TISA Working Group Update

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Fall 2024 CERES science team meeting
Lawrence Livermore National Laboratory, Livermore, CA

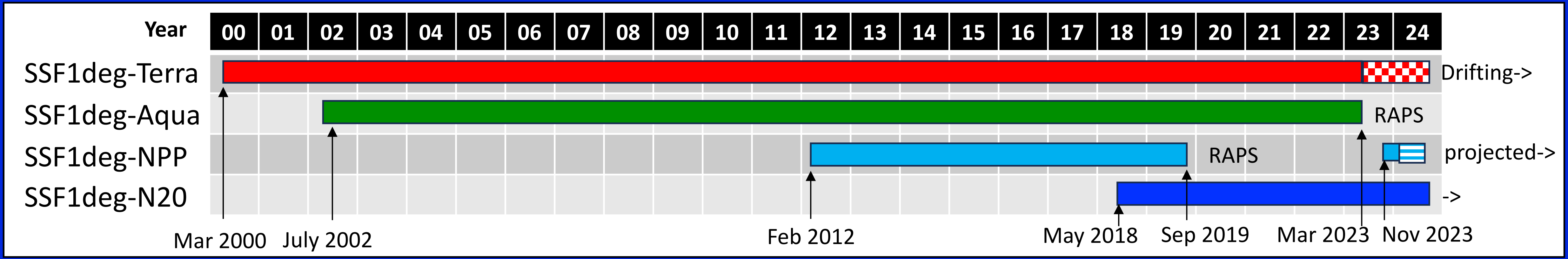
OUTLINE

- CERES L3 Products overview and status
  - EBAF Ed4.2.1 product to facilitate transitioning from GEOS 5.4.1 to MERRA2 atmosphere
- TISA Ed5 framework
  - Starting to test the framework with FLASHFlux
- Ed5 FluxByCloudType (FBCT)
  - Improved cloud layer fluxes, the Ed5 SSF L2 daytime footprint cloud layers will have 12 imager channel radiances, whereas the Ed4 had 5 channels
- GEO scan
  - Design algorithm to inter-calibrate the NOAA20-CERES and NOAA22-Libera radiances
  - Validate the GEO NB to BB coefficients

CERES L3 PRODUCTS

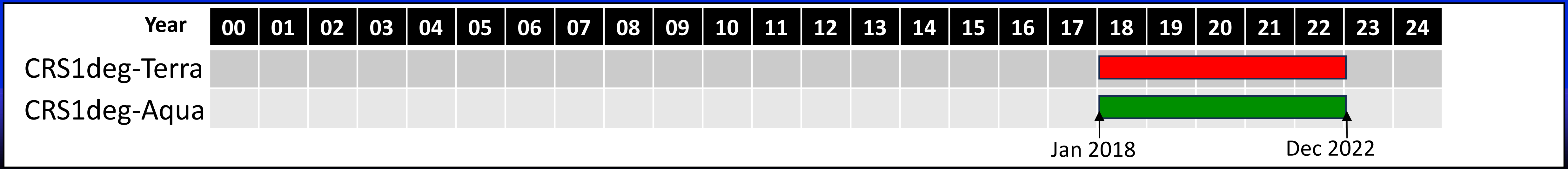
SSF1deg

- The SSF1deg product utilizes constant meteorology albedo diurnal models and LW temporal interpolation to infer the regional diurnal in between CERES measurements
- SSF1deg-hour (instantaneous gridded), day and month single satellite products



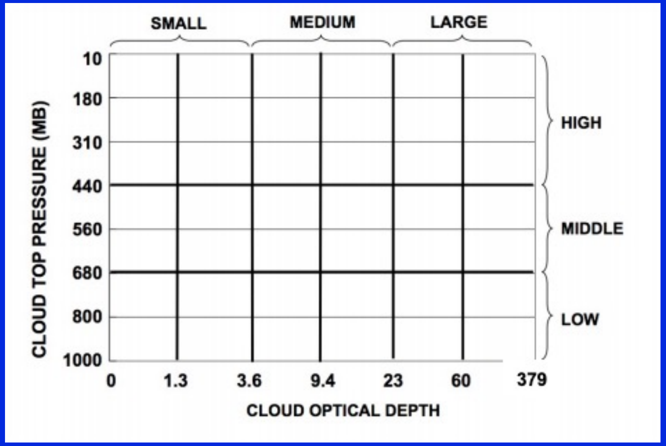
CRS1deg

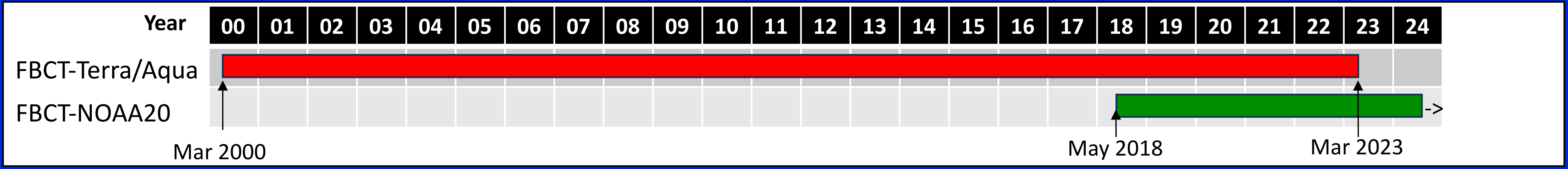
- CRS L2 provides footprint computed profile and surface fluxes with associated cloud and meteorological parameters by instrument.
- CRS1deg-hour (instantaneous gridded) 5-year products



FBCT product

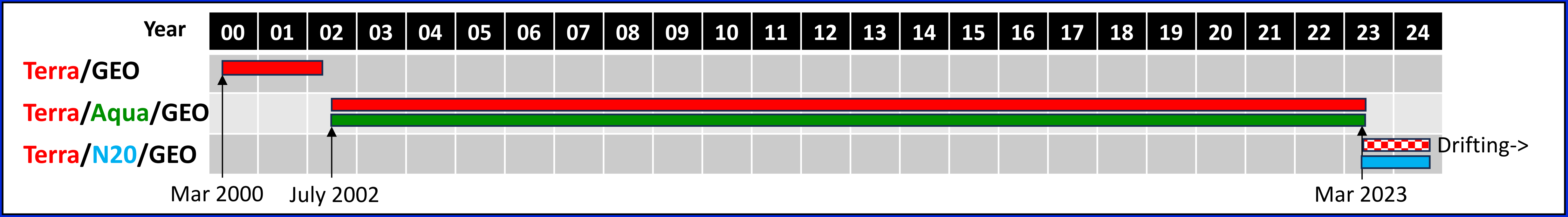
- The FluxByCloudType (FBCT) product provides observed daytime CERES fluxes stratified by 7 cloud layer and 6 optical depth bins (similar to ISCCP)
    - Subfootprint Imager narrowband to broadband derived fluxes are used to resolve the cloud layers fluxes
    - The TRMM directional models are used to compute the daily SW flux
- Efforts to bridge the gap between Terra&Aqua and a NOAA20-only records were unsuccessful
    - mostly due to optically thin cloud differences between MODIS and VIIRS





SYN1deg and CldTypHist Ed4.1 products

- The SYN1deg product utilizes hourly GEO fluxes and clouds to infer the regional diurnal flux in between CERES measurement times
  - SYN1deg-hour, SYN1deg-day, SYN1deg-mhour, SYN1deg-month
- The CldTypHist product combines the imager and GEO cloud properties and stratifies them into 3x3 cloud layer and optical bins
  - CldtypHist-mhour, CldtypHist-month(daytime, nighttime, 24-hour)



SYN1deg Ed4B product

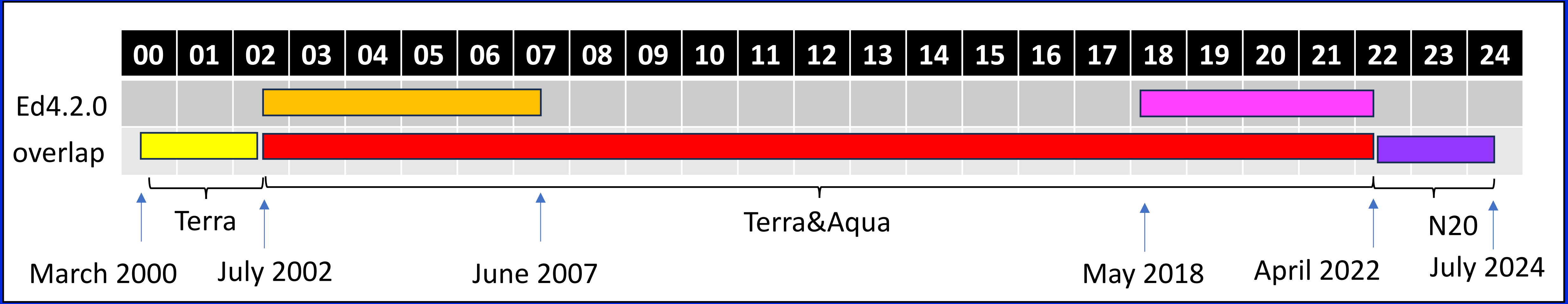
- GEO reprocessing of the entire (2000-2023) for greater computed flux and cloud consistency across the record, projected release date of December 2024
  - Met 8,9 and 10 reprocessed consistently using the latest Met-11 code
  - GEO 2-channel satellites, reprocessed with improved cloud mask and night-time optical depths
    - GMS-5 Mar 2000 to Apr 2003
    - Met-5 57° Mar 2000 to Jan 2007
    - Met-7 0° Mar 2000 to Apr 2004
    - Met-7 63° Jan 2007 to Jan 2017
- The twilight cloud retrievals (SZA>60) to be temporally interpolated across the twilight hour-boxes
  - Twilight retrieved clouds caused noisy surface fluxes, use interpolated clouds instead
- Code bug fixes
- Consistent GEO boundaries
  - Rather than the bisecting longitude between satellites

EBAF product

- The EBAF global monthly regional flux and cloud product combines the stability of the SSF1deg CERES observed fluxes and the regional diurnal flux information of the SYN1deg product free of GEO artifacts.
  - Is processed within 2-months of real-time
  - Partly cloudy footprint imager derived broadband fluxes are utilized to spatially fill regions without any clear-sky footprint fluxes.
  - The TOA net flux is constrained to the ocean heat storage.
- The Terra, Aqua, and NOAA20 CERES instrument fluxes and imager clouds are combined using climatology regional adjustment factors based on the neighboring ~5-year overlap period
  - The Terra (10:30AM) and Aqua (1:30PM) combined record is the most diurnally accurate period
  - The NOAA20-only (1:30PM) and Terra-only (10:30AM) records are tied to the joint Terra and Aqua period using climatology adjustment factors
  - Any changes in the atmosphere profile, imagers and other inputs, the NOAA20 record is reprocessed and forward processing continues. The overlap period is used to recompute the climatology adjustment. This minimizes the number of processing changes

EBAF Ed4.2 satellite records

- EBAF Ed4.2 Terra and Aqua record
- Terra&Aqua and Terra overlap to compute the climatology adjustment factors
- Terra-only record
- Terra&Aqua and N20 overlap to compute the climatology adjustment factors
- N20-only record

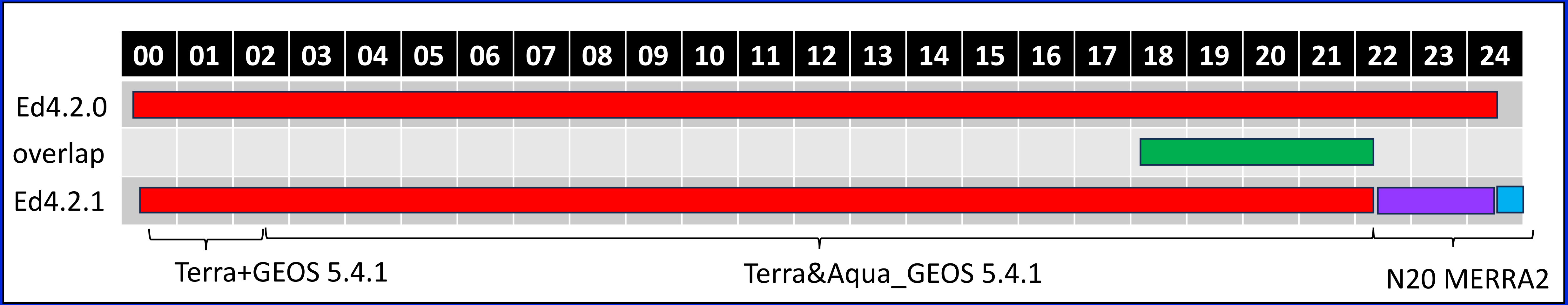


EBAF Ed4.2.1

- The EBAF Ed4.2 full record utilized GEOS 5.4.1 atmosphere
  - GEOS 5.4.1 was discontinued on July 2024
- The EBAF Ed4.2.1 will utilize the MERRA2 atmosphere beginning with the N20-only record in April 2022
- EBAF Ed4.2.1 logistics, effort began in January 2024
  - The SSF-N20 record was rerun with MERRA2 starting in May 2018
  - The GEO hourly cloud and flux record was rerun MERRA2 starting May 2018
    - The McIDAS cloud retrieval code was modified to run on the GEO hourly pixel-level netCDF files to avoid downloading the McIDAS GEO areafiles and thus greatly speeding up the reprocessing effort. The McIDAS-GEOS code was updated to facilitate forward processing with MERRA2
  - The climatology adjustment factors were computed during the 4-year Terra&Aqua and N20 overlap period (May 2018 to March 2022) using MERRA2
  - The climatology adjustment factors were applied to the N20-only record beginning in April 2022
- Several processing anomalies were noted and will be documented in the EBAF DQS
  - The Ed4.2 EBAF clear-sky imager narrowband to broadband used old LUTs, LUTs correctly applied for Ed4.2.1
  - EBAF forward processing does not utilize the first day of following month to facilitate local day processing of the GMT month
  - EBAF reprocessing utilizes both the last day of the previous month and the first day of following month
  - Several SSF (daily) datagaps were noted during forward processing. Ed4.2.1 reprocessing is more temporally complete
- EBAF Ed4.2.1 TOA available by the end of the month
- EBAF Ed4.2.1 computed fluxes available by end of the year

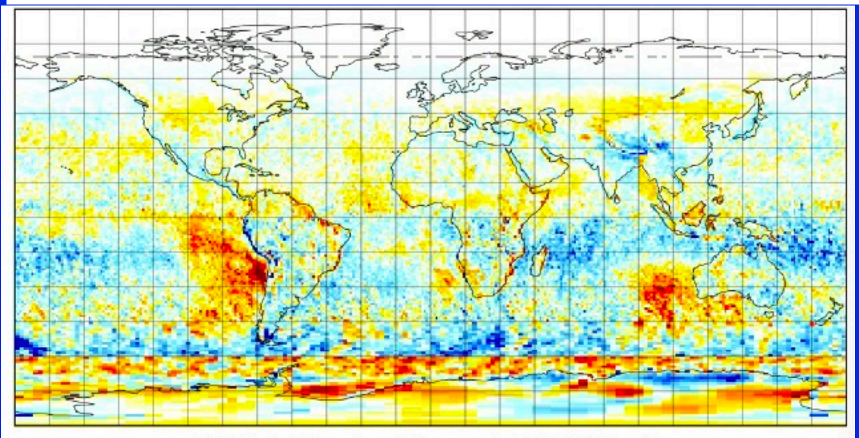
EBAF Ed4.2.1

- EBAF Ed4.2 based on GEOS 5.4.1 atmosphere
- Terra&Aqua and N20 overlap to compute the climatology adjustment factors
- N20 EBAF Ed4.2.1 based on MERRA2 atmosphere (April 2022 to July 2024)
  - Allows users to compare EBAF Ed4.2 (GEOS 5.4.1) and EBAF Ed4.2.1 (MERRA2) differences
- N20 EBAF Ed4.2.1 forward processing with MERRA2 atmosphere (August 2024->)

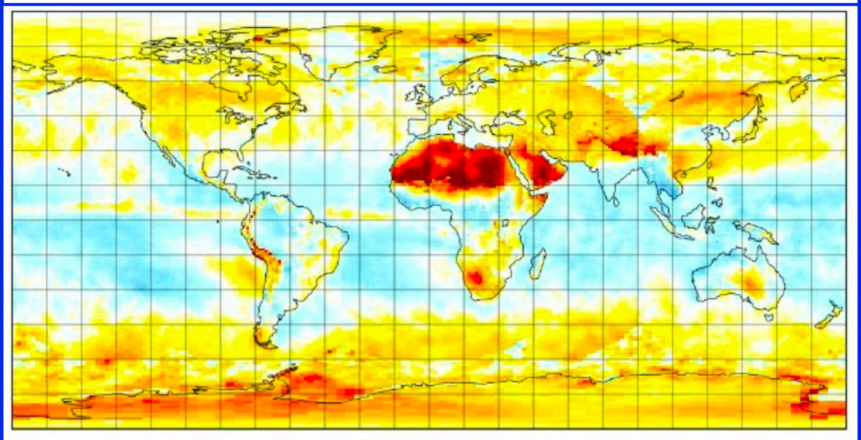


2018-2022 Climatology Adjustment Factors

EBAF Ed4.2.1 All-sky SW (MERRA2)

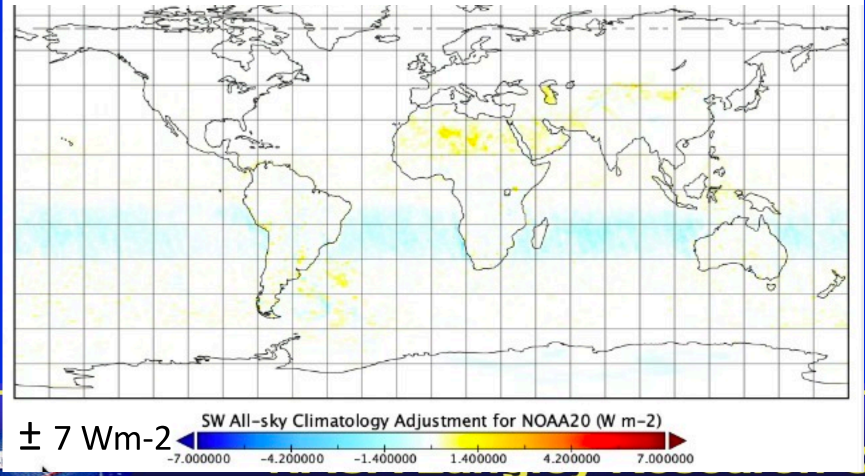


EBAF Ed4.2.1 All-sky LW (MERRA2)

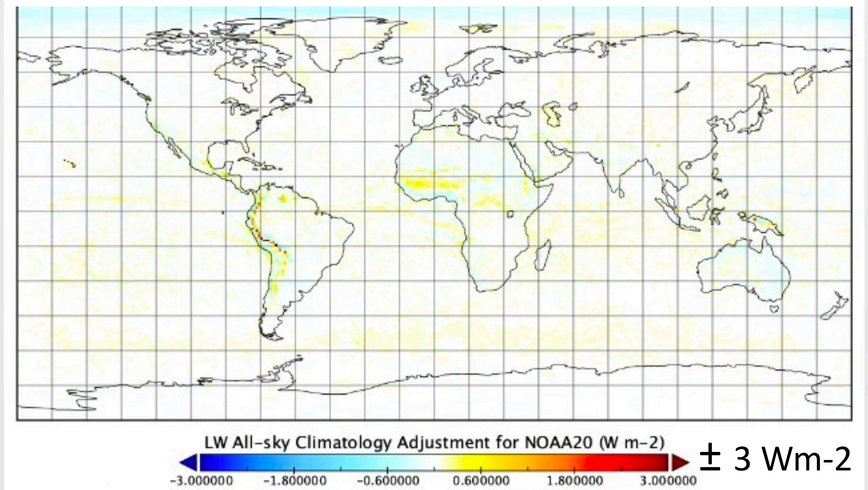


- The climatology adjustment factors take into account the the Terra and Aqua vs N20 local time sampling residual diurnal flux differences and the MODIS vs VIIRS cloud retrieval differences

All-sky SW MERRA2-GEOS5.4.1



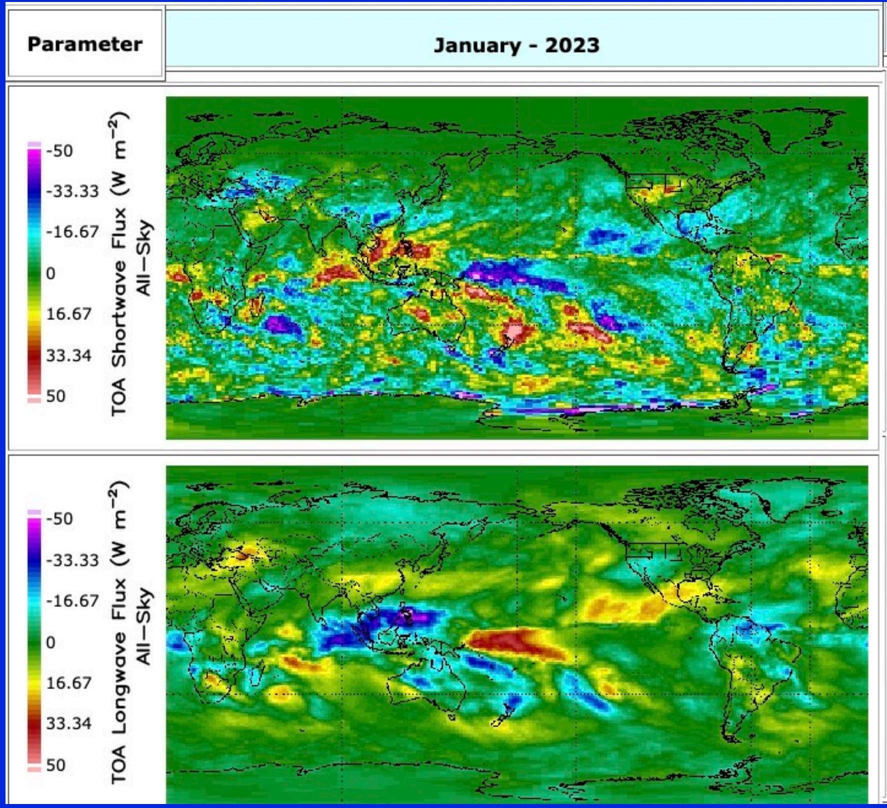
All-sky LW MERRA2-GEOS5.4.1



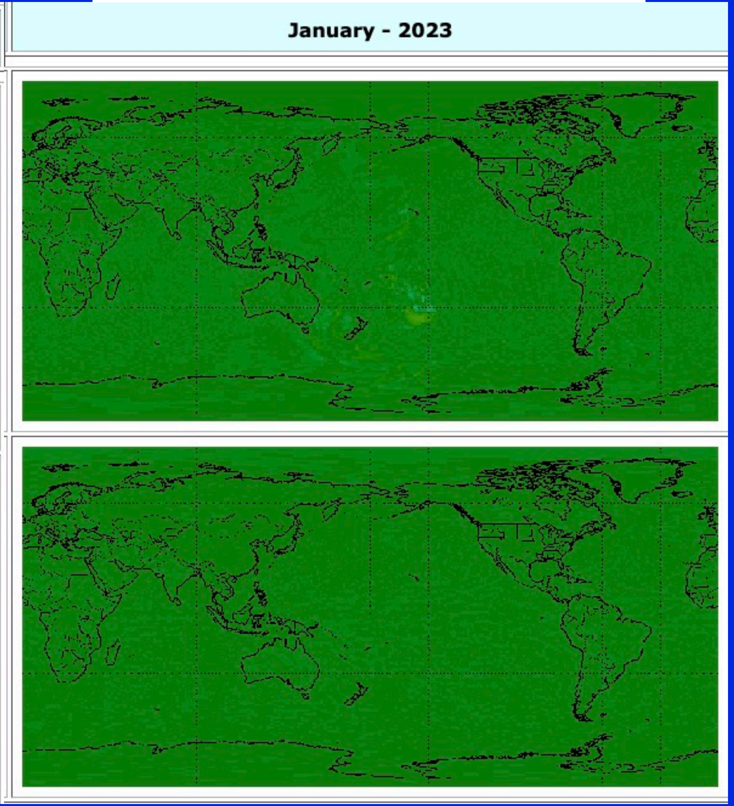
- The GEOS and MERRA2 atmosphere hardly impacted the climatology adjustment factors

EBAF Ed4.2.1 (MERRA2) minus Ed4.2 (GEOS) flux differences

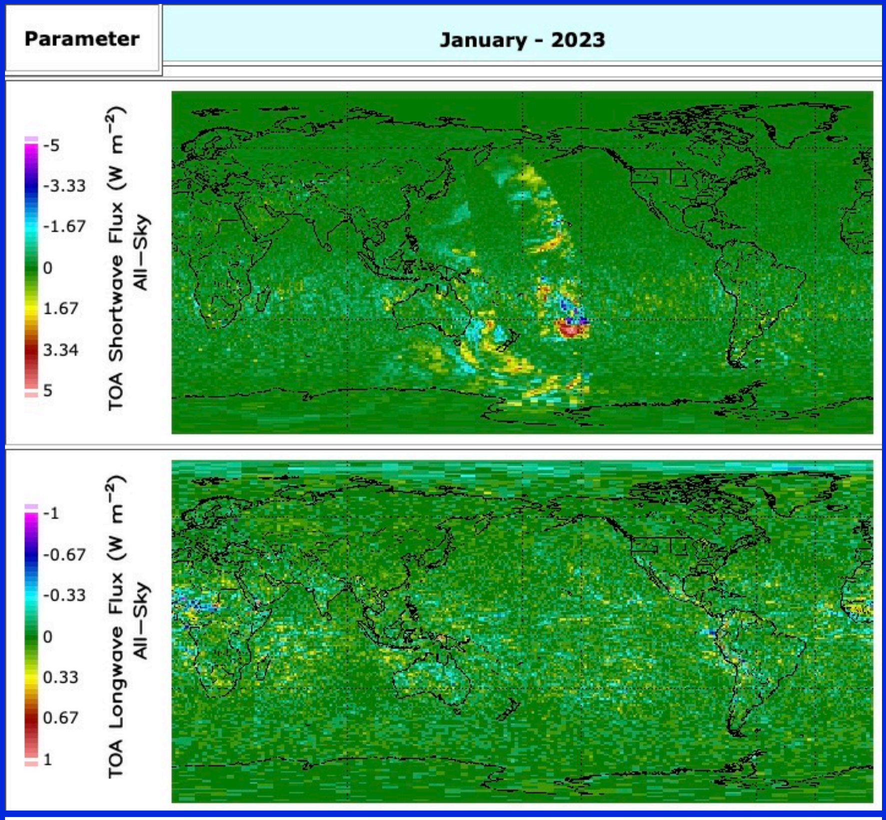
EBAF Ed4.2.1 regional flux anomalies



EBAF Ed4.2.1 minus Ed4.2 same scale as anomalies



EBAF Ed4.2.1 minus Ed4.2 rescaled to highlight flux differences



- The regional anomalies are much greater than the atmosphere difference

- Note the all-sky SW overlap flux difference
- The all-sky LW utilized hourly GEO hardly any difference

TISA Edition 5 framework

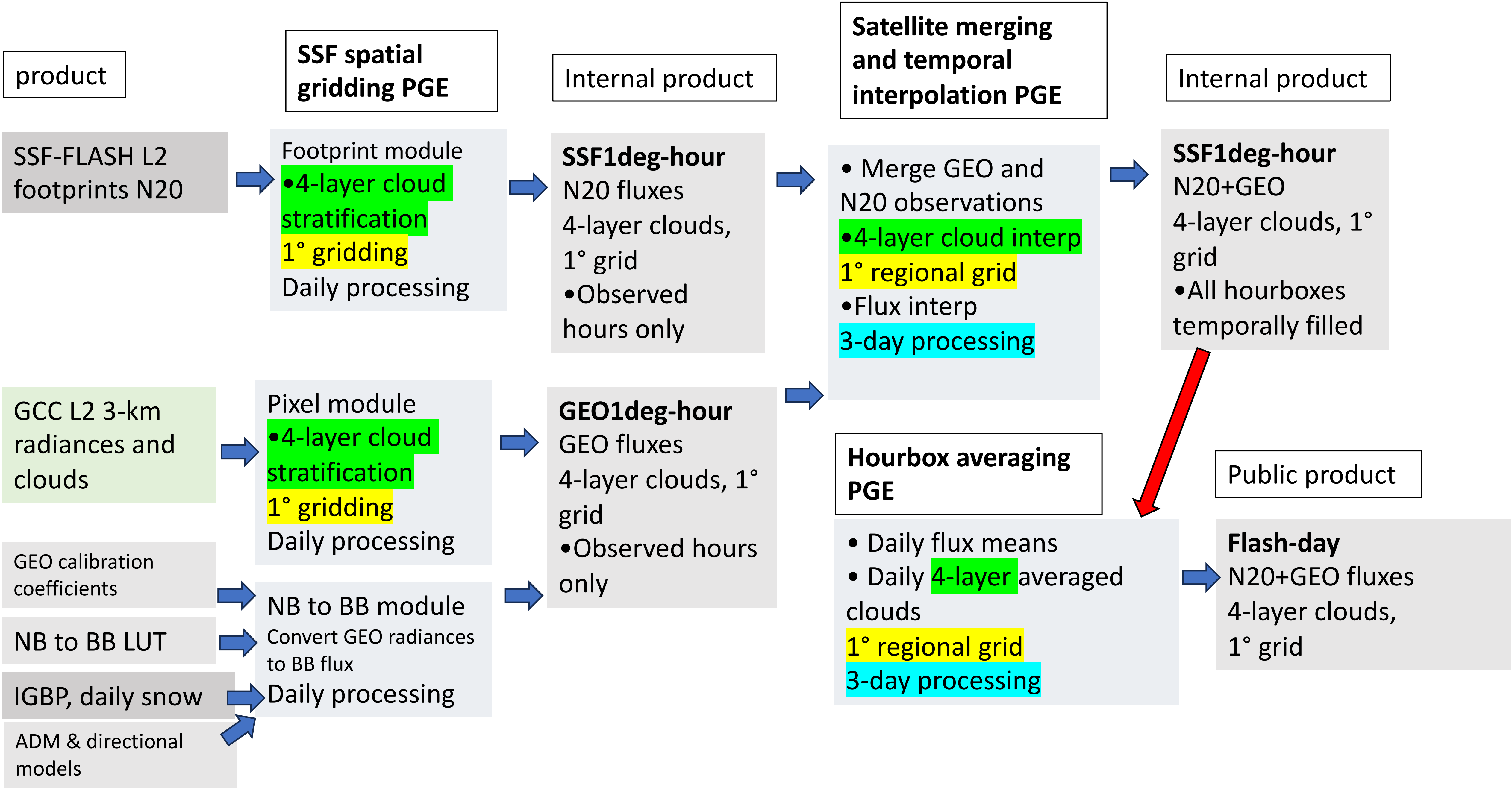
Ed5 framework updates

- FLASHFlux framework
  - The real-time GCC 3-km global pixel cloud retrievals have been gridded for low latency FLASHFlux application by CWG/TISA
    - We have implemented both the 4-pressure layer clouds or 3x3 pc-tau bins
  - The GCC gridded clouds and IGBP libraries and associated applications have been incorporated by Fu-lung for the stand alone Fu-Liou computation for surface fluxes
- The GEO scan validation used the TISA Ed5 framework
  - The McIDAS GEO channel CERES-footprint averaged radiances were treated as as proxy gridded data
  - The TRMM ADMs and directional models have been incorporated into the GEO1deg-hour file
  - The Ed5 library GEO narrowband to broadband LUTs and CERES normalization subroutines were used for the validation

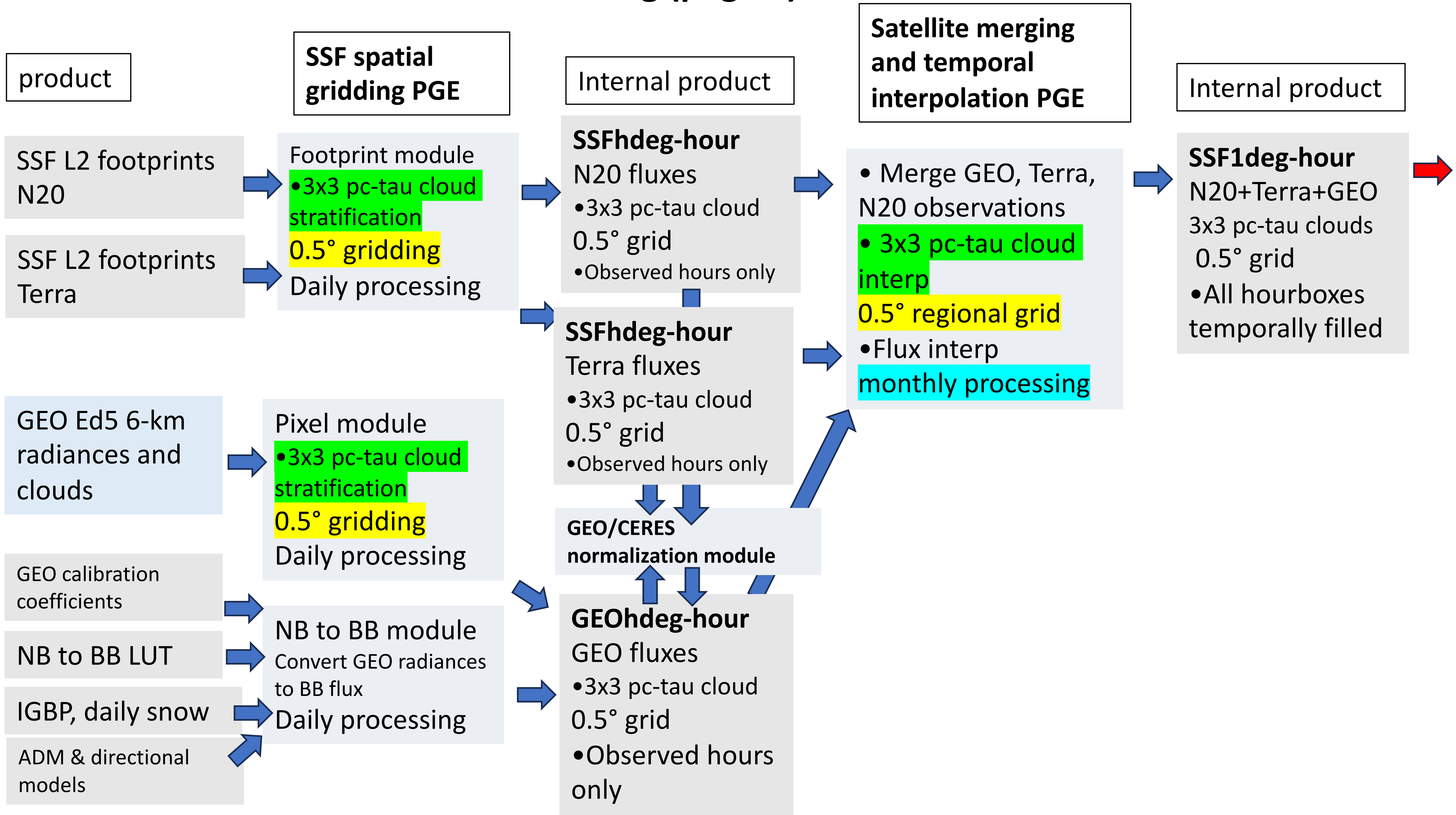
Ed5 framework updates

- The SSF1deg Ed5 alpha 2 version incrementally writes out or appends each hour onto the daily netCDF file, thereby avoiding storing 24 hours worth of data in memory.
- Tested the SSF1deg Ed5 alpha 2 version with the Ed4 SSF1deg-day/month code.
- Developed the SW TRMM and snow/ice scene ID functions to compute the instantaneous gridded directional model in the SSF1deg-hour file
- Tested and demonstrated the cloud temporal interpolation and daily/monthly averaging library subroutines in the Ed5 framework for use in FLASHFlux and CERES-TISA products

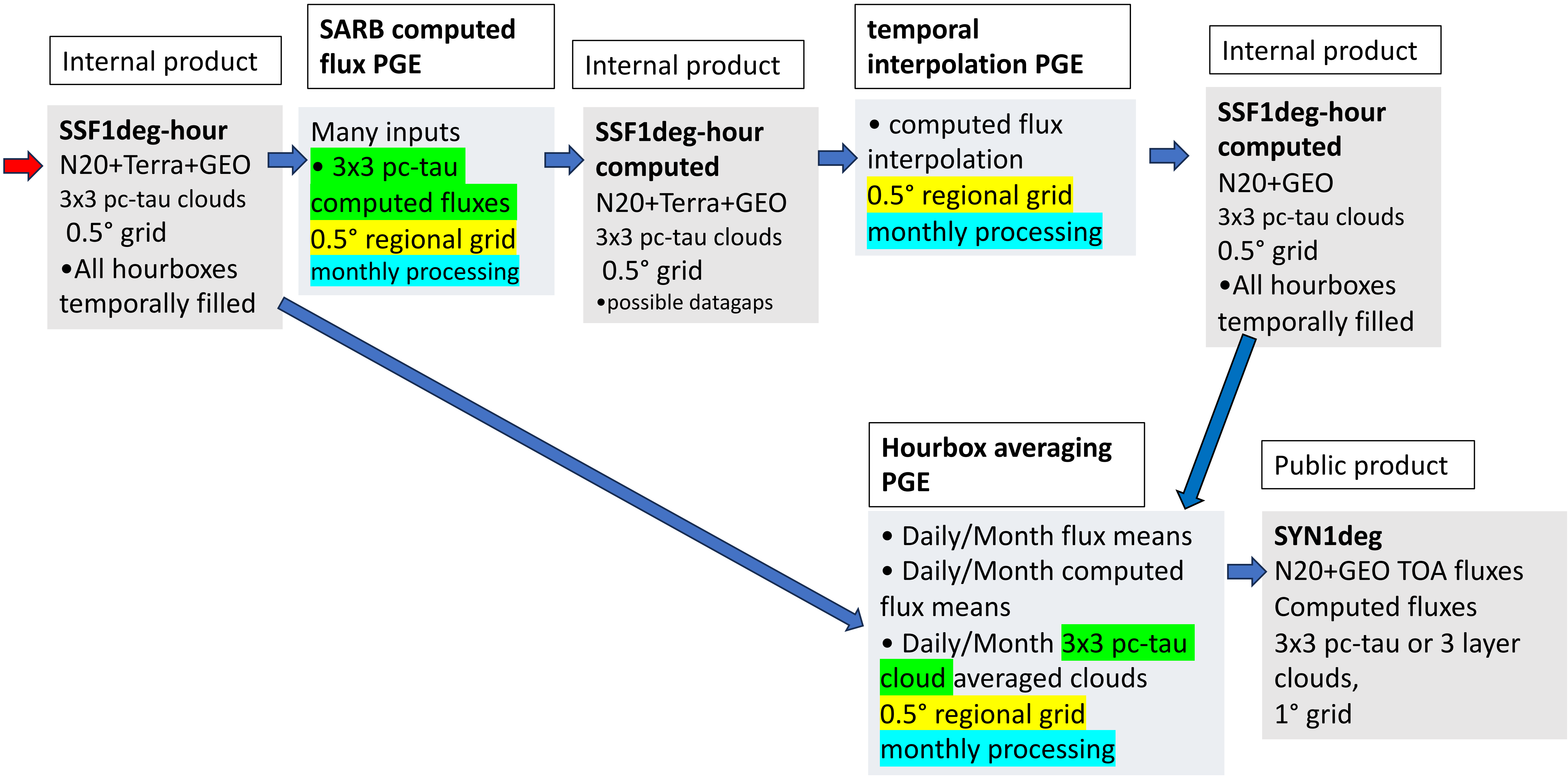
TISA Edition 5 framework for FlashFLUX



TISA Edition 5 framework for SYN1deg (page 1)



TISA Edition 5 framework for SYN1deg (page 2)

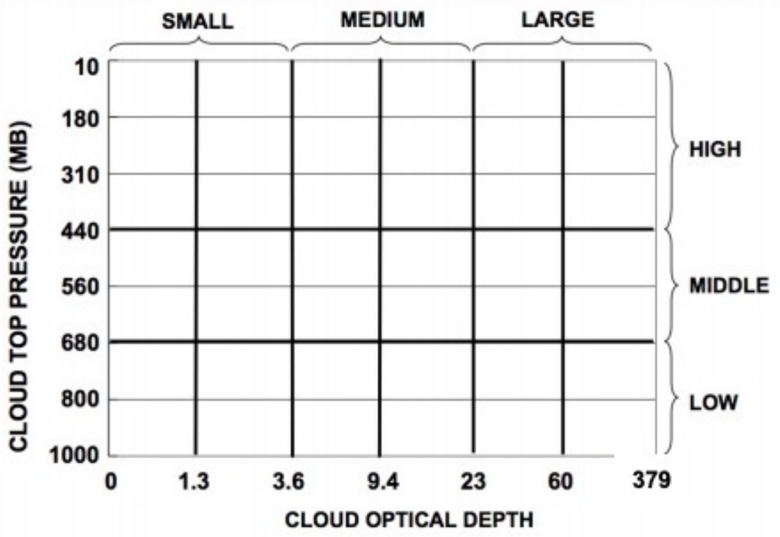


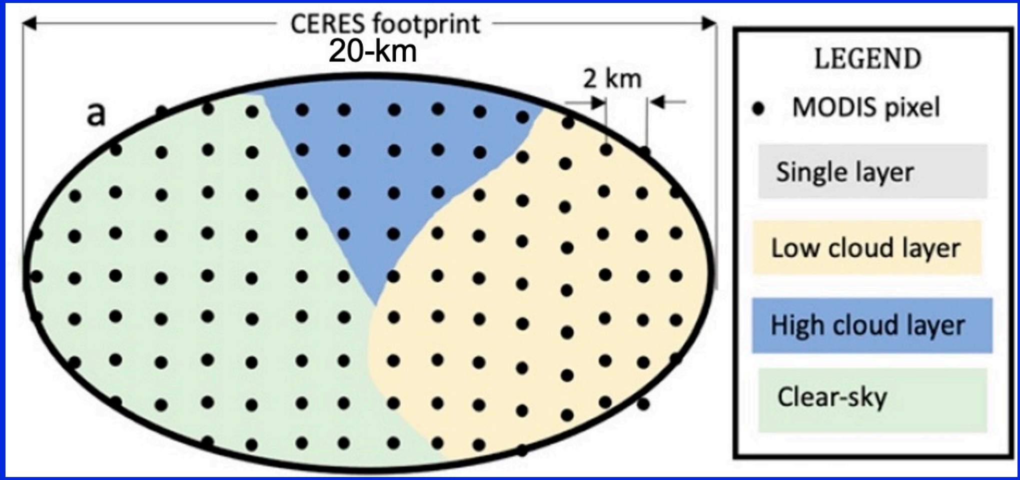
FBCT and GEO NB to BB

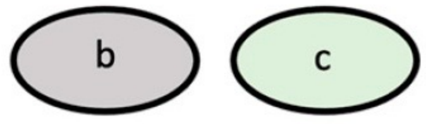
FBCT Narrowband to Broadband

- Compute the NB to BB coefficients for each of the 42 Pc-Tau cloud type bins and clear based on single scene footprints from Aqua 5-year climatology
  - 5 imager bands 0.48µm, 0.65µm, 0.86µm, 11µm, 12µm
  - 3 Angles: solar zenith, viewing zenith, relative azimuth angle
  - 7 surface types, ocean, forest, Savannas, Grass, dark desert, bright desert , snow
  - For LW precipitable water (PW)
- Apply the NB to BB coefficients to the subfootprint NB radiances
- Normalize the computed BB flux to the CERES observed flux at the footprint level

42 Pc-Tau cloud type bins







single scene footprints

FBCT NB to BB for Ed5, NB channels

- The SSF L2 Ed4 provided 0.48µm, 0.65µm, 0.86µm, 11µm, 12µm channels for the daytime cloud layer footprint portions
  - The footprint total and clear-sky provided 7 channels
- The SSF L2 Ed5 will provide 12 channels for footprint total, clear-sky, and both cloud layers
  - 0.48µm, 0.55µm, 0.65µm, 0.86µm, 1.24µm, 1.61µm, 3.8µm, 6.7µm, 8.6 µm, 11µm, 12µm, 14.2µm
- For Ed5, the NB to BB coefficients are recomputed utilizing more channels
  - Use the SSF-Aqua L2 January 2019 special processed dataset containing 19 channels to derive the NB to BB coefficients

SW NB to BB RMS (%) errors

	Ed4, SW cloud (%)	Ocean	Forrest	Grass	Dark Desert	Bright Desert	Snow
Ed4	0.48, 0.65, 0.86 µm	3.62	2.84	3.11	2.78	2.36	2.49
	0.48, 0.65, 0.86, 11, 12 µm	3.00	2.34	2.58	2.41	2.09	2.24
	0.48, 0.55, 0.65, 0.86, **1.24**	2.91	2.43	2.70	2.24	1.74	1.54
	0.48, 0.55, 0.65, 2.13, **11.0**	2.46	2.16	2.29	1.85	1.60	1.66

	Ed4, SW clear (%)	Ocean	Forrest	Grass	Dark Desert	Bright Desert	Snow
Ed4	0.48, 0.65, 0.86 µm	1.65	1.89	2.38	2.34	2.40	No clear
	0.48, 0.65, 0.86, 11, 12 µm	1.62	1.47	1.94	1.76	1.73	No clear
	0.48, 0.55, 0.65, 0.86, **2.13**	1.70	1.45	1.70	1.85	2.05	No clear
	0.48, 0.86, 2.13, 11, 12	1.73	1.16	1.61	1.50	1.63	No clear

LW NB to BB RMS (%) errors

	Ed4, LW cloud (%)	Ocean	Forrest	Grass	Dark Desert	Bright Desert	Snow
	11, 12 µm	2.89	2.34	2.86	2.66	2.72	3.25
Ed4	**0.48, 0.65, 0.86**, 11, 12 µm	2.61	2.15	2.42	2.14	2.09	0.47
	6.7, 12, 14.2 µm	1.68	1.73	1.74	1.50	1.61	1.22
	6.7, 8.6, 11, 12, 14.2 µm	1.67	1.70	1.69	1.45	1.47	1.08
	1.24, 6.7, 8.6, 12, 14.2 µm	1.55	1.58	1.56	1.37	1.35	1.04

	Ed4, LW day clear (%)	Ocean	Forrest	Grass	Dark Desert	Bright Desert	Snow
	11, 12 µm	1.86	1.57	1.75	1.88	1.90	1.34
Ed4	**0.48, 0.65, 0.86**, 11, 12 µm	1.79	1.29	1.59	1.82	1.82	0.47
	6.7, 12, 14.2 µm	0.72	0.67	0.88	1.07	1.11	0.41
	6.7, 8.6, 11, 12, 14.2 µm	0.48	0.50	0.70	0.80	0.87	0.48
	0.86, 6.7, 8.6, 11, 12, µm	0.59	0.49	0.69	0.70	0.76	0.35

SSF daytime and GEO imager channels

Ed 5 MODIS & VIIRS channels	Ed 4 MODIS & VIIRS channels	Met-5, Met-7, GMS-5	Met-8/9/ 10/11	GOES 8/9 10/11	GOES 12/ 13/14/15	GOES-16 17/18	Him-8 Him-9	MTSAT-1R MTSAT-2
0.48 µm	0.48 µm					0.48 µm	0.46 µm	
0.55 µm							0.51 µm	
0.65 µm	0.65 µm	0.65 µm	0.65 µm	0.65 µm	0.65 µm	0.65 µm	0.65 µm	0.68 µm
0.86 µm	0.86 µm		0.86 µm			0.86 µm	0.86 µm	
1.24 µm						1.24 µm		
1.64 µm			1.64 µm			1.64 µm	1.64 µm	
2.25 µm						2.25 µm	2.25 µm	
3.8 µm			3.9 µm	3.9 µm	3.9 µm	3.9 µm	3.9 µm	3.8 µm
6.7 µm FSNrad		6.7 µm	6.24 µm	6.6 µm	6.6 µm	6.2 µm	6.3 µm	6.8 µm
8.6 µm			8.6 µm			8.5 µm	8.6 µm	
10.8 µm	10.8 µm	10.8 µm	10.8 µm	10.8 µm	10.8 µm	11.2 µm	11.2 µm	10.8 µm
12.0 µm	12.0 µm		12.0 µm	12.0 µm		12.3 µm	12.4 µm	12.0 µm
14.2 µm FSNrad			13.4 µm		13.4 µm	13.3 µm	14.3 µm	

Ed5 Narrowband to Broadband

- For FBCT imager NB to BB
  - Compute the NB to BB coefficients for 12 channels
  - Compare the best 5-channels, 12 channels, IR-only, visible-only and visible and IR combinations by comparing the NB to BB and CERES observed footprint regional flux differences
- For SYN1deg GEO NB to BB
  - The Ed5 GEO framework computes the BB radiance from the GEO NB channels while spatially gridding the hourly instantaneous pixel radiances and clouds.
  - The hourly single satellite GEO pixel netCDF files contain the channel data required for the Ed4 cloud retrievals
  - The Ed5 GEO clouds will be retrieved using the GEO pixel netCDF files to avoid downloading all of the McIDAS area files – similar to the EBAF Ed4.2.1 effort
  - For each GEO, the NB to BB coefficients can be optimized depending on the available channels on the GEO pixel netCDF files
    - The number of channels is a function of the GEO imagers

GEO scan

GEO Scan Objectives

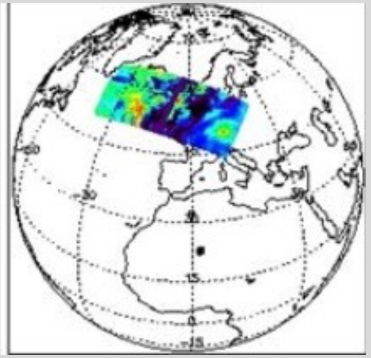
- Inter-calibrate the Terra and Aqua channel radiances
  - Ray-match the Terra/GEO and Aqua/GEO BB radiances
  - Use the GEO imager as the transfer radiometer
  - Establish methodology and uncertainty to inter-calibrate the N20-CERES and N22-Libera channel radiances
- Validate the GEO narrowband to broadband coefficients
  - SYN1deg Ed4 NB to BB coefficients
  - Future Ed5 NB to BB coefficients, adding more channels and using Machine Learning
- Test the TISA Ed5 framework
  - Input SSF1deg-Terra, SSF1deg-Aqua, GEO cloud retrieval pixel netCDF file

CERES instrument scan modes

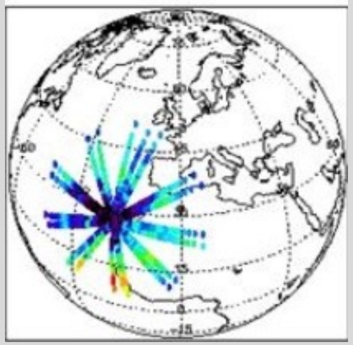
- **Cross-track** mode designed for uniform spatial sampling, for SSF1deg and SYN1deg data products
- **RAPS mode** designed to capture all view and azimuthal angles, to build ADMs
- **GEO scan mode** where the CERES instrument is pointed to the same line of sight as the GEO image
  - Coincident angle matched GEO and CERES observations

instrument	<-Jan 2023	Feb 2023->
Terra-FM1	Cross-track	Cross-track/GEOscan (every 5th day)
Terra-FM2	RAPS	RAPS (to build ADM during drift)
Aqua-FM3	Cross-track	RAPS/GEOscan (every 5th day)
N20 (FM6)	Cross-track	Cross-track (CERES products)

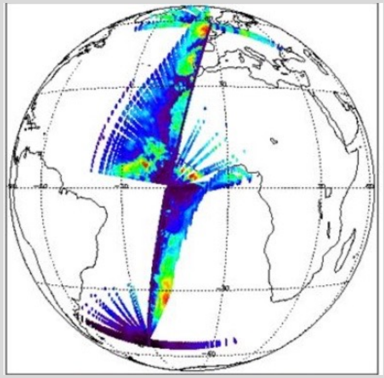
cross-track mode



RAPS mode

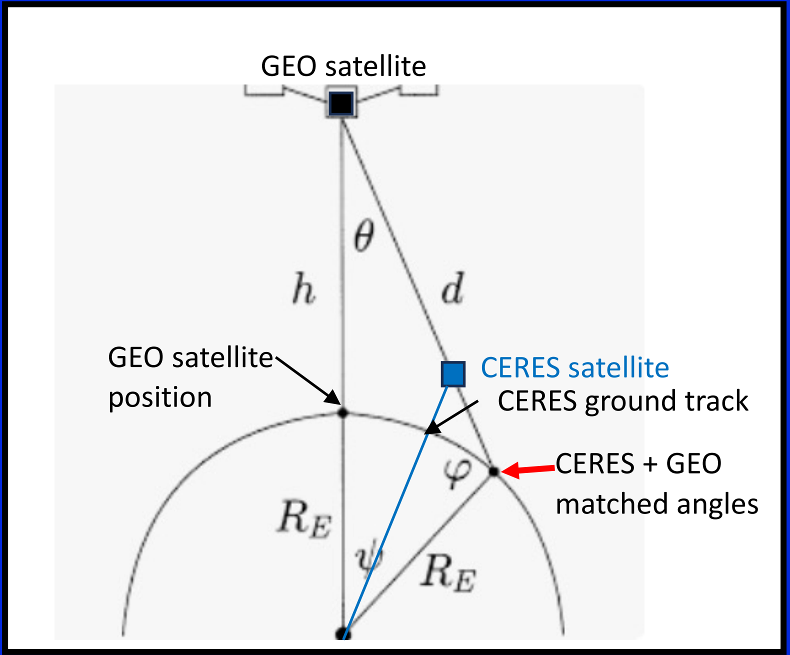


GEO scan mode

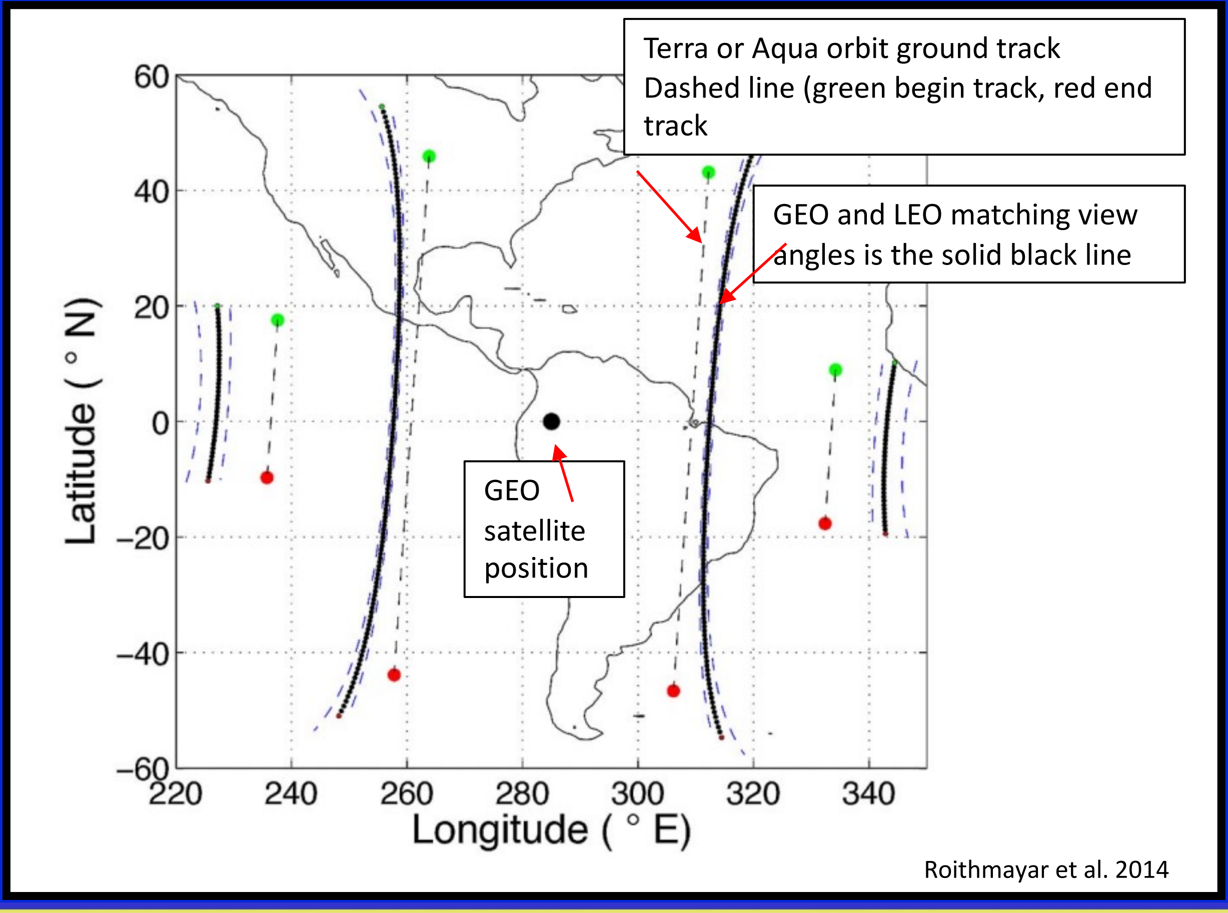


GEO scan strategy

Terra-CERES-channel → GEO NB to BB radiances → Aqua-CERES-channel



Vertical view

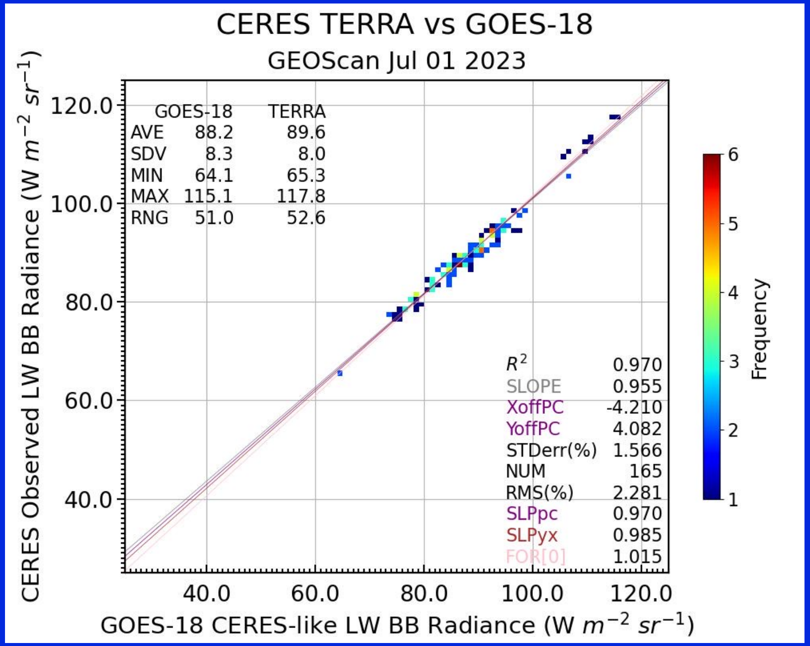


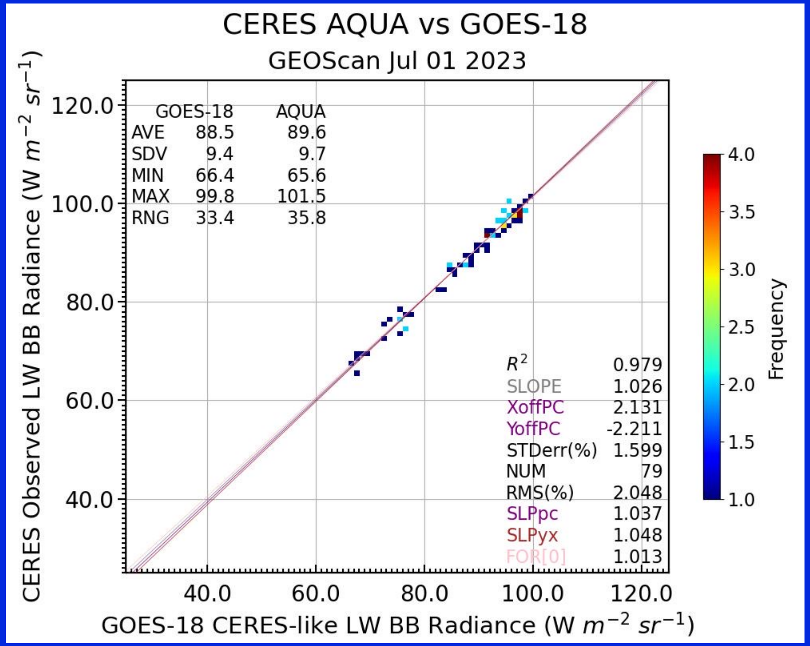
Roithmayar et al. 2014

July 2023 GEO scan validation

- Terra FM1 and Aqua FM3 are in GEO scan mode over the same GEO domain every 7 days
- To avoid scanning in the RAM direction or in the satellite direction
  - Terra (ascending orbit) GEO scans are in the Northern Hemisphere, @ 10:00AM
  - Aqua (descending orbit) GEO scans are in the Southern hemisphere, @ 2:00PM
- Apply the SYN1deg Ed4 GEO narrowband to broadband coefficients
  - Inter-calibrate the GEO radiances with the imager radiance to the MODIS calibration reference
  - Convert the GEO 6.2µm and 11µm channel radiances into broadband radiances
  - Theoretically convert the GEO 0.65µm channel radiances to an equivalent MODIS radiance and empirically convert to a broadband radiance
- Angle and time match the GEO BB radiances and CERES observed radiances
  - Most modern GEOs scan scans a full disc image every 10 minutes, ensuring 5-minute time matches
- Linearly regress the derived GEO fluxes/radiances with the observed CERES fluxes
  - Over each GEO domain
  - Compare the CERES and GEO fluxes to validate the SYN1deg Ed4 NB to BB coefficients
  - Compare the relative the Terra and Aqua CERES/GEO slopes to obtain the Terra and Aqua instrument relative radiance

GEO scan July 7, 2023, 1° gridded preliminary study



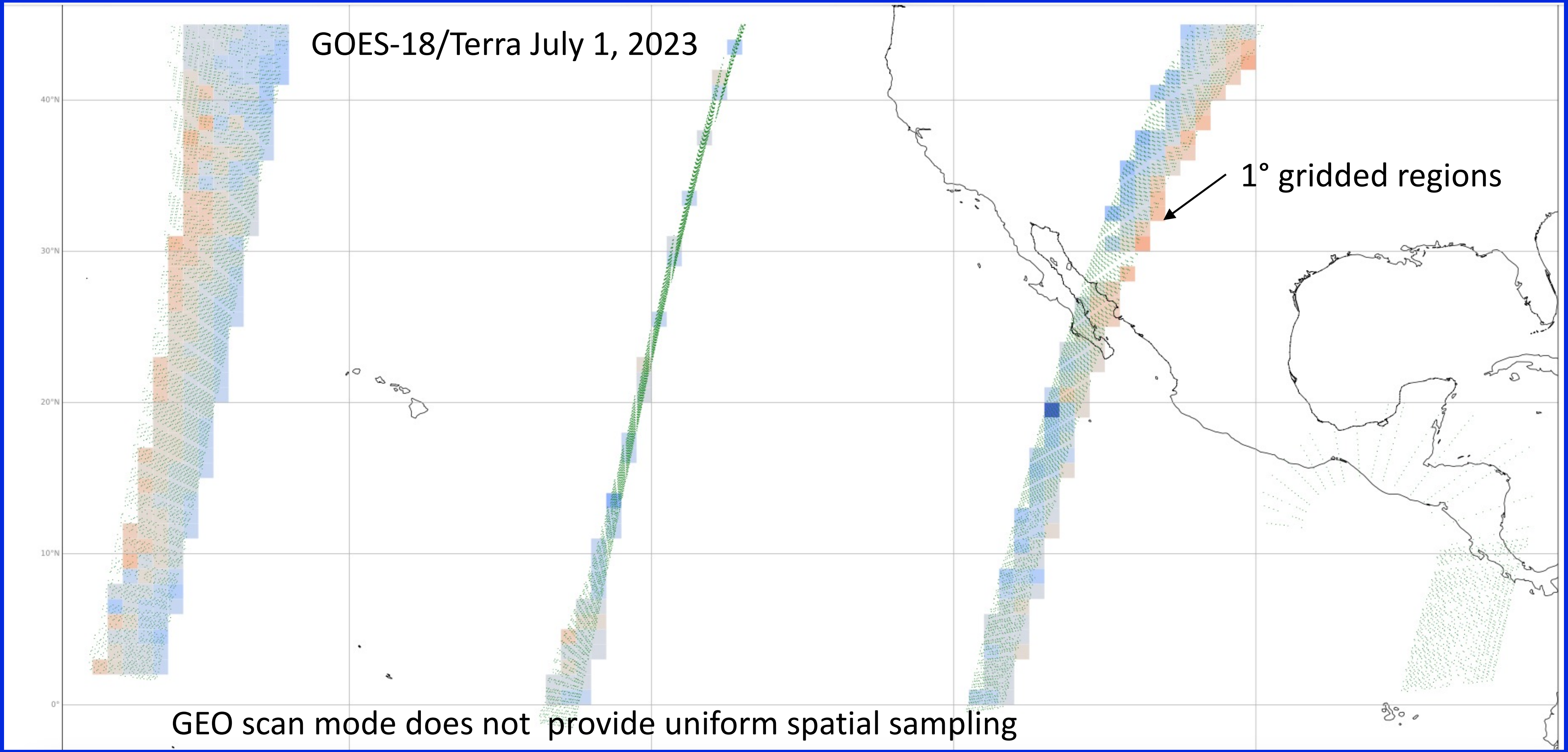


LW 1° lat/lon gridded intercalibration
ΔVZA<7.5°, Δtime <5 minutes,
footprints>40

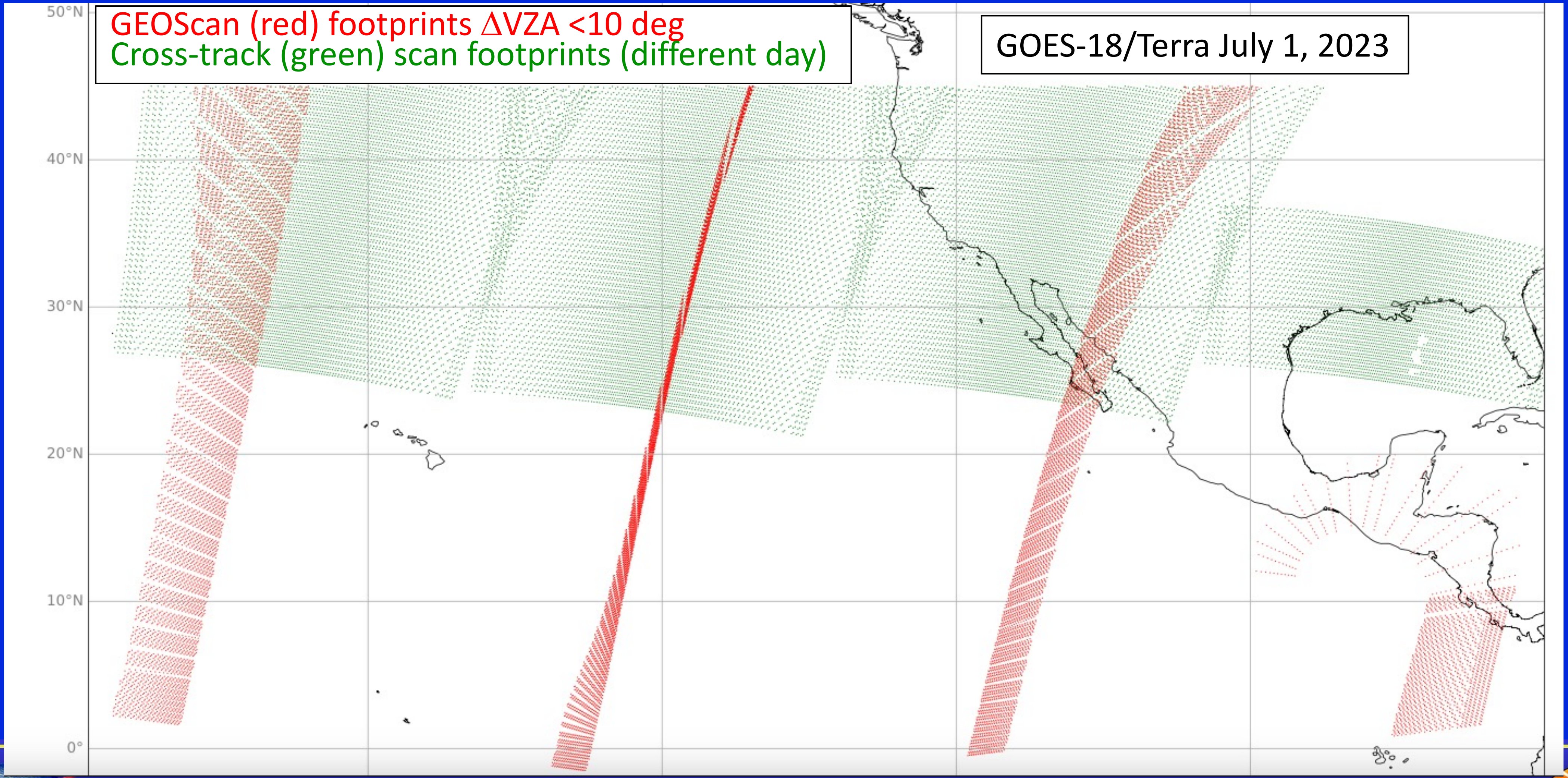
GEO LW	Terra slope	Aqua slope	Δ slope	Terra/Aqua Stderr
GOES-18	1.015	1.013	-0.2%	1.6%/1.6%
GOES-16	1.017	1.020	+0.3%	2.0%/1.4%
Met-10	1.016	1.014	-0.2%	1.5%/1.7%
Met-09	1.012	1.012	0.0%	2.4%/1.7%

- For cross-track scan nadir 1° lat/lon regions has ~20 footprints
- reducing the VZA<2.5° resulted in greatly reducing the number of matches
- Note the lack of dynamic range

GEO scan mode footprint distribution



GEO scan mode footprint distribution



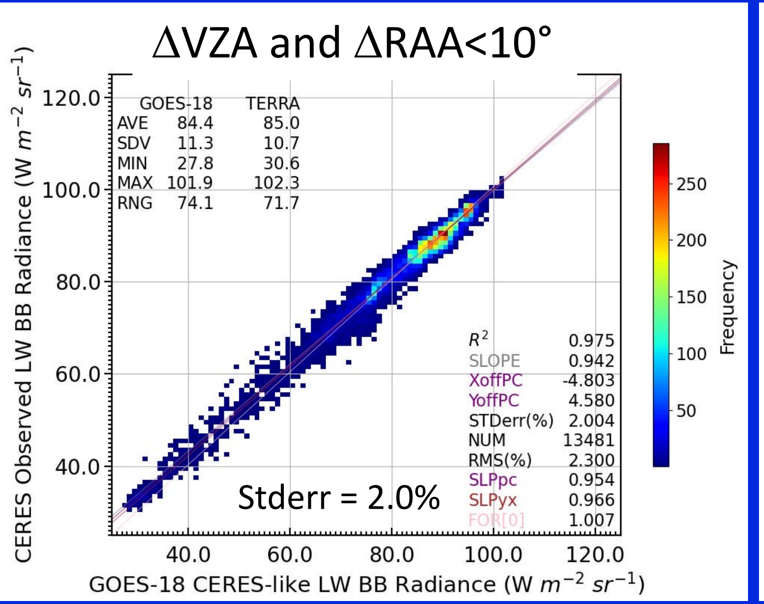
- Need to match footprint radiances

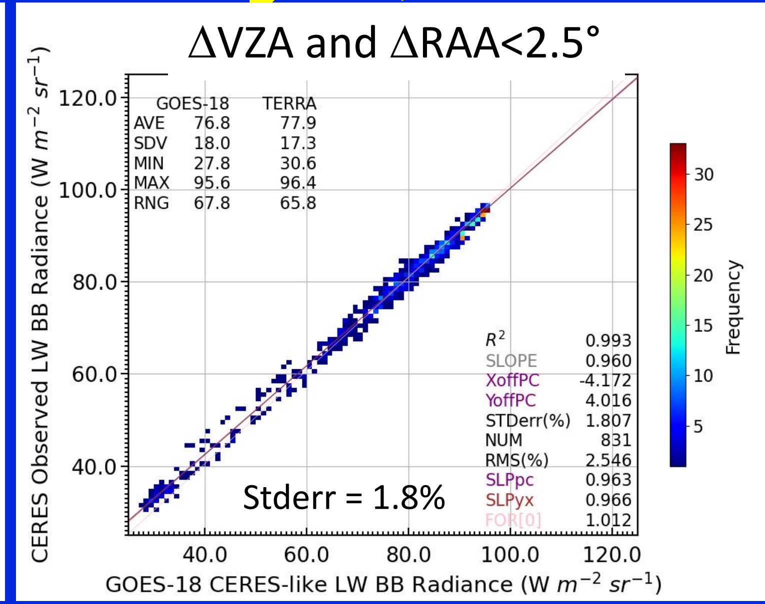
July 2023 GEO scan footprint validation

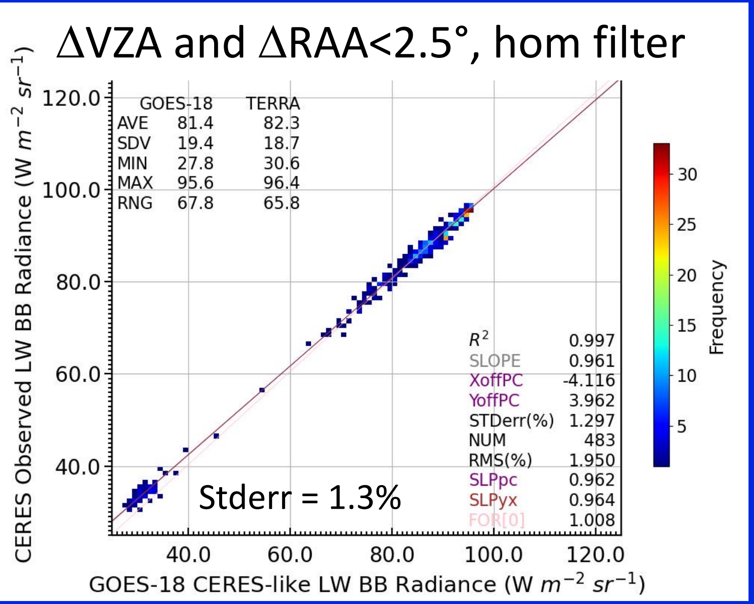
- For each footprint latitude and longitude center average the GEO 2-km pixel IR and visible radiances within a 30-km diameter
  - Applying the CERES point spread function (PSF) would need the scan direction
  - Compute the footprint spatial homogeneity, footprints with little spatial variability should match the observed CERES instrument footprint radiance without the use of the PSF
  - Process 3 10- minute GEO full disc scans centered at either the Terra or Aqua overpass time and match the GEO closest in time
- The 1° gridded instantaneous matches aggregated GEO pixel radiances at 6-km resolution

GOES-18/Terra July 1, 2023

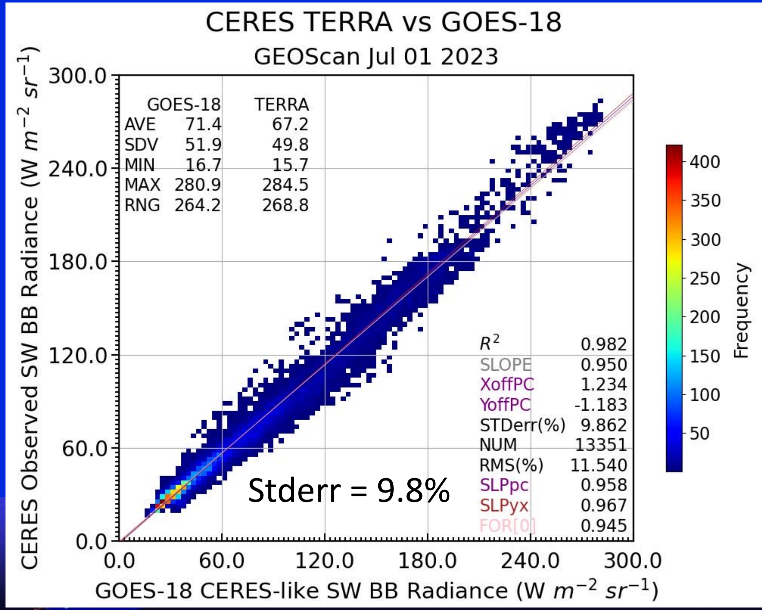
LW radiances

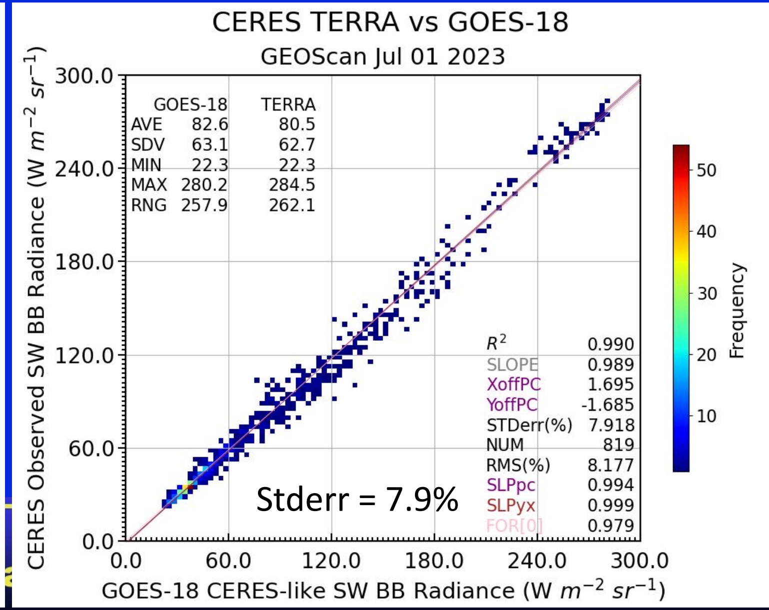


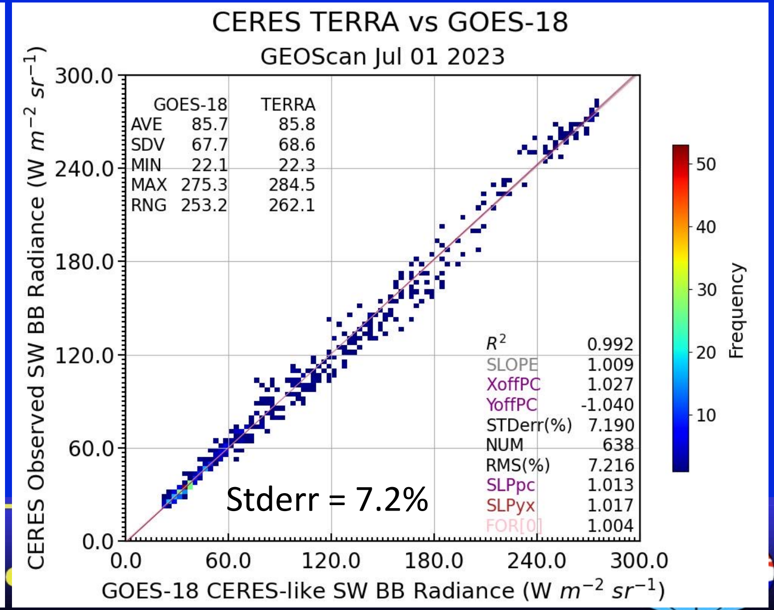




SW radiances

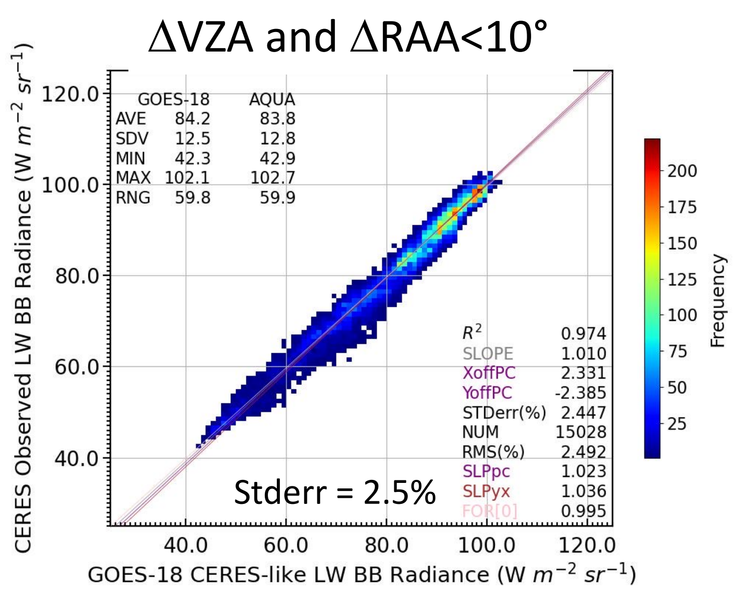


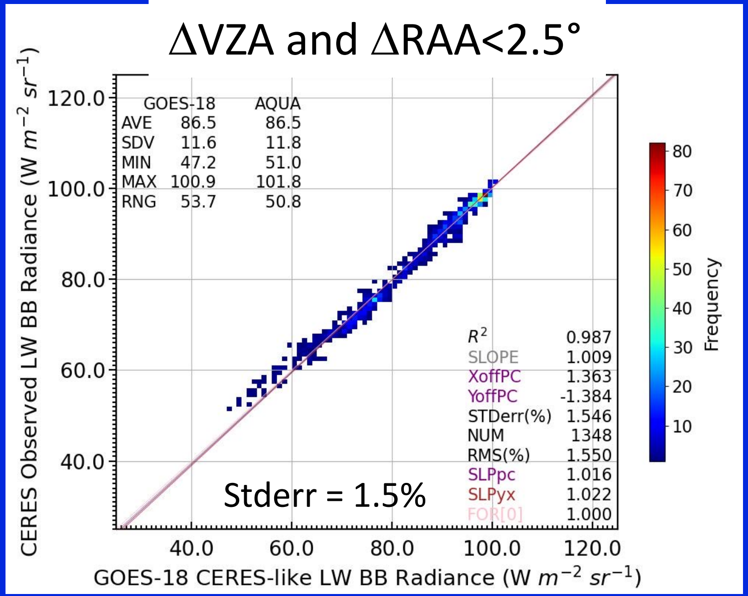


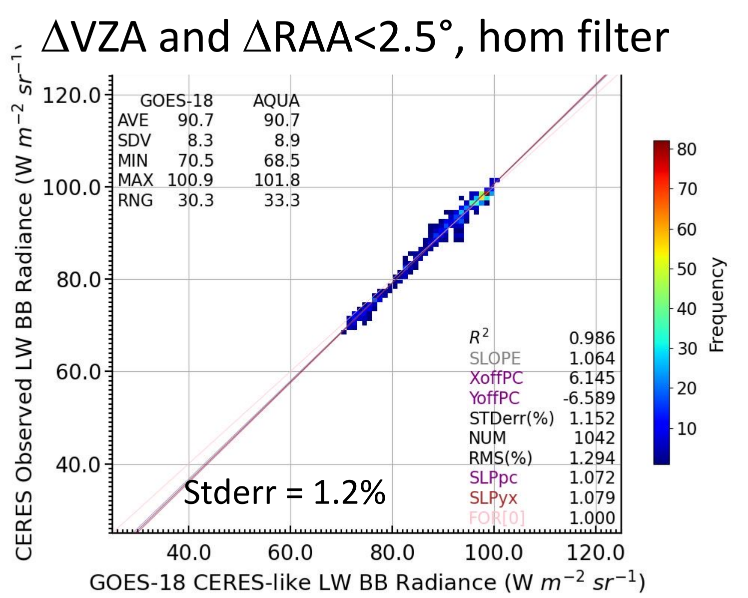


GOES-18/Aqua July 1, 2023

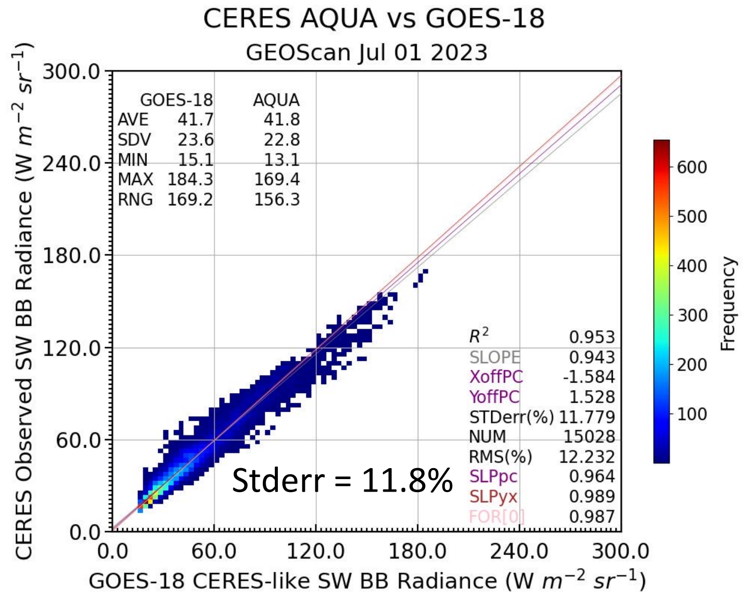
LW radiances

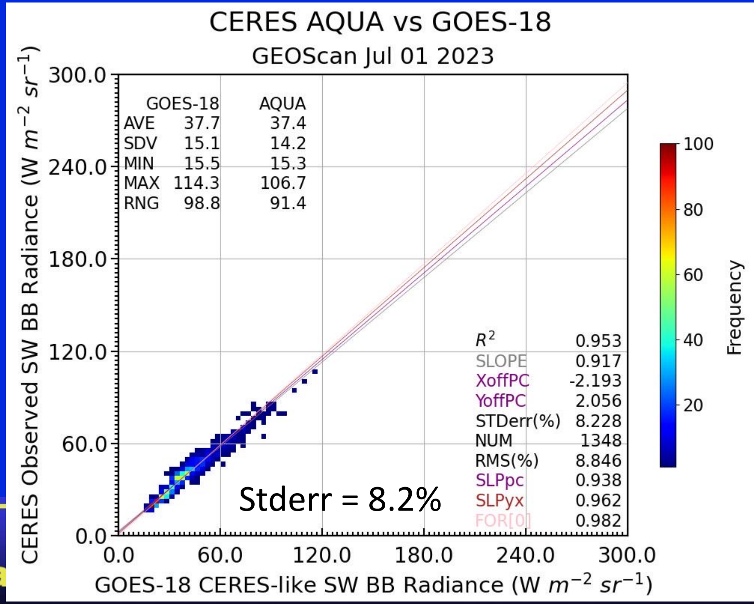


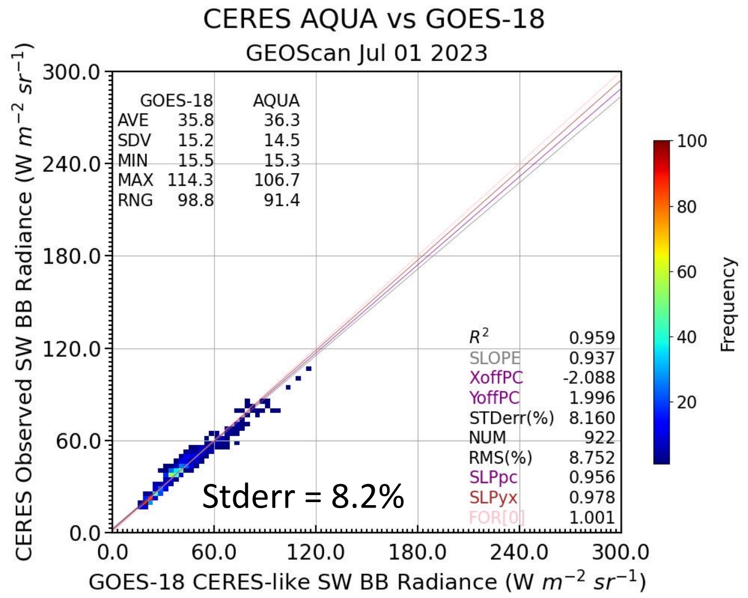




SW radiances







GEO scan future work

- Terra and Aqua GEO scans are being performed every 7th day over the same GEO domain
  - The Terra and Aqua drifting orbits will allow the GEO narrowband to broadband coefficients to be validated over a wide range of solar zenith angles, not possible with maintained orbits
- Need to refine the ray-matching angle, time, homogeneity and point spread function matching
- The GEOscan operations will be very beneficial to validated the TISA NB to BB algorithms
  - The Terra northern and Aqua southern hemisphere GEO scans during summer and winter will have differing solar zenith angles, scene conditions, and dynamic ranges
  - The future N20-CERES and N22-Libera GEOscan for inter-calibration will be performed over the same hemisphere, where the angular and scene conditions will be similar thus reducing the NB to BB impact