TISA Working Group Update

CERES TISA Sublead: D. Doelling
TISA: B. Branch, A. Gopalan, K. Itterly, E. Kizer, P. Mlynczak,
M. Nordeen, M. Sun, J. Wilkins,
GEO and Imager calibration: C. Haney, P. Khakurel, B. Scarino
K. Dejwakh, W. Miller & subsetter team
Raj Bhatt (CLARREO),

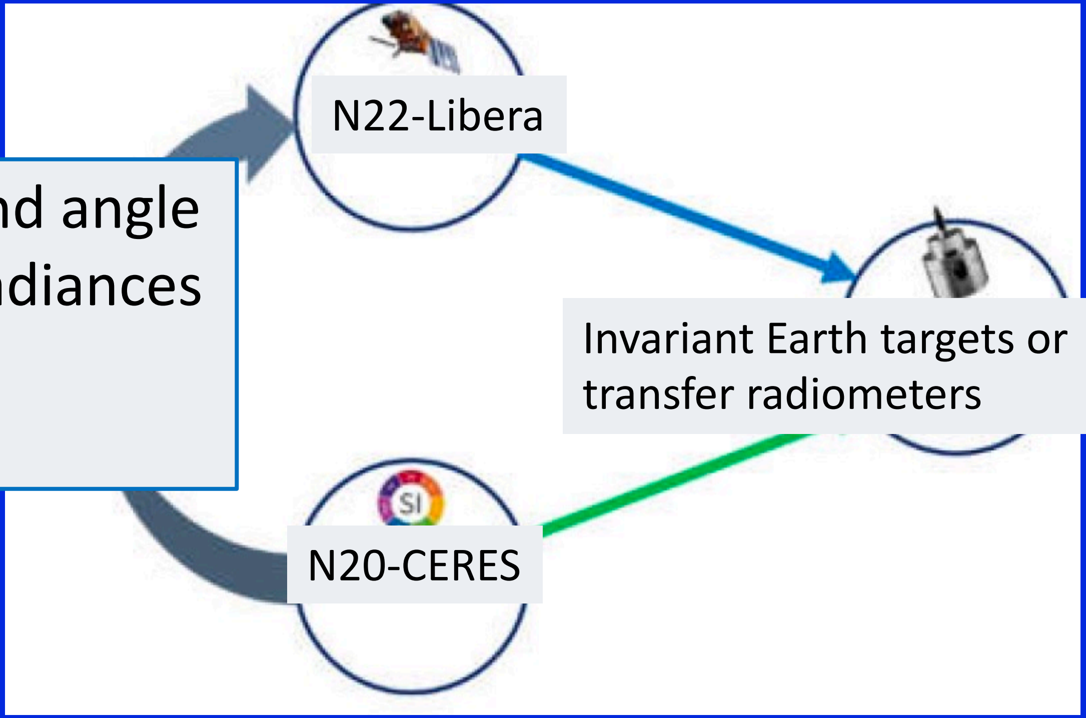
Spring 2024 CERES science team meeting
NASA-Langley, Hampton, VA, May 14-16, 2024

OUTLINE

- Develop methods to radiometrically scale CERES instrument channel radiances in the same orbit but without time matched observations
  - **Libya4 INVARIANT TARGET**: desert invariant target characterized with SW channel – use the Libya-4 surface to transfer the calibration
  - **DCC RAYMATCH**: VIIRS narrowband to broadband – transfer the calibration between VIIRS using GEO – use DCC targets
  - **GEOSCAN:** - GEO narrowband to broadband ray-matched with GEOscan CERES instrument radiances – transfer the CERES calibration using GEO
- Ed5 Machine Learning narrowband to broadband (NB to BB) progress
  - VIIRS narrowband to broadband FLuxByCloudType **(FBCT) fluxes**
  - **GEO LW** narrowband to broadband fluxes
- TISA Ed5 framework status

Inter-calibration Strategies

Use direct time and angle matched CERES radiances
- NPP/Aqua and N20/Aqua SNOs



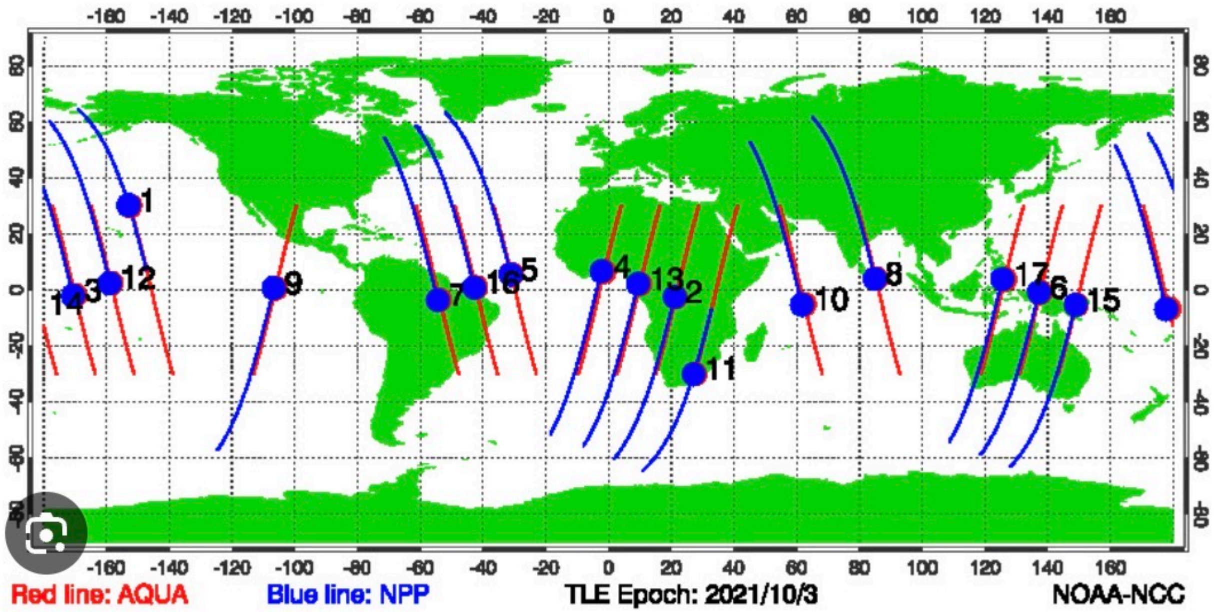
Use GEO as a transfer radiometer
- DCC RAYMATCH
- GEOscan

Use Earth invariant target reflectance to transfer calibration
- Libya4 INVARIANT TARGET

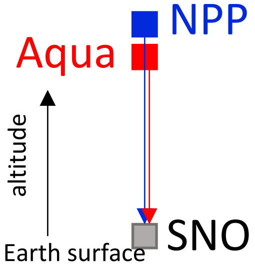
- Aqua has exited the 1:30 orbit and is drifting towards the terminator, to be decommissioned in 2027
- NPP, N20 and N22 are in the same 1:30 orbit, but positioned apart along the orbit – no time matched measurements
- Use Libya4 INVARIANT TARGET, DCC RAYMATCH, GEOSCAN to inter-calibrate N20 CERES with the future N22 Libera

Simultaneous Nadir Observations (SNO)

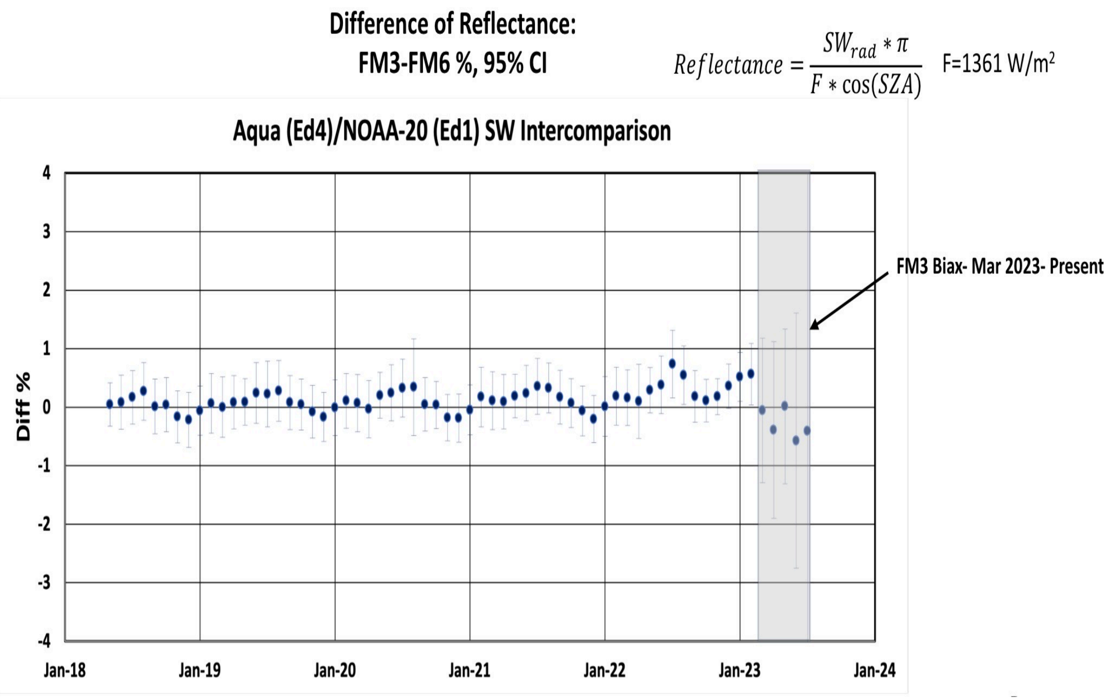
Between 2012 to 2022, NPP/Aqua before Aqua drifting orbit



- The lower the altitude the faster the orbit time
  Aqua, 1:30PM-MLT, 705-km, 99-minutes
  SNPP, 1:30PM-MLT, 830-km, 101 minutes
- Allows for a ground track intersect every 64-hours and provides a simultaneous nadir observation pair for CERES instrument inter-calibration



Monthly SNO Aqua/NOAA-20 CERES-SW intercomparison

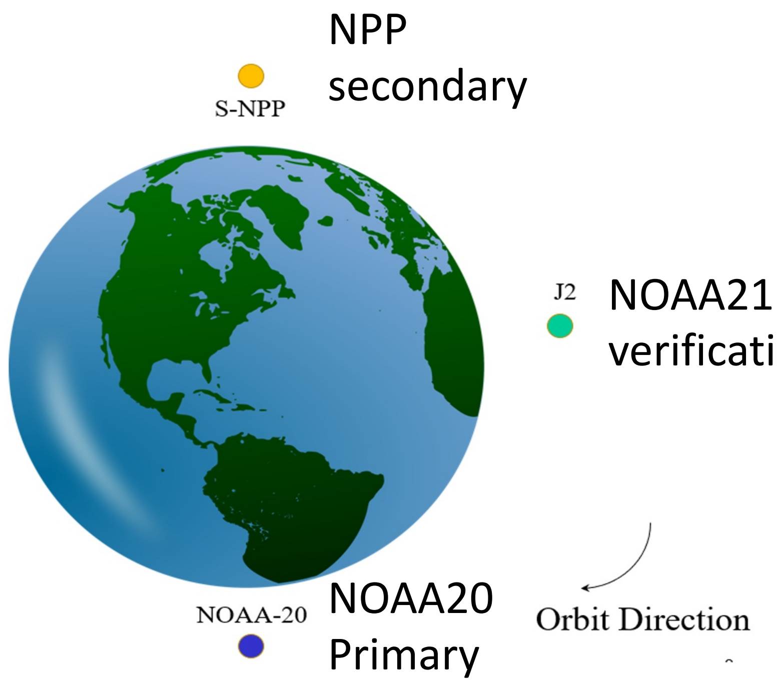


CERES STM Fall 2023, CERES instrument update, page 15

NOAA satellite orbit placement

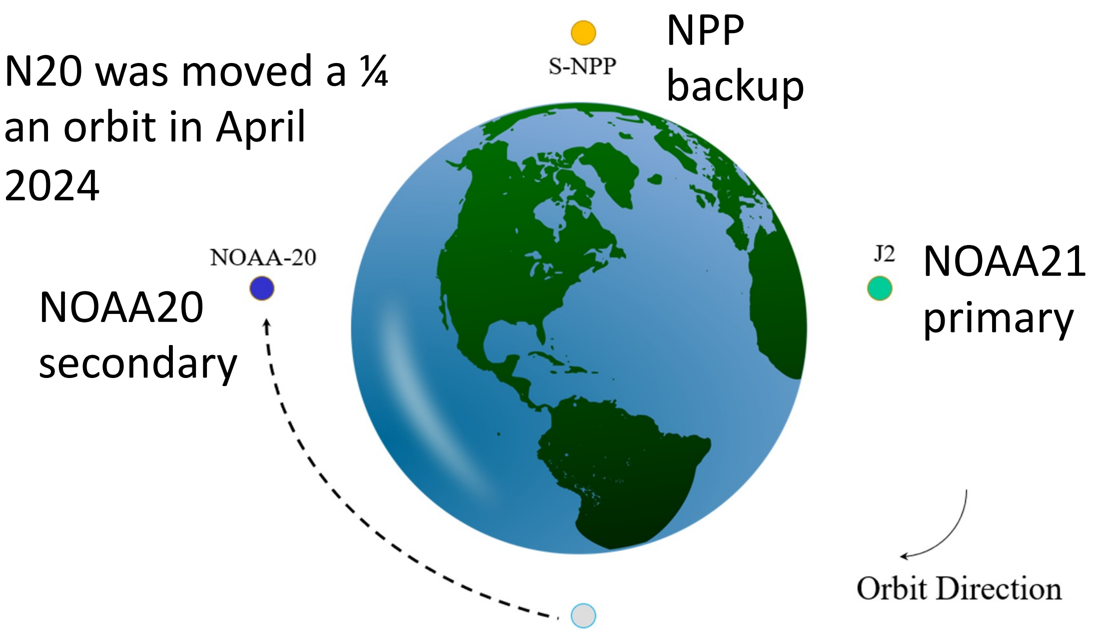
NOAA 3-satellite constellation prior to March 2024

Orbit time 101 minutes for 360°



NPP/N20 time difference is 50 minutes, no time matches

NOAA 3-satellite constellation post March 2024

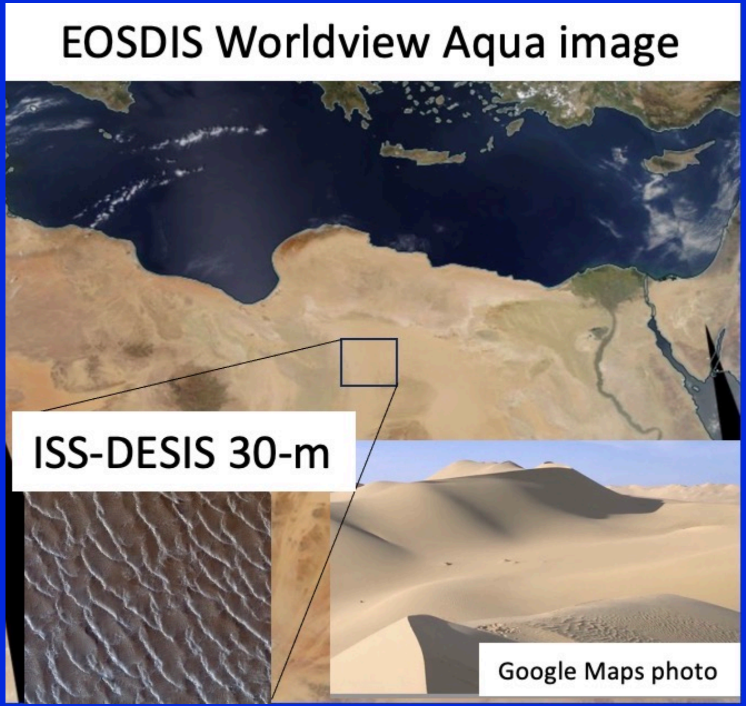


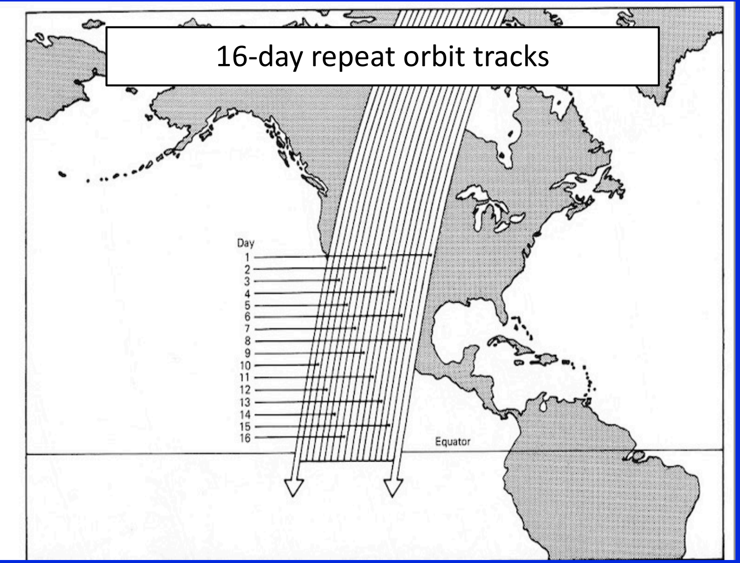
N21 (primary satellite) and N20 (secondary satellite) are a half orbit apart
NPP (backup satellite) is a quarter orbit apart

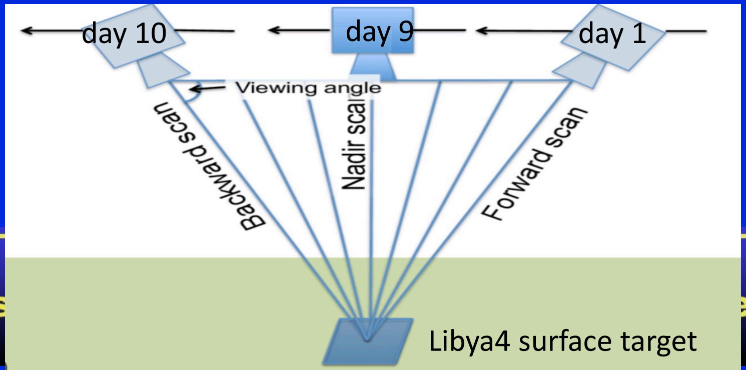
Libya4 invariant target

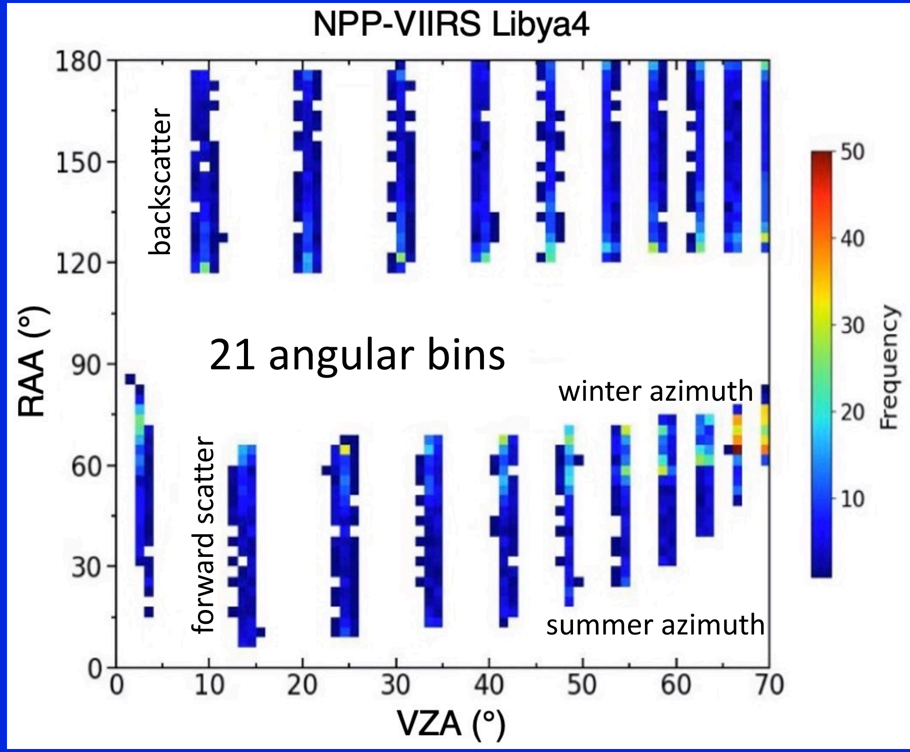
NPP-SW-channel → Libya4 surface → N20-SW-channel

- Libya4 (28°-29°North and 22° to 23° East) highly reflective sand dunes with no vegetation and little cloud cover
- Bin the CERES SW radiances into 16 repeat day angular bins
- Libya4 SZA range between 10° and 60° over the year





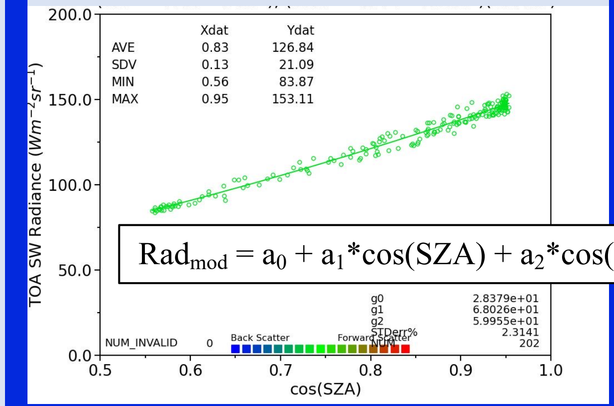




Libya-4 angular and atmospheric CERES Aqua SW reflectance characterization

Aqua-CERES SW radiance

(0°VZA<14° backscatter) angular model

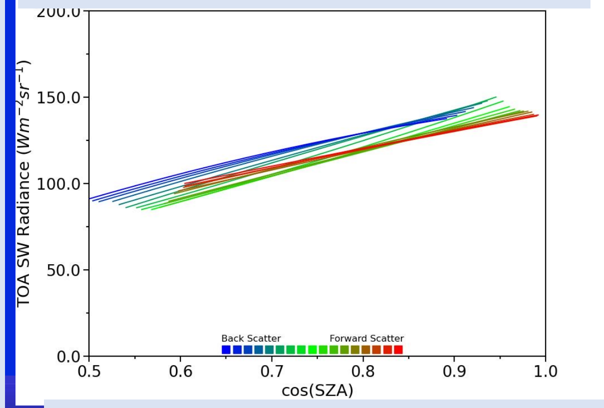


$Rad_{mod} = a_0 + a_1*\cos(SZA) + a_2*\cos(SZA)^2$

(0°VZA<14° backscatter) angular model

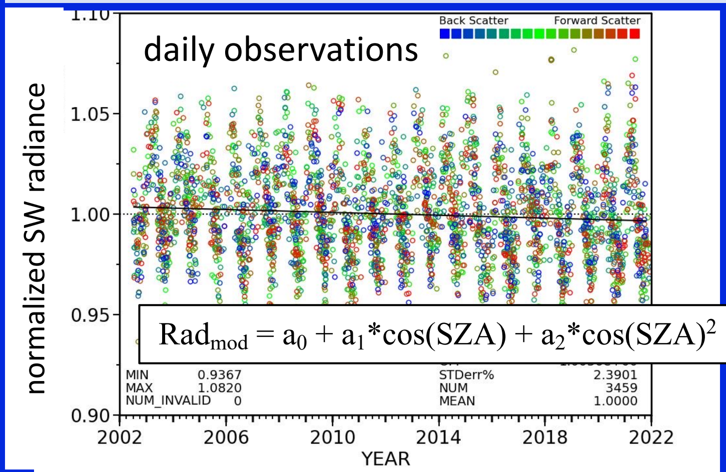
Aqua-CERES SW radiance

All angular models



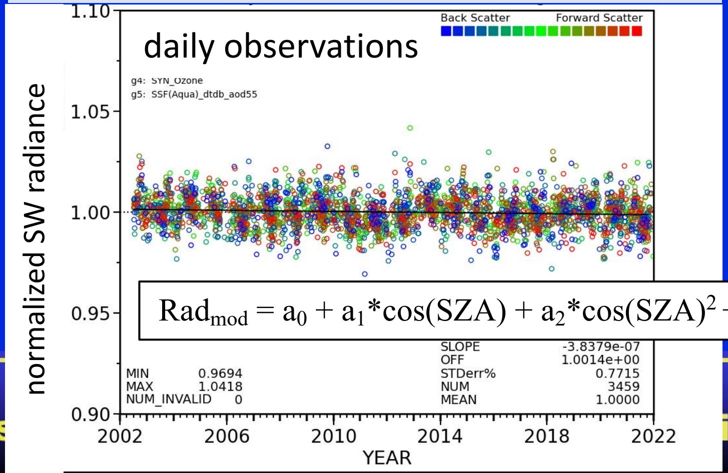
All angular models

SZA terms only



$Rad_{mod} = a_0 + a_1*\cos(SZA) + a_2*\cos(SZA)^2$

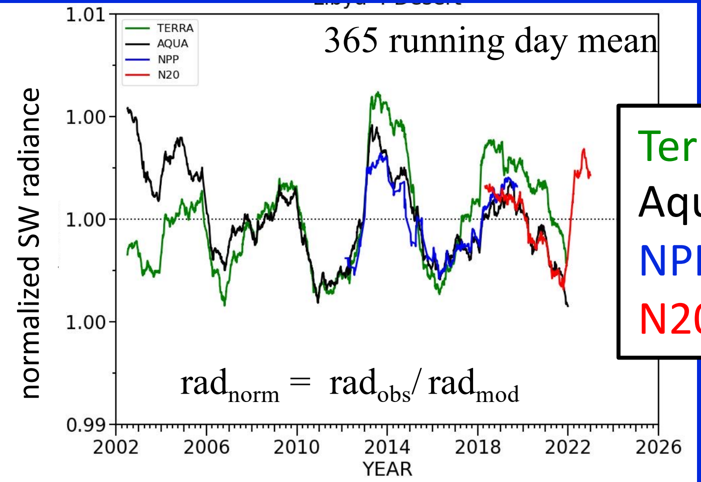
with atmospheric terms



$Rad_{mod} = a_0 + a_1*\cos(SZA) + a_2*\cos(SZA)^2 + a_3*PW + a_4*O3 + a_5*AOD$

Terra/Aqua/NPP/N20 relative ratios

Lbya-4 CERES radiance



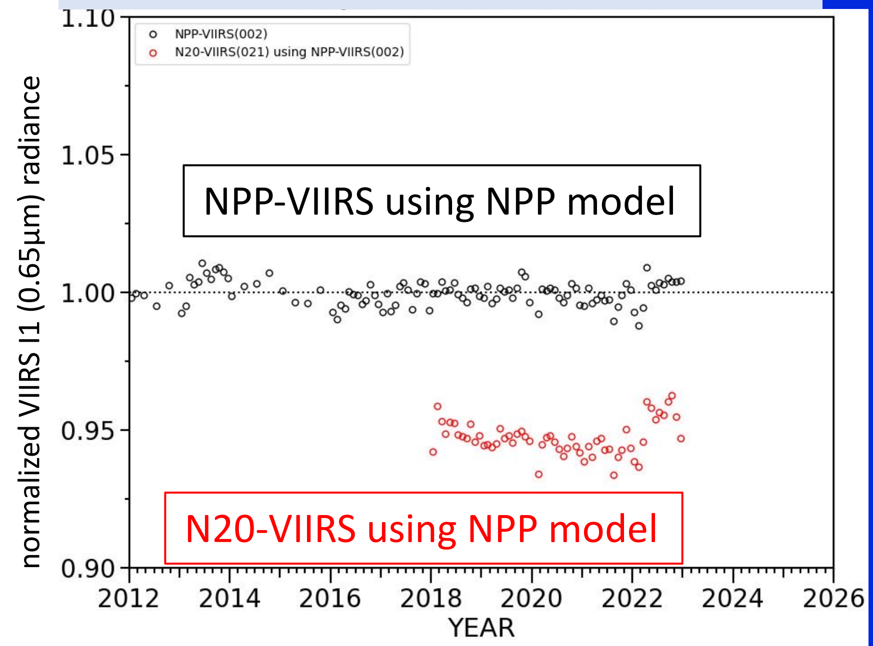
$rad_{norm} = rad_{obs} / rad_{mod}$

Terra
Aqua
NPP
N20

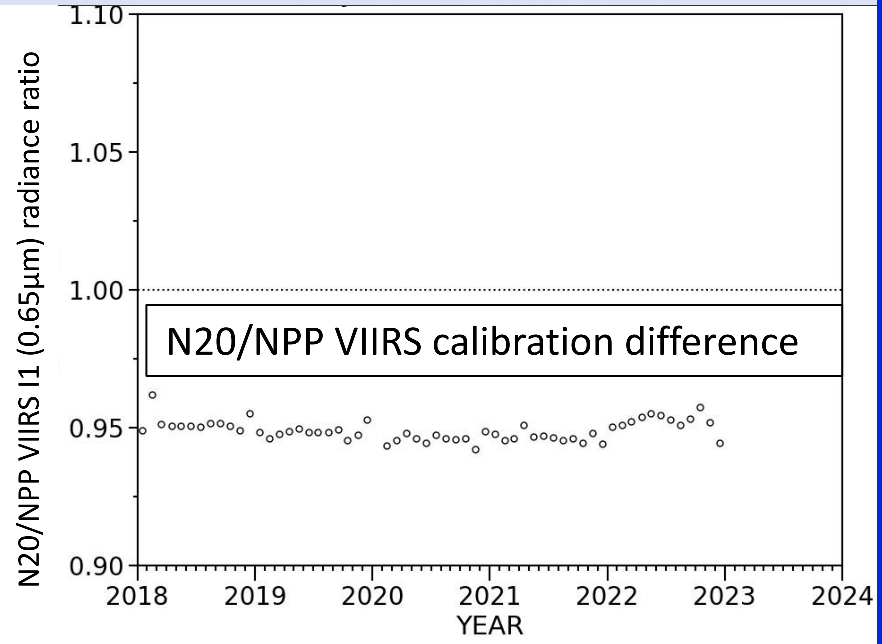
The CERES instrument ratios are temporally consistent suggesting excellent CERES onboard calibration

Libya-4 VIIRS normalized visible radiances

NPP and N20 VIIRS monthly radiances



N20/NPP VIIRS monthly radiance ratio



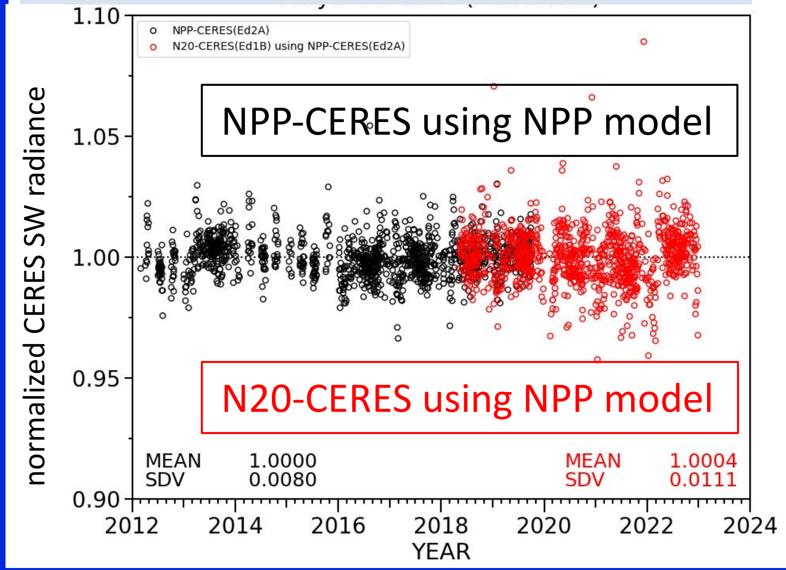
Band Pair	SNPP/N20		
	S/N	S/N	S/N
B8/M1	5.5	5.9–7.9	–
B3/M2	6.5	5.8–6.6	–
B3/M3	4.8	4.4–5.2	5.6 ± 0.2
B4/M4	5.5	3.4–5.5	5.8 ± 0.2
B1/M5	4.4	3.4–5.4	5.4 ± 0.2
B2/M7	3.8	2.5–4.0	4.2 ± 0.2
B5/M8	2.6	1.8–2.9	2.0 ± 0.2
B6/M10	2.2	1.2–2.9	2.5 ± 0.3
B7/M11	2.0	1.2–2.1	1.6 ± 0.5
B1/I1	4.0	3.0–4.8	4.8 ± 0.2
B2/I2	4.2	2.6–3.1	–
B6/I3	5.4	3.1–3.9	5.0 ± 0.3
	MAIAC	VCST	CERES-IGCG

lyapustin et al. 2023

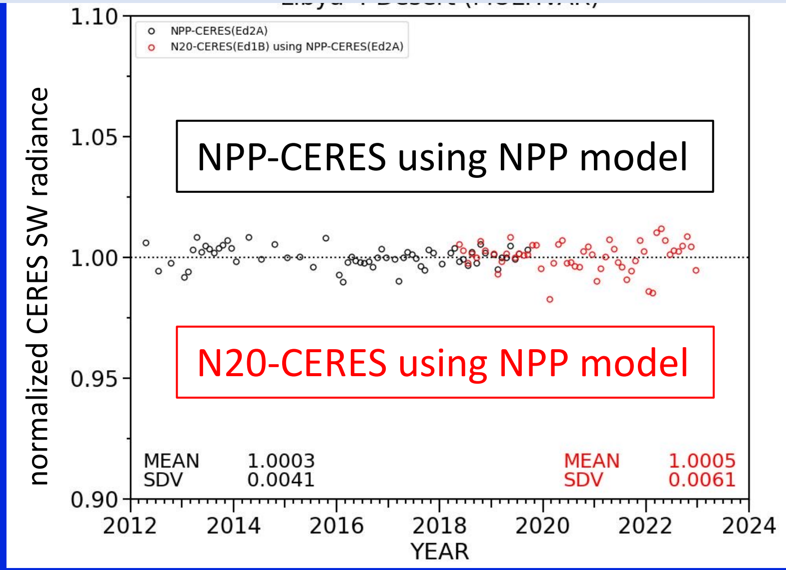
The Libya-4 invariant target N20/NPP ~ -5.0% is consistent with Lyapustin et al. 2023 results
Mostly based on NPP/Aqua and N20/Aqua comparisons

Libya-4 CERES SW normalized radiances

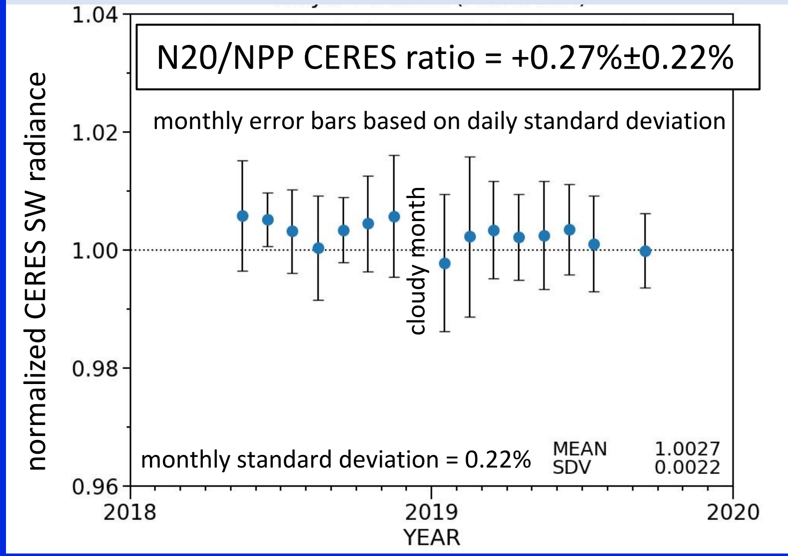
NPP and N20 CERES daily radiances



NPP and N20 CERES monthly radiances



N20/NPP CERES SW monthly radiance ratio



The N20 CERES SW channel is +0.3%±0.2% brighter than NPP CERES

DCC RAYMATCH

NPP-SW-channel → NPP-VIIRS → Himawari-8 → N20-VIIRS → N20-SW-channel

linearly regress NPP CERES footprint SW channel and NPP VIIRS I1 (0.65µm) radiances

linearly regress NPP VIIRS I1 (0.65µm) and Himawari-8 B3 (0.65µm) radiances

Himawari-8 transfers the NPP VIIRS calibration to N20 VIIRS

linearly regress NPP VIIRS I1 (0.65µm) and Himawari-8 B3 (0.65µm) radiances

linearly regress N20 CERES footprint SW channel and N20 VIIRS I1 (0.65µm) radiances

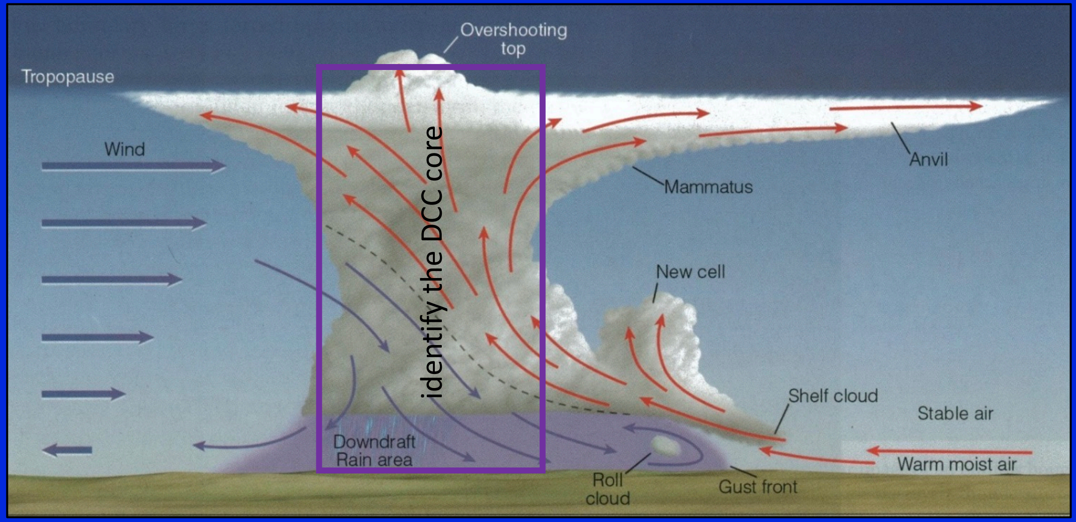
- Use Tropical Western Pacific (TWP) domain Deep Convective Cloud (DCC) targets
- DCC are the most Lambertian, brightest, near overhead sun, TOA, spectrally flat (<1µm) Earth targets
- Easily identifiable by cold brightness temperatures
- Most of the DCC are located in the TWP over the Himawari-8 domain
- The DCC reflectance is a function of domain, month, diurnal, BT threshold

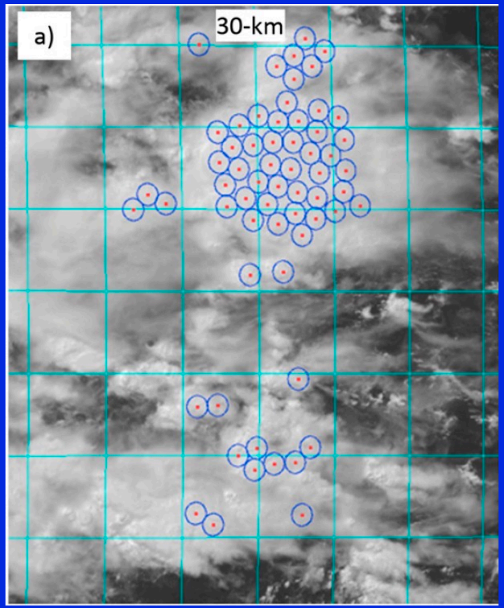
DCC Identification

DCC SSF L2 24-km footprints
SZA<40°
VZA<40°
10°<RAA<170
11µm BT<220K
30°N to 30°S
100°E to 180°E

DCC VIIRS/Him8 30-km footprints
SZA<40°
VZA<40°
10°<RAA<170
11µm BT<220K
30°N to 30°S
100°E to 180°E

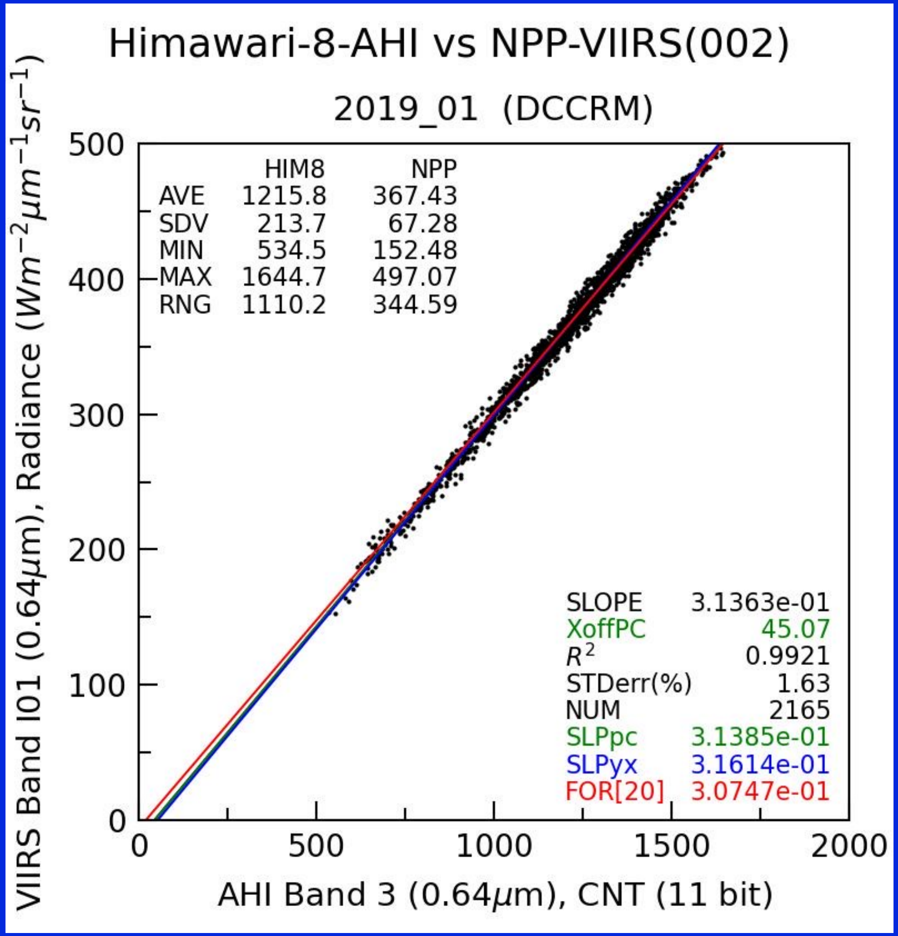
The DCC identification must be consistent for both CERES/VIIRS and VIIRS/Him8

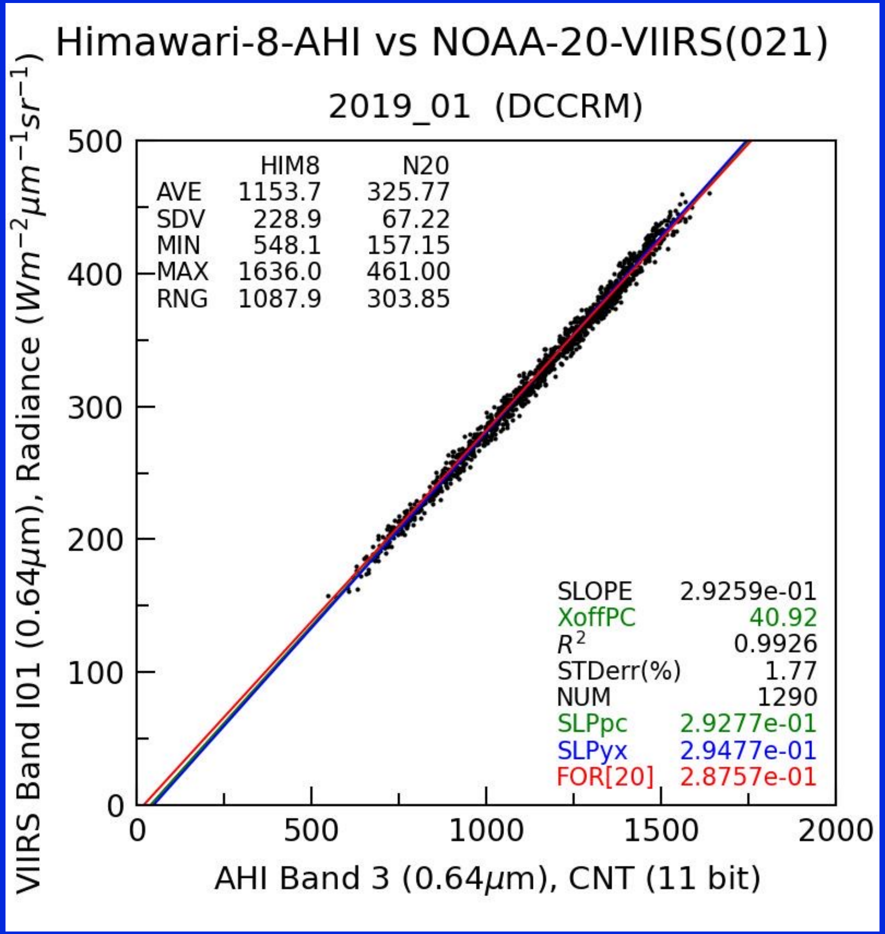




- 30-km DCC cells are identified by finding the coldest temperature and averaging the pixel reflectances within a 15-km radius – the DCC cell temperature < 220K
- repeat the process till all pixels <220K have been isolated

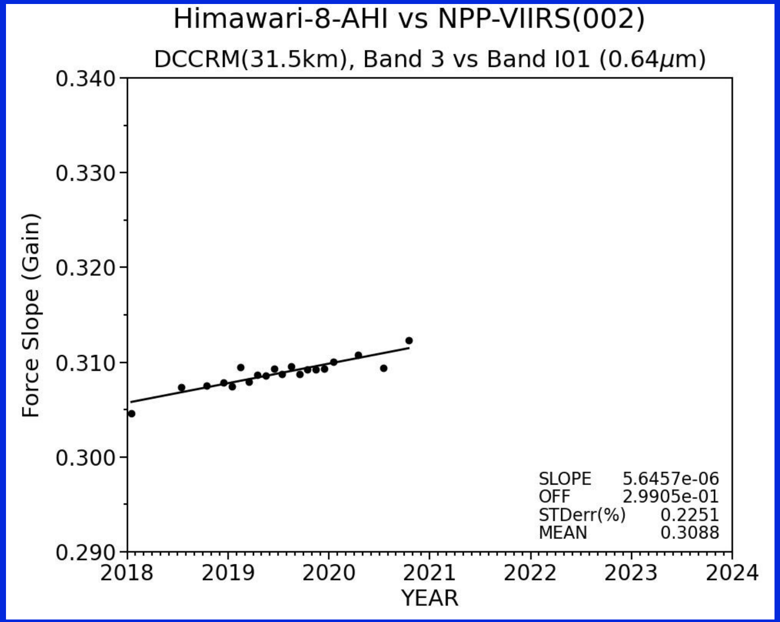
VIIRS/Him-8 DCC radiance pair scatter plots

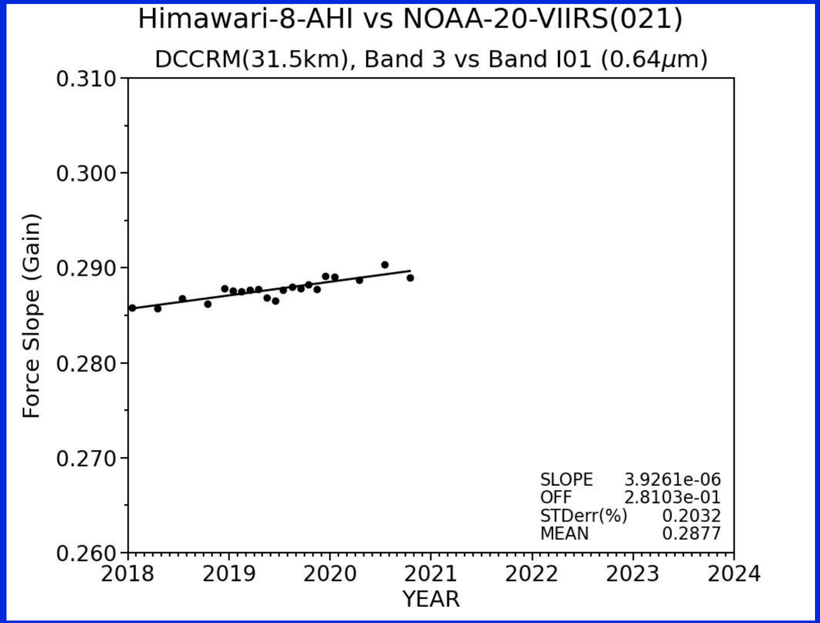


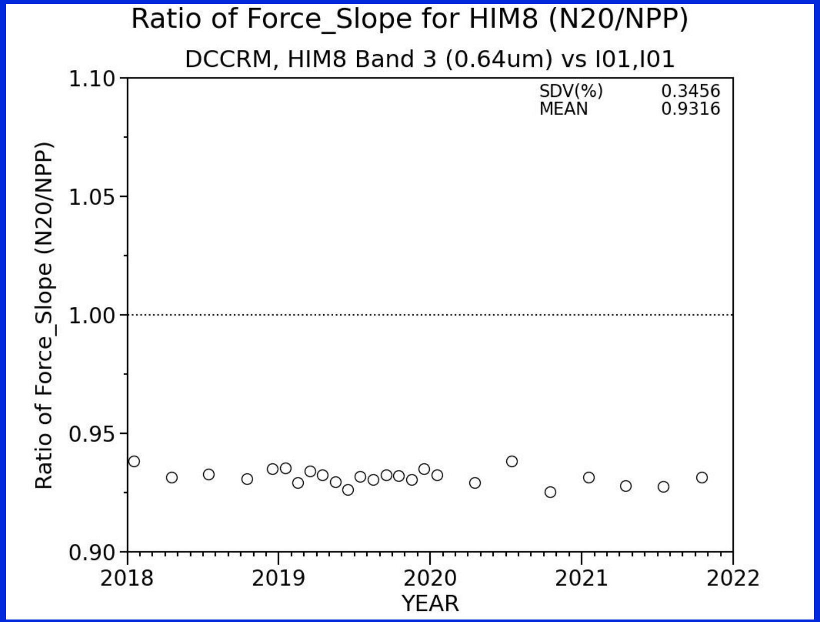


N20/NPP VIIRS I1 (0.65µm) relative ratio 0.28757/0.30747 = 0.935 or -6.5%

Normalized NPP and N20 VIIRS I1 (0.65µm) radiances



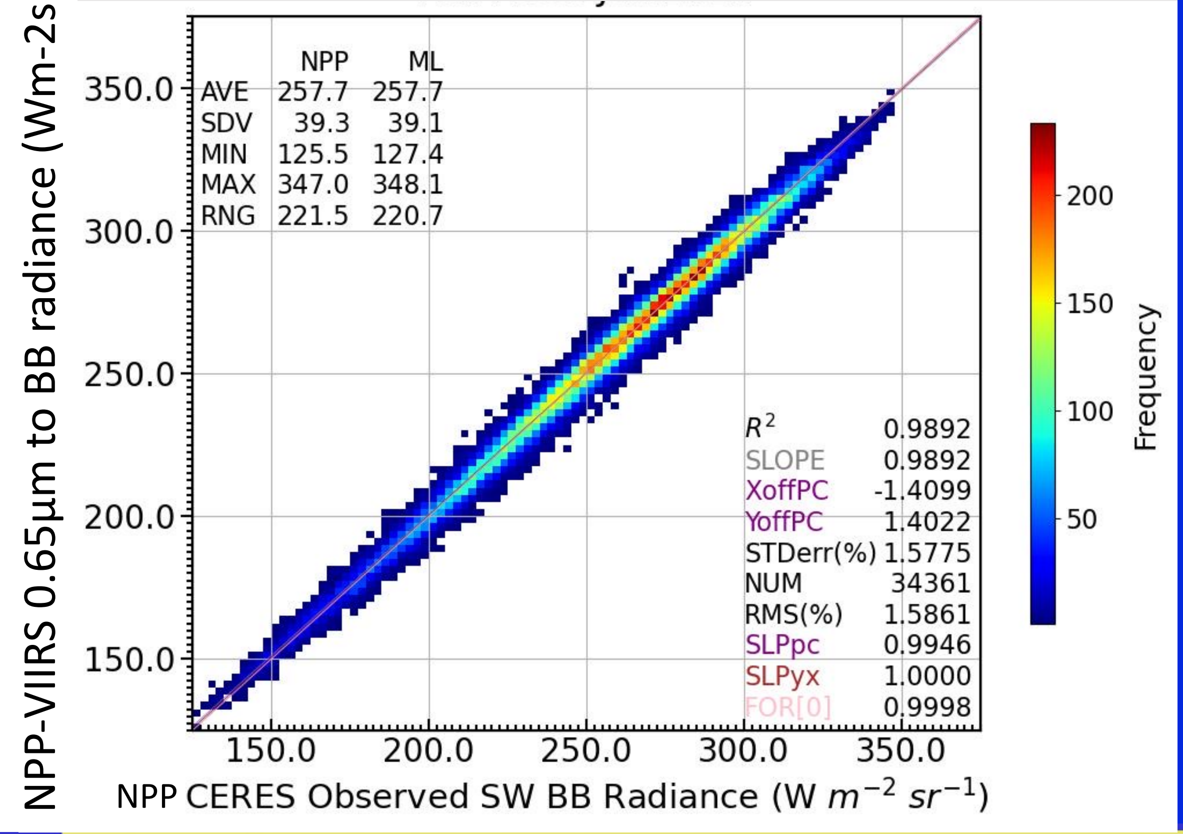




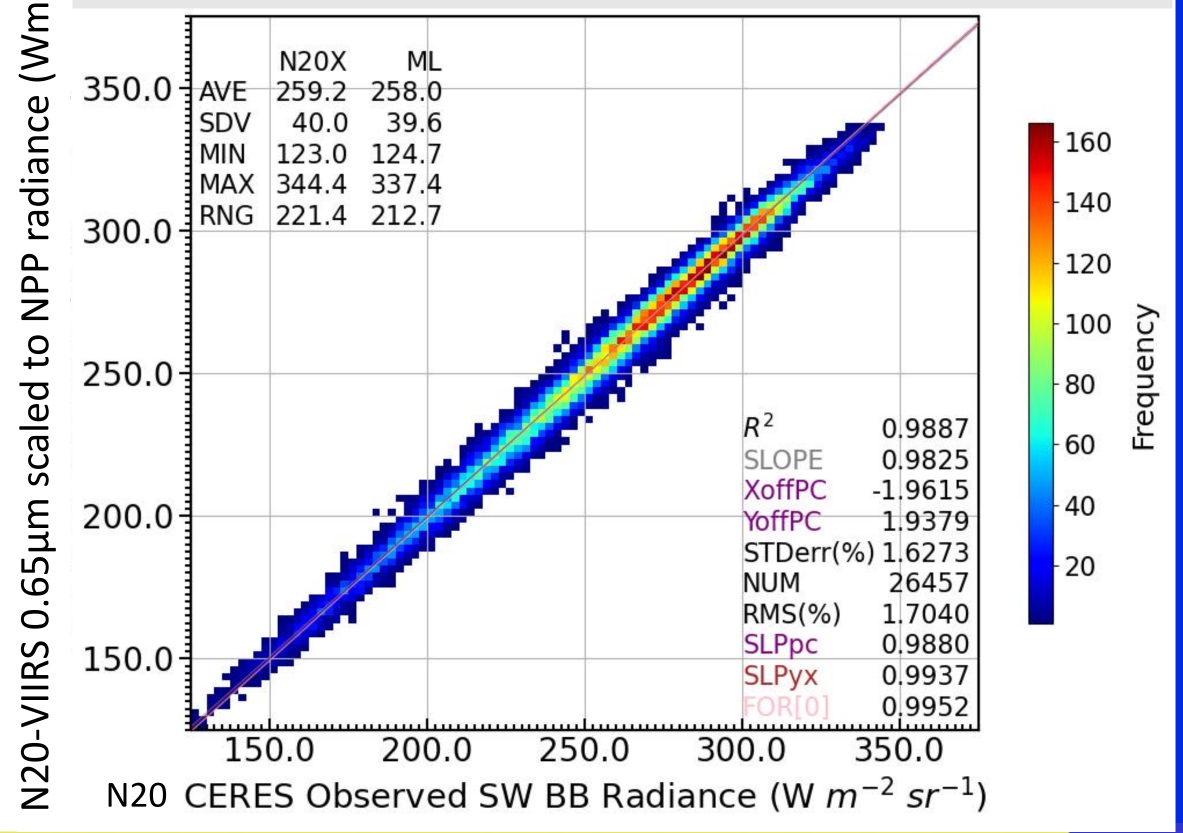
N20/NPP VIIRS I1 (0.65µm) relative ratio -6.84%±0.35%

DCC CERES/VIIRS SW radiance pair scatter plots

NPP-VIIRS I1 (0.65µm) linear regression with NPP-CERES SW channel, Jan 2019

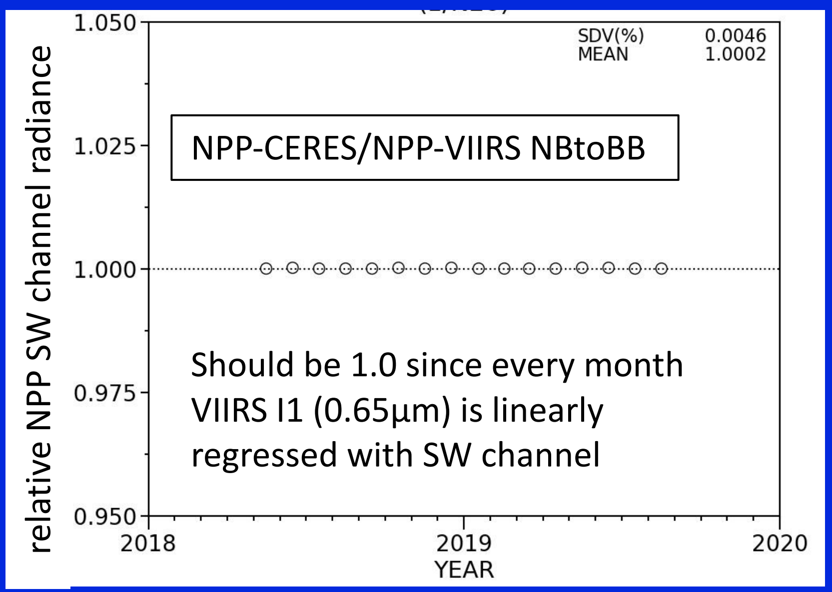


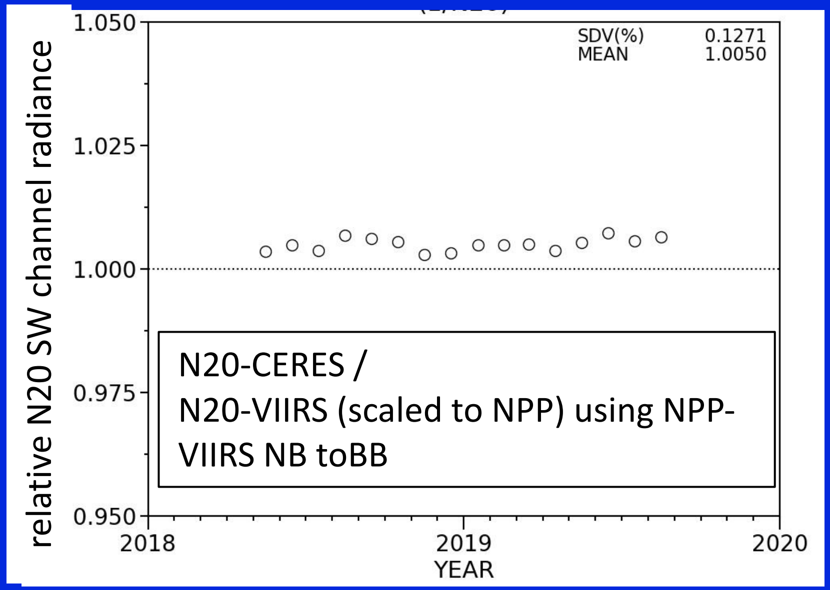
N20-VIIRS I1 (0.65µm) scaled to NPP-VIIRS using NPP-VIIRS to CERES linear regression coefficients compared with N20 SW radiance, Jan 2019

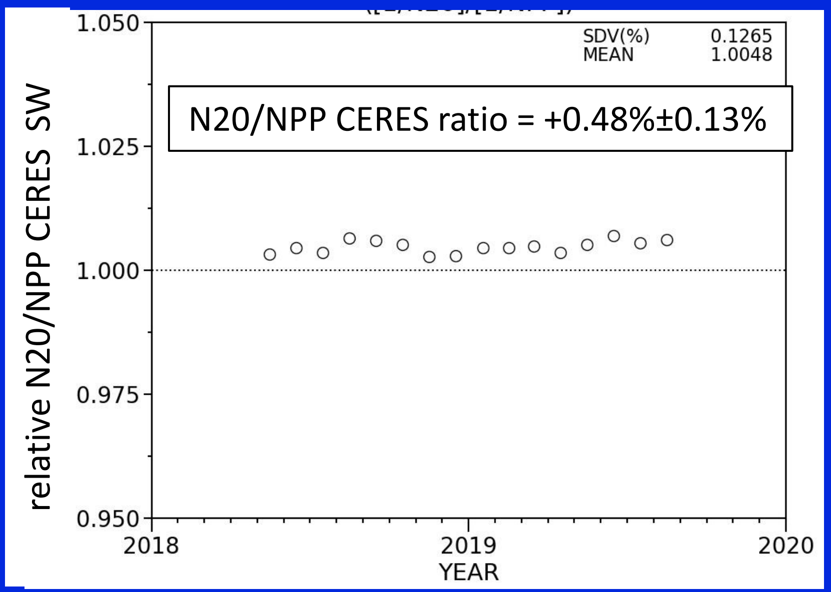


N20/NPP SW channel relative ratio 1.0/(0.9952/0.9998) = 1.0046

DCC normalized NPP and N20 CERES SW radiances





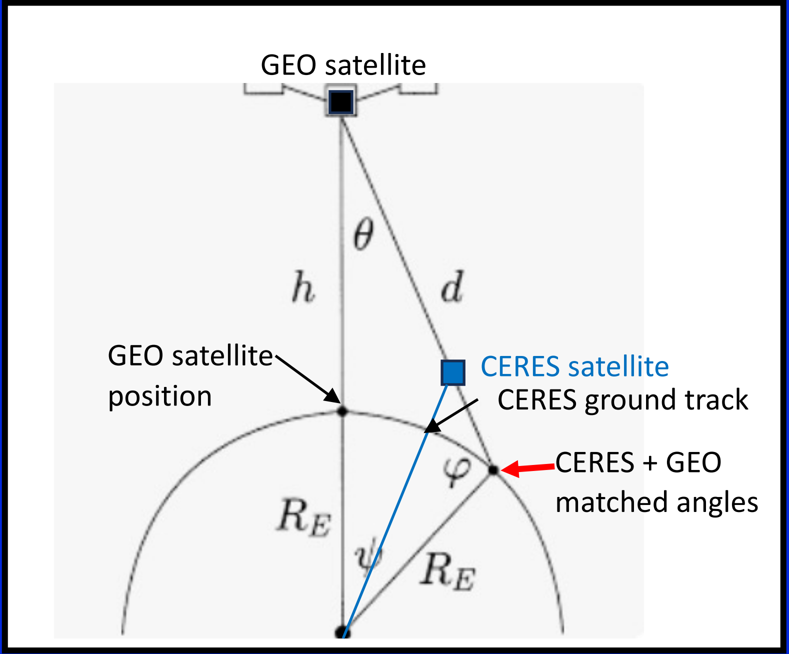


DCC ray-matching: N20 CERES SW channel is +0.5%±0.1% brighter than NPP CERES
Libya4 invariant target: N20 CERES SW channel is +0.3%±0.2% brighter than NPP CERES

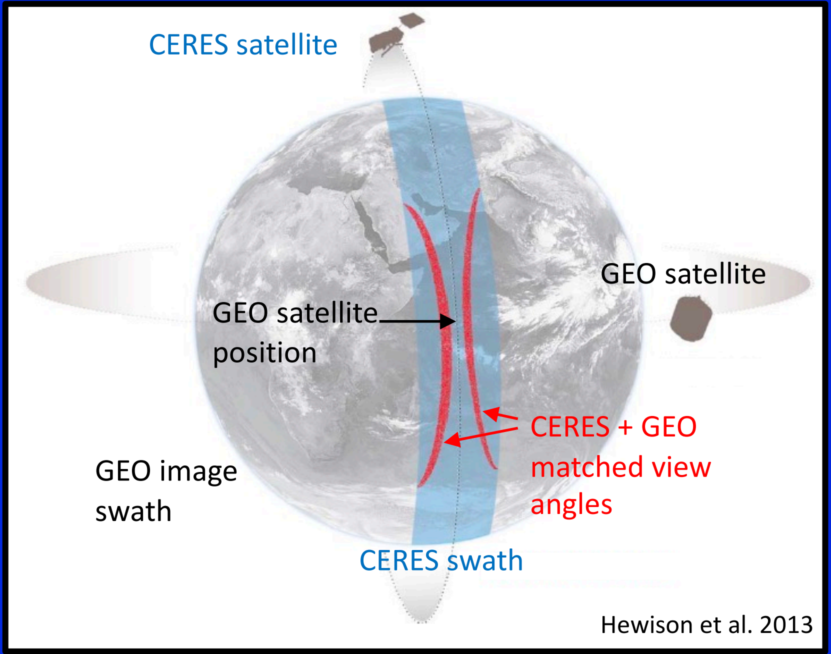
GEO scan

NPP-SW-channel → GEO NB to BB radiances → N20-SW-channel

CERES and GEO viewing geometry



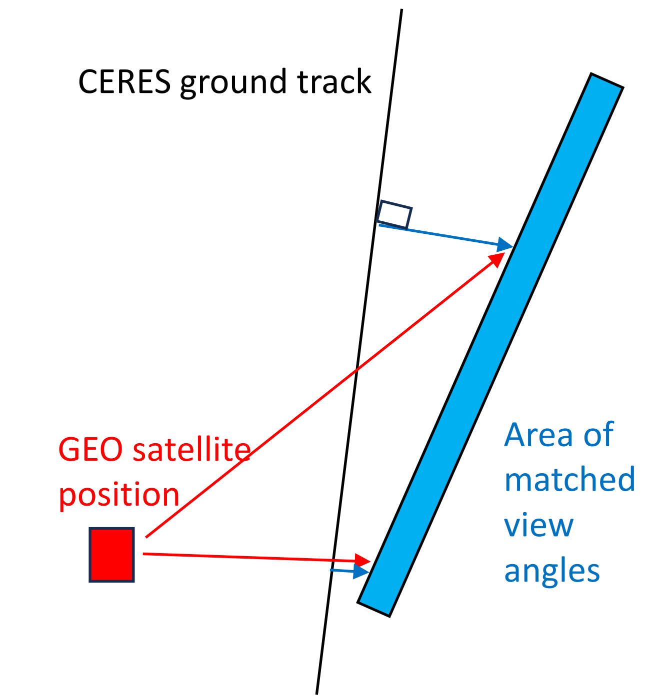
Vertical view



spatial view

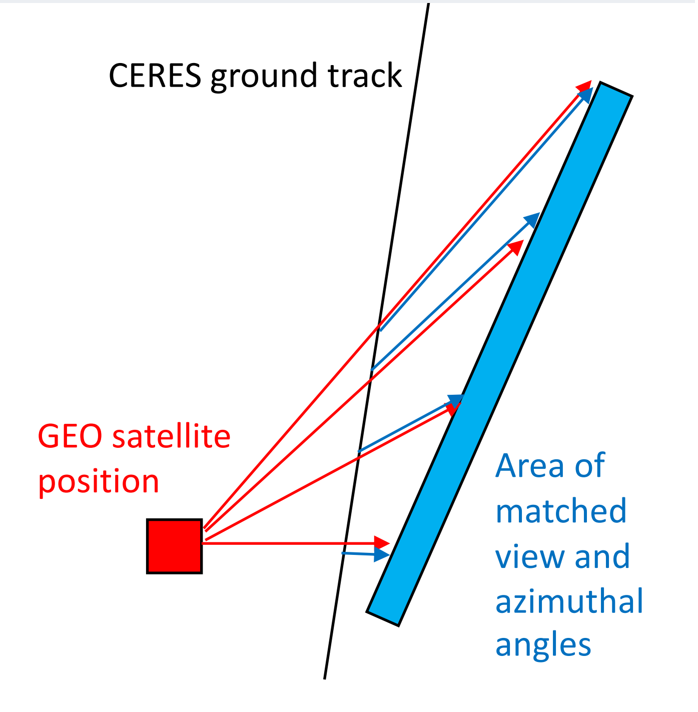
GEO scan

CERES in cross track scan mode



GEO and CERES only matched in VZA in blue region

CERES in GEO scan mode

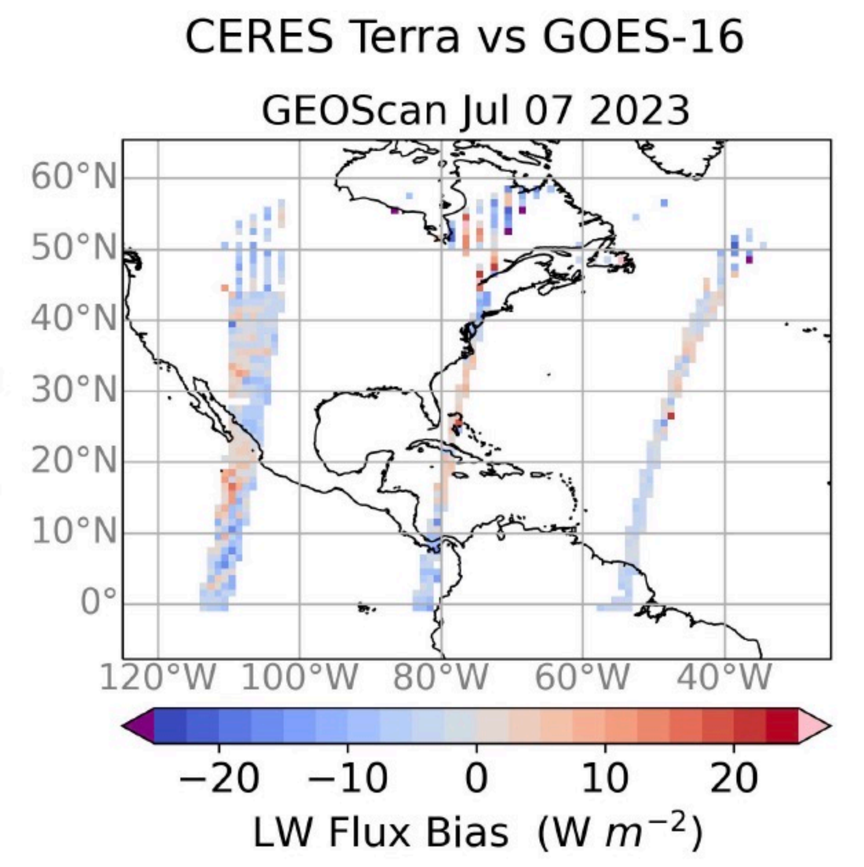


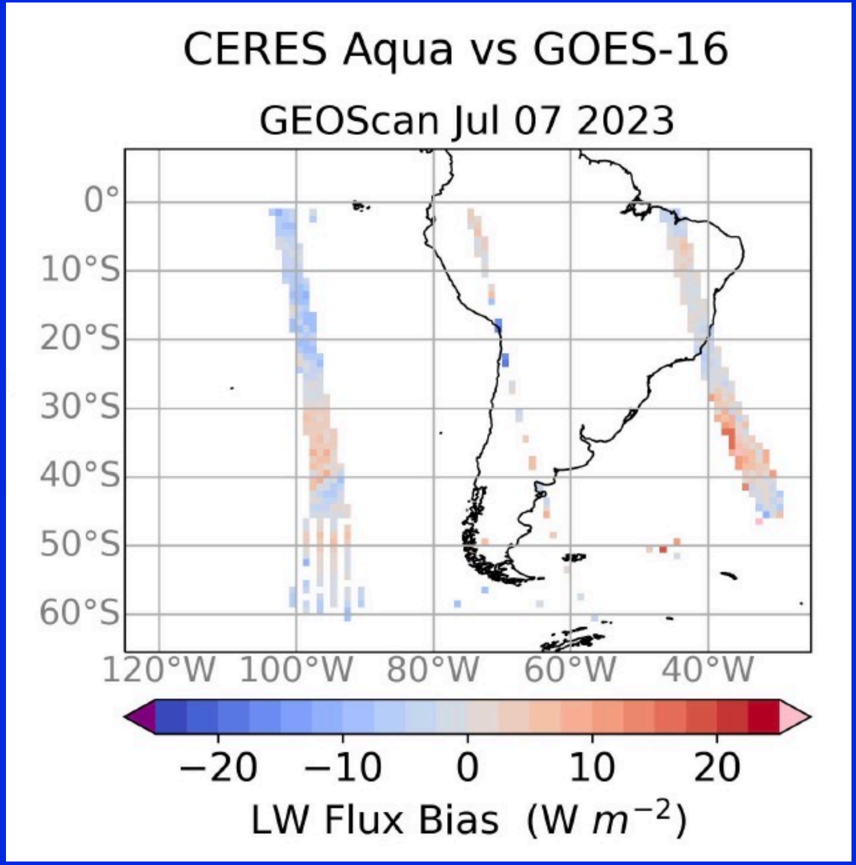
GEO and LEO matched in VZA, SZA and RAA over all locations in blue region

GEO scan July 7, 2023, preliminary study

- Terra FM1 and Aqua FM3 are in GEO scan mode for one GEO domain every 7 days during July 2023 – started Feb. 2023
  - To avoid scanning in the RAM direction or in the path of the satellite forward motion, Terra (ascending orbit) GEO scan are in the Northern Hemisphere, whereas Aqua (descending orbit) are in the Southern hemisphere
- At the Equator the mean local time for Terra is 10:30AM, whereas the Aqua is 1:30PM or a 3-hour time difference
  - The calibration of the GOES-16 imager should not change in 3-hours
- Apply GOES-16 window and water vapor channel to broadband LW flux conversion
  - NB to BB based onEd4 SYN1deg LW empirical coefficients
- Linearly regress the GOES-16 LW fluxes with the CERES LW fluxes over the GEOscan time and angle matched domain.
  - The GOES-16 scans a full disc image every 10 minutes, ensuring that the GOES and CERES angle matches are within 5 minutes

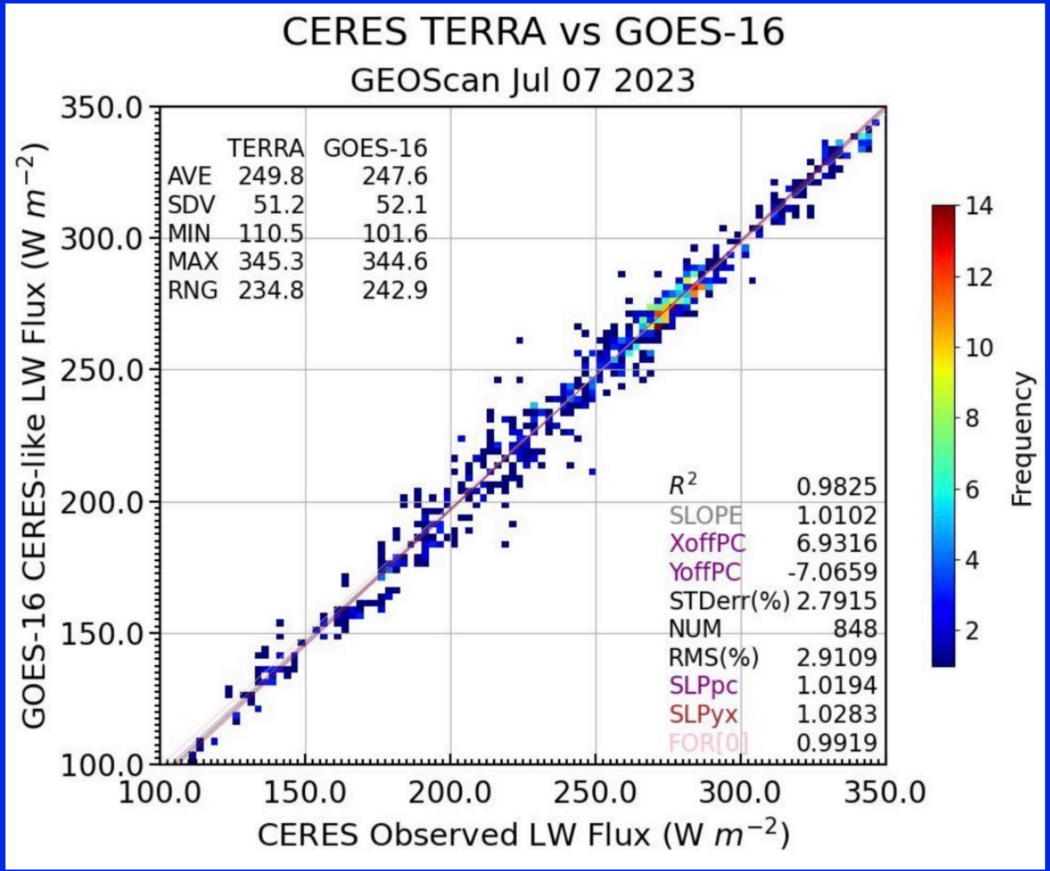
GEO scan July 7, 2023, preliminary study

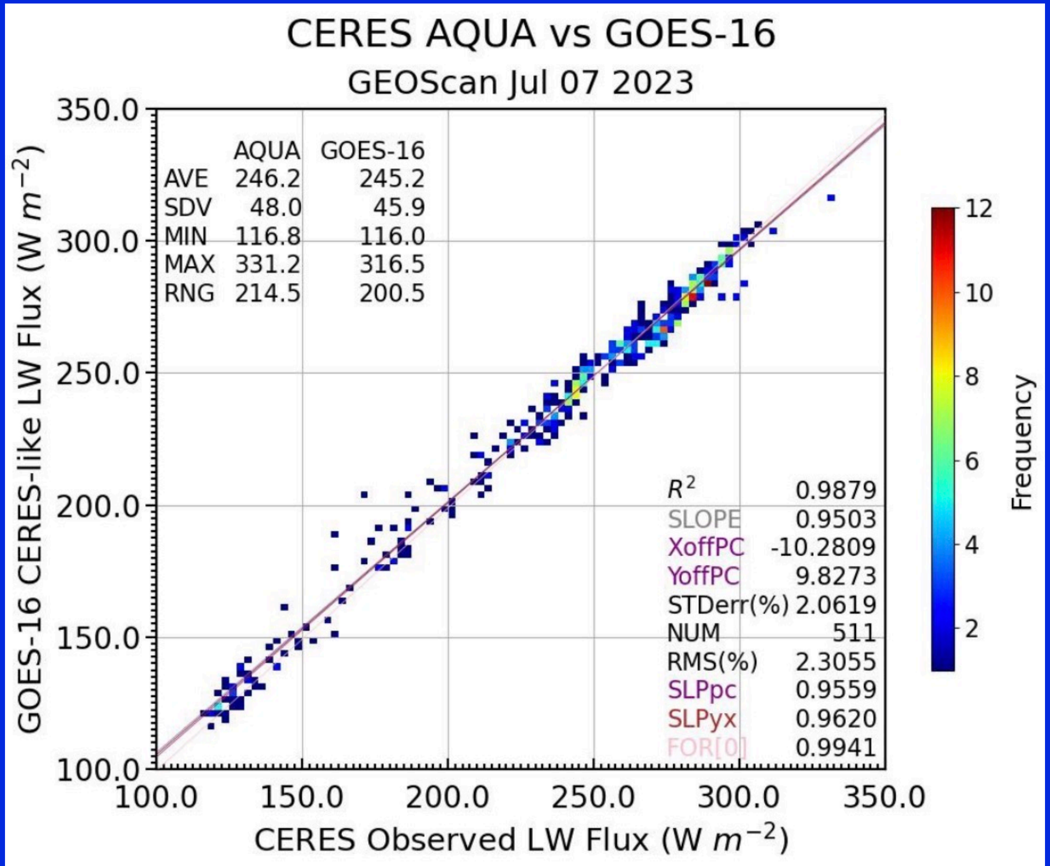




- Will be working with LW and SW radiances in future studies

GEO scan July 7, 2023, preliminary study



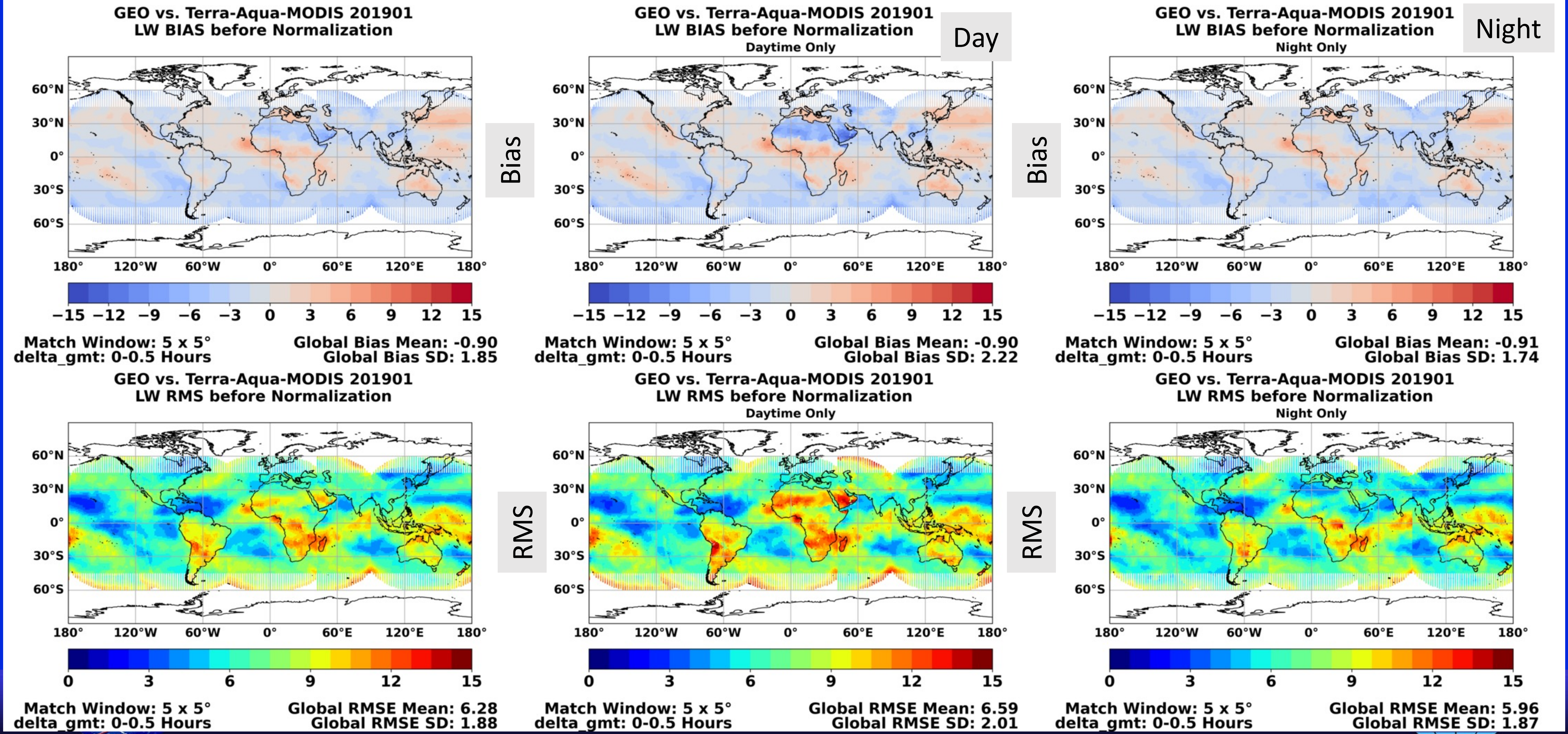


- The relative CERES LW channel linear regressions (that go through the origin) are within 0.2%

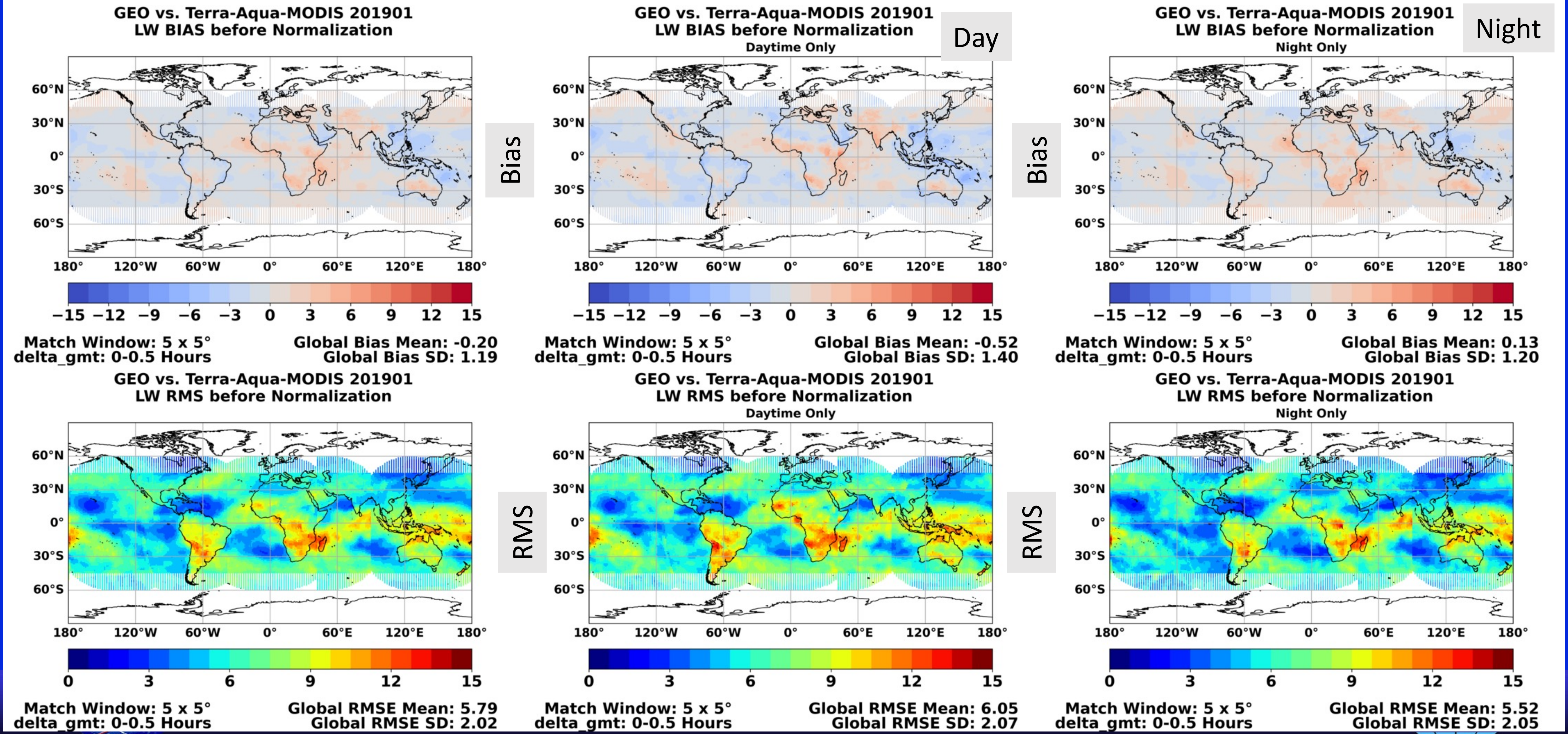
GEO narrowband to broadband LW SYN1deg fluxes

- Ed4 GEO narrowband to broadband LW SYN1deg fluxes are based on empirical multi-linear window and water vapor channel radiances
  - Determine MODIS window and water vapor channel to LW flux coefficients using Aqua SSF L2 footprints
  - Linearly regress the MODIS and GEO window and water vapor channels to radiometrically scale the GEO channel radiances to MODIS
- Ed5 GEO narrowband to broadband LW SYN1deg fluxes are based on machine learning WN, WV, VZA, PW, surface type, lat, lon inputs
  - Trained with SSF Terra and Aqua 2003, 2005, 2010, 2014, 2018, 2022
- Compare during January 2019 using coincident within 30-minute Terra and Aqua time matched fluxes

SYN1deg Ed4 Terra+Aqua January 2019



SYN1deg Ed5 Terra+Aqua January 2019



January 2019 GEO LW flux comparison

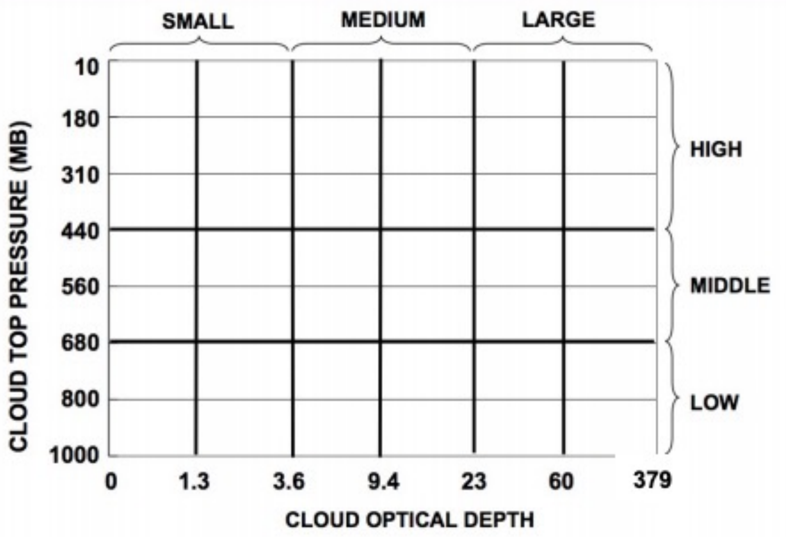
dataset		BIAS			RMSE	
	All	**Day**	**Nit**	**All**	**Day**	**Nit**
Ed4	-0.90	-0.90	-0.91	6.28	6.59	5.96
Ed5 ML	-0.20	-0.52	0.13	5.79	6.05	5.52

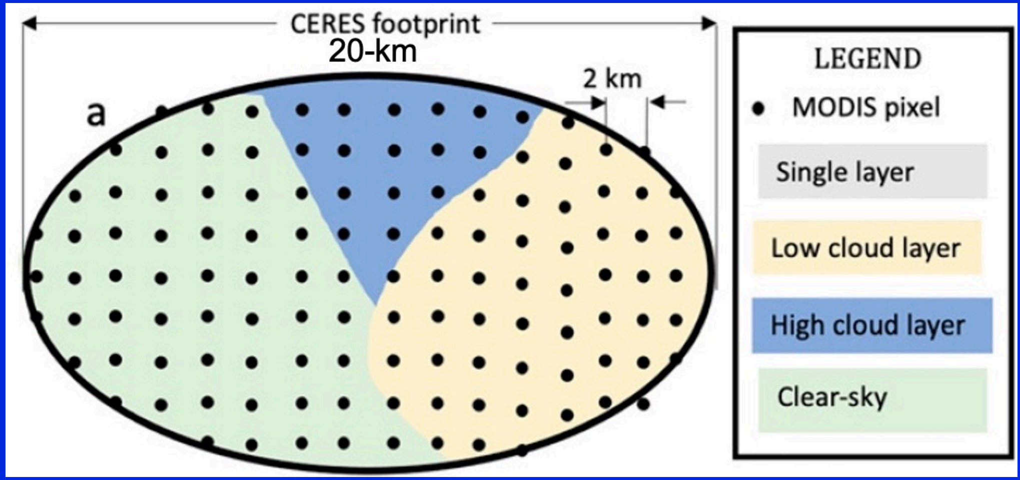
- ML reduced the monthly bias from -0.9 Wm-2 to -0.2 Wm-2
- ML Reduced the monthly regional bias standard deviation from 1.9 Wm-2 to 1.2 Wm-2, by ~40%
- ML reduced the the regional RMS error from 6.3 Wm-2 to 5.8 Wm-2, by 9%
- ML mitigated the GEO large VZA RMS error
- ML mitigated the GEO large Saharan desert bias

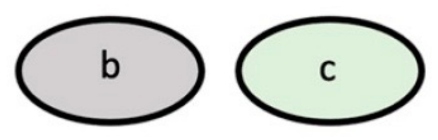
FBCT (FluxByCldTyp) product

- Terra+Aqua gridded daily and monthly averaged daytime (SZA<82, no nighttime or twilight) fluxes stratified by cloud top pressure and optical depth
- Compute BB fluxes for each of the 42 Pc-Tau cloud type bins
  - Compute BB fluxes for each sub-footprint area from empirical NB to BB coefficients based on single scene Pc-Tau and clear-sky CERES footprints
  - Normalize the computed BB flux to the CERES observed flux at the footprint level

42 Pc-Tau cloud type bins







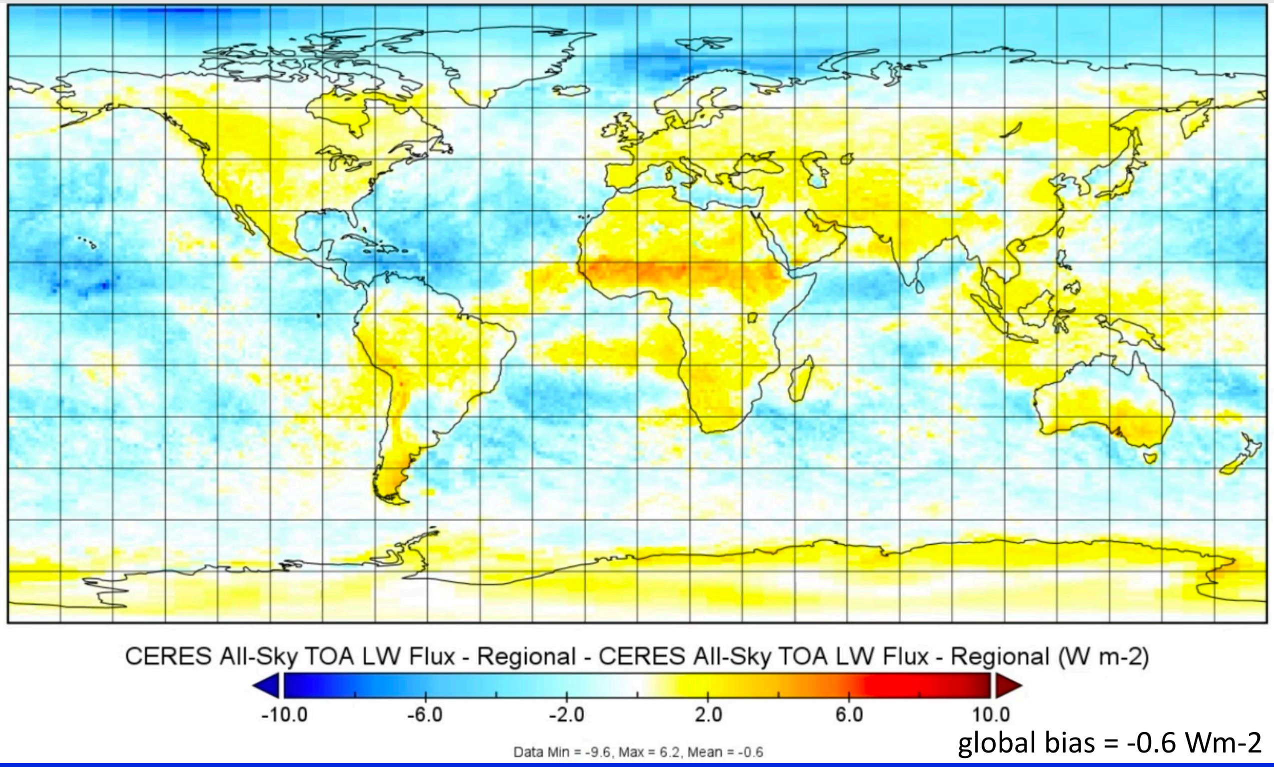
single scene footprints

FBCT Machine learning NB to BB for Ed5

- Machine Learning inputs:
  - 5 imager bands3 0.48μm, 0.65μm, 0.86μm, 11μm, 12μm
  - 3 Angles: solar zenith, viewing zenith, relative azimuth angle
  - Longitude and latitude
  - 7 surface types, ocean, forest, Savannas, Grass, dark desert, bright desert , snow
  - precipitable water (PW) and skin temperature (Tskin)
- Training dataset 2019 to 2023, single scene N20 SSF footprints
  - 5 hidden layers with 100, 50, 30, 20 , 10 neurons, respectively
  - Compute for each of the 42 PC Tau and clear-sky bin
- Validate by substituting the VIIRS FBCT (not normalized) flux into the SSF-N20 L2 product
  - Compare the SSF1deg-FBCT and the SSF1deg-CERES product monthly means
  - Also derive the FBCT ML coefficients at night (FBCT is a daytime product)

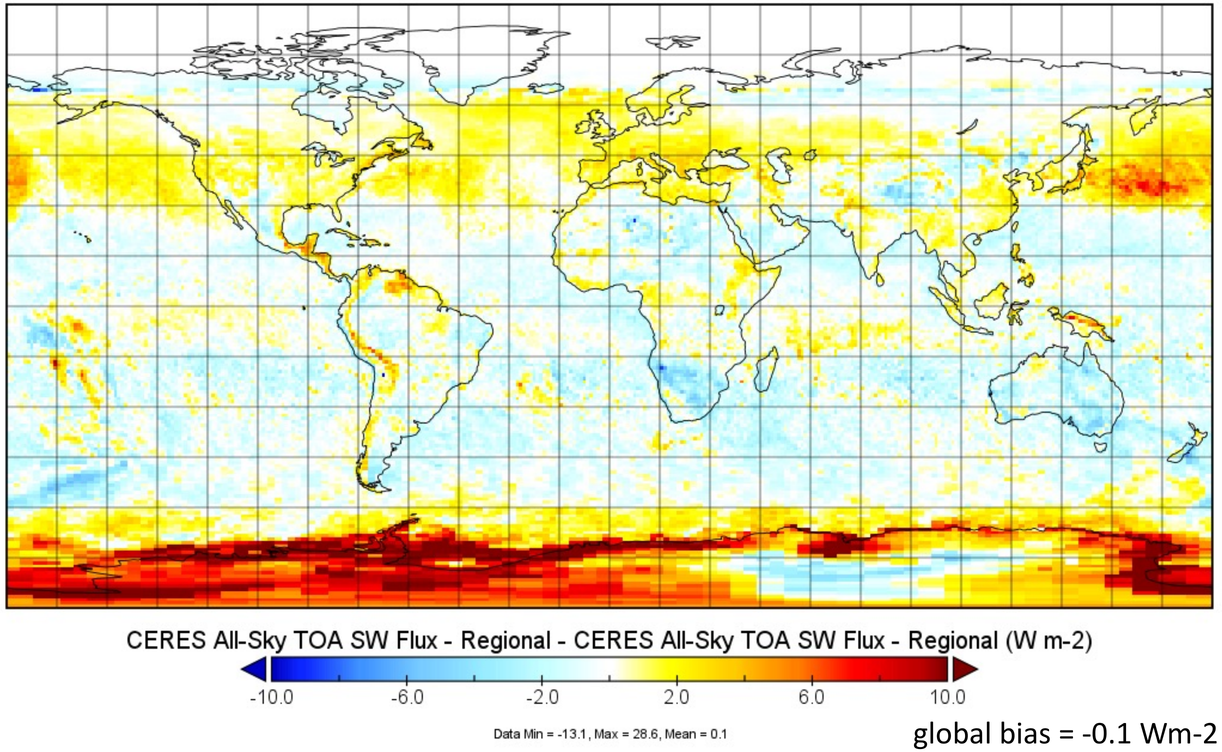
SSF1deg N20 FBCT minus CERES Ed4, Jan 2019

LW flux



global bias = -0.6 Wm-2

SW flux



global bias = -0.1 Wm-2

Some of the FSNrad granules were not available over the Sahel and South of Hawaii, developing 3-channel FBCT narrowband to broadband based on VIIRS-only

Ed5 Framework Concept

Possible Ed5 and validation Scientific Algorithms

Code Review

Developer implementation of existing framework

modular product , input and, validation routine library

GITHUB repository

algorithm and input testing/comparison branch

product debug branch

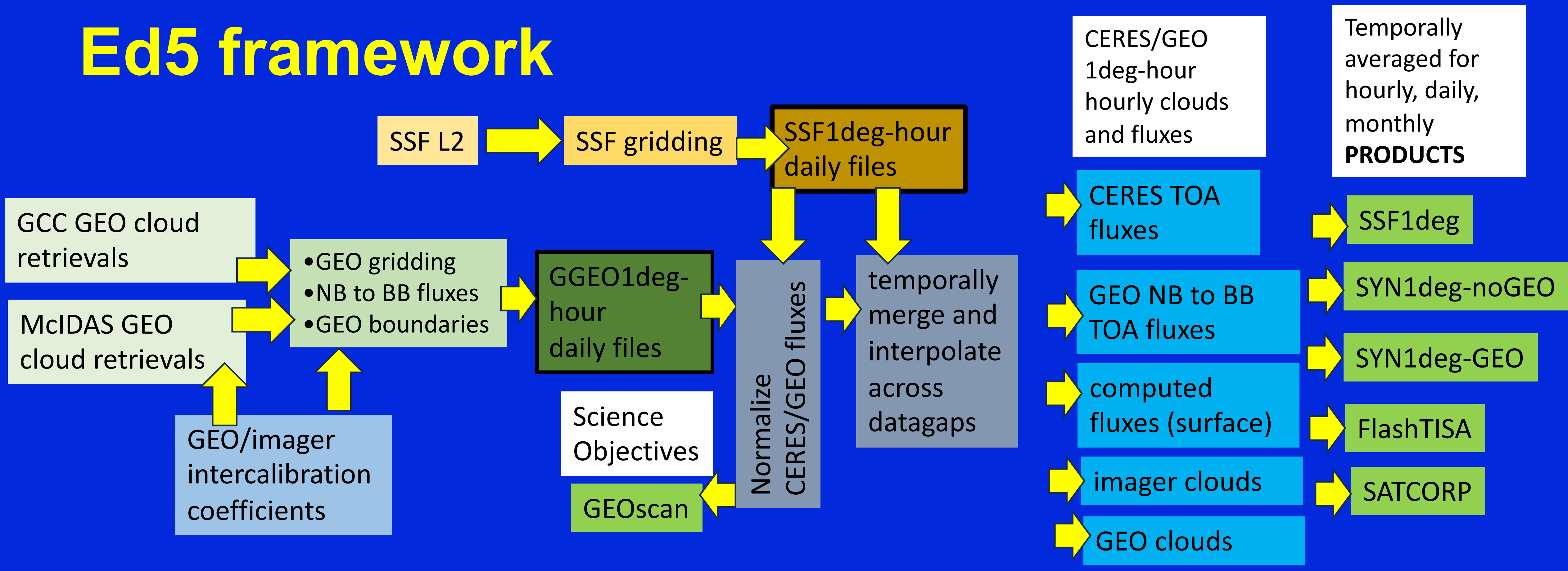
product delivery branch

JSON files set the processing parameters, approaches, inputs, validation approaches

- Version Control
- Module documentation
- traceability
- reproducibility
- interoperability

- Eliminate single point failures
- All scientists and developers can make modular improvements without having knowledge of the complete code
- Continuous improvement possible

Ed5 framework



Resolution
spatial 0.5°, 1.0°
4 cld layers
3x3 pc-tau

Atmosphere
GEOS 5.4.1
Merra2

Aerosols
MATCH
deep blue
dark target

Surface Type
IGBP
snow/ice
emissivity
albedo history map
ADM types

Fu-liou
Gamma – 4layer
3x3 cld types
# of streams
aerosol LWC profile flag

TISA coding achievements

- CRS1deg Ed4 delivered and promoted using the Ed5 framework
- SSF1deg-hour Ed5 Alpha-1 processed for July 2008 using Ed5 framework
- Integrated the FBCT NB to BB module into the SSF1deg-hour product
- SSF1deg-hour Ed5 converted to Ed4 zonal binary files to facilitate comparisons with Ed4 SSF1deg-day/month
- Facilitated FlashFLUX real-time gridded cloud inputs using the Ed5 framework
  - Used JSON files, self described netCDF files, and generic netCDF read modules to transfer the parameters, spatial resolution, cloud types, etc.
  - Worked with CWG for the GCC cloud property spatial gridding module
  - Worked on gridding the CERES GEO pixel level cloud properties and incorporated GEO calibration and narrowband to broadband modules
  - Temporally merged the GGEO1deg-hour and SSF1deg-hour and interpolated the GEO and imager clouds across datagaps
  - Worked with FlashFLUX to integrate the imager and GEO clouds into the existing computed surface flux Fu-Liou algorithm

TISA Ed5 goals

- Implementing the TISA Ed5 framework
  - Use flashFLUX implementation to test the new framework
- Science
  - Improved imager stability and MODIS/VIIRS radiometric scaling
  - Improved SYN1deg imager/GEO radiometric scaling
  - Improved SYN1deg GEO narrowband to broadband relationships
  - Improved FBCT imager narrowband to broadband relationships
  - Improved SYN1deg GEO and CERES flux normalization

BACKUP slides