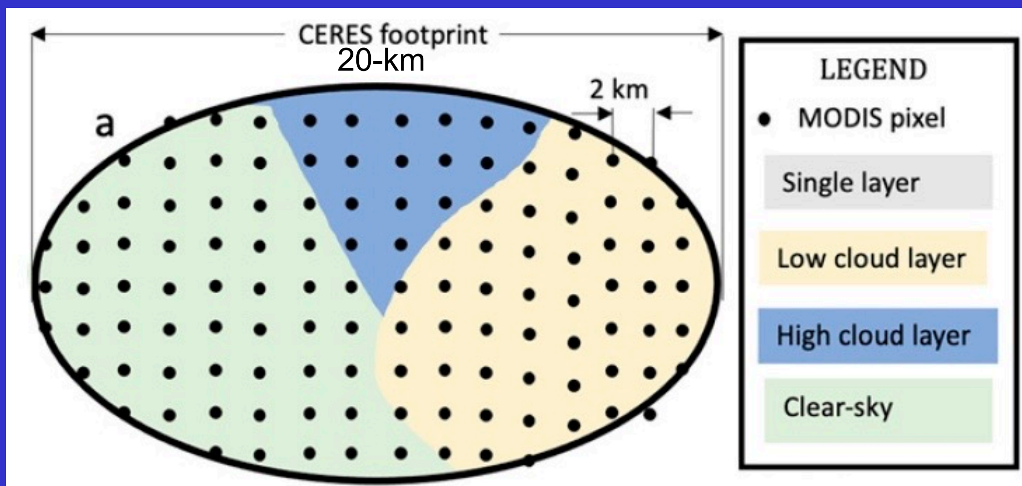


Before working on SW and LW flux N20 and Aqua FBCT differences, need to resolve the cloud property FBCT differences

FBCT Edition 5 work

- The Edition 4 methodology to derive FBCT subfootprint cloud-layer fluxes
  - MODIS 5-channel multi-variate linear regression with CERES fluxes from a 5-year monthly climatology (2007 to 2011) based on single scene overcast/clear footprints
  - 0.47µm, 0.65-µm, 0.86-µm, 11-µm and 12-µm MODIS channels for both SW and LW, these were the only channel radiance for cloud-layers
  - Apply the NB to BB coefficients to the cloud-layer and clear-sky portions of the multi-scene footprints.
  - Apply the CERES Ed4 ADMs and normalize the footprint cloud-layer and clear-sky flux with the CERES observed flux
- The Edition 5 methodology
  - Utilize Machine learning to derive the subfootprint BB radiances from MODIS channels and possibly directly to flux based on single scene footprints from a 5-year climatology
  - Add latitude, longitude (SW and LW), and Tskin (LW) to the Ed4 7 surface types, VZA, PW, clear/cloud (SW and LW) and SZA and RAA (SW) parameter binning
  - Add new MODIS channels, there are a possible of 19 MODIS channels on the CERES MODIS L1B subset
  - Normalize the subfootprint fluxes with the CERES observations

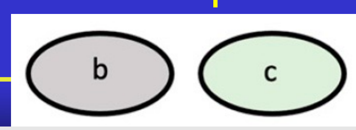
CERES footprint



$$\text{Flux}_i^{\text{normalized}} = \left[\frac{\text{Flux}_{\text{CERES}}}{\text{Flux}_{\text{footprint}}}\right] \times \text{Flux}_i.$$

$$\text{Flux}_{\text{footprint}} = \Sigma\ \text{Flux}_i * \text{Frac}_i$$

Derive the clear-sky, low-cloud and high-cloud broadband radiance individually using MODIS channel to broadband relationships based on single scene footprints



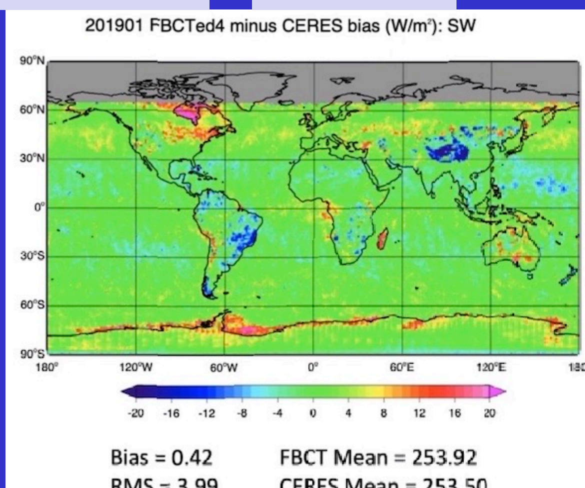
single scene footprints

Normalize the individual clear-sky, low-cloud and high-cloud derived fluxes (Flux_i) (after applying ADM to the BB radiance) with the CERES observed footprint flux

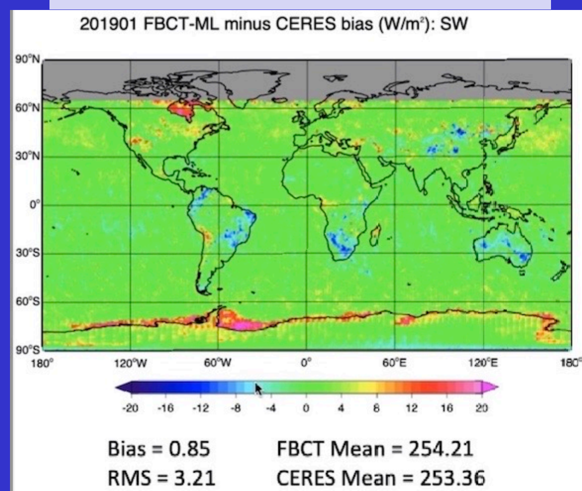
Comparison of FBCT ML algorithms with Ed4 SW

Jan 2019

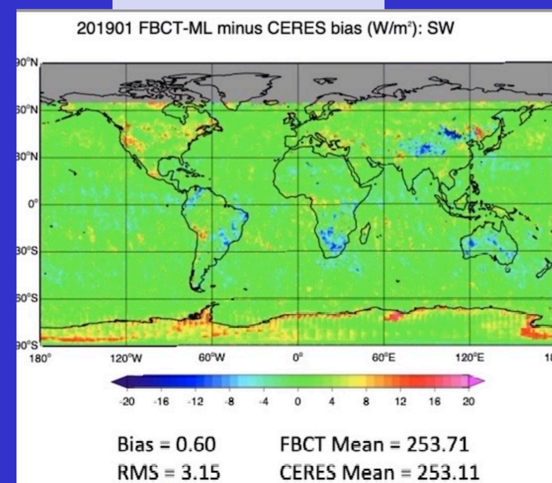
SW Ed4



SW ML radiance/ADM



SW ML flux

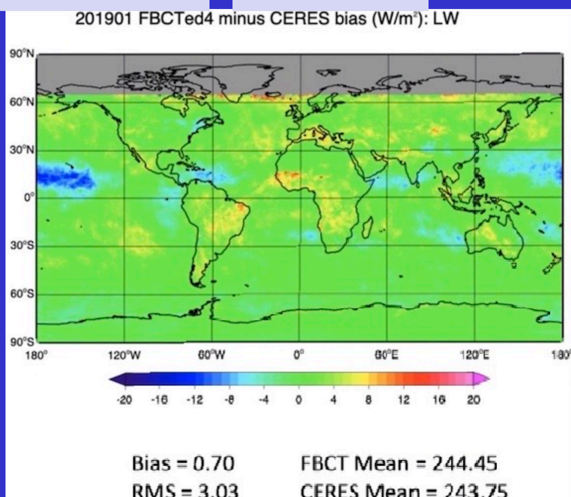


Use ML from 2007 to 2011 Januaries and apply to Jan 2019

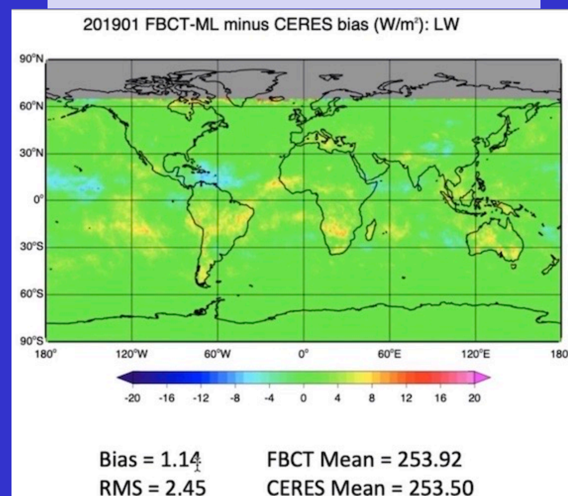
Comparison of FBCT ML algorithms with Ed4 LW

Jan 2019

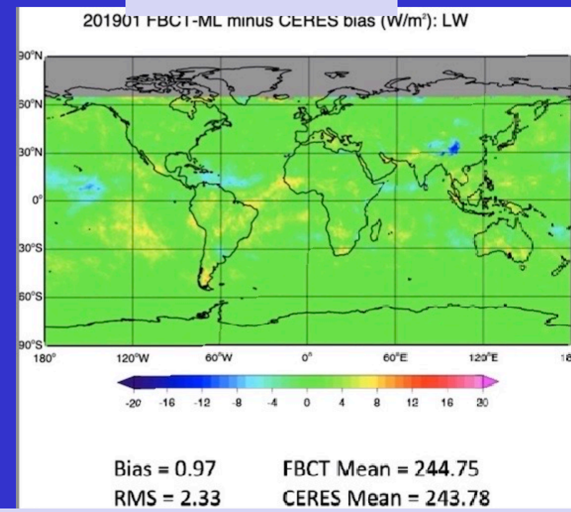
LW Ed4



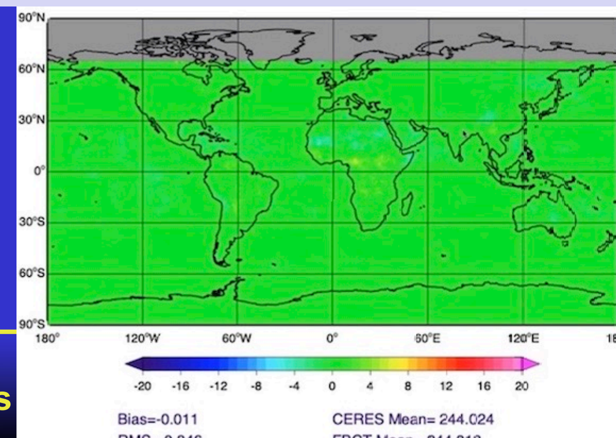
LW ML radiance/ADM

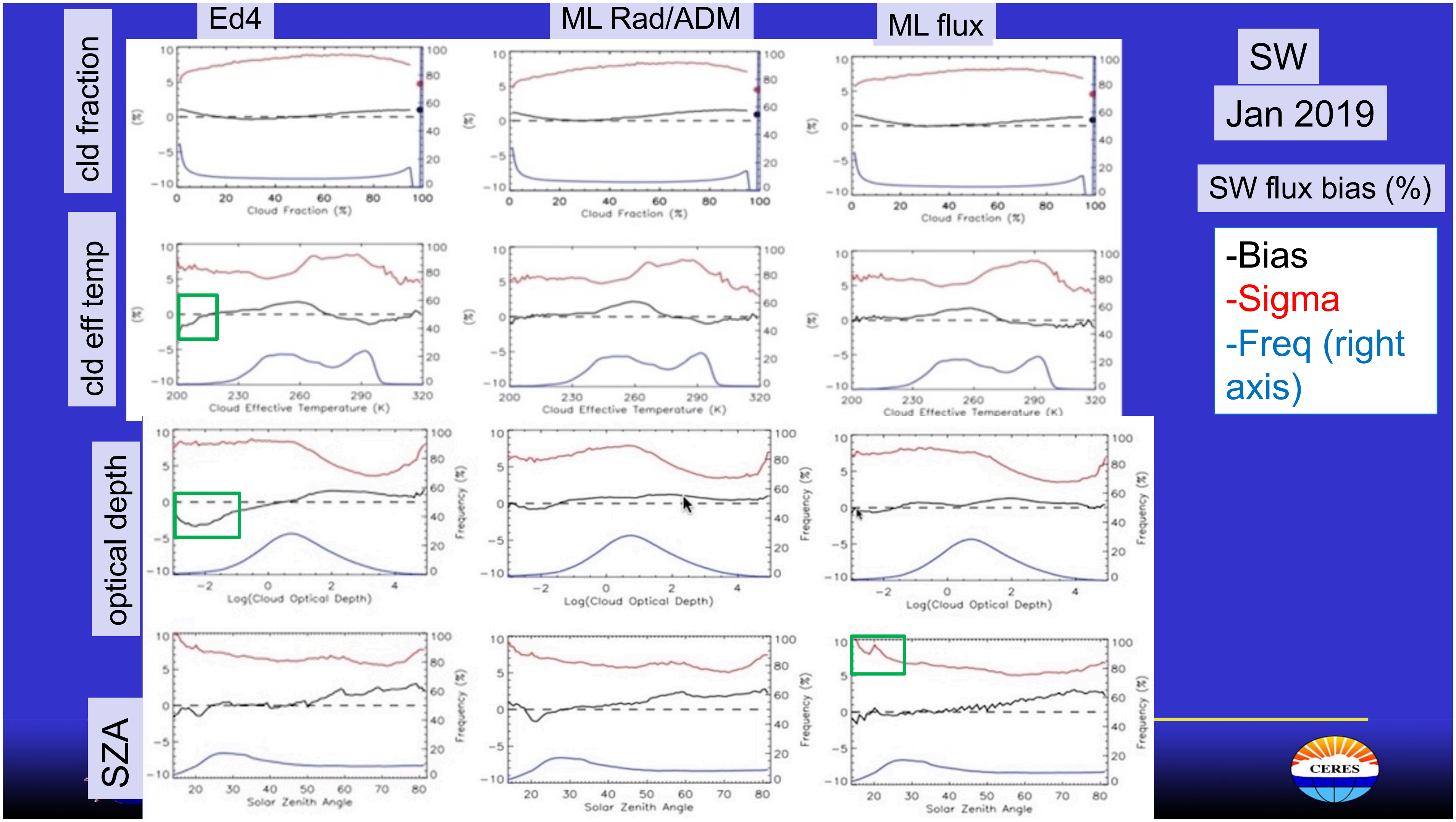


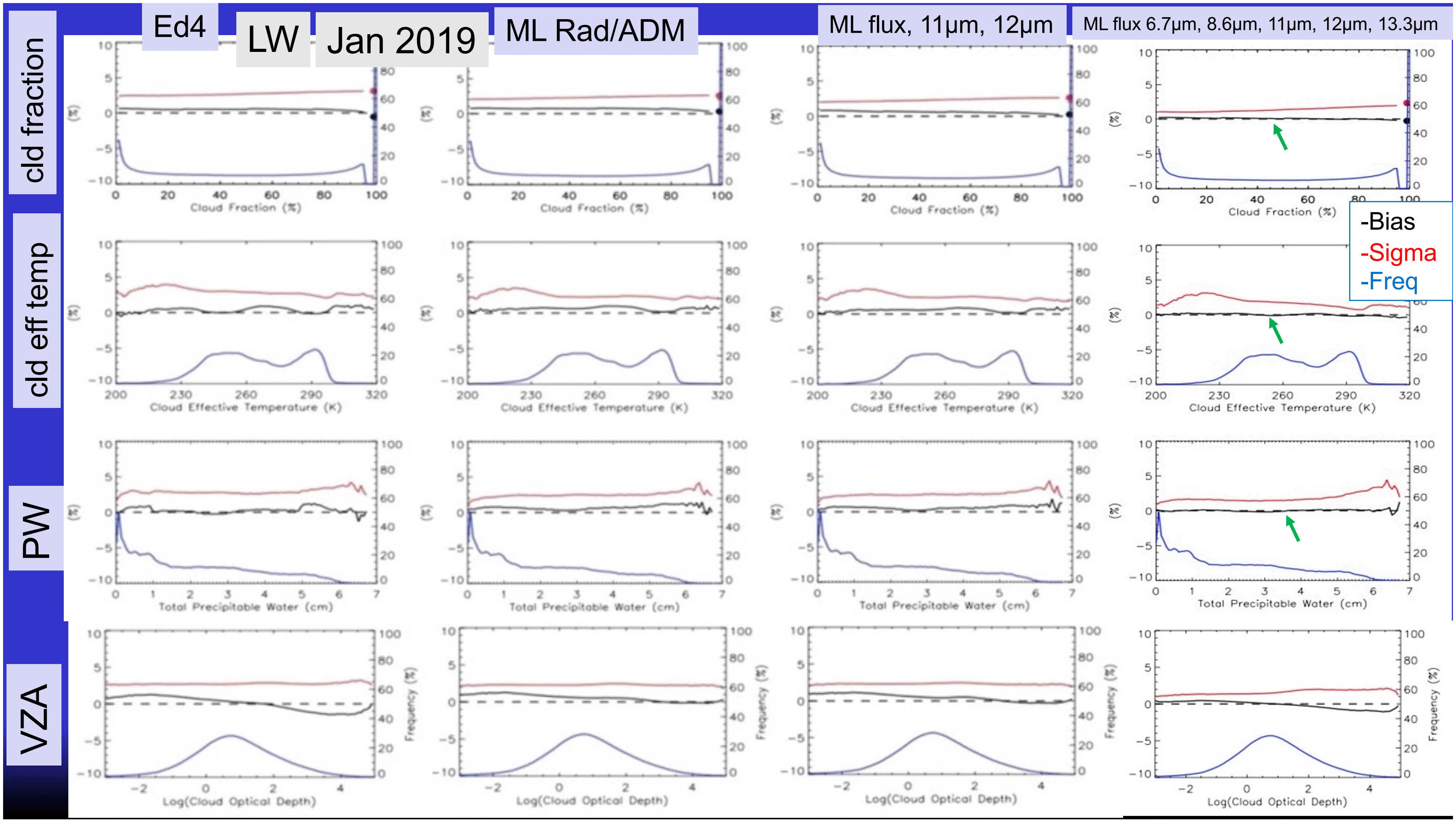
LW ML flux



Ed5, MLflux 6.7μm, 8.6μm, 11μm, 12μm, 13.3μm




Ed4
ML Rad/ADM
ML flux
cld fraction
cld eff temp
optical depth
SZA
Cloud Fraction (%)
Cloud Effective Temperature (K)
Log(Cloud Optical Depth)
Solar Zenith Angle
Frequency (%)
(%)
SW
Jan 2019
SW flux bias (%)
-Bias
-Sigma
-Freq (right axis)
CERES



Ed4
LW
Jan 2019
ML Rad/ADM
ML flux, 11µm, 12µm
ML flux 6.7µm, 8.6µm, 11µm, 12µm, 13.3µm
cld fraction
cld eff temp
PW
VZA
Cloud Fraction (%)
Cloud Effective Temperature (K)
Total Precipitable Water (cm)
Log(Cloud Optical Depth)
Frequency (%)
-Bias
-Sigma
-Freq

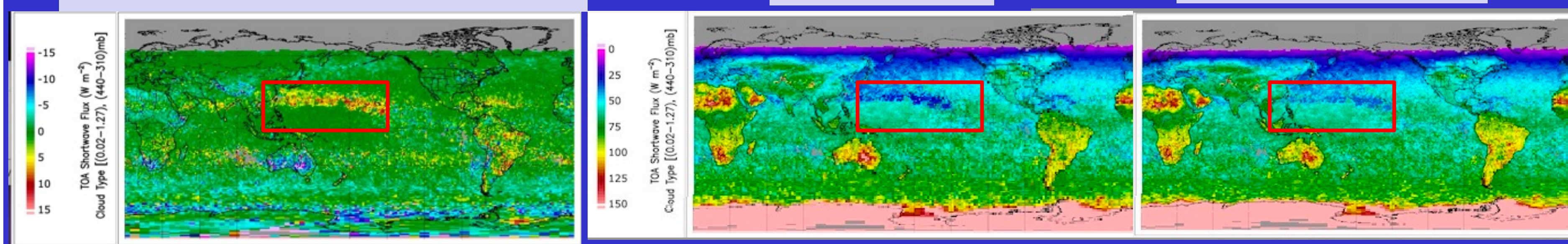
FBCT Ed5 status

- Continue to improve the Machine Learning MODIS to broadband flux relationship over the 5-year climatology period
- Optimize MODIS channels for SW
- Compare Ed4 and Ed5 42-cloudtype regional fluxes and 7x6 cloud-type plots

FBCT SW Ed4MLflux – ED4

Ed4 SW

SW Ed4MLflux



Jan 2019 Cloudtype 0.0-1.27 optical depth and 440-310mb pressure layer

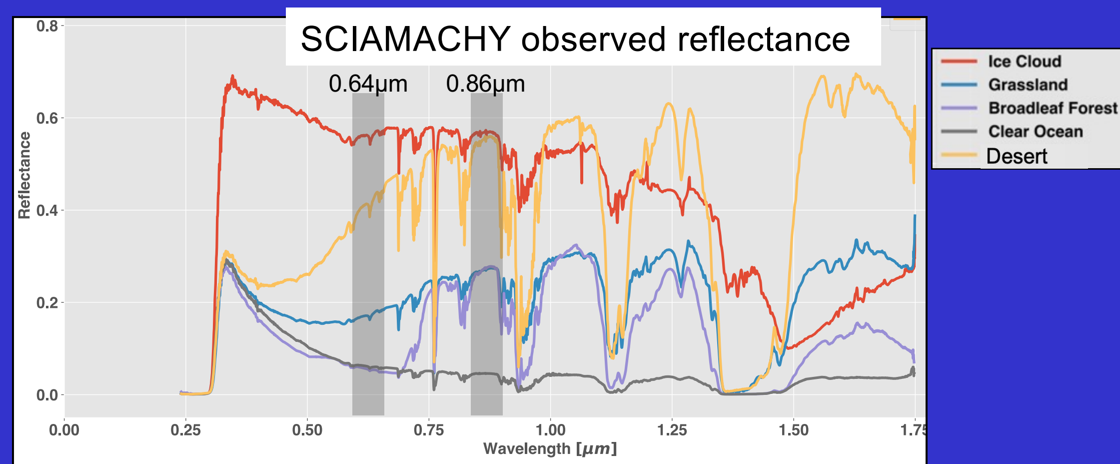
GEO SW NB to BB

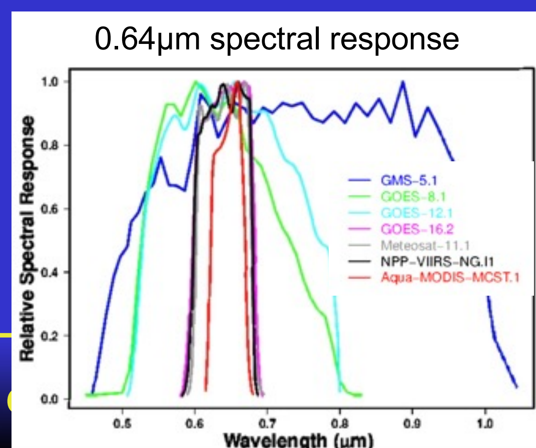
GEO SW NB to BB Ed5

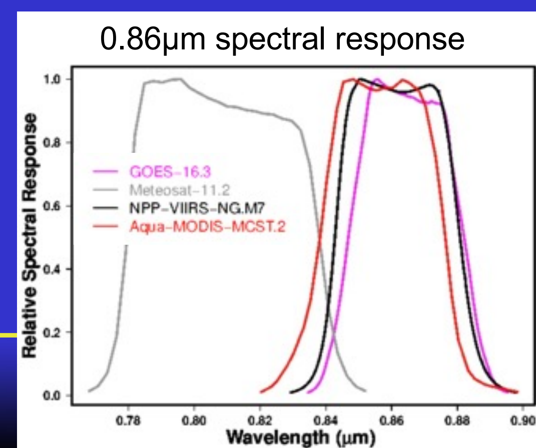
- Convert GEO visible narrowband (NB) channel directly to broadband (BB) radiance using hyper-spectral RTM, ~ 2500 wavelengths (0.2µm to 5µm)
  - Eliminate the Ed4 two step process of converting GEO to MODIS-like and then using empirical MODIS-like to BB radiance (Ed2 SW NB to BB LUT codes no longer exist)
  - Each GEO will have its own customized RTM LUT by convolving the RTM hyper-spectral radiances with the GEO spectral response function
- Continue to use the CERES TRMM ADMs to convert BB radiance to SW flux
  - TRMM orbit precesses and provides complete solar zenith angle sampling
- GEO Ed4 LW NB to BB uses window (11µm) and water vapor (6.7µm) channel radiances to CERES flux relationships based on Aqua and applied to GEO radiances
  - not planning on updating for Ed5, gridded instantaneous uncertainty ~1.5%

SW NB to BB over land

- The 0.86µm (NIR) bright vegetation reflectance is not captured by the 0.64µm (red) channel.
- The Ed4 SW NB to BB relies on the 0.64µm channel only, because most GEOs over the CERES record do not have a 0.86µm channel
- The older GEOs have a broader spectral response
- The new GEO imagers have similar spectral responses with VIIRS
  - Include more channels for Ed6

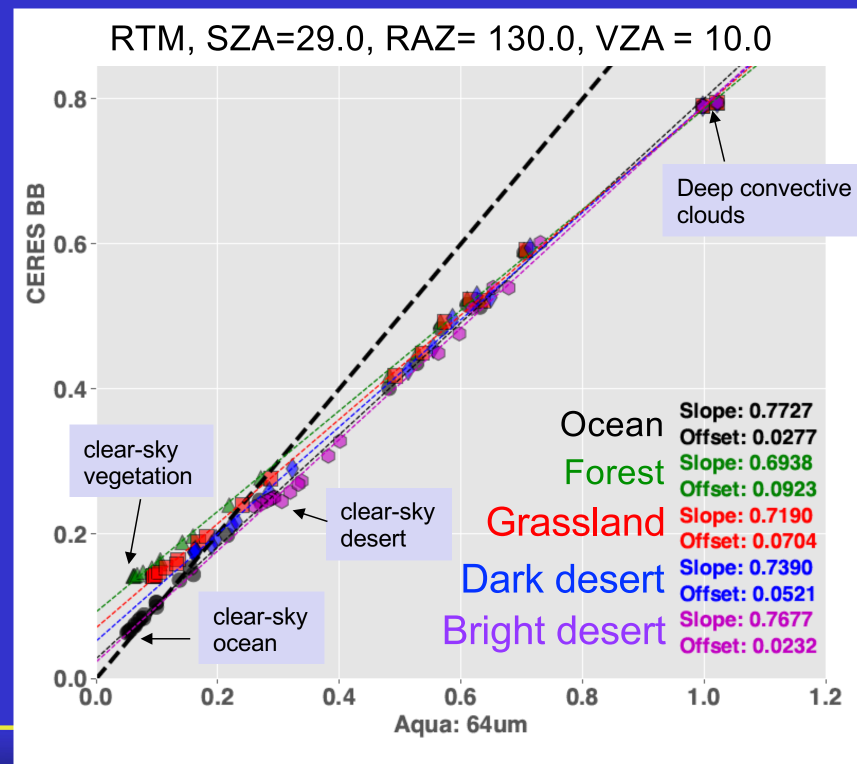






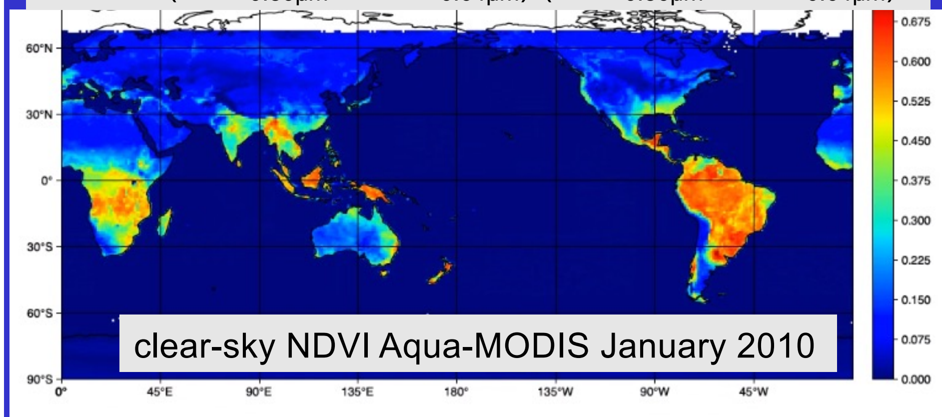
SW NB to BB over land

- RTM hyper-spectral radiances are convolved over the Aqua-MODIS 0.64µm band spectral response function over multiple clear-sky and cloud optical depths
- For each angular bin the NB and BB reflectance pairs are regressed
- Over land, the RTM surface BRDF and spectra are based on MODIS and stratified by IGBP type
- However, the 0.86µm (NIR) bright vegetation reflectance is not captured by the 0.64 µm (red) channel. Most GEOs do not have a 0.86µm channel



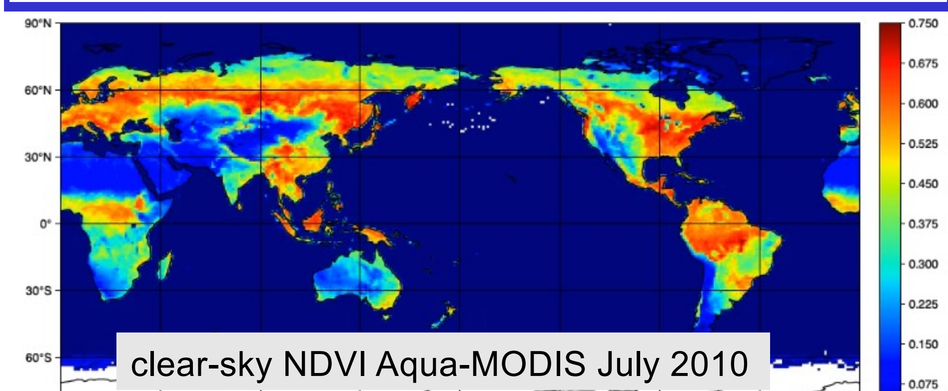
NDVI vs Land IGBP types

$NDVI = (REF_{0.86\mu m} + REF_{0.64\mu m})/(REF_{0.86\mu m} - REF_{0.64\mu m})$

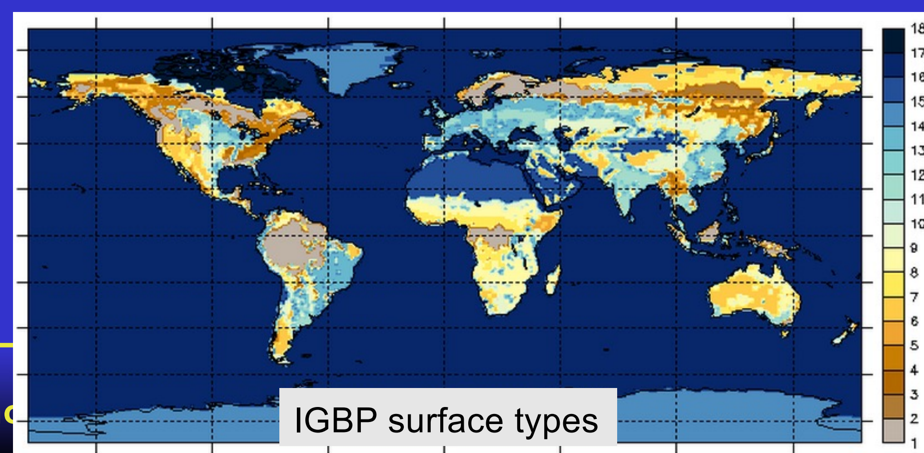


clear-sky NDVI Aqua-MODIS January 2010

- IGBP maps are static and do not change by season
- NDVI describes the seasonal NIR reflection variation of vegetation
- Convert the 0.64μm reflectance to the broadband SW reflectance using a single IGBP type (grassland) for vegetation. For dark and bright deserts used the assigned IGBP type

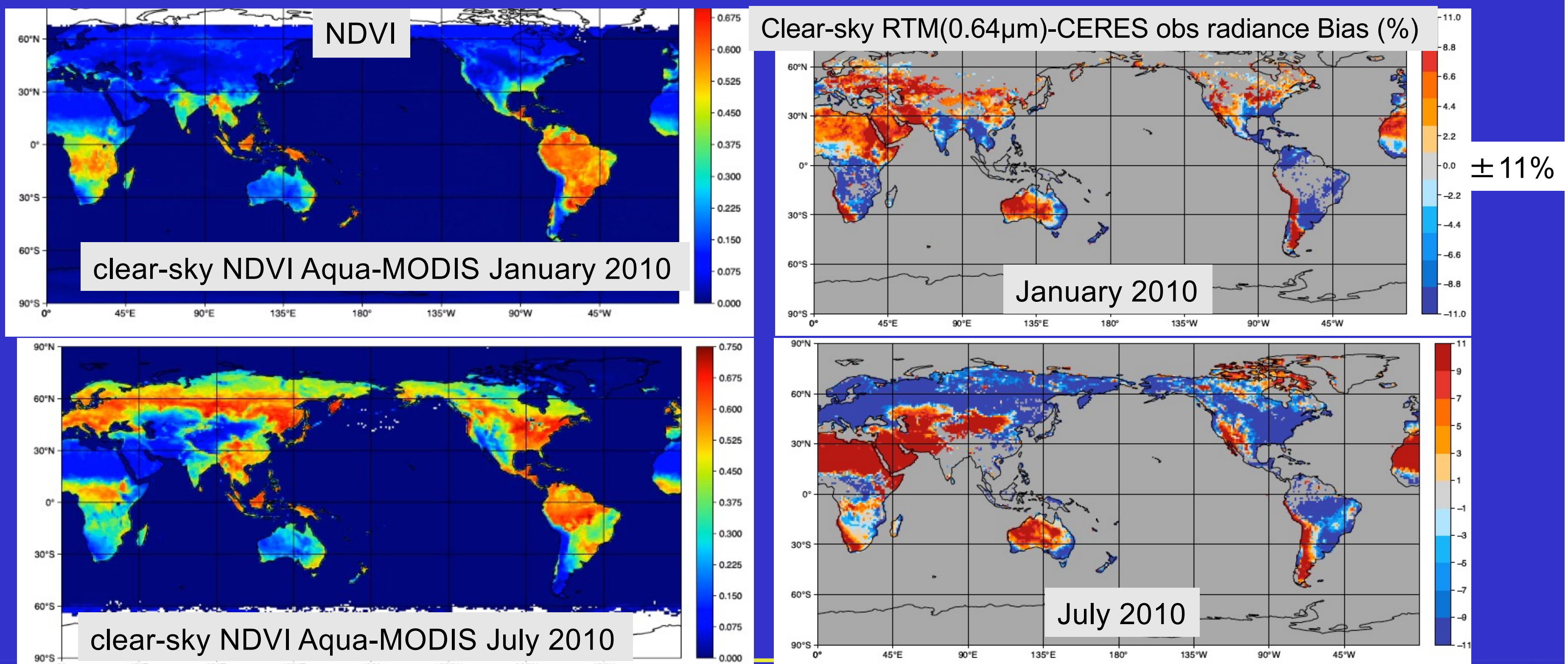


clear-sky NDVI Aqua-MODIS July 2010



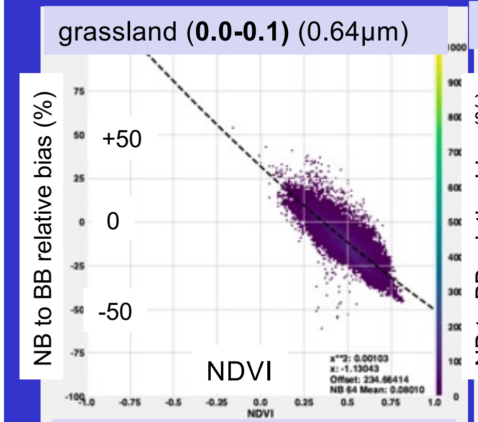
IGBP surface types

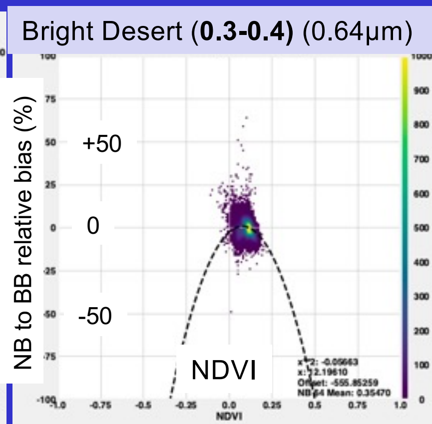
Comparison of NDVI and the SW NB to BB bias

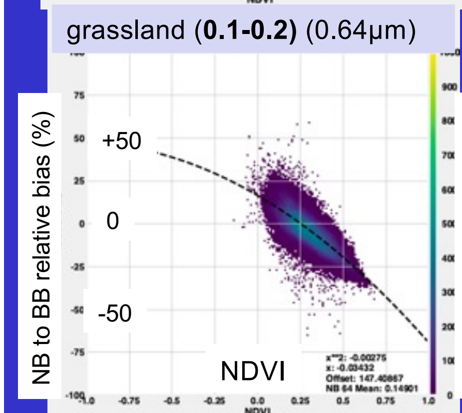


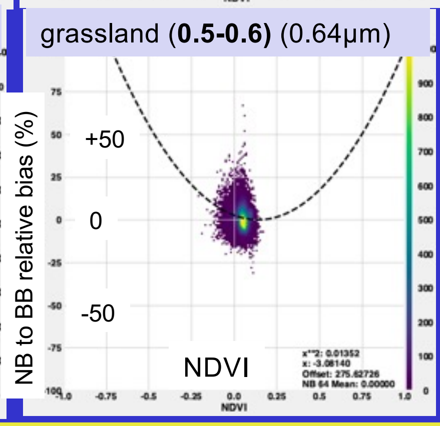
- Note how the SW NB (0.64μm channel) to BB biases over vegetation are inversely correlated to NDVI
- The SW NB (0.64μm channel) to BB biases over deserts (low NDVI) are opposite in sign than over vegetation

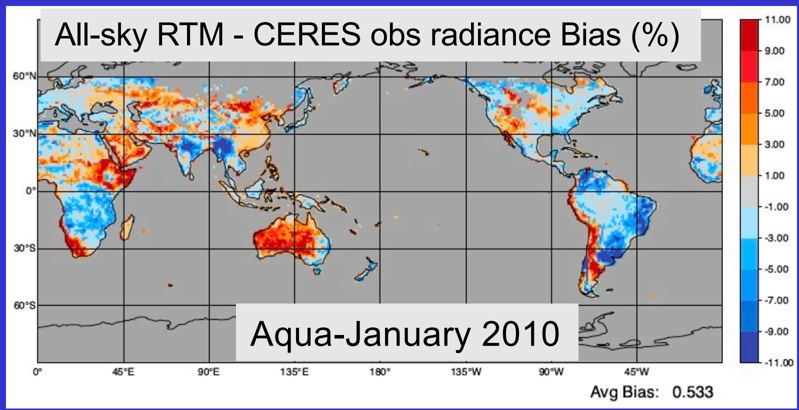
NDVI based bias adjustment

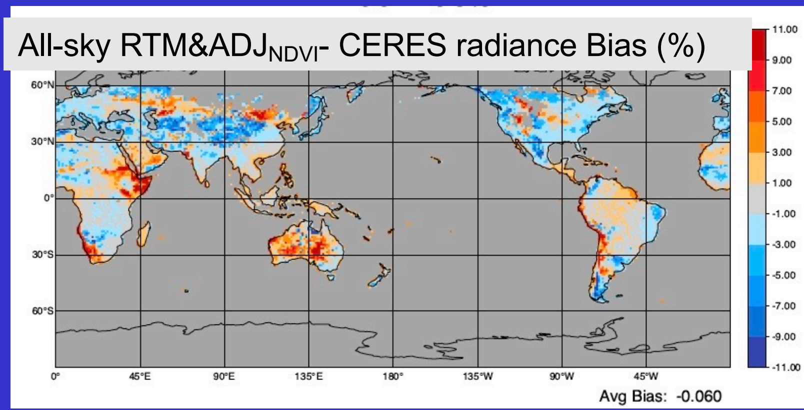








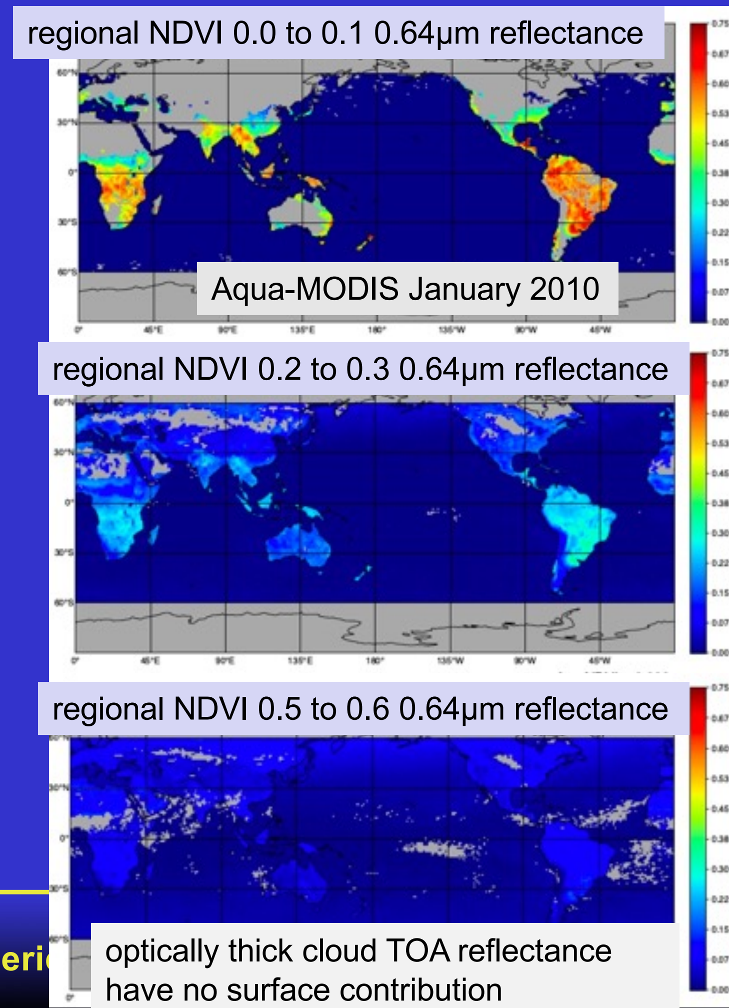




- ADJ$_{NDVI}$ 12 monthly bins, 10 reflectance bins, 3 surface types (vegetation, dark and bright desert)
- Performs well over vegetation and bright deserts. Dark deserts not so well.

Regional NDVI LUT

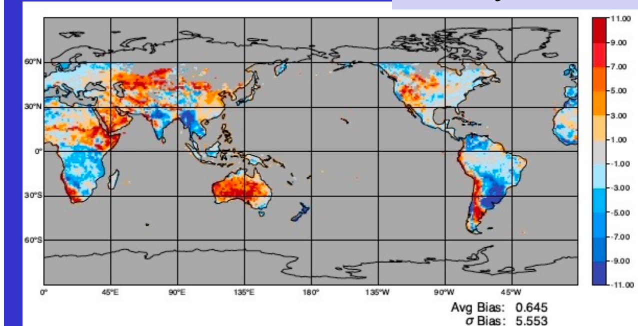
- Most GEOs do not have a 0.86μm channel to compute the observed pixel-level NDVI
- Use MODIS imager regional NDVI LUT by 0.64μm reflectance
  - (10 all-sky reflectance bins by 360x180 regions)
  - The reflectance bins account the cloud conditions
- Construct monthly regional NDVI LUTs
  - Captures the interannual NDVI variability
  - Increases the forward processing effort
- Construct climatology regional NDVI LUTs
  - Does not capture the interannual NDVI variability
  - Decreases the forward processing effort
- Compare to observed footprint NDVI

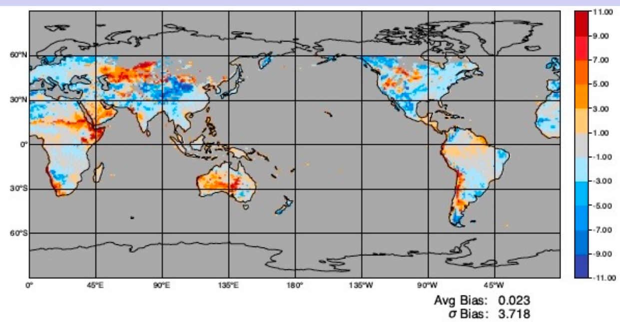


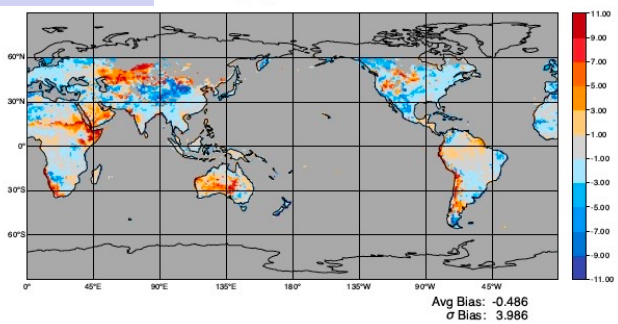
Bias Adjustment with NDVI

no NDVI adjustment | observed NDVI adjustment | 2013 Climatology NDVI adjustment

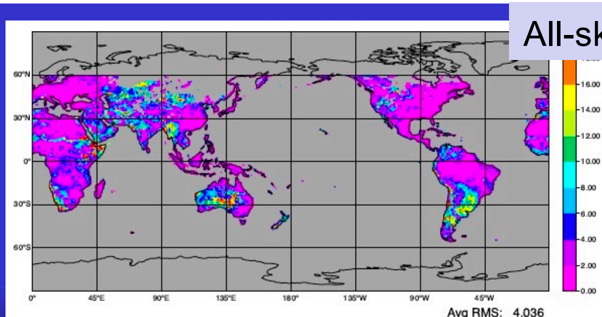
All-sky RTM minus CERES radiance Bias (%) for January 2013

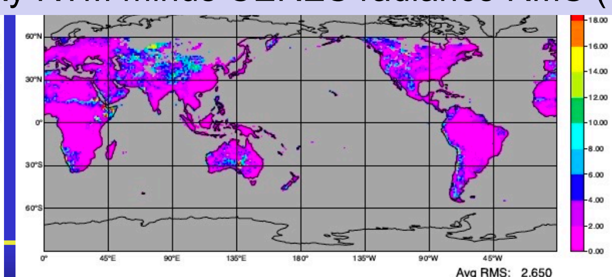


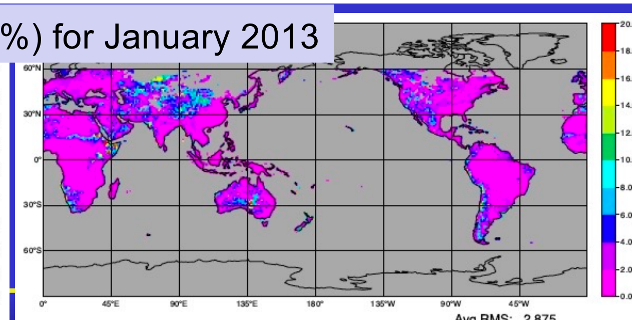




All-sky RTM minus CERES radiance RMS (%) for January 2013



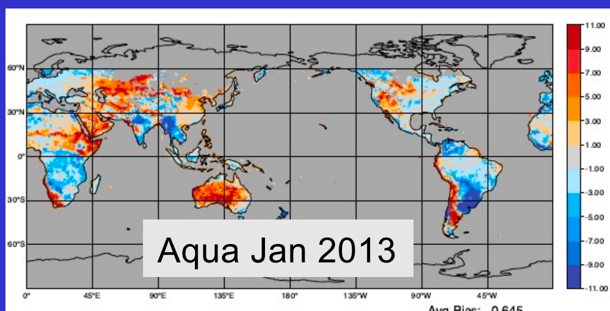


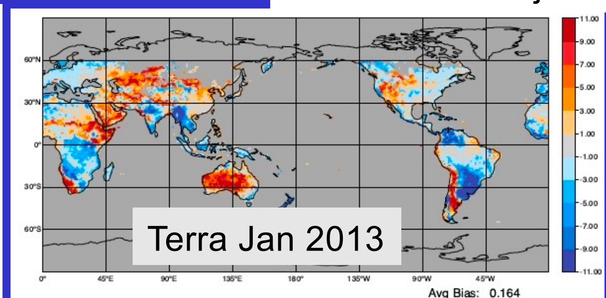


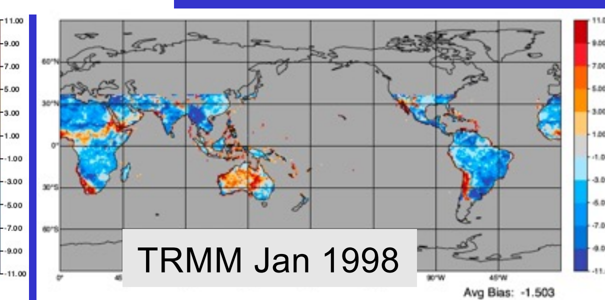
Bias Adjustment with NDVI

All-sky RTM minus CERES radiance Bias (%)

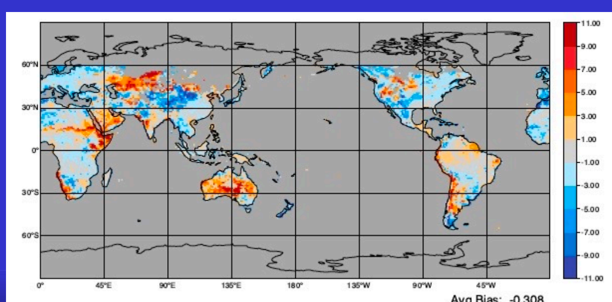
no NDVI adjustment

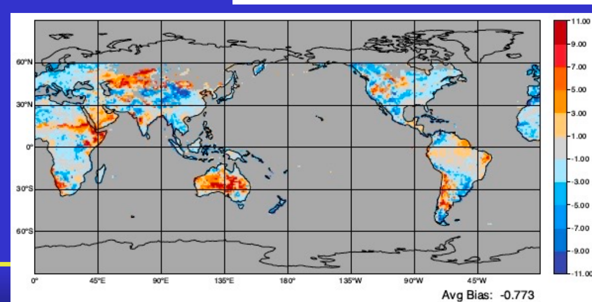


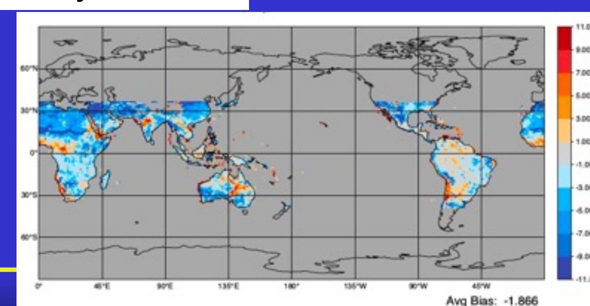




2010 Climatology NDVI adjustment







NDVI Bias Adjustment with differing sources

Dataset	NDVI adjustment	Bias (%)	Sigma Bias (%)	RMS (%)
Jan 2013 Aqua	Observed NDVI	0.023	3.718	2.650
	ADJ_{NDVI}(2013)	-0.486	3.986	2.875
	ADJ_{NDVI}(2010)	-0.424	4.213	2.998
	Unadjusted RTM	0.645	5.553	4.036
Jan 2013 Terra	Observed NDVI	-0.496	3.478	2.615
	ADJ_{NDVI}(2013)	-0.969	3.947	3.030
	ADJ_{NDVI}(2010)	-0.773	4.260	3.175
	Unadjusted RTM	0.164	5.774	4.178
Jan 1998 TRMM	Unadjusted RTM	-1.503	7.320	5.487
VIRS has no 0.86µm channel	ADJ_{NDVI}(2010)	-1.866	6.311	4.720

GEO SW NB to BB Summary

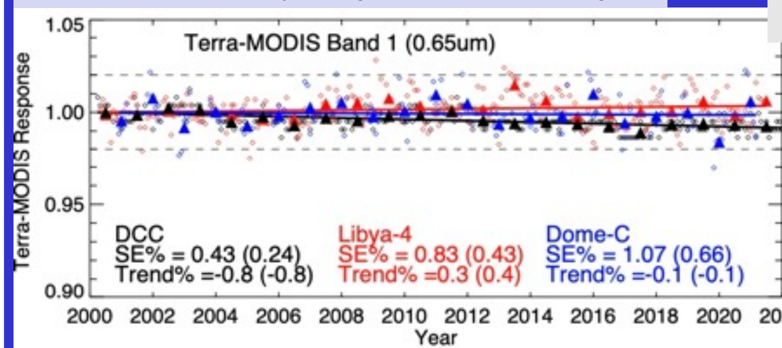
- Use RTM 0.64µm channel and BB clear-sky and cloud optical depth based reflectance pair regressions by angular bin similar to the ocean methodology
- The RTM hyper-spectral reflectances are computed by IGBP type
  - Use grassland, dark desert and bright desert
- The RTM biases are dependent on the NDVI
  - NDVI based adjustment are a function of month, 0.64 reflectance and surface type
- Most GEOs do not have the 0.86µm channel,
  - Construct regional NDVI maps as a function of 0.64 reflectance
- Future work
  - Validate GEO SW NB to BB using coincident GEO and MODIS, GEO and GERB, and TRMM datasets

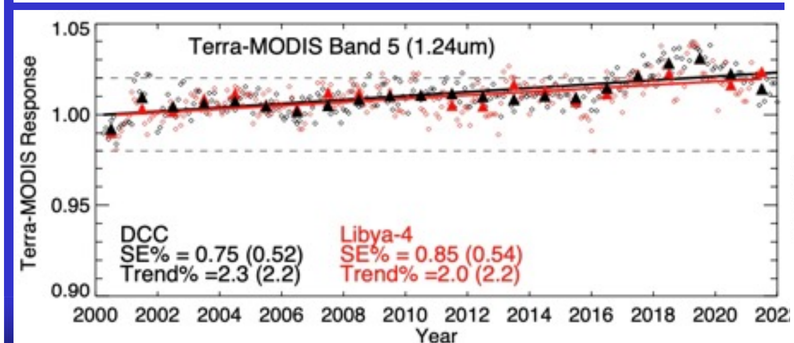
Calibration

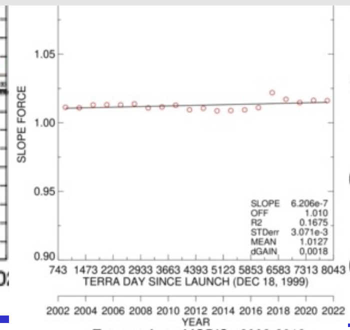
Terra and Aqua MODIS C6.1 stability and scaling

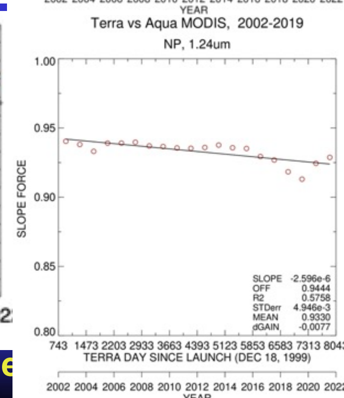
Terra to Aqua-MODIS scaling based on monthly regressions of ray-matched reflectance pairs over all-sky tropical ocean

Terra-MODIS Stability using Earth invariant targets

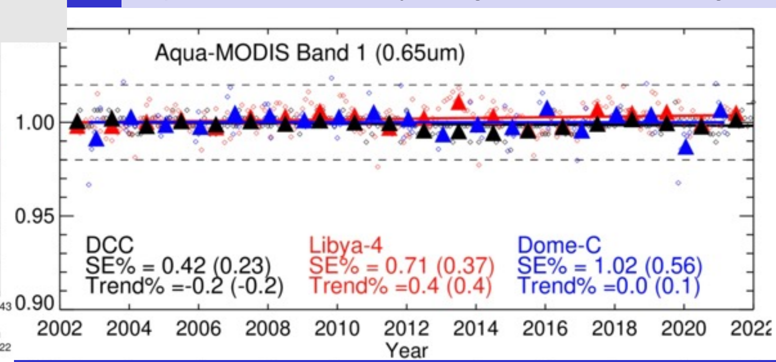


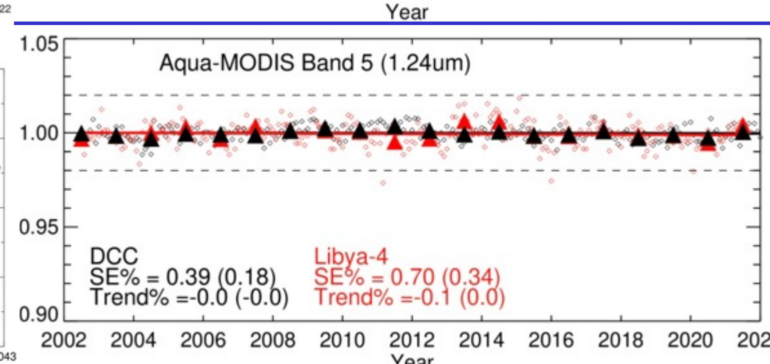






Aqua-MODIS Stability using Earth invariant targets

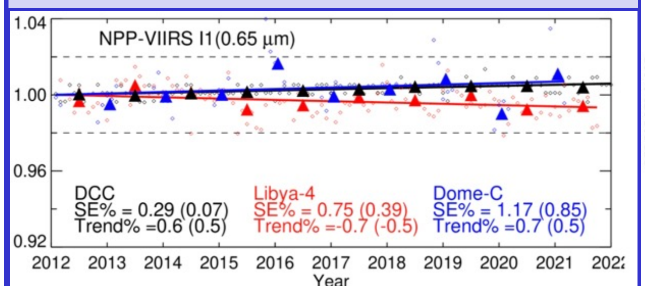


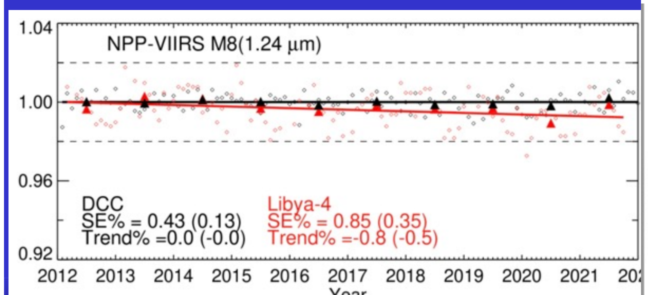


https://satcorps.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=SAT_CALIB_USER

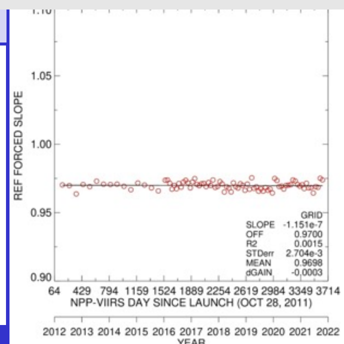
NPP VIIRS C2 and NOAA-20 VIIRS C2.1 stability and scaling

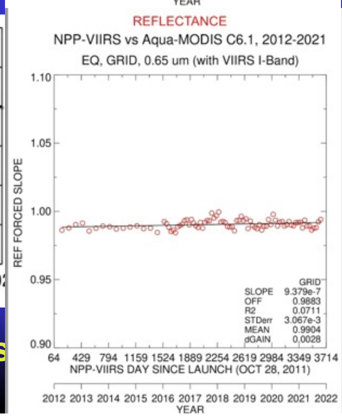
NPP-VIIRS Stability using Earth invariant targets



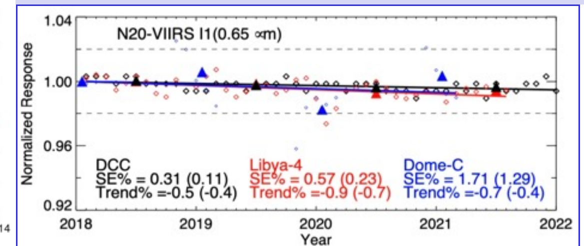


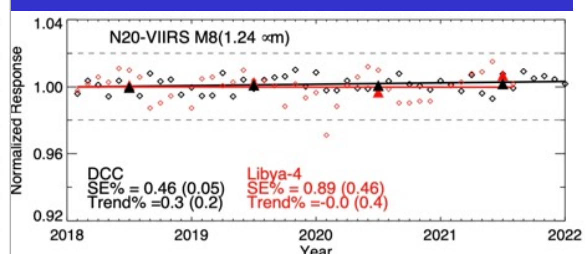
NPP-VIIRS to Aqua-MODIS scaling based on monthly regressions of ray-matched reflectance pairs over all-sky tropical ocean



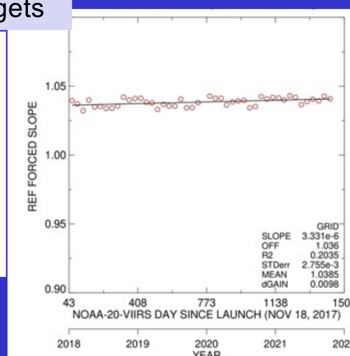


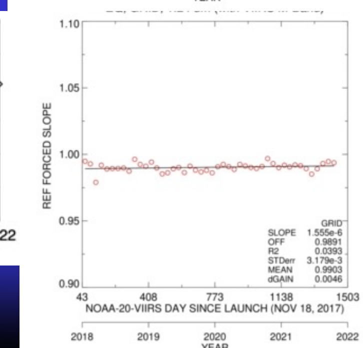
N20-VIIRS Stability using Earth invariant targets



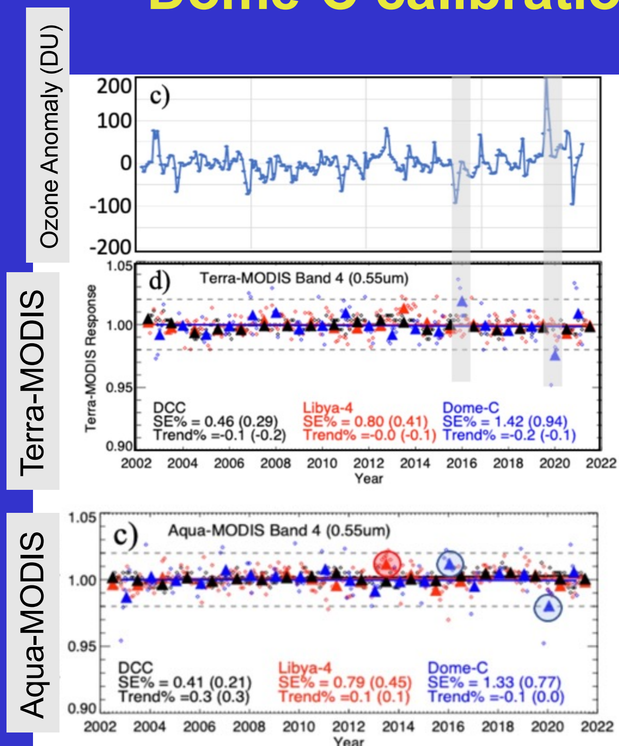


N20-VIIRS to Aqua-MODIS scaling based on monthly regressions of ray-matched reflectance pairs over all-sky tropical ocean





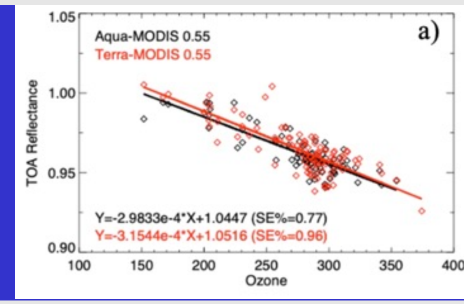
Dome-C calibration stability improved with ozone



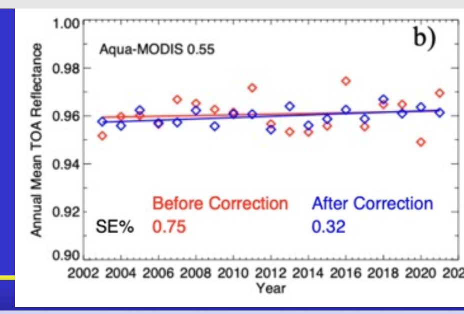
MODIS Stability using Earth invariant targets

Note how the Dome-C anomalies (blue filled circles) are correlated to the Ozone anomalies

Linearly regress the Dome-C reflectance anomaly with the ozone DU



The annual Dome-C reflectance trend standard error before (red) and after (blue) applying ozone correction



David R. Doelling, Rajendra Bhatt, Benjamin R. Scarino, Arun Gopalan, David Rutan, Ryan Scott, Conor O. Haney, "Additional characterization of Dome-C to improve its use as an invariant visible calibration target," Proc. SPIE 11829, Earth Observing Systems XXVI, 118290D (1 August 2021); doi: 10.1117/12.2594294

TISA ED5

TISA ED5 improvements

- FBCT incorporate Machine Learning multi-channel imager radiance to broadband flux utilizing optimized channels
- GEO narrowband to broadband
  - Utilize Ed4 GEO LW NB to BB utilizing both the 11µm and 6.7µm channels – no Ed5 improvements planned
  - Replace the Ed4 GEO to MODIS theoretical and MODIS to CERES empirical SW NB to BB, with the hyper-spectral RTM based NB to BB angular regressions and land NDVI adjustment
- Convert the Ed4 code into a more object-oriented-code or modular Ed5 framework
  - Provide daily SYNI output as regional maps for SARB
  - Perform GEO NB to BB at the instantaneous GEO pixel
  - Place the gridding and temporal interpolation routines into a library and construct SW, LW and cloud specific containers
  - The SSF1deg and SYN1deg lite and full parameter products will use the same code base with built in flags