Surface Atmosphere Radiation Budget (SARB) working group update

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CERES Science Team Meeting
May 12-14, 2026

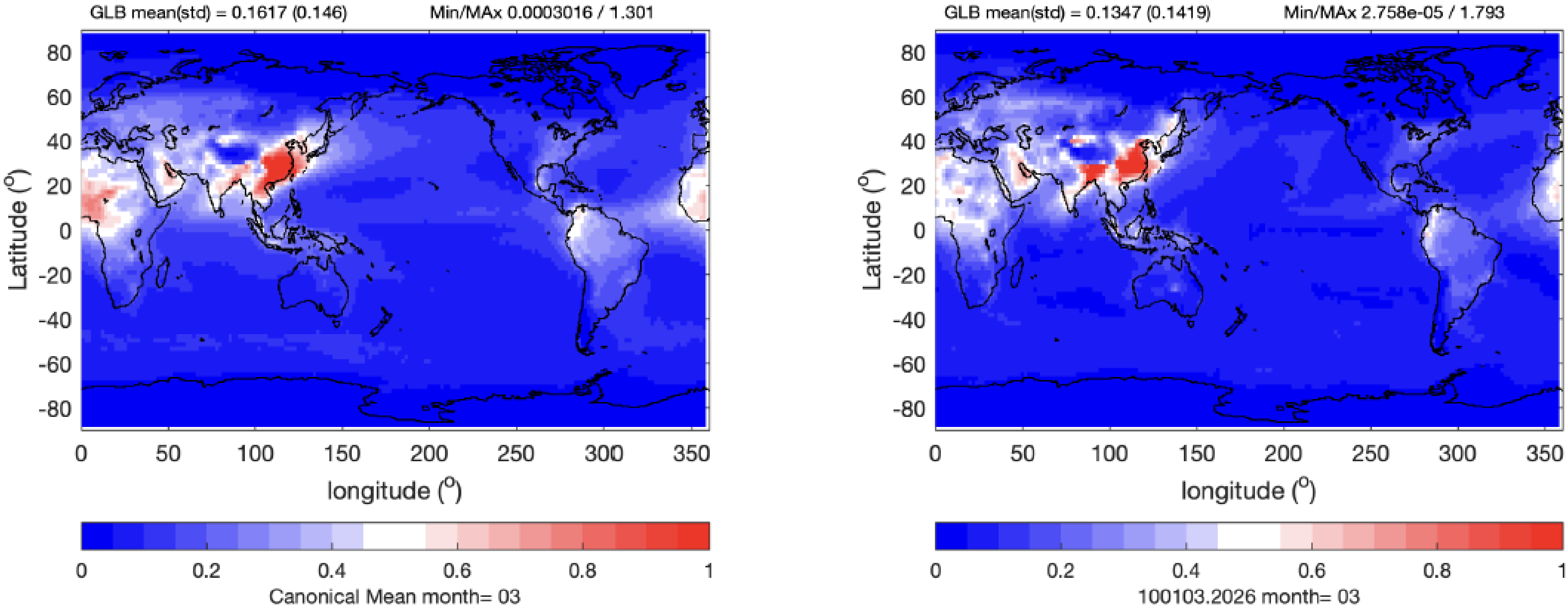
Outline of this presentation

- Edition 4 data product update
  - Edition 4.2.1 EBAF was released through December 2025
    - MERRA-2 issues though March 2006 (See SARB presentation in the Spring 2025 CERES STM).
  - Edition 4 MATCH input change
    - Aerosol optical thicknesses produced with the new input are scaled to match aerosol optical thicknesses produced with old input.
- Edition 5 algorithm developments
  - GEOS-IT aerosol optical thickness
    - Pre-process to take mixing ratio of aerosol species to convert 3-hourly aerosol optical properties
    - GEOS-IT aerosols will be used in Level 2 products (e.g. CRS)
  - SYN1deg noGEO Alpha4
    - Comparisons with baseline (Edition 4)
  - Edition 5 CRS improvements
    - Temperature and humidity GEOS-5.4.1 to ERA5
    - TOA longwave bias
    - Spectral surface albedo of snow and sea ice

Edition 4 MATCH aerosol

- NCEP’s Climate Data Assimilation System (CDAS) product is only available through February 2026 due to NOAA’s decommission of the product.
  - CDAS files provide meteorological data, winds, soil moisture etc. to MATCH
- CDAS product was switched to Conventional Observation Reanalysis (CORe) product
- CORe’s files are reformatted to match CDAS’s format
- Surface aerosol fluxes (dust, sea salt, SO2, DMS, organic carbon, and black carbon) are modified to reduce aerosol optical thickness differences.

March 2026 aerosol optical thickness



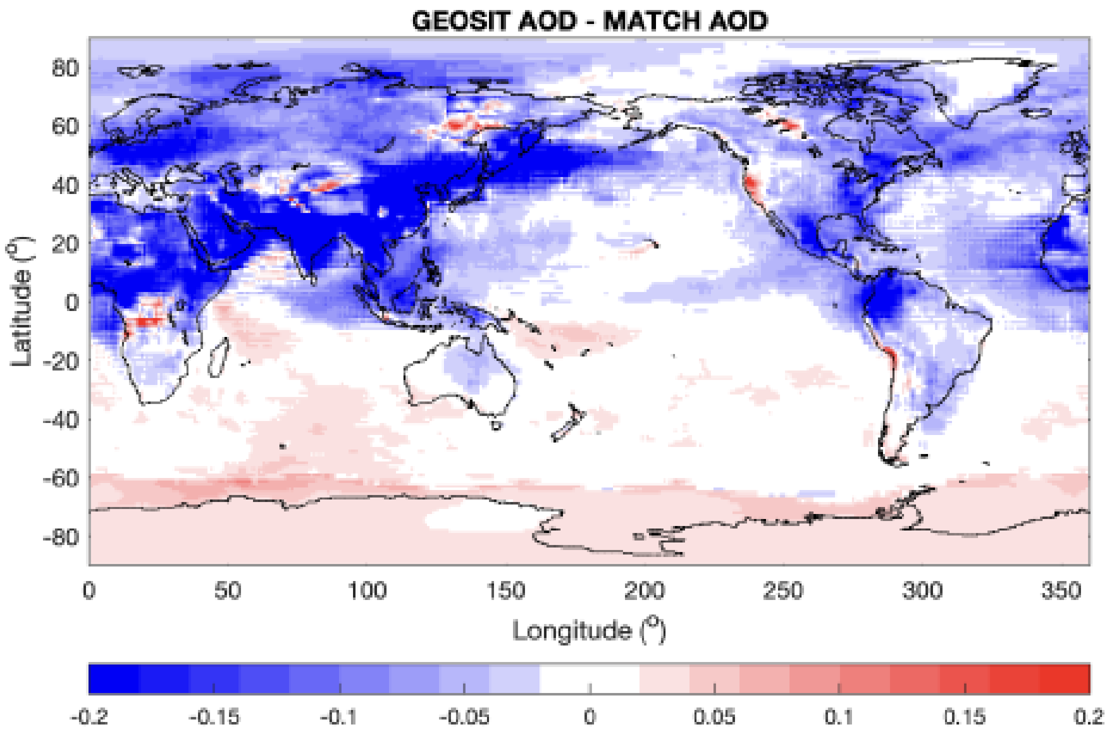
Global mean aerosol optical thickness produced with CORe input is smaller.
The input file for April 2026 will be adjusted so that aerosol optical thickness difference will be smaller

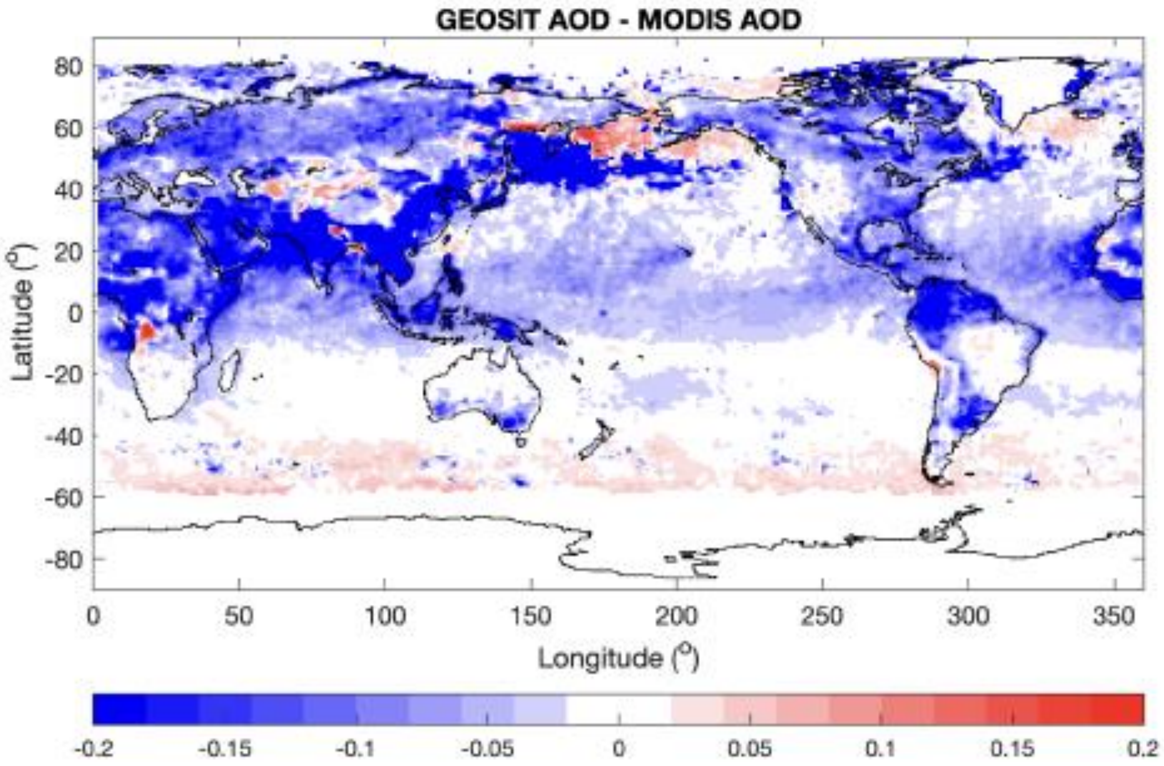
Edition 5 aerosols

GEOS-IT aerosol

- Mixing ratios of aerosol spices are converted to optical properties (extinction coefficients, single scattering albedo, and asymmetry parameter) using GMAO's optical property files.
  - Longitude: 288, latitude: 180, levels: 24
- Optical property files by aerosol species are combined and 3 hourly optical property files by wavelength (14 bands shortwave and 12 bands longwave) are generated.

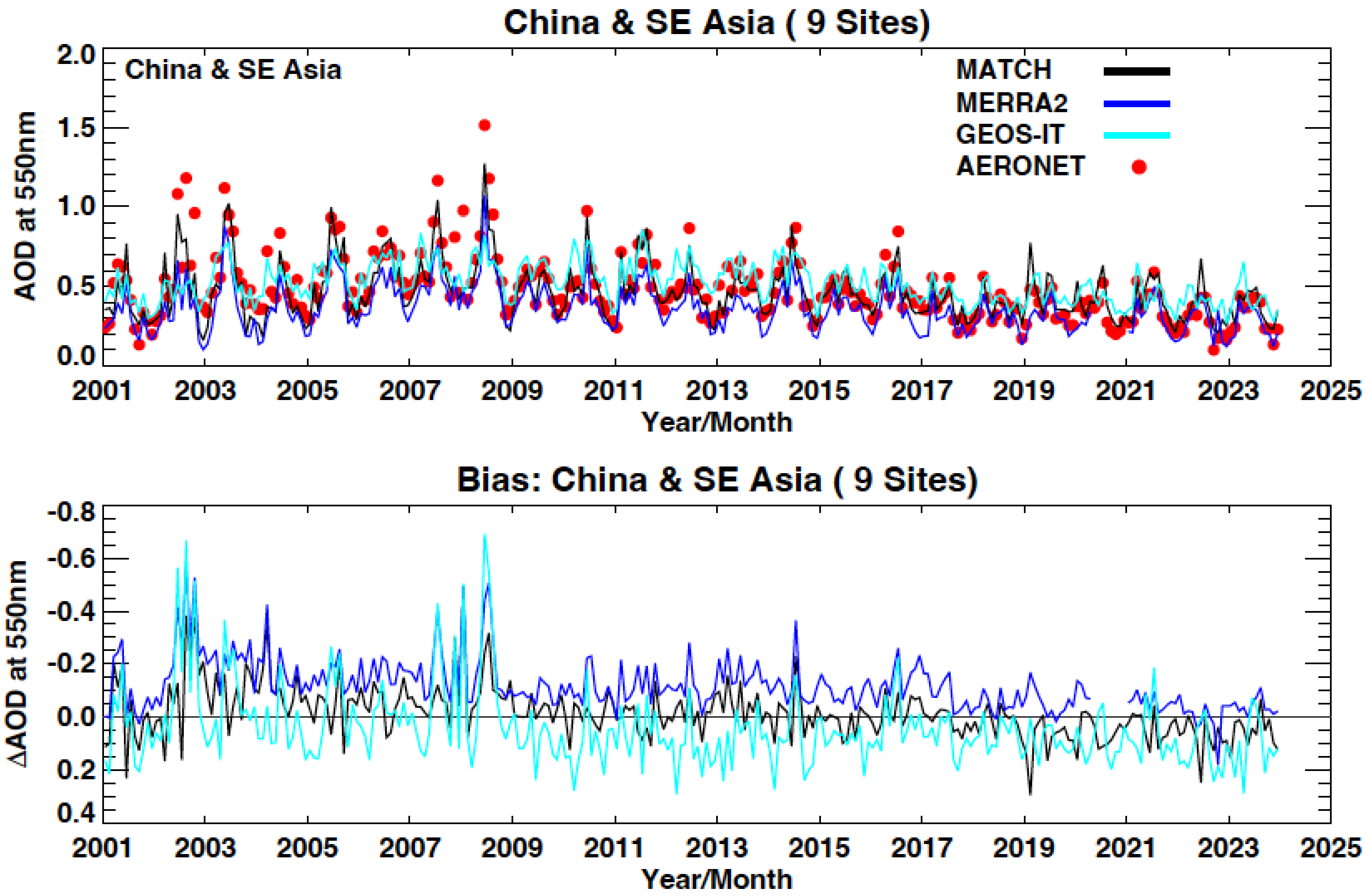
GEOS-IT versus Ed4 MATCH aerosol optical thickness for July 2008



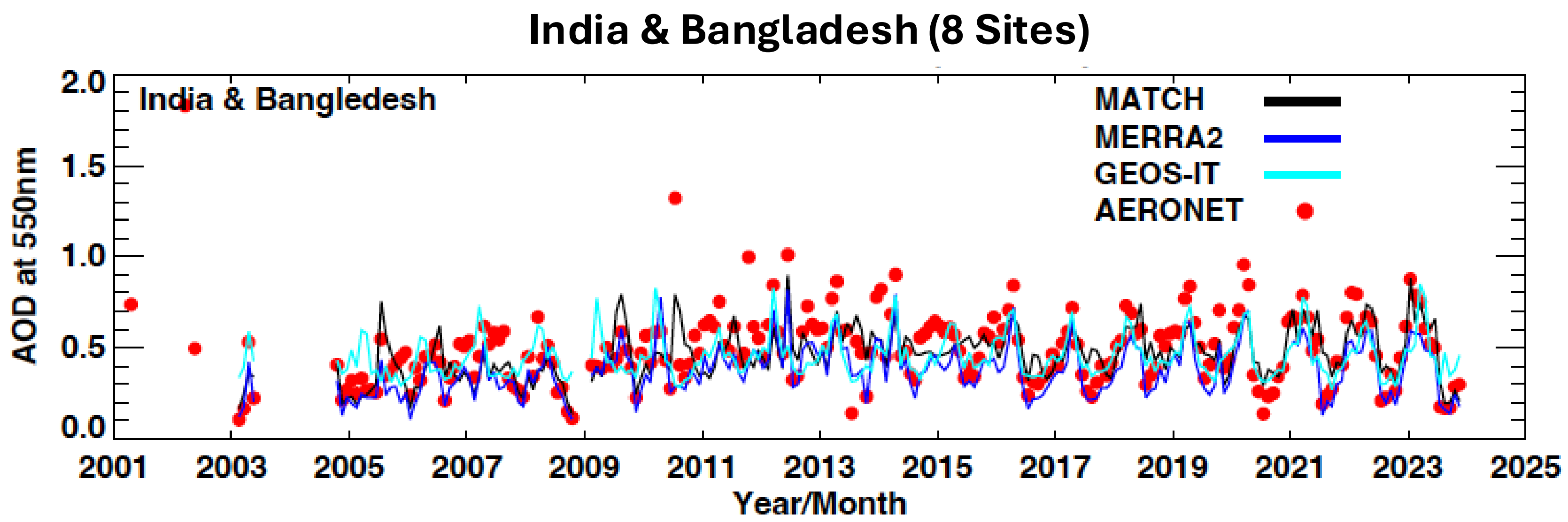


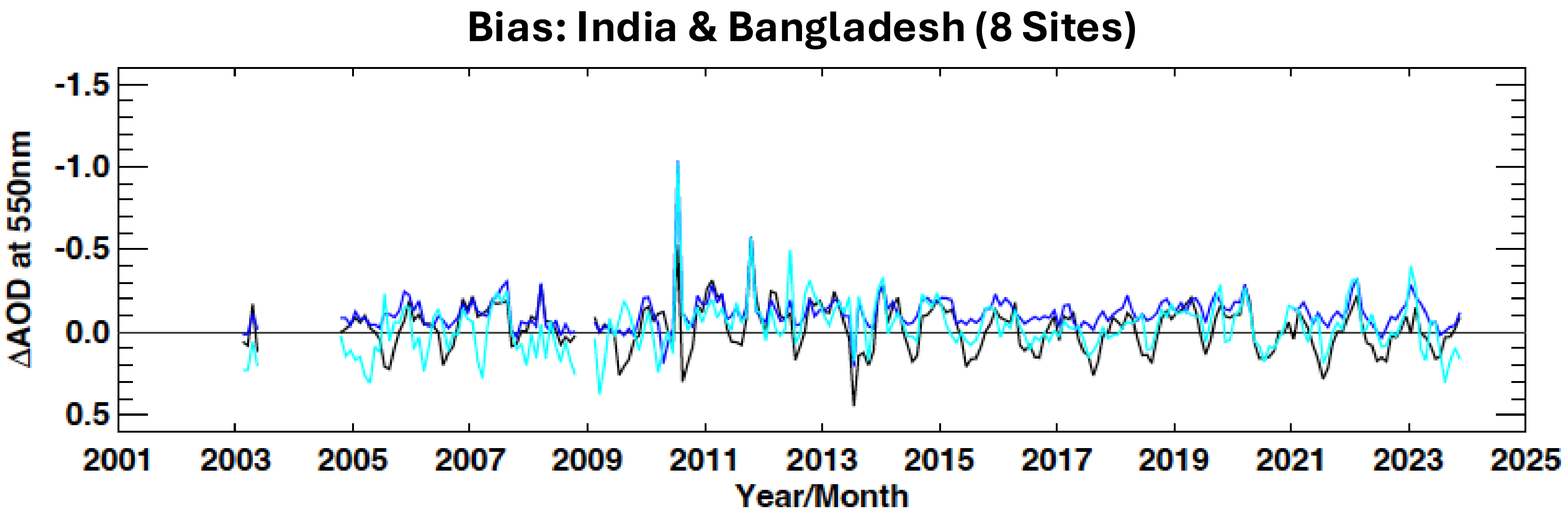
GEOS-IT aerosol optical thicknesses are smaller than MATCH aerosol optical thickness, especially over land

Comparison with AERONET: China & SE Asia



Comparison with AERONET: India & Bangladesh



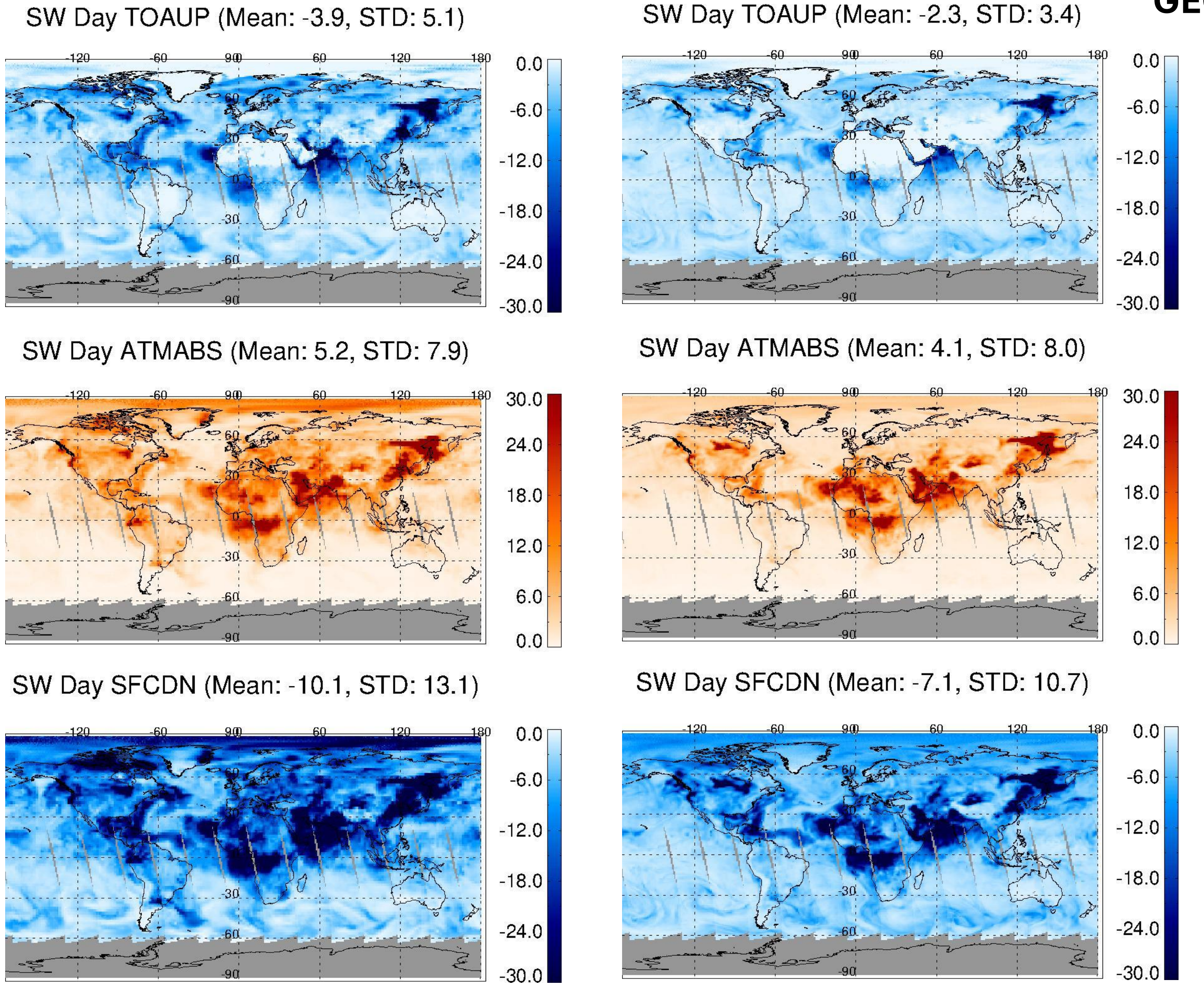


Clear-sky Southwest Direct Aerosol Radiative Effect (DARE) corrected using the monthly diurnal integration of F0

Clear – Pristine Aqua 2008070101

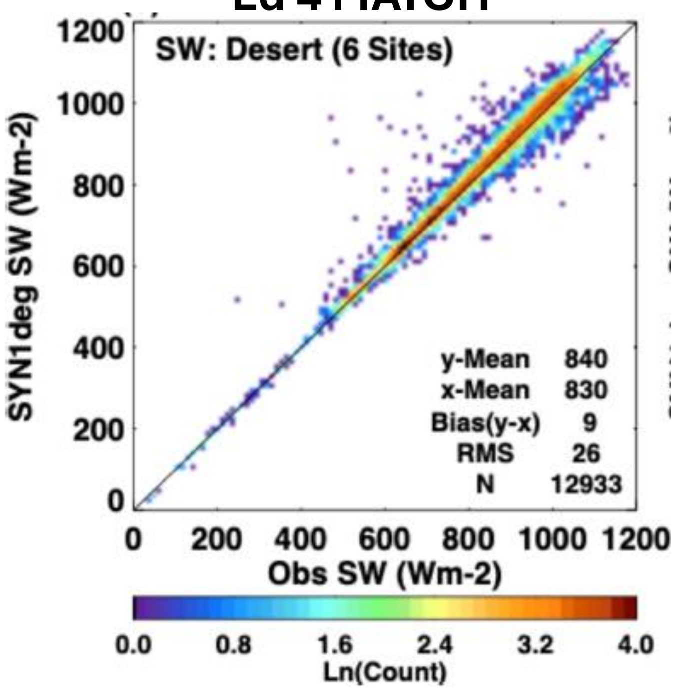
MATCH Aerosol

GEOSIT Aerosol



Smaller direct aerosol radiative effects are consistent with smaller aerosol optical thickness than MATCH

Ed 4 MATCH

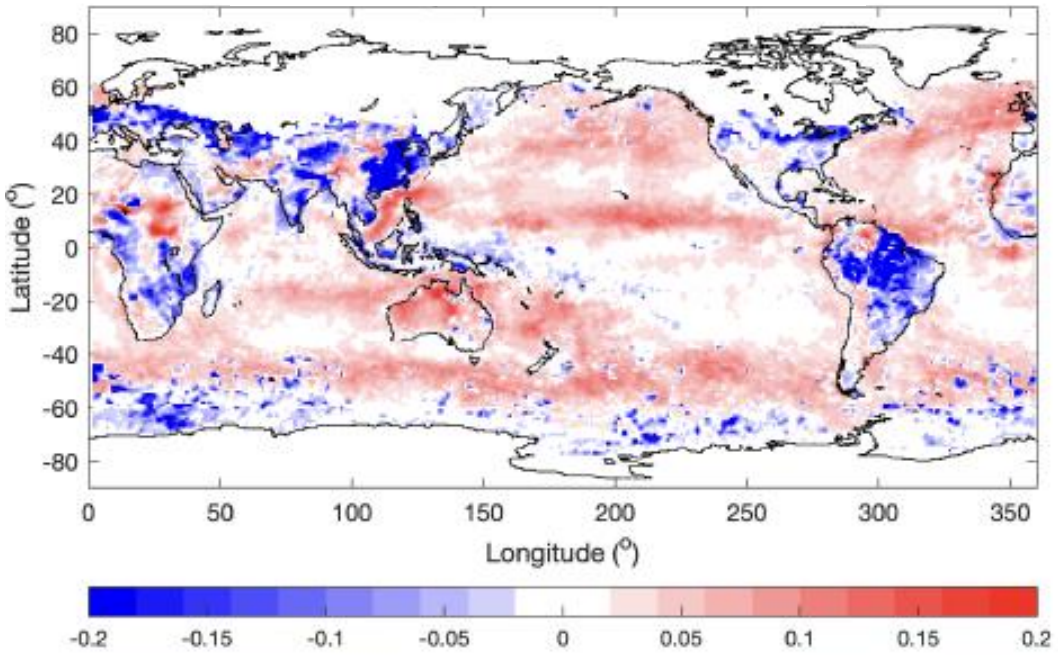


Fillmore et al. 2022 ACP

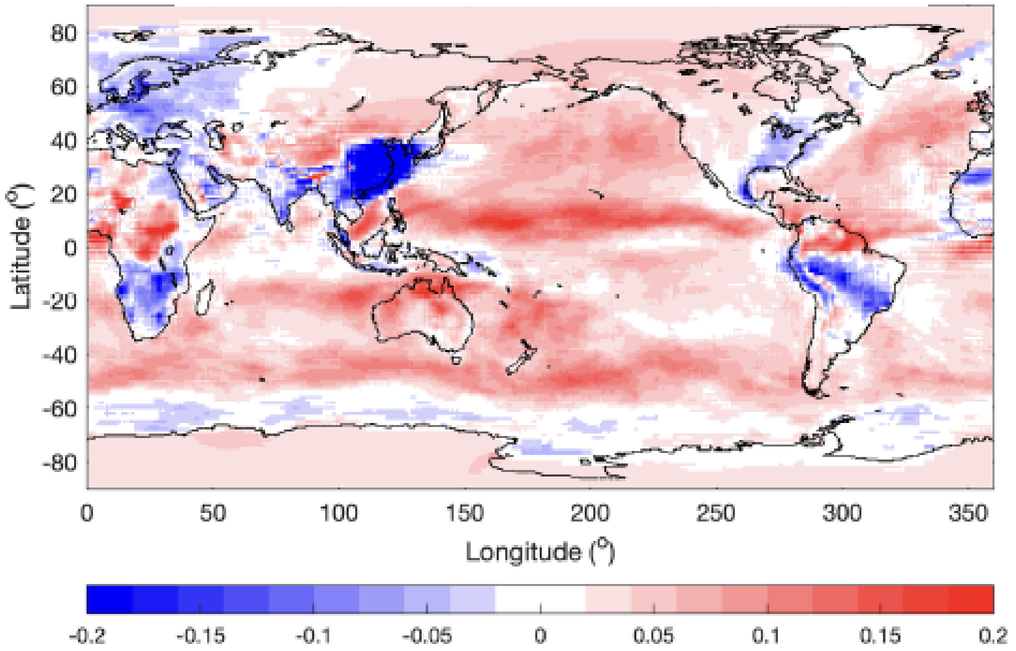
Ed5 CERES Model for Atmospheric Transport and Chemistry (MATCH) aerosol optical thickness (AOT), January 2008

Ed5 MATCH assimilates MODIS and VIIRS AOT produced by the MODIS dark target and deep blue teams.

Ed5 C-MATCH – MODIS AOT



Ed 5 C-MATCH – Ed 4 MATCH AOT



Sea salt optical thickness might be too large

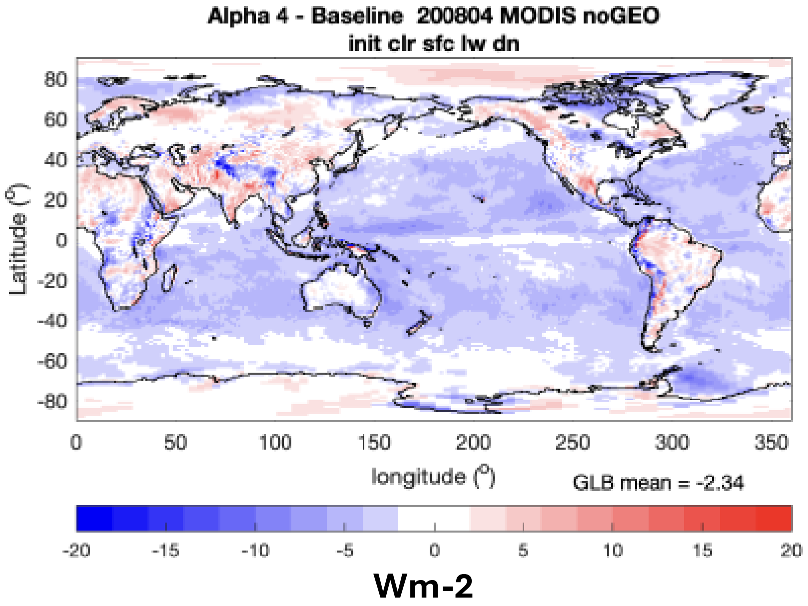
Alpha 4 SYN1deg-Month

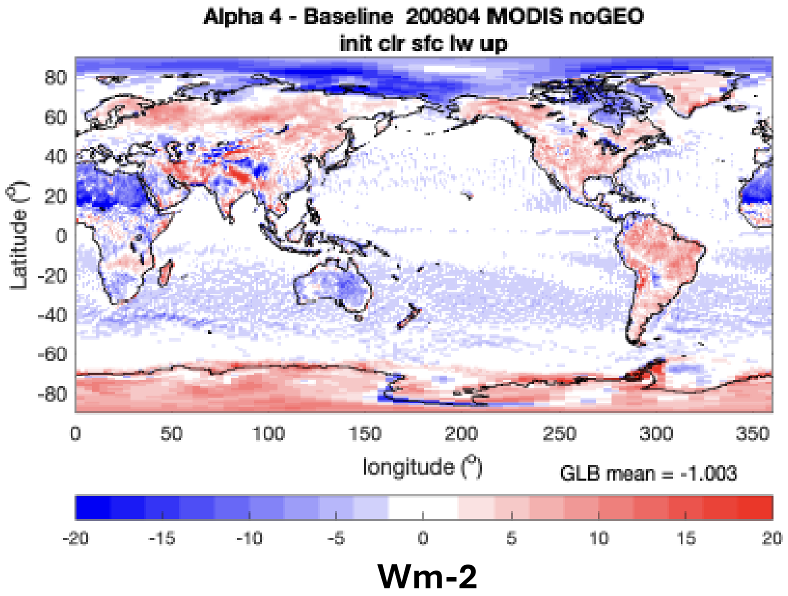
- Edition 5 Alpha 4 cloud properties (Aqua MODIS and GEO)
  - Run both GEO and noGEO.
- ERA5 temperature and humidity
- Edition 4 aerosols (MATCH)
- Edition 5 Surface albedo history map
- Ed4 radiative transfer model (Langley Fu-Liou)

SYN1deg Alpha 4 (Edition 5) versus Baseline (Edition 4) Longwave up and downward irradiances

Clear-sky

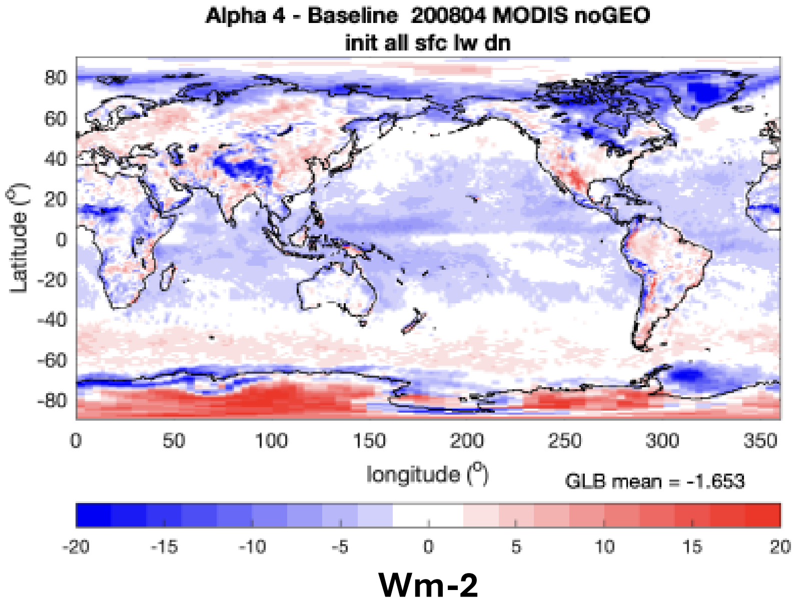
ERA5 provides smaller LW down

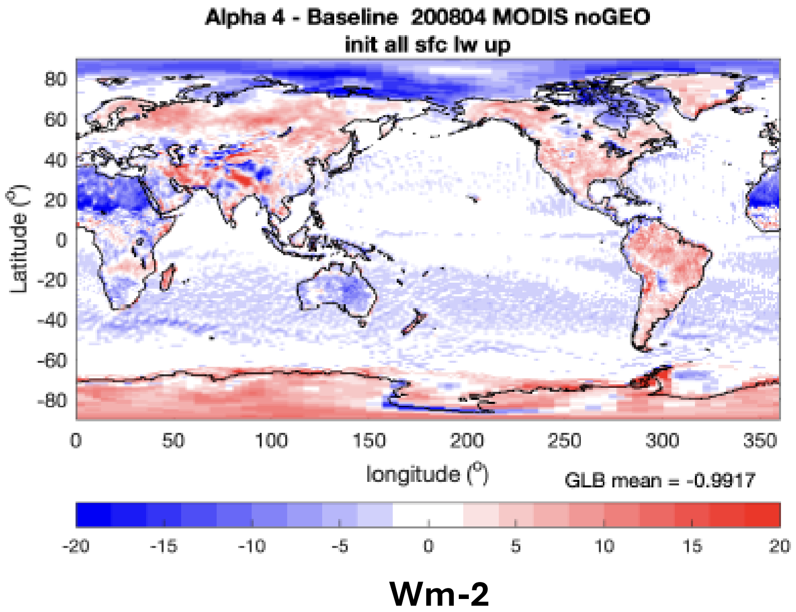




Alpha 4 LW up over land is larger than Ed4

All-sky





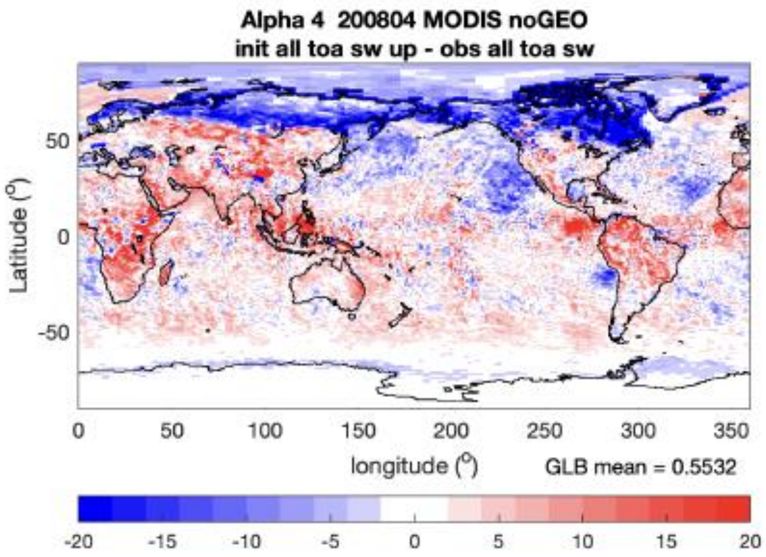
TOA irradiances, computed versus observed

Alpha 4 – Obs.

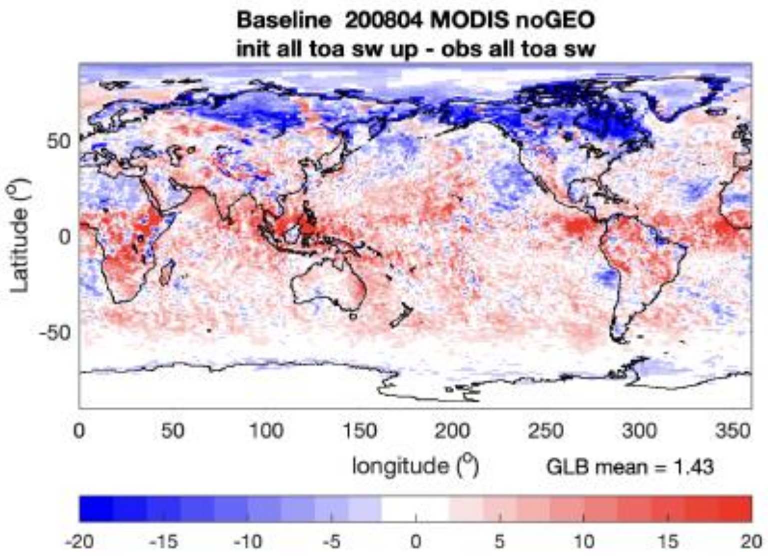
Ed4 – Obs.

Shortwave up

Smaller differences over ocean

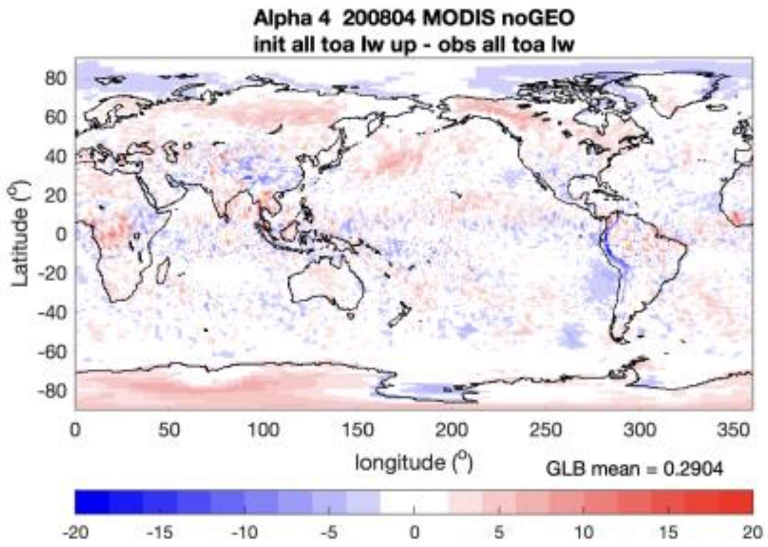


Wm-2

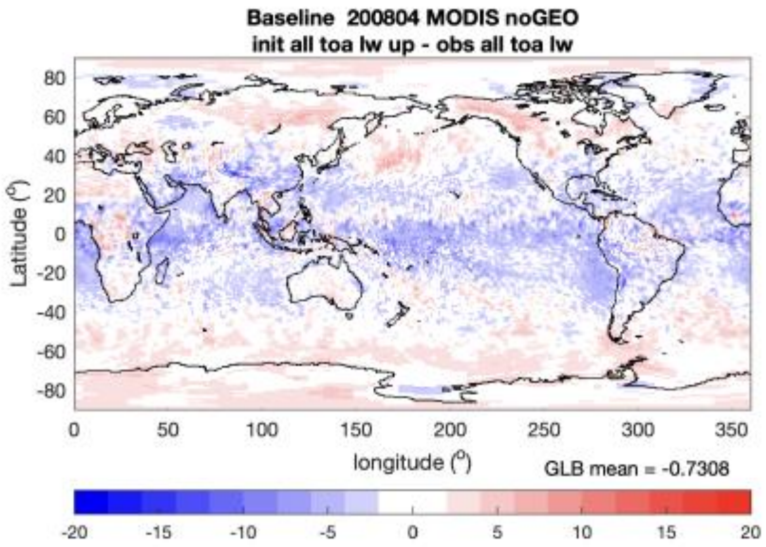


Wm-2

Longwave up



Wm-2



Wm-2

SYN1deg-Month noGEO Alpha4 vs baseline, global mean irradiances in Wm^{-2}

	200801 Aqua		200804 Aqua		200807 Aqua		200810 Aqua		202004 Aqua		202004 NOAA20	
	Alpha4	Baseline	Alpha4	Baseline	Alpha4	Baseline	Alpha4	Baseline	Alpha4	Baseline	Alpha4	Baseline
TOA SW Comp.-Obs.	-0.04	0.86	0.55	1.43	0.95	1.48	0.58	1.31	0.89	1.09	-0.34	2.21
TOA LW Comp. - Obs.	0.29	-0.67	0.29	-0.73	0.26	-1.01	0.01	-1.27	0.82	-0.93	1.31	-1.93
All-sky Sfc SW dn		2.99		3.12		2.74		2.92		3.17		6.65
All-sky Sfc SW up		0.94		0.99		1.24		0.84		1.68		2.05
All-sky Sfc LW dn		-1.56		-1.66		-1.65		-2.20		-1.03		-1.67
All-sky Sfc LW up		-0.81		-0.99		-0.42		-1.02		-1.05		-1.05
Clear-sky Sfc LW dn		-2.02		-2.34		-2.58		-2.51		-1.83		-1.78
Clear-sky Sfc LW up		-0.82		-1.00		-0.44		-1.03		-1.06		-1.05

Surface irradiance differences are Alpha 4 irradiances minus Baseline irradiances

CRS presentation

Level 2 CRS Flux Algorithm

Inputs

Atmospheric Profiles	Reanalysis p(z), T(z), q(z), and O_3(z)
Surface	Surface Skin Temperature Surface Emissivity Surface Albedo
Clouds	Clouds retrieved from satellite imagers
Aerosol	Satellite and assimilated aerosol properties

↓

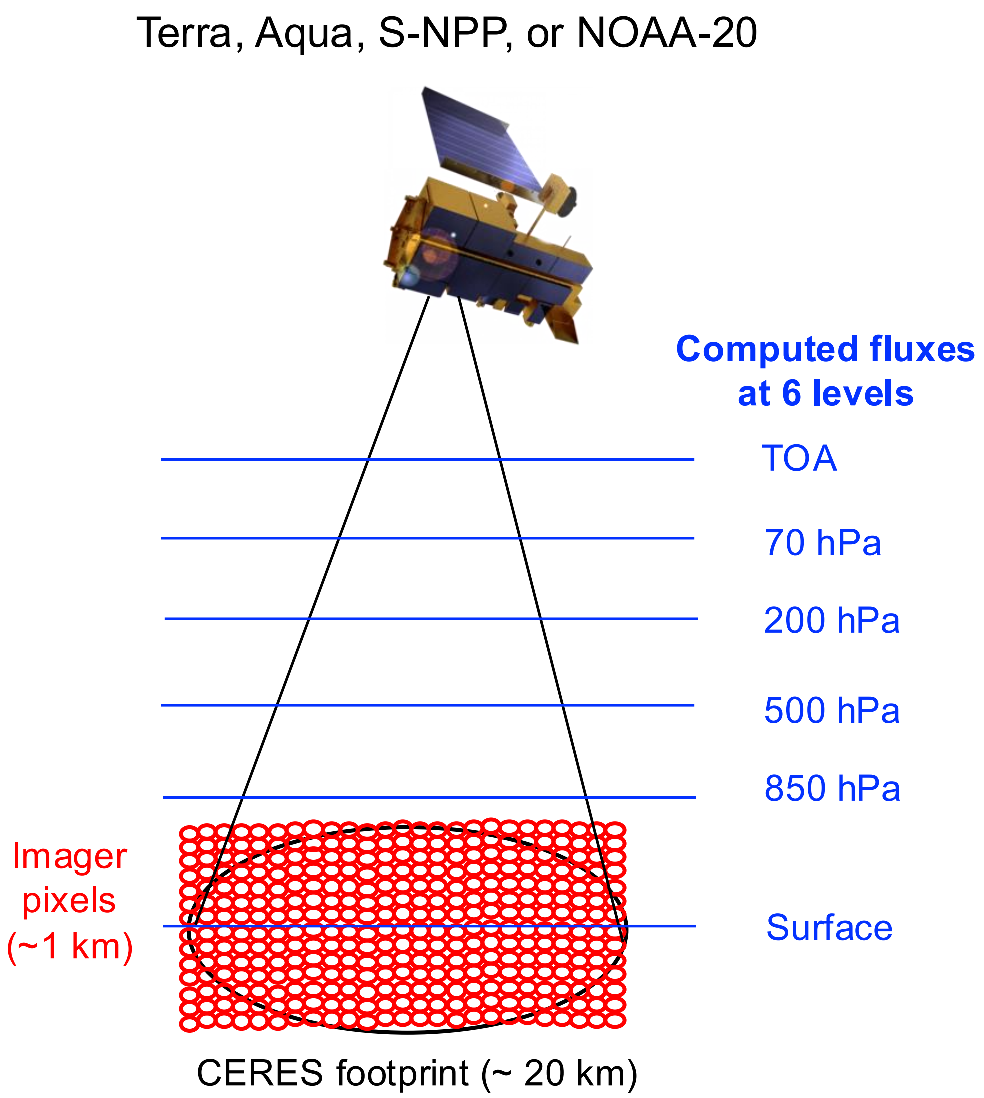
Fu-Liou Radiative Transfer Model

Four Conditions:

Total Sky	(Aerosol o Clouds o)
Clear Sky	(Aerosol o Clouds x)
No Aerosol	(Aerosol x Clouds o)
Pristine	(Aerosol x Clouds x)

↓

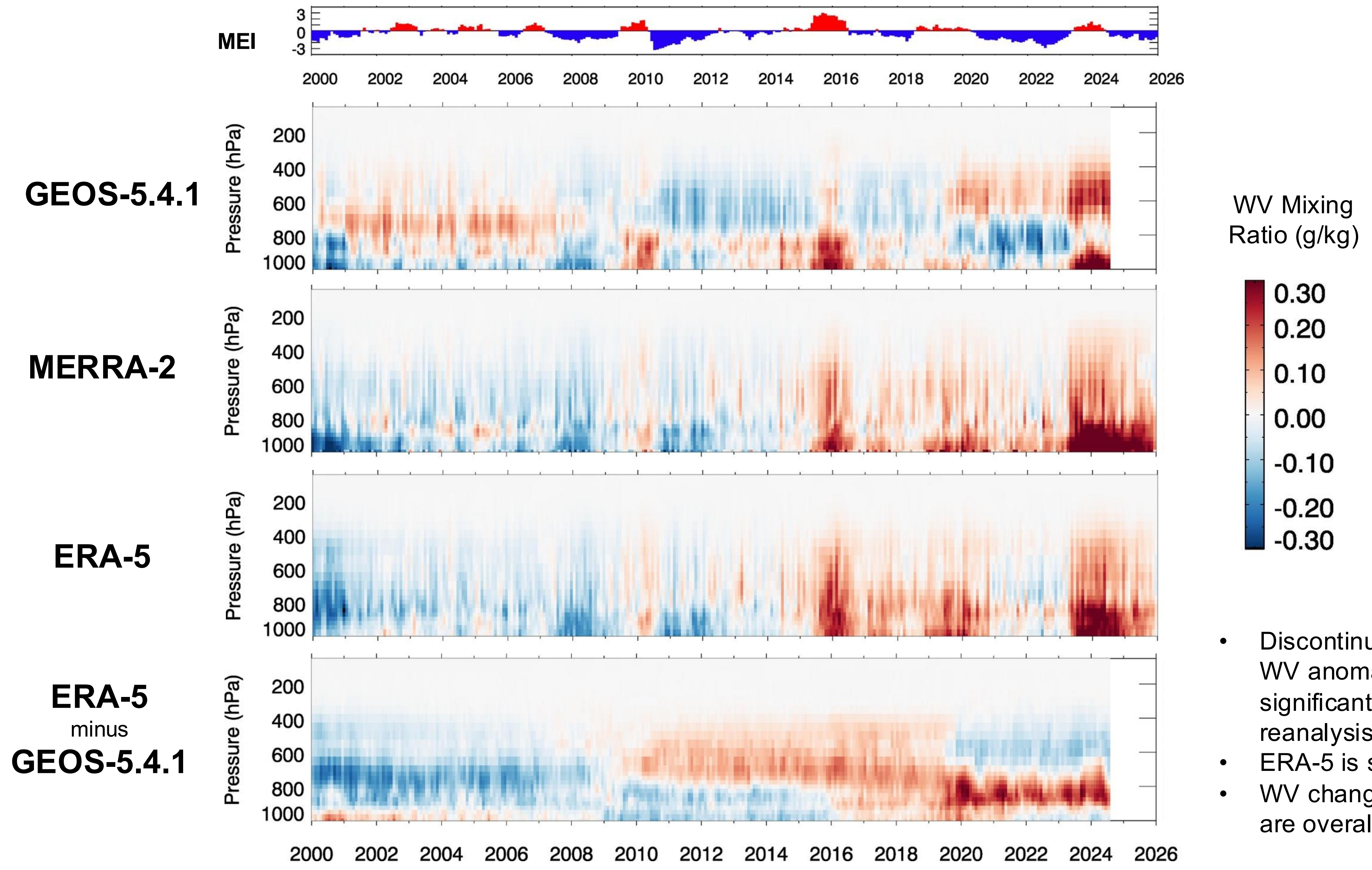
Computed Instantaneous Fluxes at 6 vertical levels for every CERES footprint



Updates in the CRS Algorithm

- T & q properties (GEOS-5.4.1 to ERA-5)
  - ✓ Better diurnal cycle of surface temperature in ERA-5 (cold bias during daytime and warm bias in nighttime over desert regions)
  - ✓ UTH biases and WV discontinuities in GEOS-5.4.1 can be improved by ERA-5
- Better surface albedos over sea ice and snow-covered regions
  - ✓ Use ground (MOSAiC and ARCSIX) measurements to understand the spectral albedos of sea ice and snow surface.
  - ✓ Use the MODIS/VIIRS BRDF model to identify snow-covered sea ice.
  - ✓ Check the absolute BB albedo value to determine whether it is bare ice or snow-covered ice
- Aerosol properties (Seiji's talk in the CERES STM)
  - ✓ MATCH (aerosol chemistry transport model) → GEOS-IT (reanalysis) aerosol
- Ed5 Cloud properties (CWG talk in the CERES STM)
  - ✓ New scattering properties of ice cloud particles (Two-habit model; THM)
  - ✓ NN cloud algorithm
- Ed5 Fu-Liou radiative transfer model
  - ✓ Increased SW bands (18 → 32 bands for SW)
  - ✓ Better cloud forward scattering features by using 4 moments of the cloud scattering phase functions
  - ✓ Updated gas absorption properties
  - ✓ Minor bugs are fixed

WV Anomaly (g/kg) Time Series (Climatology from 2000-2023) (60°S-60°N Ocean)

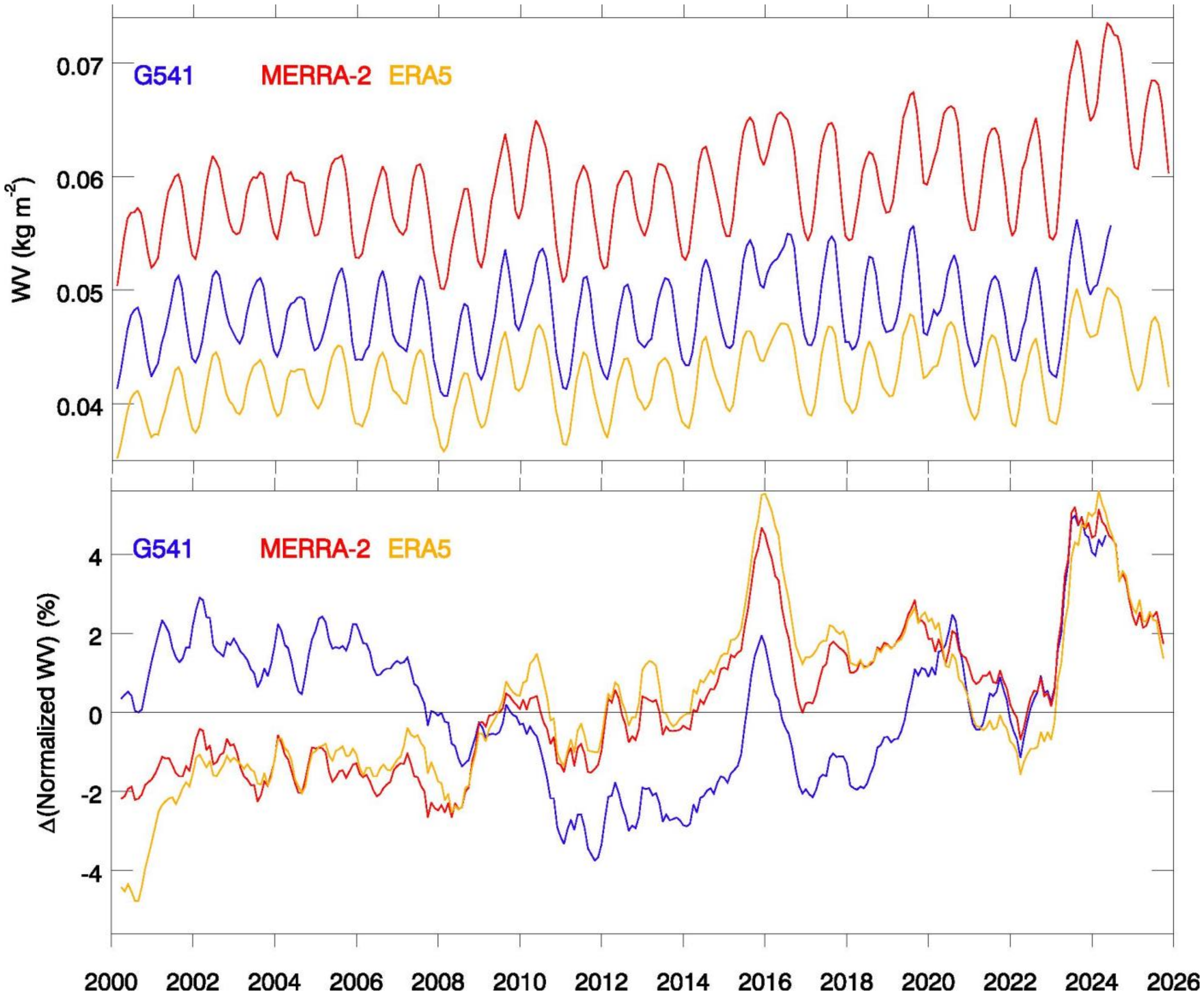


- Discontinuities existed in the G541 WV anomalies, which were significantly different from other reanalysis datasets.
- ERA-5 is similar to MERRA-2
- WV changes from G541 to ERA5 are overall significant.

WV Time Series (60°S-60°N Ocean)

Absolute WV
at TOA – 250 hPa
(3-month running means)

Anomalies of WV
at 500-800 hPa
(6-month running means,
2000-2023 climatology)



- Upper tropospheric humidity (TOA-500 hPa) biases appeared in the G541 dataset are improved by using ERA5.
- Discontinuities appeared in the G541 WV anomalies are improved by ERA5.

CRS TOA LW Biases for Cloud-Free (CF < 1%) Footprints

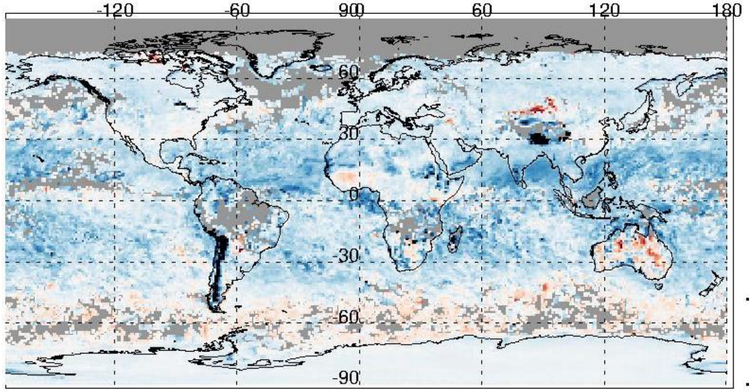
Ed4

Preliminary Ed5

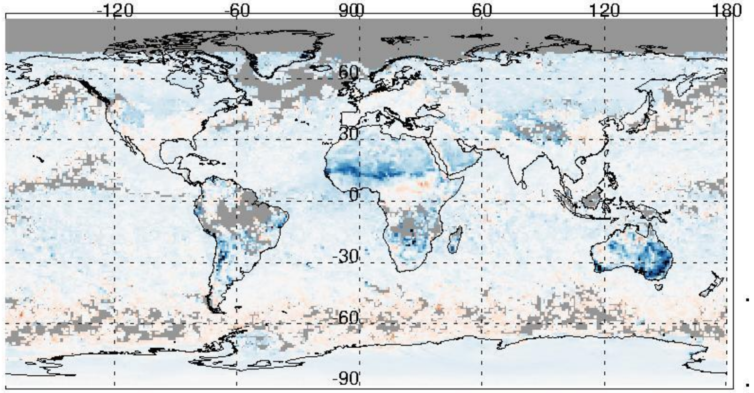
Ed5 - afterNNsz75Tau-sz90NiteTau

Day

LW Day Sim - Obs (Mean: -4.12, STD: 4.48)

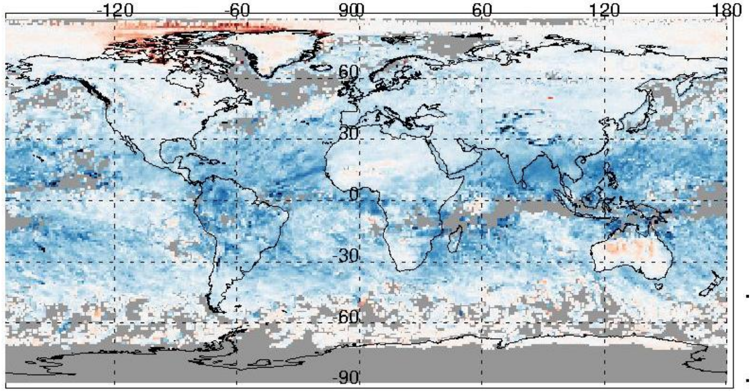


LW Day Sim - Obs (Mean: -1.61, STD: 2.52)

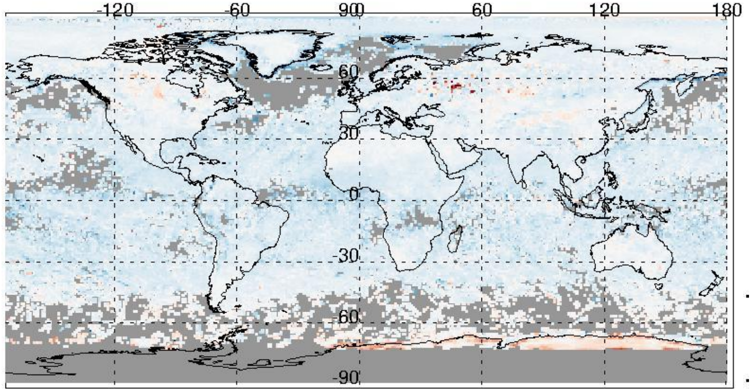


Night

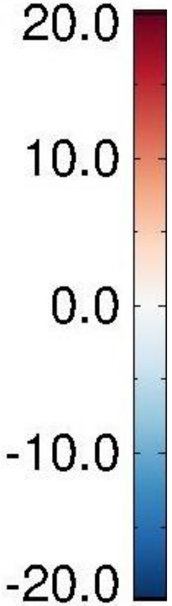
LW Ngt Sim - Obs (Mean: -5.20, STD: 4.16)



LW Ngt Sim - Obs (Mean: -2.12, STD: 2.03)



TOA LW Bias ($W\ m^{-2}$)



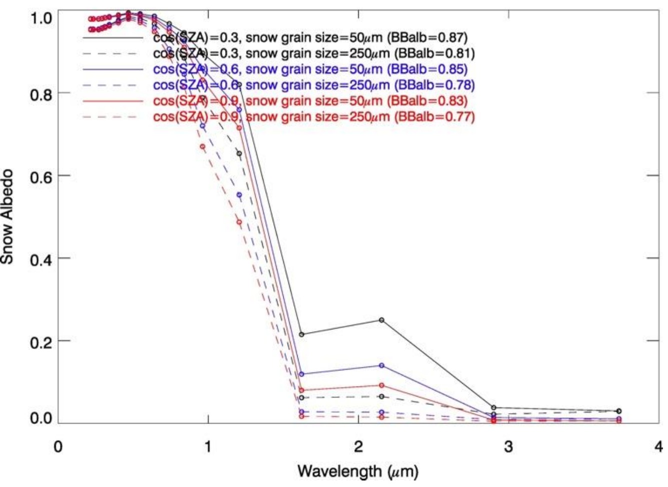
- UTH issues (too moist) in G541 caused negative LW TOA biases in the Ed4 CRS product, which is improved by ERA5.
- The new Ed5 Fu-Liou model gives smaller LW TOA Upward fluxes by 1 $W\ m^{-2}$, compared to the Ed4 Fu-Liou model for the same humidity/temperature profiles.

Surface Albedo Assumptions over the Polar Regions

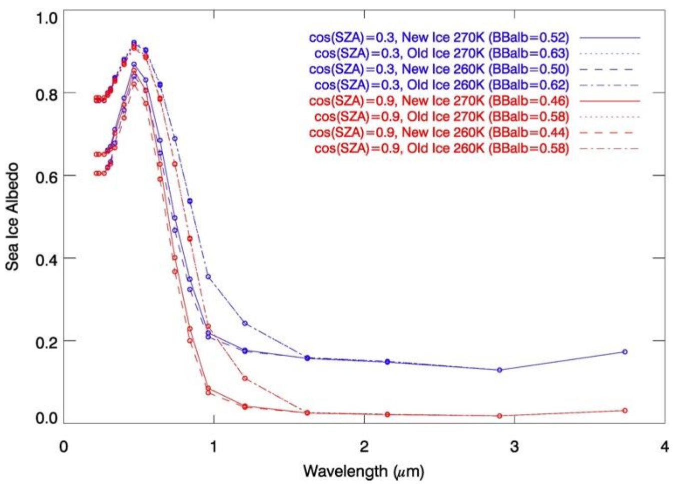
- Spectral features of sea ice and snow albedos are quite different, particularly around around 1 µm. In the Ed4 CRS algorithm, snow and sea ice spectral albedos are described by Jin's albedo model.
- The spectral albedo values are normalized by the "observed" broadband (BB) surface albedo from MODIS/VIIRS or CERES clear-sky measurements.
- If the wrong spectral albedo values are assumed, we cannot get the right flux values, even with the normalizing process using the observed BB albedo.

Jin's Snow/Ice Albedo Model Used in the Ed4 CRS Algorithm (2008)

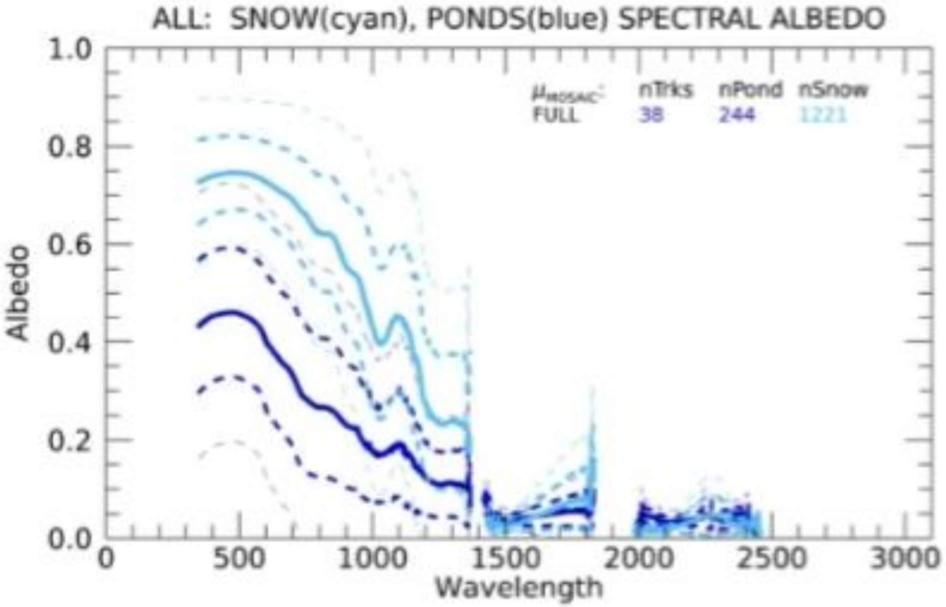
Snow Albedo



Sea Ice Albedo



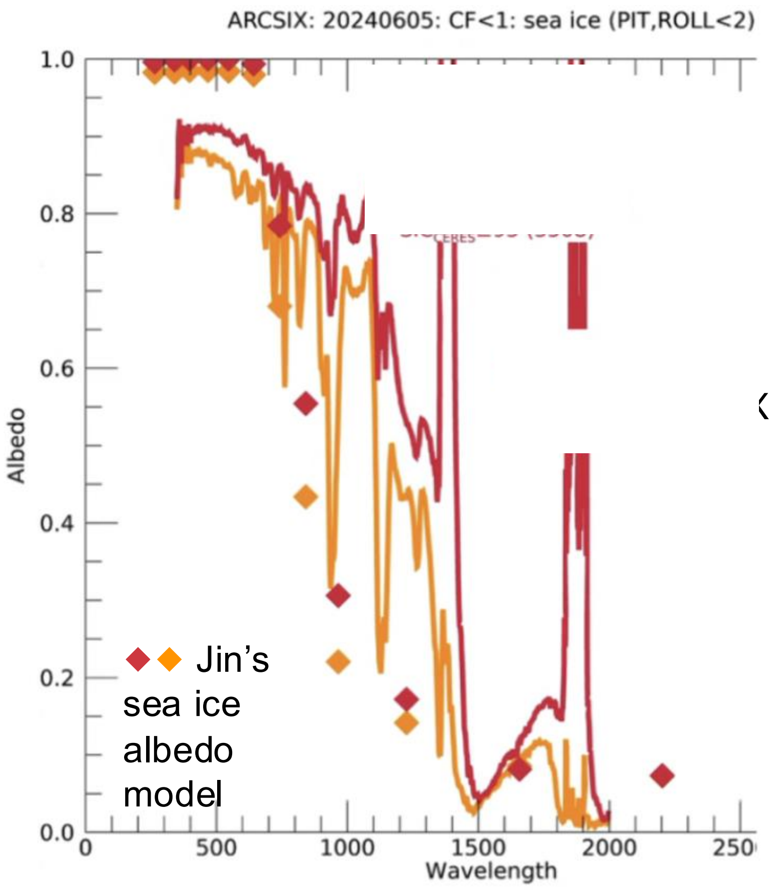
MOSAiC Measurements

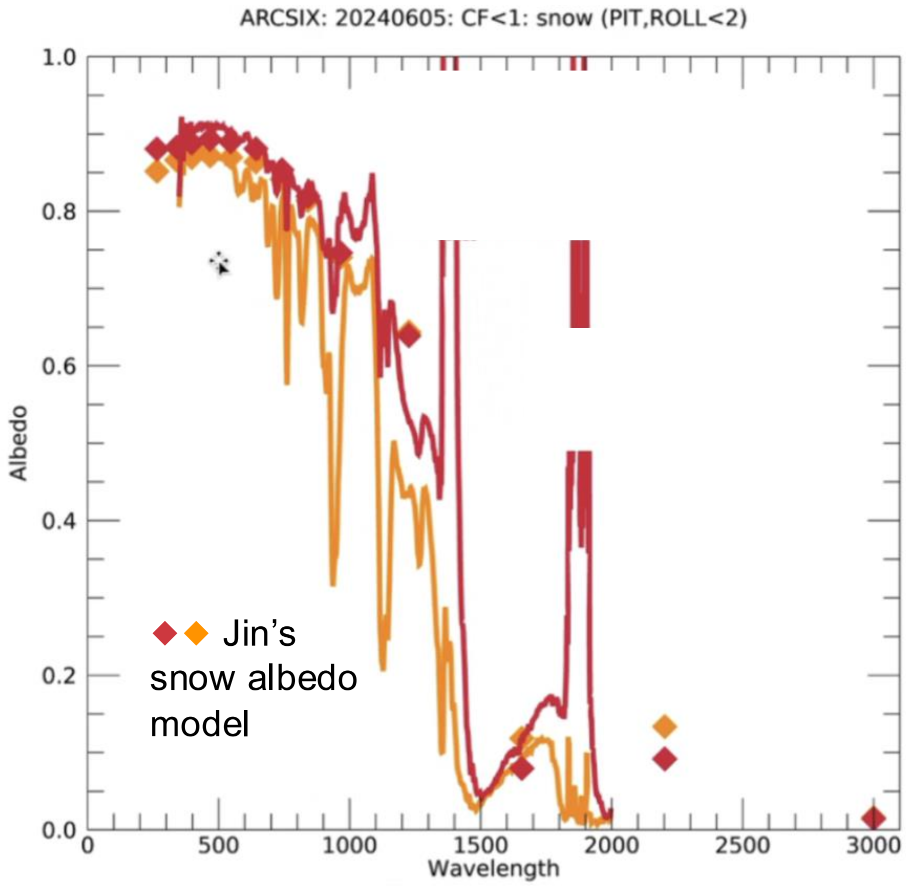


Understanding Spectral Albedo Using ARCSIX Measurements

ARCSIX included two aircraft deployment periods. Flights during the spring deployment took place between 28 May and 14 June 2024. The summer deployment flights took place between 25 July and 16 August 2024.

80% ≤ SIC < 95%
SIC > 95%





- During the pre-melt season (early June), the measured spectral albedo values are close to Jin's snow model since the sea ice is likely to be covered by snow. In other words, even if the surface type is classified as sea ice, if it is covered by snow, we'd better to use snow albedo model.

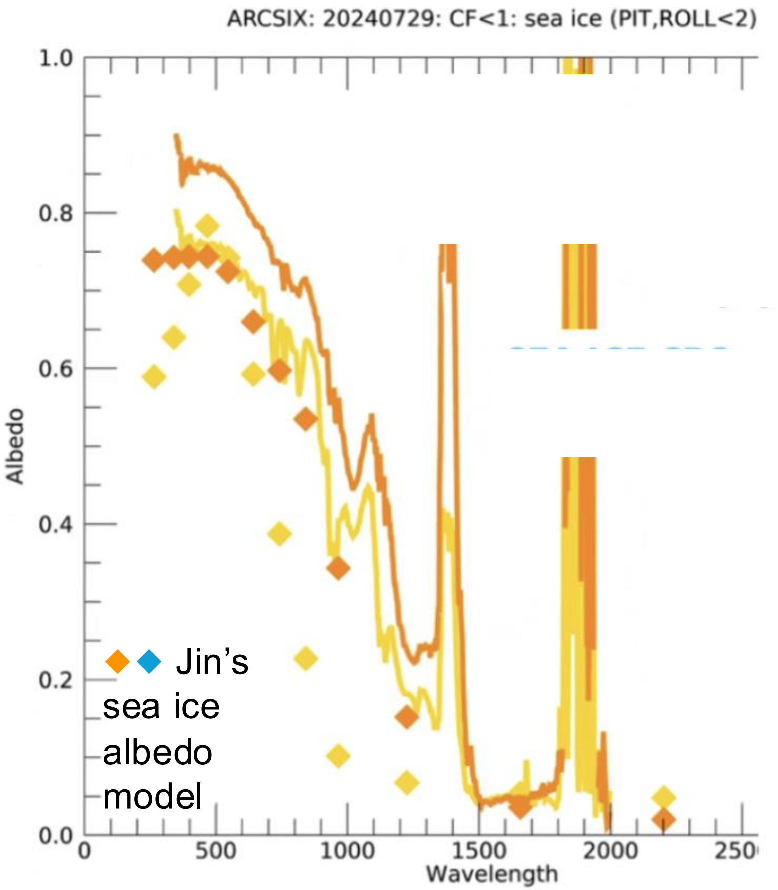
Understanding Spectral Albedo Using ARCSIX Measurements

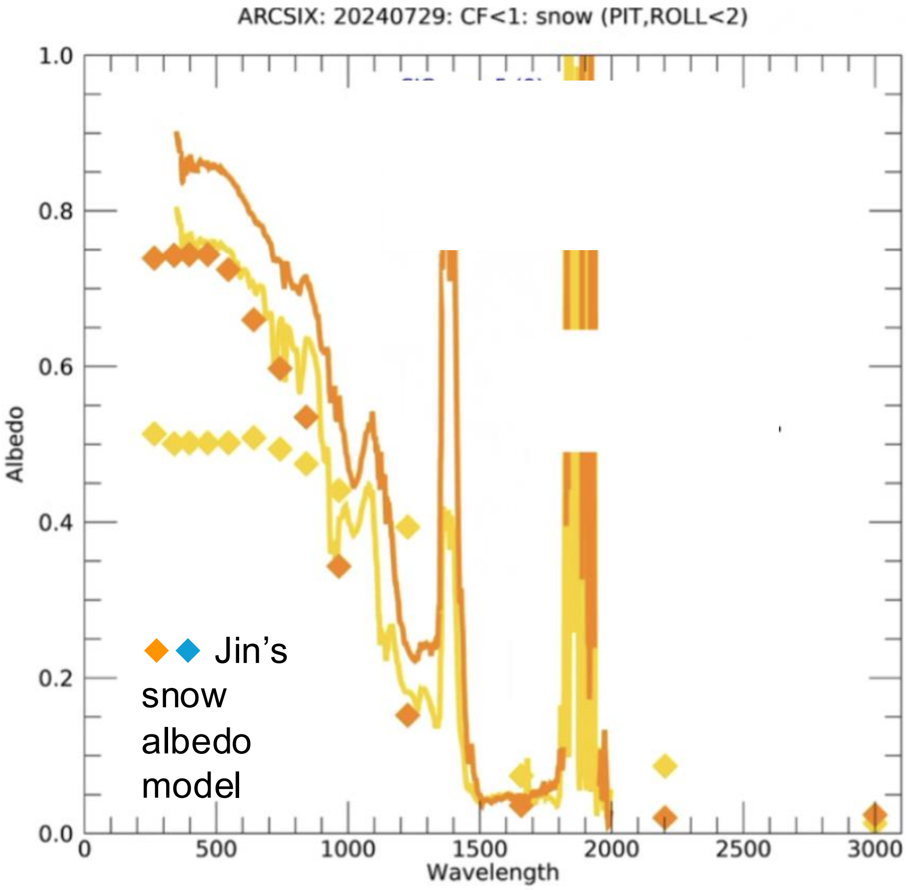
ARCSIX included two aircraft deployment periods. Flights during the spring deployment took place between 28 May and 14 June 2024. The summer deployment flights took place between 25 July and 16 August 2024.

60% ≤ SIC < 80%

80% ≤ SIC < 95%

—— —— ARCSIX

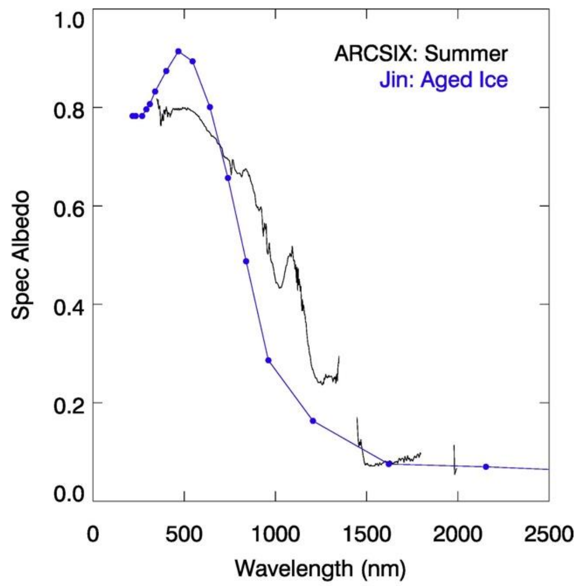


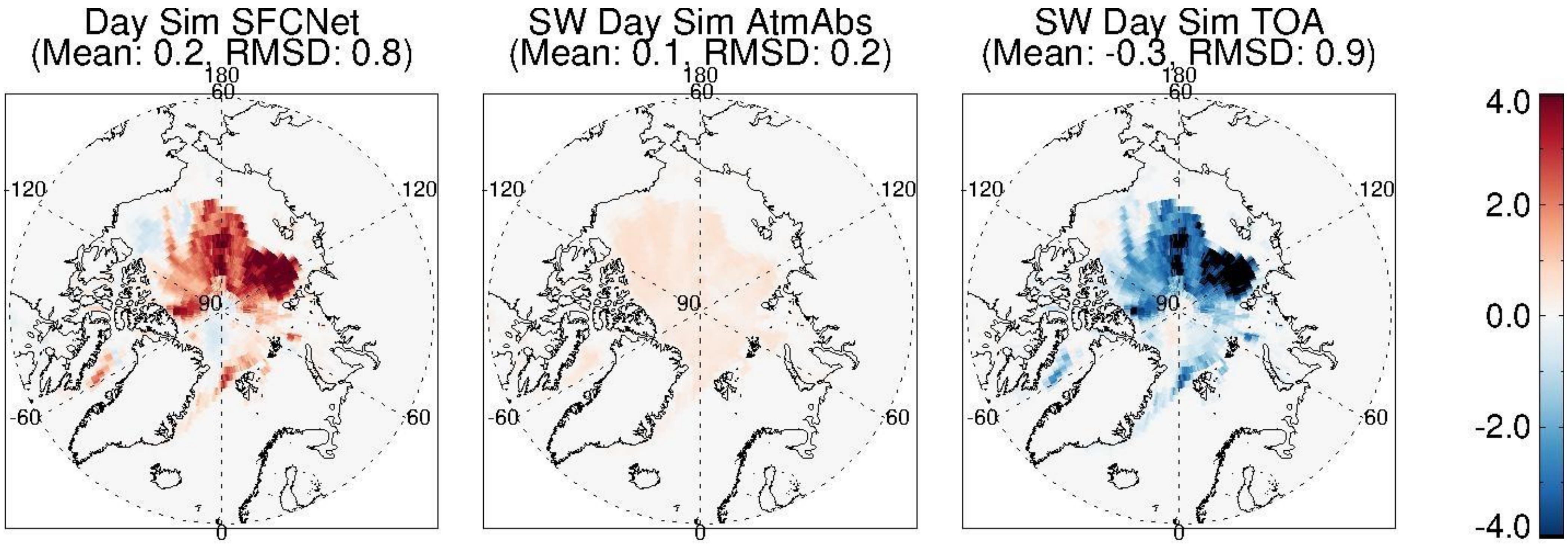


- During the melting season (late July), sea ice coverage (SIC) drops, and it is likely to be bare sea ice (without snow). The measured ARCSIX spectral albedo is getting close to the Jin's sea ice model rather than Jin's snow model, but there are also differences around 1 μm. The spectral albedo assumption can be improved if we can take information from the ARCSIX measurements for the bare sea ice cases.

Impact of Implementing ARCSIX Sea Ice Spectral Albedo Instead of Jin's Spectral Albedo

- Jin's sea ice albedo model is different from ARCSIX measurements.
- With the keeping the broadband albedo, switching spectral shapes of the sea ice albedo can change surface radiation balance (increasing surface energy and decreasing outgoing solar radiation).

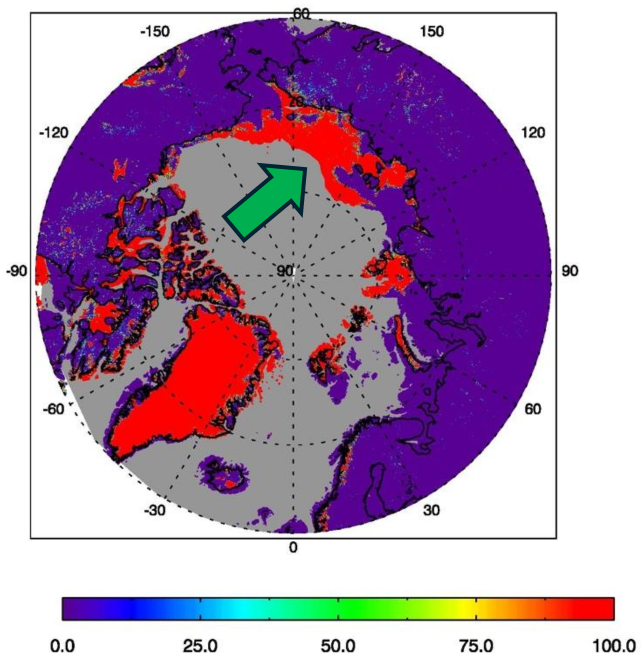




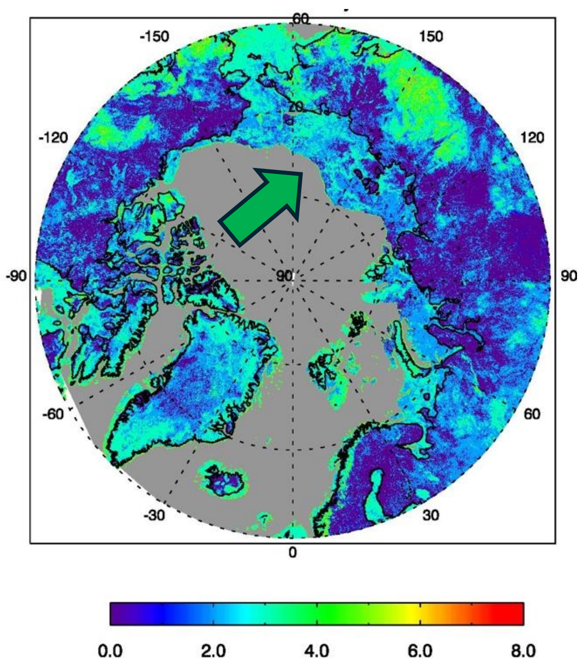
Additional Source (MODIS/VIIRS BRDF) for the Spectral Albedo for the Snow-Covered Sea Ice

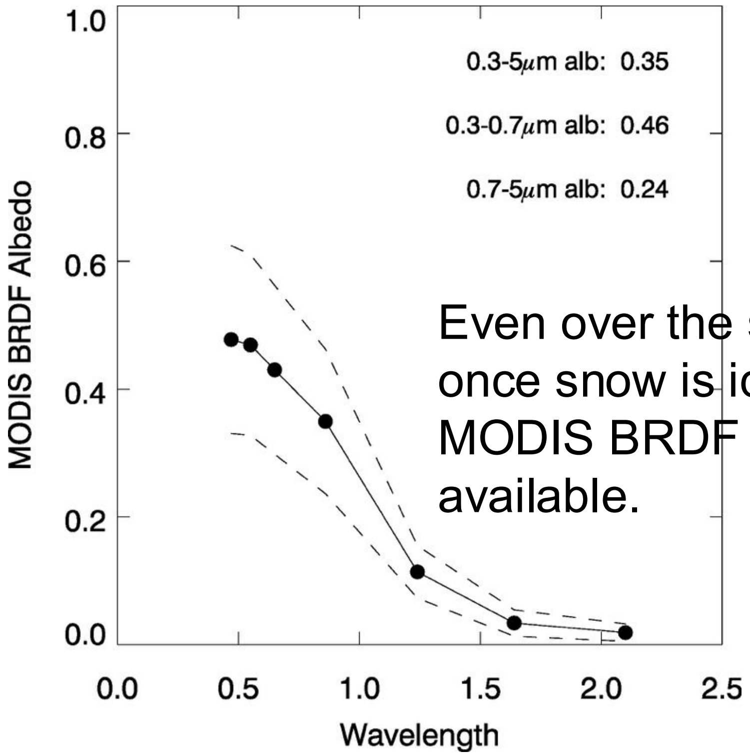
- For the given sea ice surface type, distinction between snow-covered and bare sea ice is critical in describing spectral surface albedos.
- MODIS/VIIRS BRDF product provides the observed spectral features of the surface albedo.
- The usage of the BRDF product was limited to land regions in the Ed4 CRS algorithm but it will be expanded to snow-covered region in Ed5. For example, the BRDF product is also available over snow-covered sea ice region.

Snow Coverage (%)



MODIS BRDF QA





Even over the sea ice, once snow is identified, MODIS BRDF is available.

TOA Biases (CRS Calculated minus CERES Observed) for Total Skies (All CERES Footprints)

Aqua 202001

- Ed4 clouds
- Ed4 surface properties
- GESO-5.4.1 T & q
- MATCH aer
- Ed4 Fu

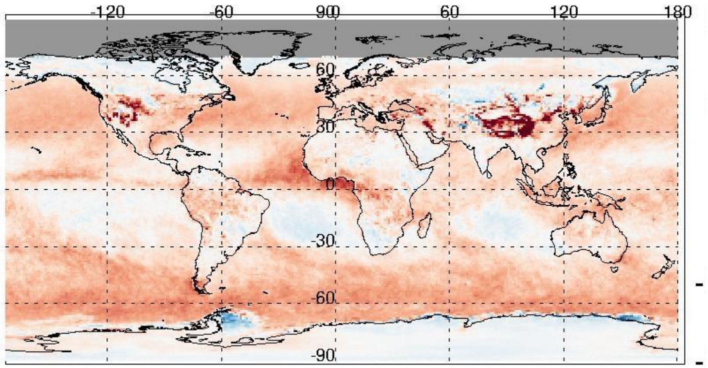
- Ed5 clouds
- Ed5 surface properties
- ERA-5 T & q
- MATCH aer
- Ed5 Fu

Ed4

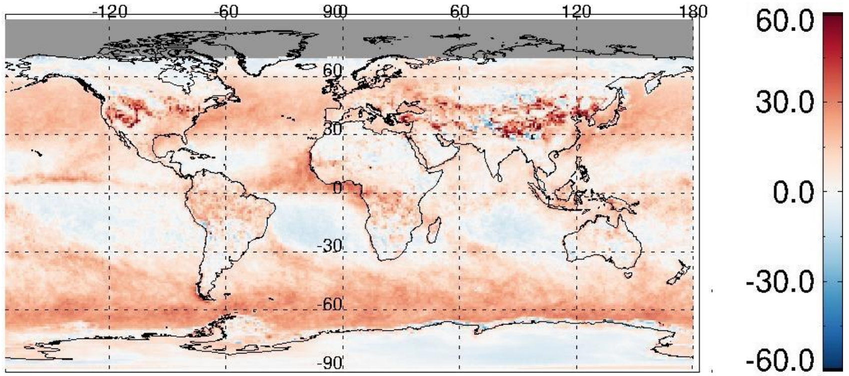
Preliminary Ed5

SW Day TOA Bias

SW Day Sim - Obs (Mean: 10.78, STD: 11.55)

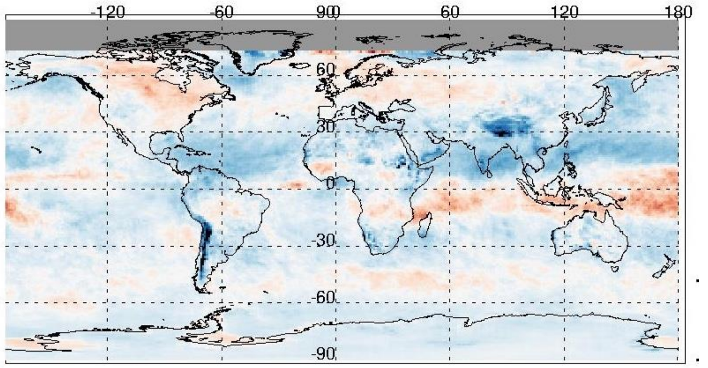


SW Day Sim - Obs (Mean: 9.02, STD: 9.98)

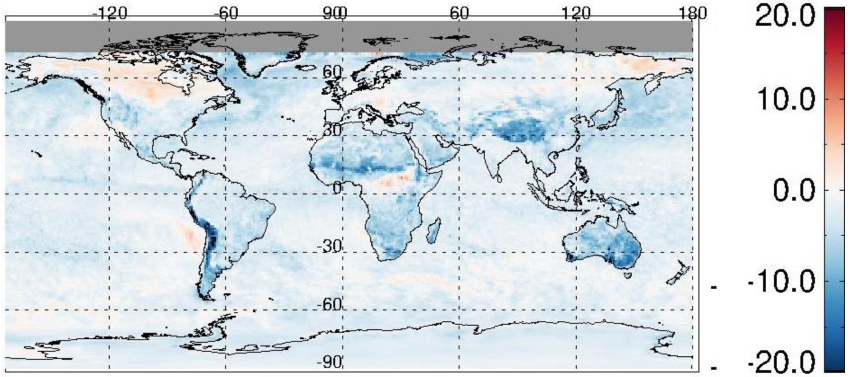


LW Day TOA Bias

LW Day Sim - Obs (Mean: -2.05, STD: 3.51)



LW Day Sim - Obs (Mean: -2.65, STD: 2.37)



- Both mean biases and RMSE are improved in the Ed5, compared to Ed4 CRS fluxes.
- Spatial distribution of the biases are more homogeneous in the Ed5 results.
- Positive SW biases are still persistent over the cloud regions.

Summary (CRS part)

- Clear-sky computed fluxes in the Ed5 CRS algorithm are improved by using better T(z) and q(z) profiles from the ERA-5 reanalysis dataset.
- For the sea ice surface type, distinction between the snow-covered and bare sea ice is critical in describing spectral shapes of sea ice.
- For bare sea ice, switching from Jin’s model to ARCSIX measurements give larger surface net fluxes.
- MODIS BRDF product can be used in identifying snow-covered ice from bare ice cases.
- Mean biases and RMSE in TOA SW and LW biases are overall improved in the Ed5 algorithm, compared to the Ed4 results.

Summary

- Input files used for Edition 4 MATCH were no longer available. MATCH model is run with new input files. Aerosol optical thickness discontinuities will be mitigated.
- The code to produce 3-hourly 3D aerosol optical properties was developed. Edition 5 CRS code can use GEOS-IT aerosols.
- Edition 5 MATCH assimilates MODIS and VIIRS aerosol optical thickness produced by the MODIS aerosol team.
- SYN1deg-Month Alpha 4 noGEO, which uses Edition 5 clouds and ERA5 shows better agreement with observed TOA irradiances (Edition 4) than Baseline products (Edition 4).
- Clear-sky computed irradiances in the Ed5 CRS algorithm are improved by using better T(z) and q(z) profiles from the ERA-5 reanalysis dataset.
- For the sea ice surface type, distinction between the snow-covered and bare sea ice is critical in describing spectral shapes of sea ice.
- For bare sea ice, switching from Jin's model to ARCSIX measurements give larger surface net irradiances.
- MODIS BRDF product can be used in identifying snow-covered ice from bare ice cases.
- Mean biases and RMSE in TOA SW and LW biases are overall improved in the Ed5 algorithm, compared to the Ed4 results.

Publications (since spring 2025)

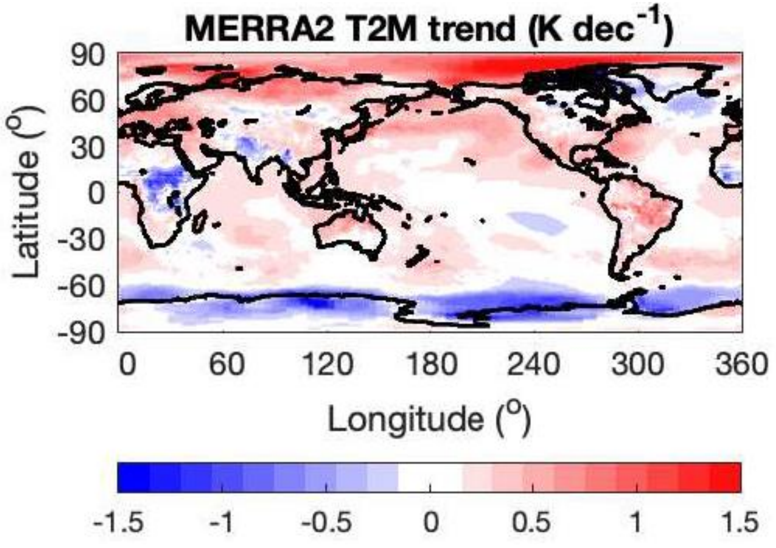
- Rutan, D. A., E. Monroe, S.-H. Ham, F. G. Rose, S. Kato, D. Lubin, D. R. Doelling, P. Taylor, and W. L. Smith, 2026: Broadband surface albedo for snow derived from satellite observations, submitted to *J. Atom. Ocean. Technol*.
- Ham, S.-H., S. Kato, F. G. Rose, R. J. Hogan, and L. Liang, 2026: Improving the accuracy of the correlated-k distribution (CKD) method by considering the adaptive Gaussian quadrature (AGQ) integral method, submitted to *J. Atms. Sci*.
- Kato, S., T.J. Thorsen, F. G. Rose, N. G. Rose, S.-H. Ham, D. A. Rutan, Z. Li, M. Mayer, R. P. Allan, R. F. Adler, G. Gu, S. Lee, J. Lee, 2025: Satellite observed trend of global mean net atmospheric shortwave and longwave irradiances and diabatic heating by precipitation, Science Advances, 11 DOI: 10.1126/sciadv.adz1292.
- Ham, S.-H., N. G. Loeb, S. Kato, T. J. Thorsen, A. Voigt, W. L. Smith Jr., and D. Winker, 2025: Zonal cloud trends observed by passive MODIS and active CALIOP and CPR sensors, J. Climate, 38, 2605-2622, DOI: 10.1175/JCLI-D-23-0722.1.
- Kato, S., N. G. Loeb, F. G. Rose, S.-H. Ham, T. J. Thorsen, D. A. Rutan, W. F. Miller, T. E. Caldwell, D. R. Doelling, S. Sun-Mack, 2025: Seamless continuity in CERES Energy balanced and Filled (EBAF) surface radiation budget across multiple satellites, J. Climate, 38, 2461-2478, doi: 10.1175/JCLI-D-23-0568.1.

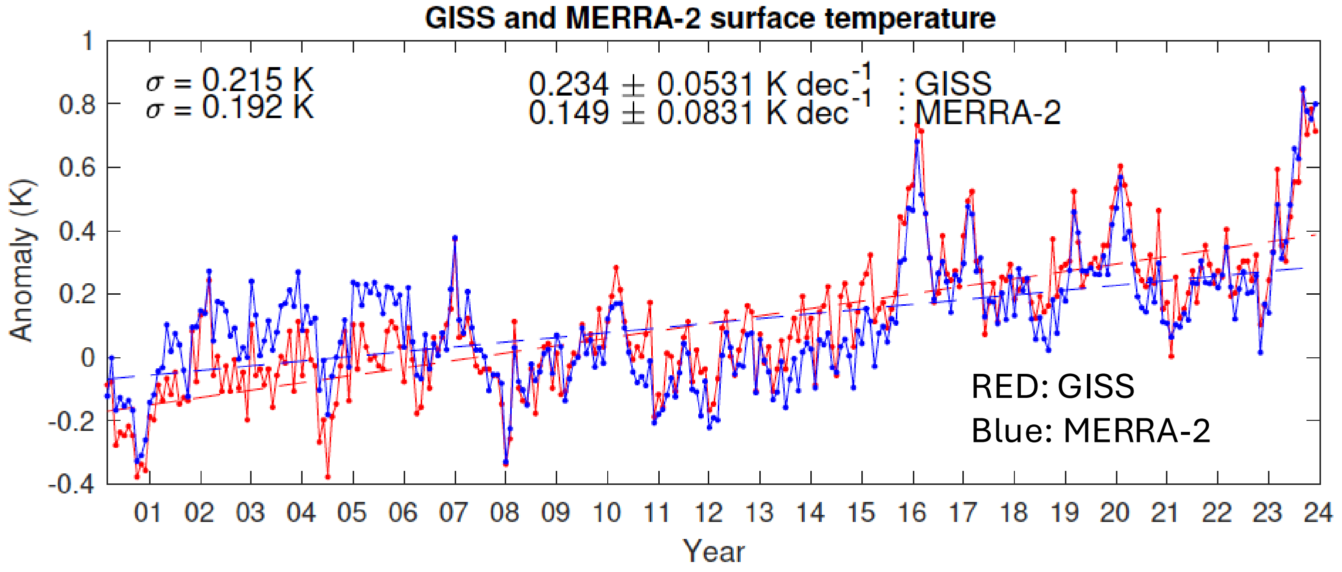
Back-ups

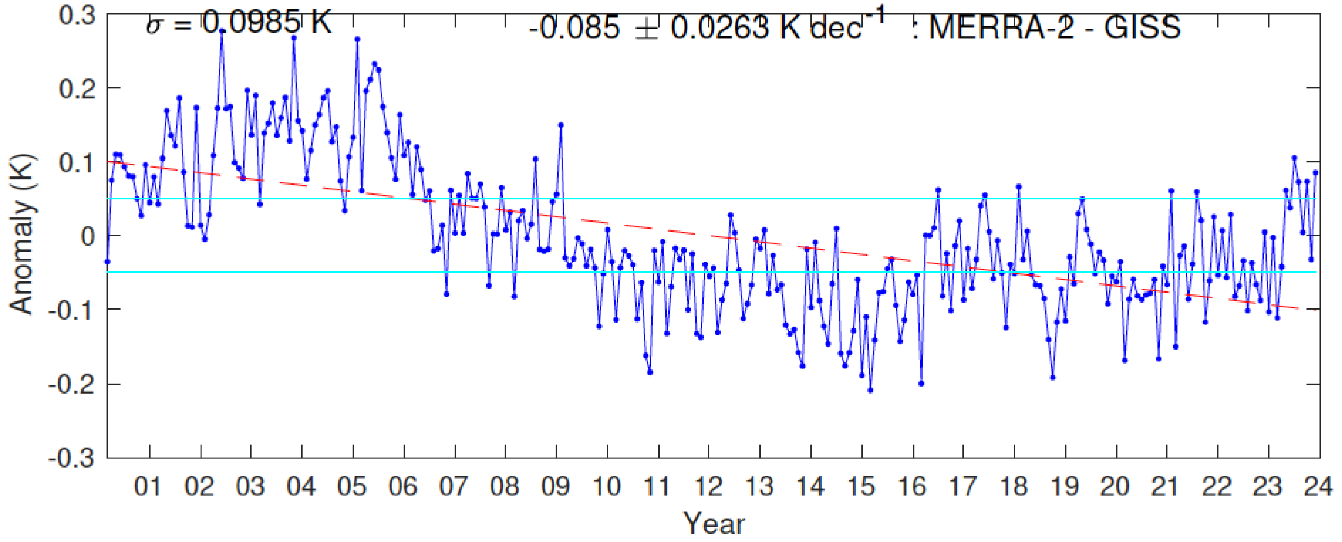
Ed4 EBAF surface longwave irradiances

A Coarse resolution of sea ice and ocean skin temperature sources used in MERRA-2 through March 2006 gives higher near surface temperature, which affects downward longwave irradiances.

MERRRA-2 2m air temperature trend from March 2000 through December 2024







Comparison with GEOS-IT original AOD