Surface Atmosphere Radiation Budget (SARB) working group update

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Tyler J. Thorsen[1], David Fillmore[3], and Xianglei Huang[4]

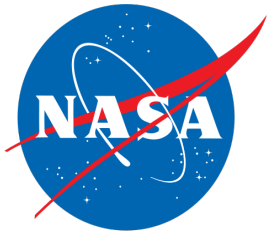
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[3]ADNET Systems, Inc

[4]NCAR

[5]University of Michigan





CERES Science Team Meeting
October 27-29, 2026

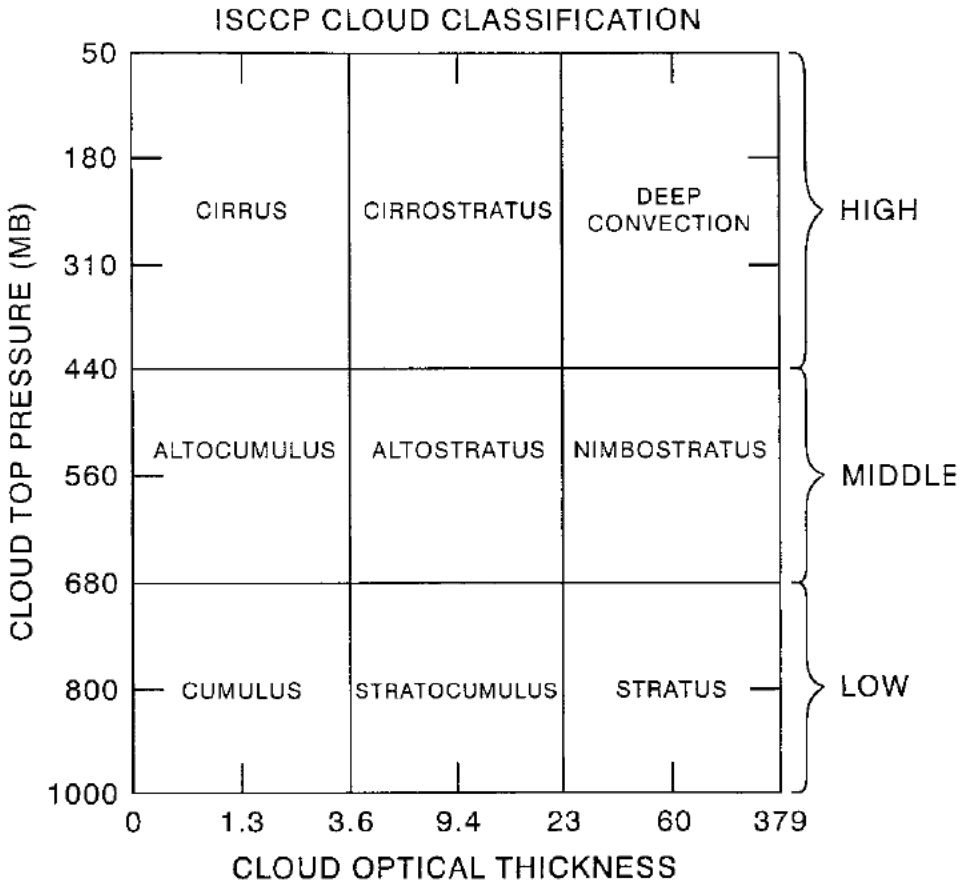
Outline of this presentation

- Edition 4 SYN and EBAF are available through July 2026.
- Edition 4 SYN and EBAF aerosol issue
- Edition 5
  - SYN: Cloud classification used in SYN surface irradiance computations
  - Aerosol optical thickness products comparison
  - Revised k-distributions for the Ed5 radiative transfer model
  - CRS: Edition 4 and Edition 5 Level 2 (i.e. instantaneous) irradiance comparisons.
  - Fu-Liou code revision
  - Sub-footprint scale cloud flux output

Edition 4 SYN aerosol issue

- Too small aerosol optical thicknesses were used in processing SYN from March 2026 to May 2026. Three months were reproduced using correct files in September 2026.
- March 2026 EBAF-surface was affected by this issue. An e-mail notification to download a reprocessed file was sent out in September 2026

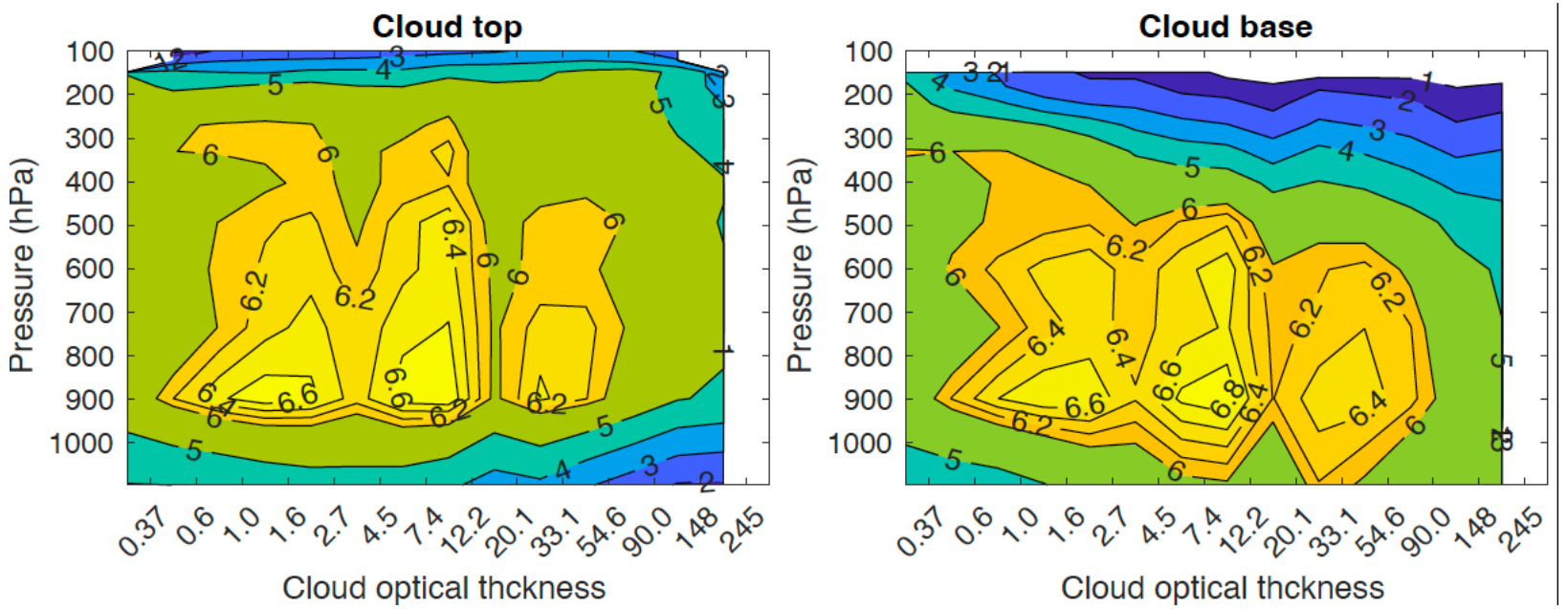
Edition 5 cloud classification for SYN irradiance computations



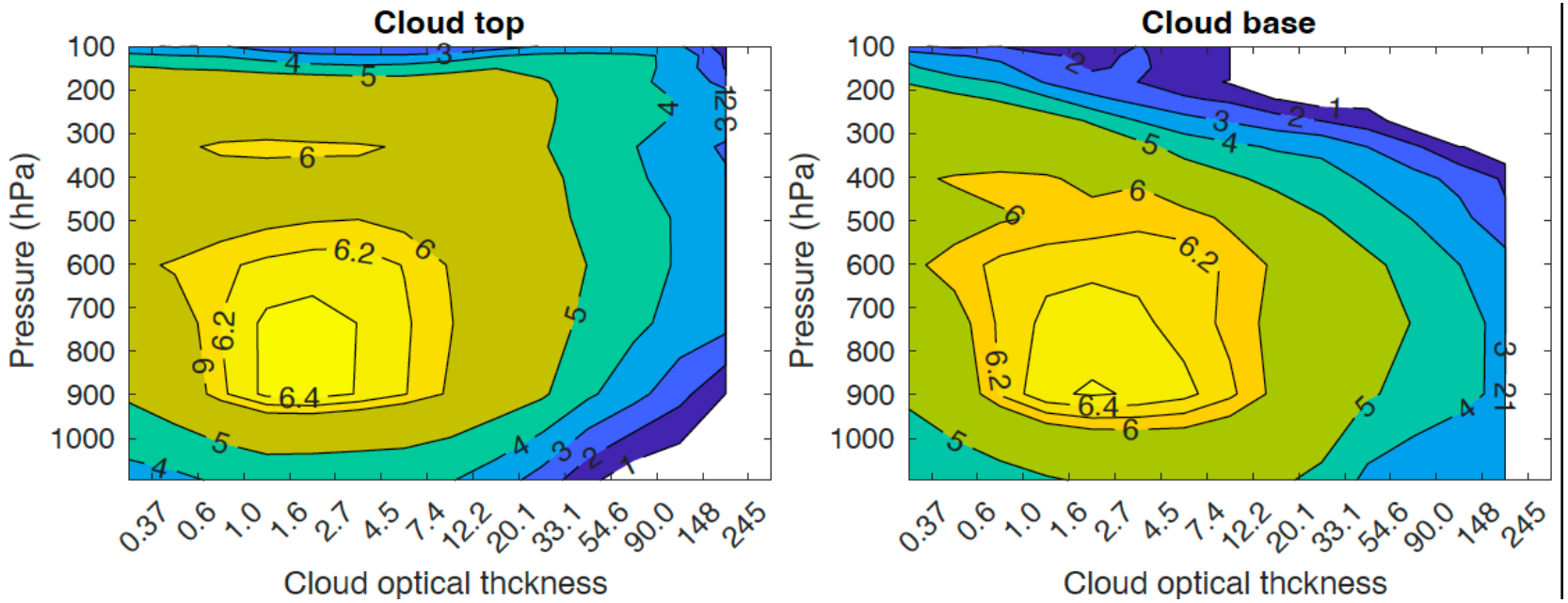
- Clouds in an 1°×1° and 1-hour box are separated into the ISCCP type 3 by 3 cloud classification using their cloud top pressure and optical thickness.
- Irradiances are computed for each cloud type separately using a 4-stream radiative transfer model.
- No overlap
- Minor water phase (i.e. fewer occurrence) is ignored but the cloud fraction is maintained.
- Cloudy-sky irradiances and clear-sky irradiance are averaged weighted by occurrence.

Cloud top and base occurrence comparison Aqua+GEOs: July 2020

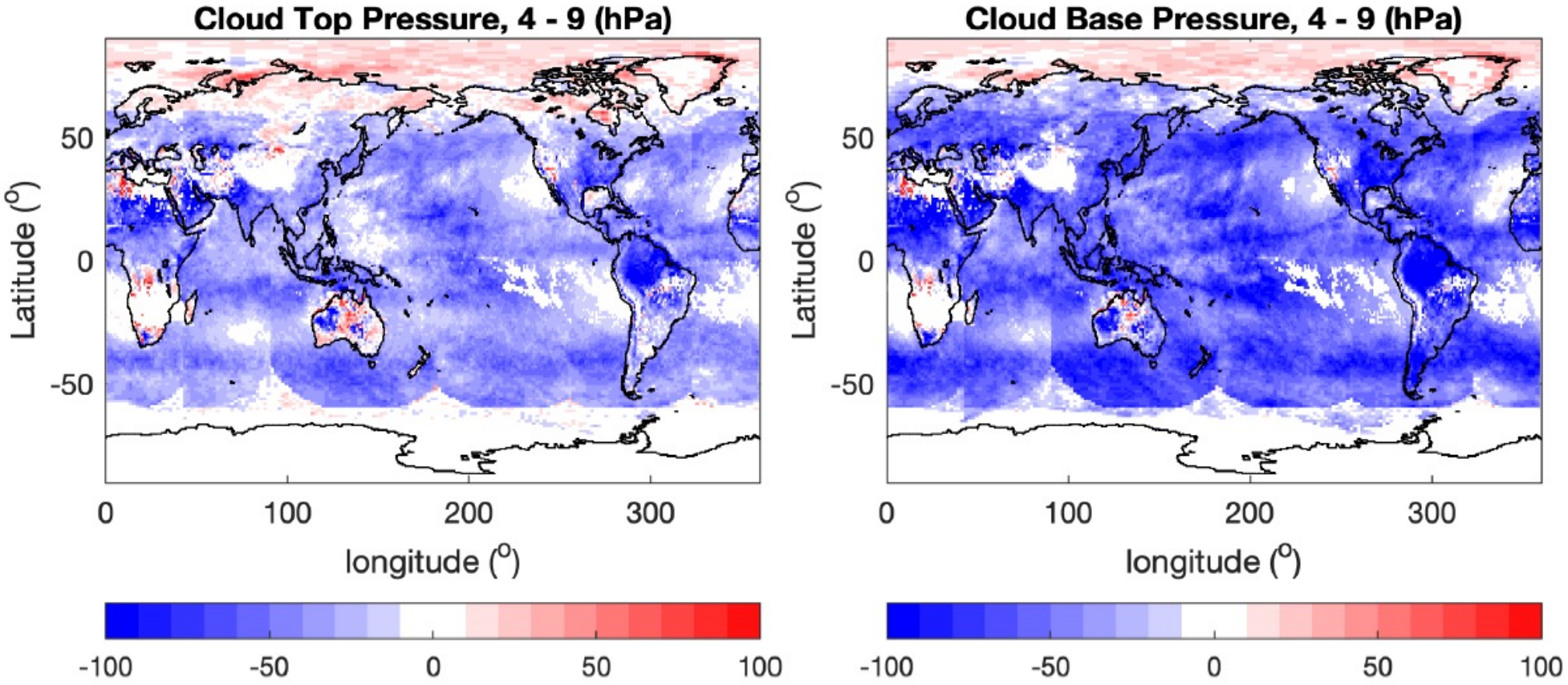
Ed5 3 by 3



Ed4 4 layers



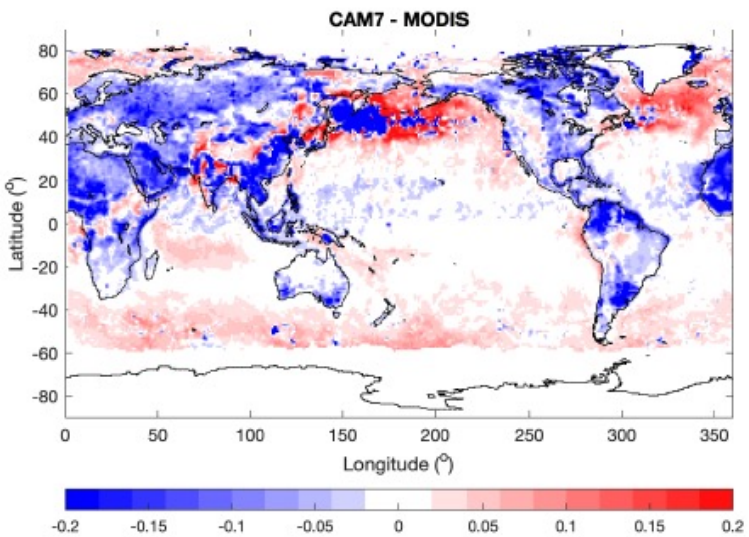
Cloud top and base pressure differences, Aqua+GEOs: July 2020

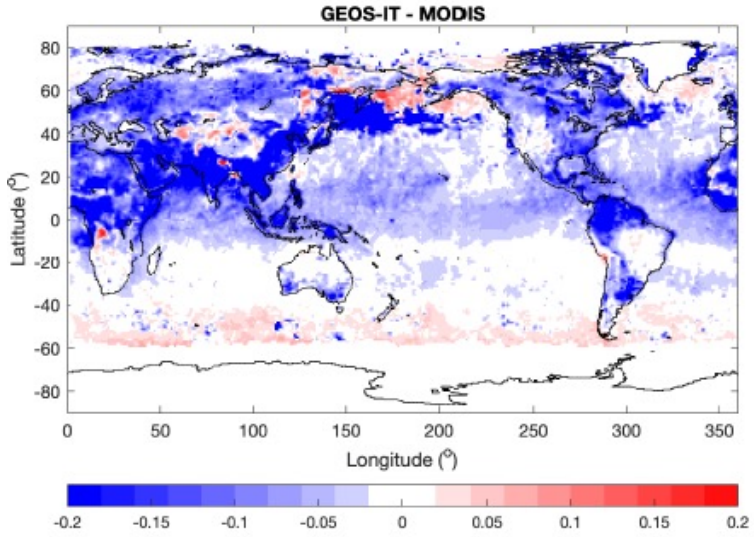


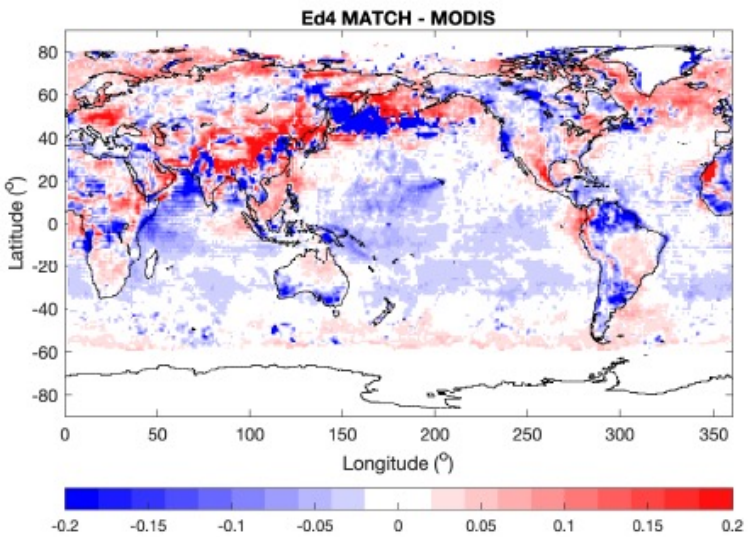
4-layer classification gives higher cloud top height
3 by 3 cloud classification gives lower cloud base height

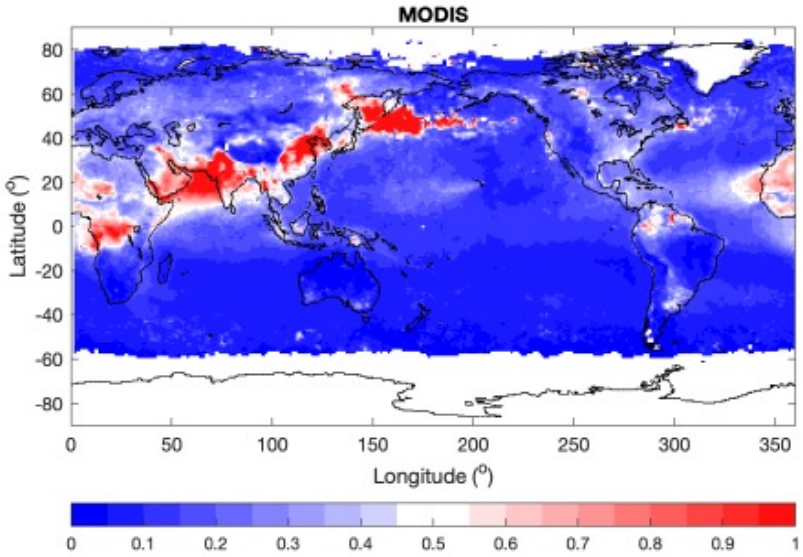
Edition 5 Aerosol transport models

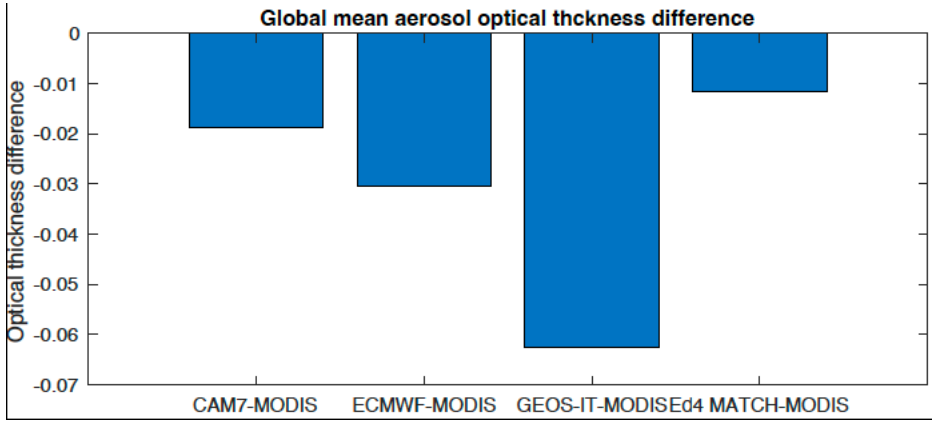
Aerosol optical depth comparisons: 200807





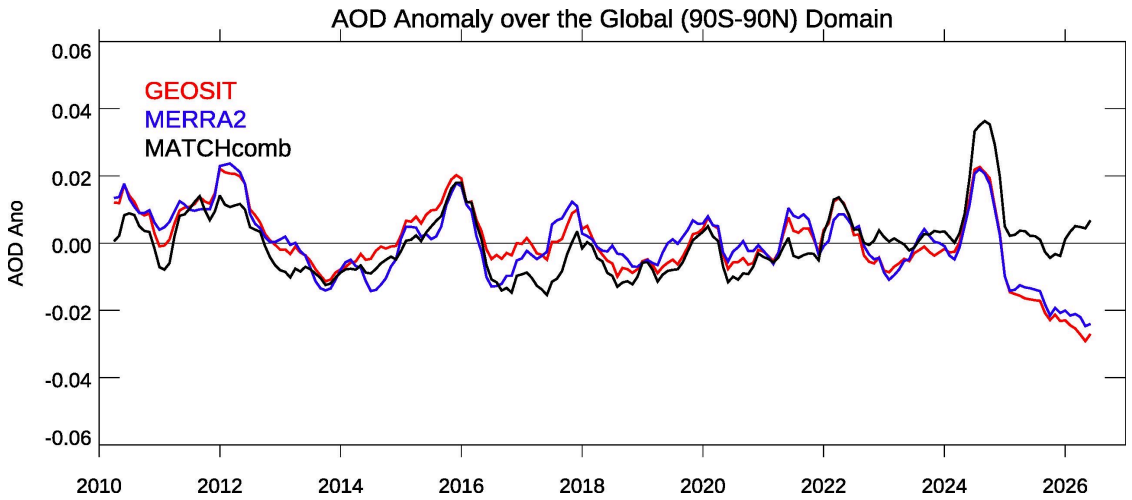




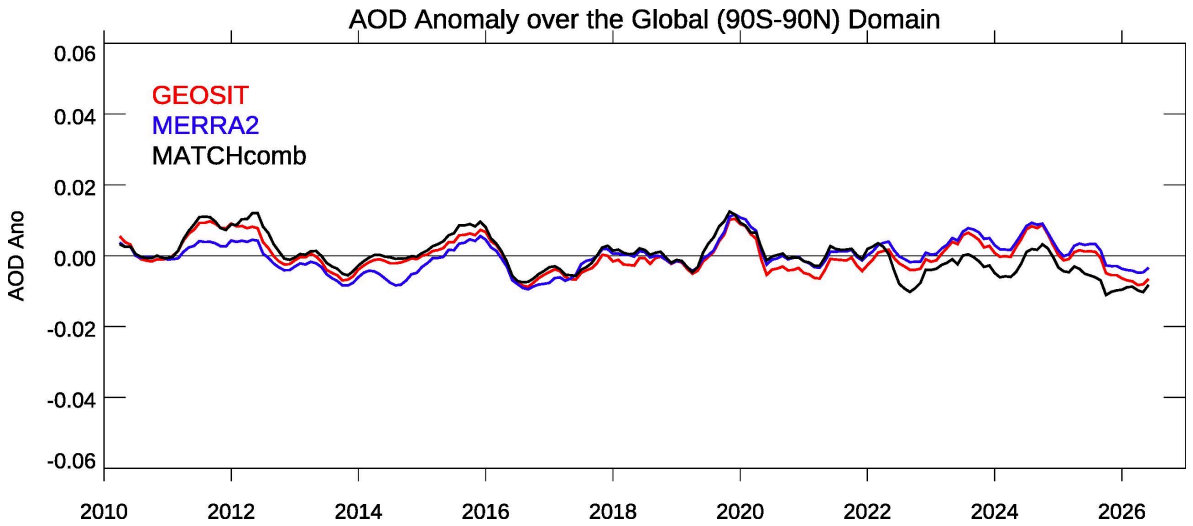


GEOS-IT, MERRA2, MATCH aerosol optical depth (AOD) anomaly timeseries

Global land



Global ocean



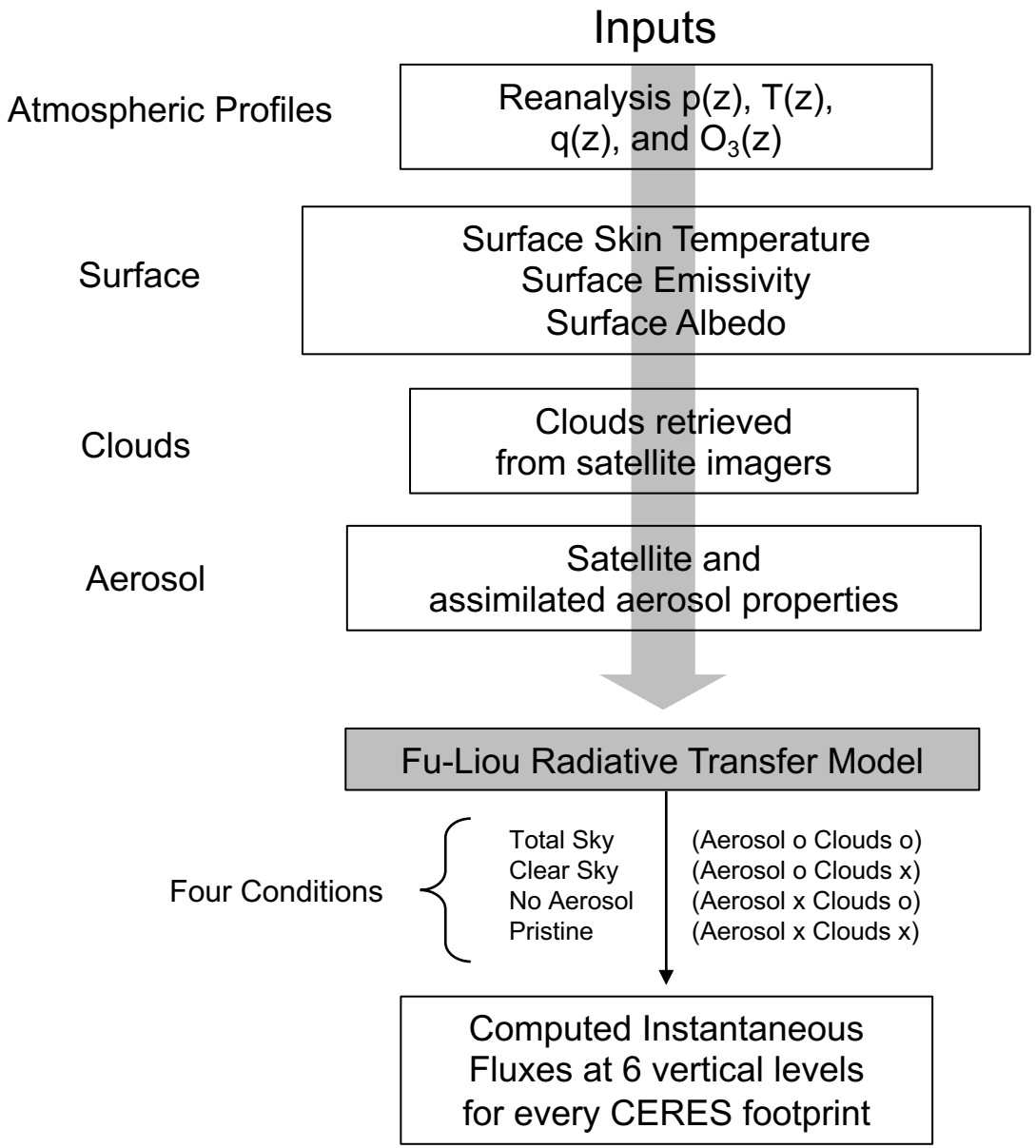
A 6-month running window is applied to smooth AOD anomalies

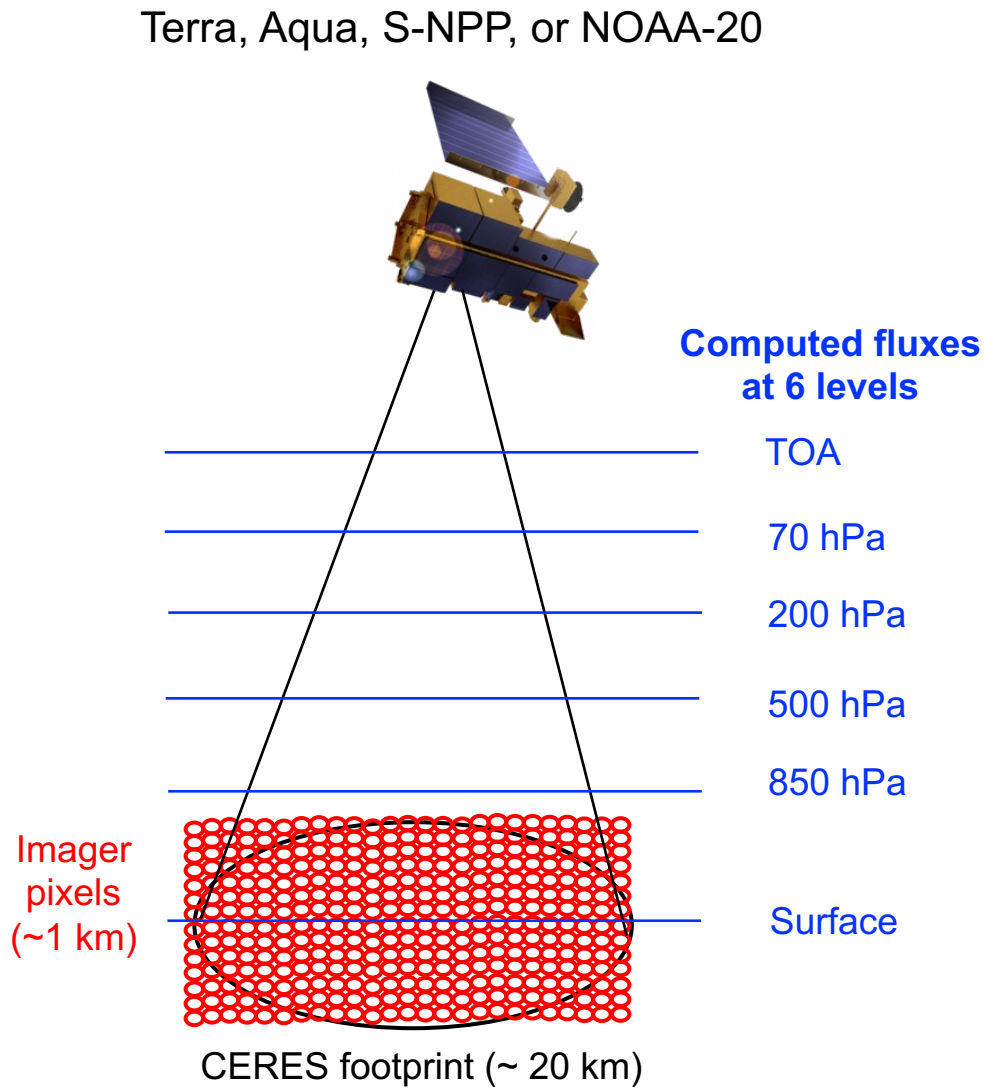
Terra's orbit drift started in 2020
Aqua's orbit drift started in 2021

MATCH switched from Terra+Aqua to NOAA20 in April 2022
GEOS-IT uses Terra Dark Target clear-sky radiances

Edition 5 CRS

Level 2 CRS Flux Algorithm





Changes from the Ed4 to Ed5 CRS Algorithm

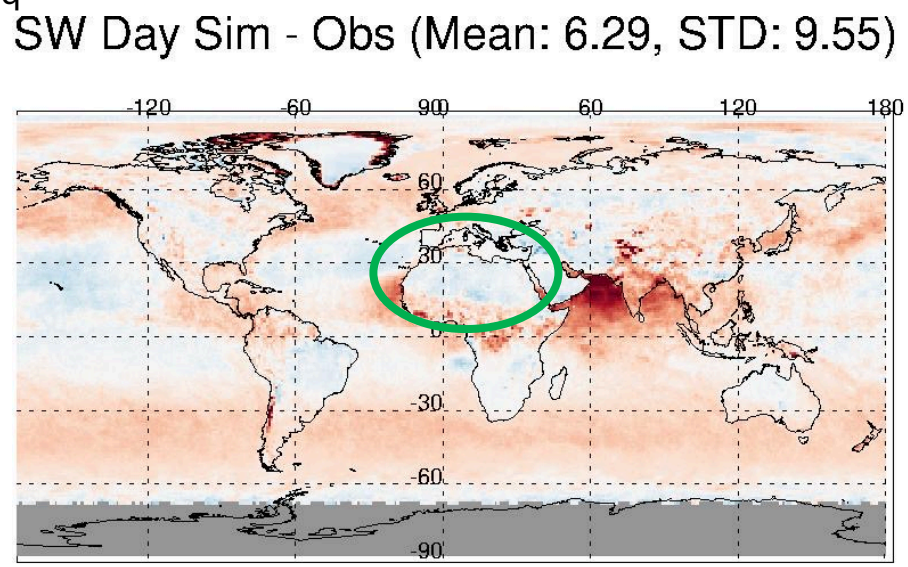
	Ed4	Ed5 (Validation Stage)
T(z)/q(z)/O_3(z) profiles & wind speed	MOA-GEOS-5.4.1 (1° grid)	MOA-ERA5 (0.5° grid)
Skin Temperature	• T_{skin} derived from the MODIS 11-μm channel • GEOS-5.4.1 T_{skin}	• T_{skin} derived from the imager 11-μm channel • T_{skin} derived by the Neural Network (NN) algorithm • ERA5 T_{skin}
Surface Albedo	• Parameterized albedo model from Jin's model (2004, 2008) • MODIS BRDF spectral albedo • Surface albedo history (SAH) Ed4 map derived from clear-sky CERES measurements	• Parameterized spectral albedo model from Jin's model (2004, 2008) • MODIS BRDF spectral albedo • Broadband surface albedo history (SAH) Ed5 map derived from clear-sky CERES measurements • ARCSIX-based sea ice spectral albedo
Surface Emissivity	• CERES Emissivity for 11-12 μm bands • Climatological emissivity based on IGBP	• New LW emissivity maps derived from far IR (Huang et al. 2016) and IASI-derived LW (Zhou et al. 2013) emissivity models.
Cloud properties	• MODIS clouds from Ed4 Cloud Algorithm • Roughened hexagonal (RHex) ice scattering parameters • Heney-Greenstein cloud scattering function	• MODIS clouds from Ed5 Cloud Algorithm • Two-Habit Model (THM) ice scattering parameters • 4-moments of the cloud scattering phase function
Aerosol Properties	• Ed4 Hourly MATCH (Fillmore et al., 2022) • MODIS C6 multi-channel aerosol optical depths	• GEOS-IT aerosol
RTM	Ed4 Langley Fu-Liou model	Ed5 Langley Fu-Liou model with updated correlated k gas absorption features

Biases of CRS TOA SW Upward Fluxes (Aqua, July 2008)

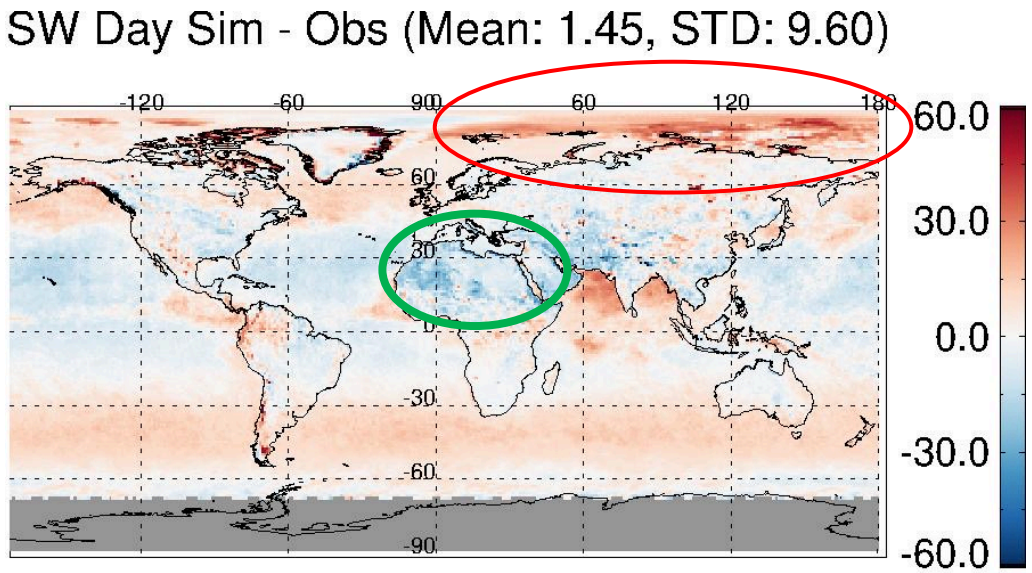
- Ed4 clouds
- Ed4 surface
- GESO-5.4.1 T & q
- MATCH aer
- Ed4 Fu

- Ed5 clouds
- Ed5 surface
- ERA-5 T & q
- GEOS-IT aer
- Ed5 Fu

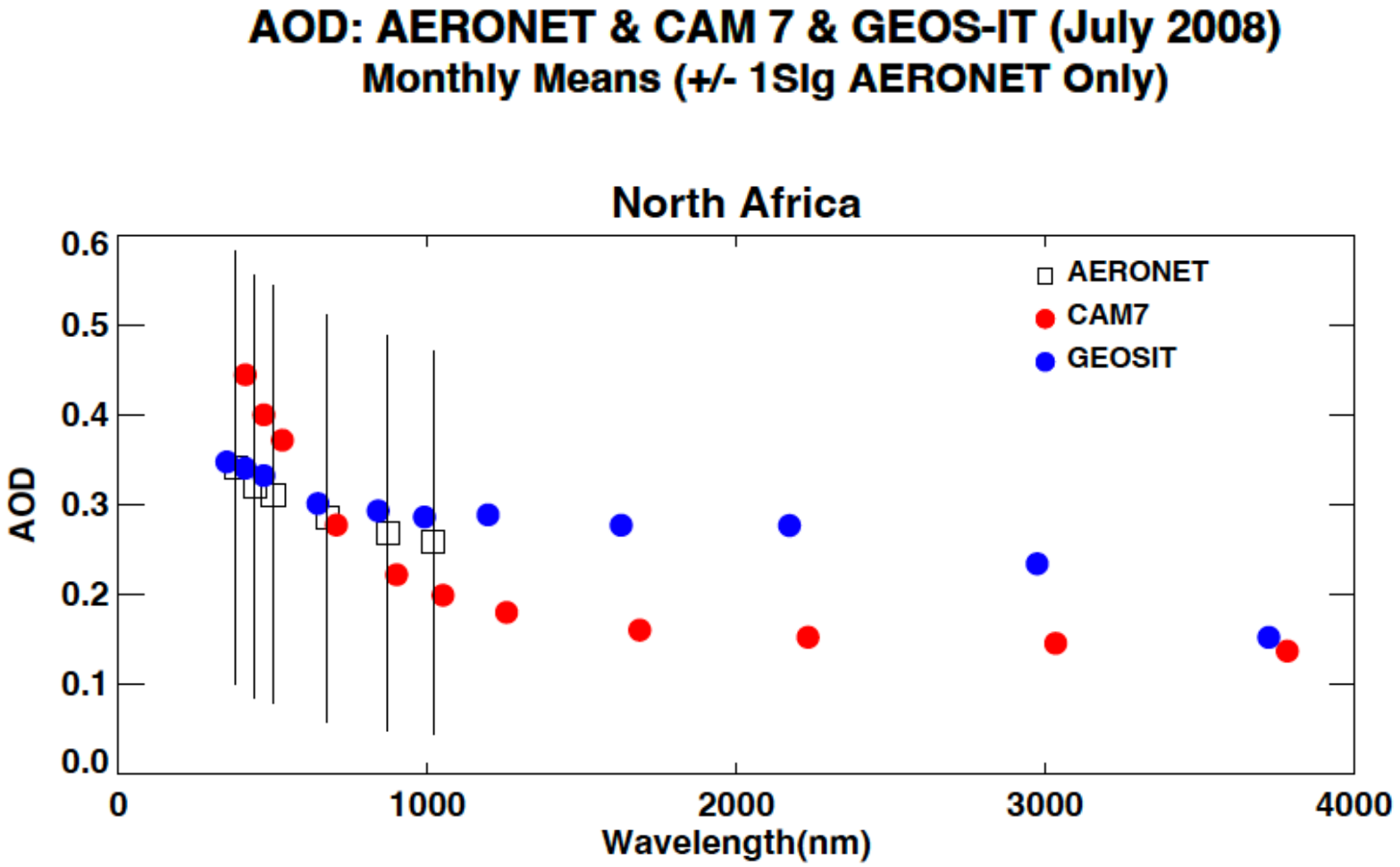
Ed4 (Offline)



Ed5-Beta (Sep 2026 ver)



- The smaller biases in the Ed5 CRS SW TOA fluxes are primarily associated with the smaller GEOS-IT AOD compared to MATCH AOD (TOA SW ARE changed by 3-4 W m^{-2} globally).
- The positive SW biases in Arabian Peninsula are significantly reduced in Ed5, but the SW negative biases over tropical oceans are still an open question (possibly due to the underestimated AOD).
- The Ed5 surface albedo map is not finalized yet and it is contributing to the positive biases over the Arctic: The Ed5 surface albedo map is in the process.
- Changes in cloud fractions and cloud optical depths jointly influence the SW fluxes (TOA SW CRE changed by ~2 W m^{-2} globally).
- Over the Saharan region, negative SW TOA biases occur due to stronger aerosol absorption for NIR (next slide).



* Standard deviation was computed using the daily data points for the month.

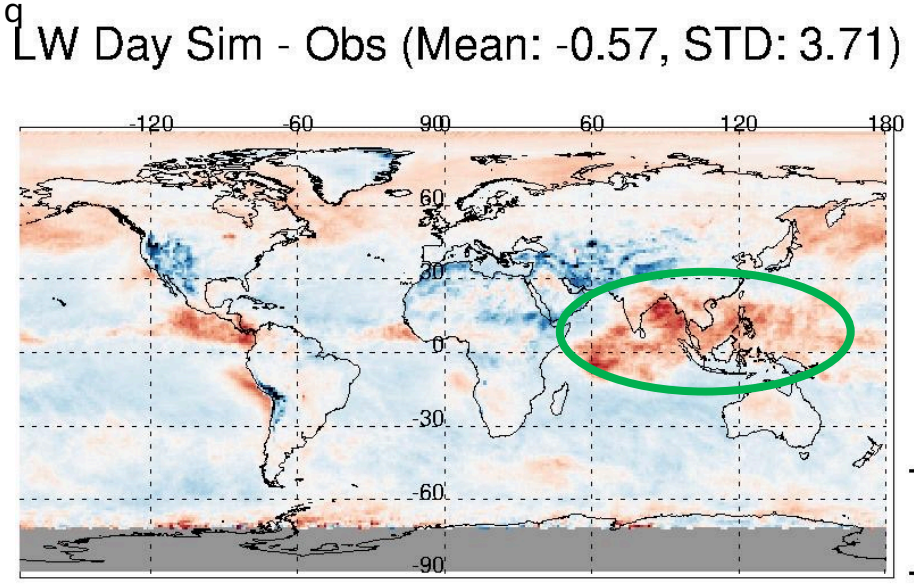
- SW TOA fluxes computed with GEOS-IT AOD are slightly negatively biased over the North Africa region.
- In contrast, when MATCH AOT is used, the SW biases are smaller (Ed4).
- Comparison with AERONET data suggests that GEOS-IT AOD for the Near-infrared (NIR) spectral region might be too excessive, causing overestimation of aerosol, and underestimation of TOA SW fluxes.
- CAM7 AOD is smaller than GEOS-IT AOD for the NIR spectral region.

Biases of CRS Daytime TOA LW Upward Fluxes (Aqua, July 2008)

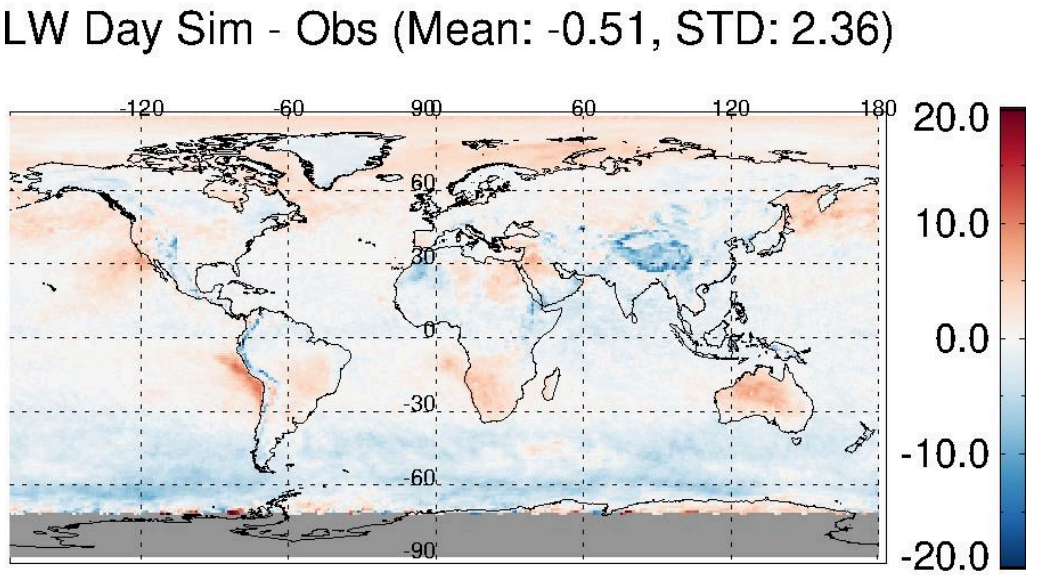
- Ed4 clouds
- Ed4 surface
- GESO-5.4.1 T & q
- MATCH aer
- Ed4 Fu

- Ed5 clouds
- Ed5 surface
- ERA-5 T & q
- GEOS-IT aer
- Ed5 Fu

Ed4 (Offline)



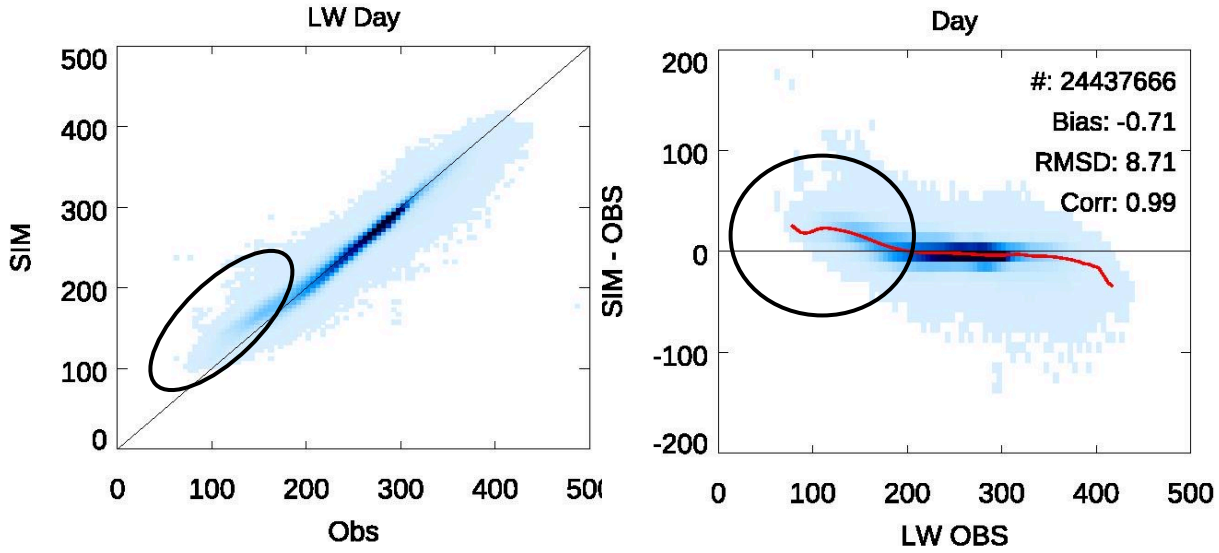
Ed5-Beta (Sep 2026 ver)



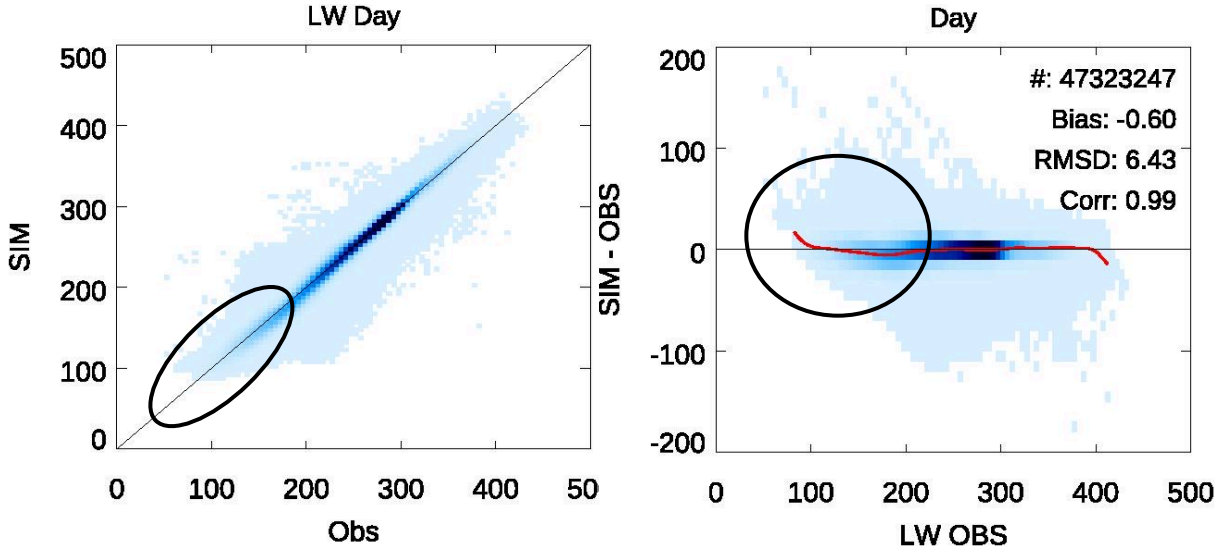
- The impact of the reanalysis (T(z) and q(z)), along with the new gas absorption module, is more important for LW flux calculations, compared to SW.
- Smaller upper tropospheric water vapor in Ed5 improves LW TOA fluxes (less negative).
- LW TOA biases over land are smaller in Ed5, due to the improved skin temperatures.
- Improved cloud top and base heights for deep convective regions in Ed5, resulting in smaller LW biases.
- A bug in Ed4 affecting reflected LW component, which caused underestimation of TOA LW fluxes (~ 0.5 W m^{-2}), has been corrected in Ed5.

Histogram of Daytime LW TOA Fluxes over the 60S–60N (Aqua, July 2008)

Ed4 (Offline)



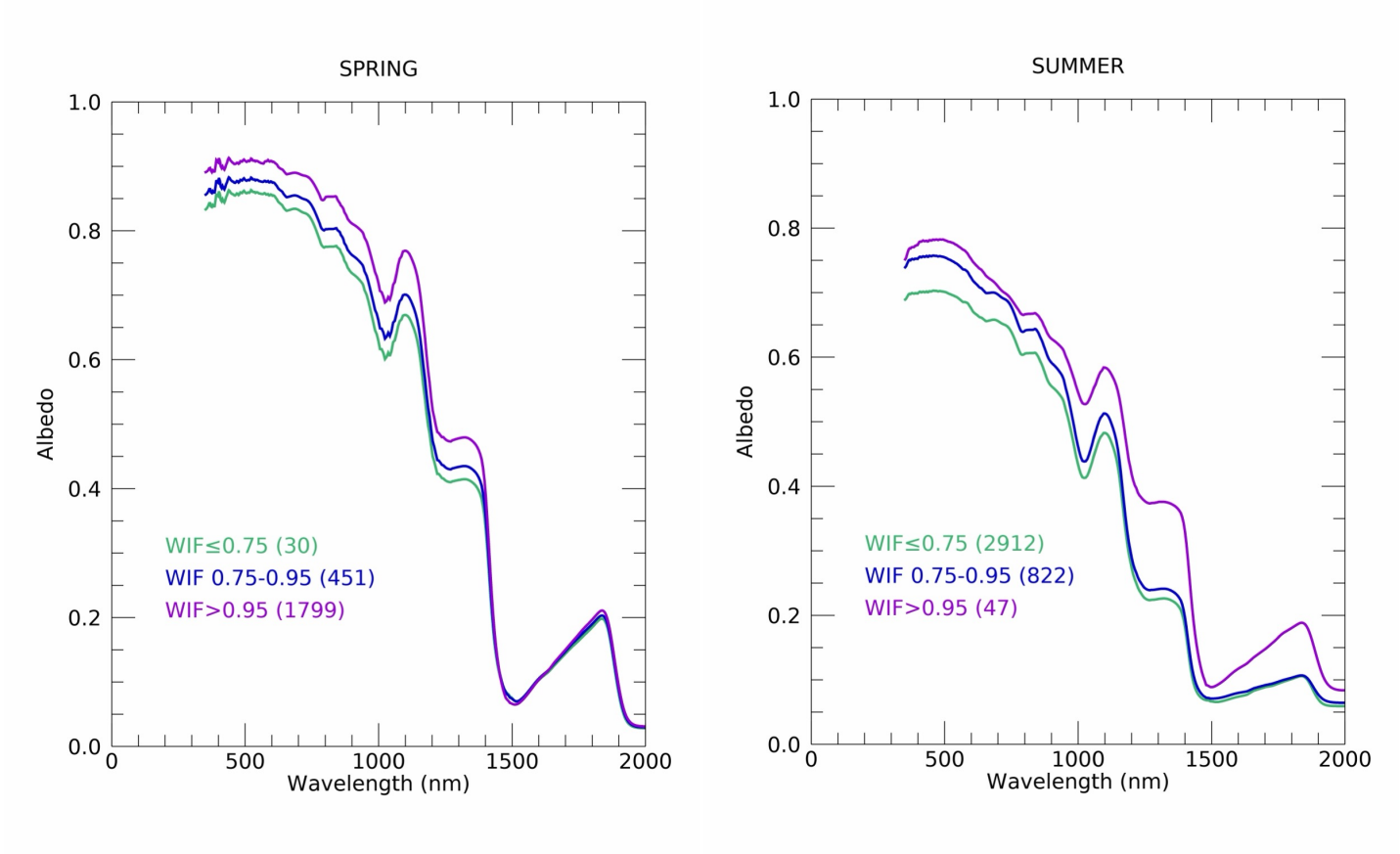
Ed5-Beta (Sep 2026 ver)



- In Ed4, positive LW TOA biases occur at the lower end of LW flux range, likely associated with deep convective cloud regions.
- The dependency is largely removed in Ed5, primarily due to improved cloud boundaries.

Sea Ice Spectral Albedo Based on ARCISX Measurements

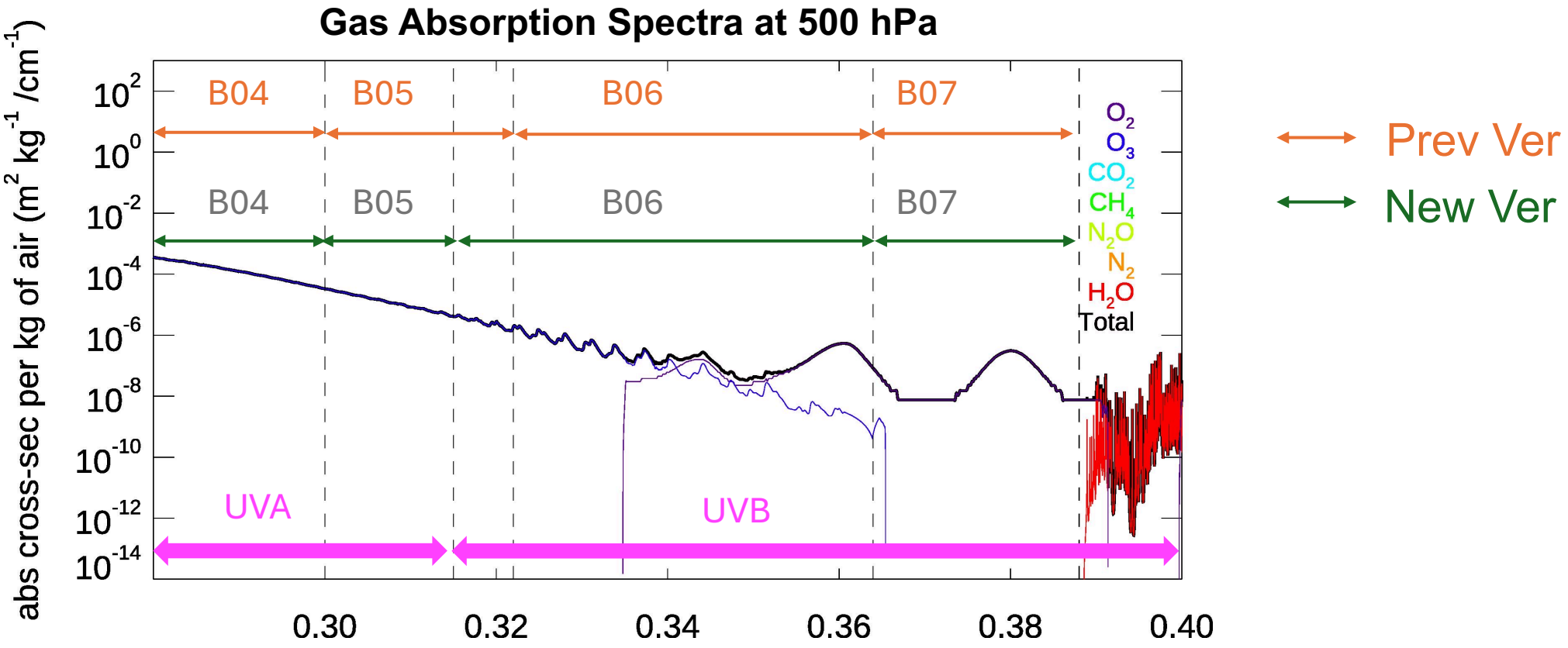
Surface Spectral Albedo by White Ice Fraction (WIF) Measured During the ARCSIX Campaign



- ARCSIX-based sea ice spectral albedo was implemented in Ed5 CRS processing (See slides in the previous spring CERES STM).
- To further improve the sea ice spectral assumptions, the updated albedo dataset with atmospheric correction (Chen et al., in prep) are being considered.
- Also, the scene identification method based on Machine Learning Method (Wright and Polashenski 2018; Kurtz et al.) are being considered to analyze spectral surface albedo by specific sea ice types.

Scene types from Machine Learning (ML) method:
“White ice, gray ice, melting ponds, open water, or shadow”

Slight Modification of Ed5 Fu-Liou Model Band Structure for UVA and UVB



- In Ed4, a parameterization scheme (Su et al. 2005) was used to estimate UVA (280-315 nm) and UVB (315-400 nm) from other Fu-Liou bands.
- In Ed5, Bands 5 and 6 were slightly modified to allow direct estimation of UVA and UVB.
- PAR (400-700 nm) remains available both before or after this modification.
- The Ed5 band structure enables Libera-related studies using VIS (0.3-0.7 μm) and NIR (0.7-5 μm) spectral regions.
- The impact of the SW band structure change is very small for SW BB fluxes (< 0.1 W m^{-2}).

Modified Ed5 Fu-Liou Model Band Structure (Validation Stage)

Band	Wavelength (μm)
1	0.175–0.225
2	0.225–0.244
3	0.244–0.280
4	0.280–0.300
5	0.300–0.315
6	0.315–0.364
7	0.364–0.388
8	0.388–0.400
9	0.400–0.438
10	0.438–0.497
11	0.497–0.556
12	0.556–0.595
13	0.595–0.625
14	0.625–0.687
15	0.687–0.700
16	0.700–0.759

Band	Wavelength (μm)
17	0.759–0.779
18	0.779–0.889
19	0.889–1.042
20	1.042–1.410
21	1.410–1.905
22	1.905–1.940
23	1.940–1.990
24	1.990–2.034
25	2.034–2.080
26	2.080–2.128
27	2.128–2.275
28	2.275–2.500
29	2.500–3.509
30	3.509–4.000
31	4.000–5.000
32	5.000–12.500

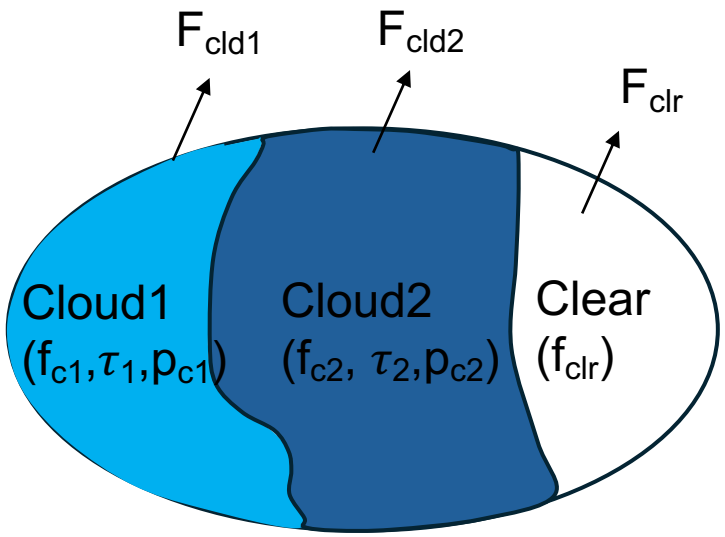
- UVA (280-315 nm): B04 to B05
- UVB (315-400 nm): B06 to B08
- PAR (400-700 nm): B09 to B15
- Visible (300 – 700 nm): B05 to B15
- NIR (0.7 – 5 μm): B16 to B31
- SW (0.175 – 12.5 μm): B01 to B32

❖ The updated Fu-Liou band structure will be used for both SYN and CRS processing.

❖ The Ed5 Fu-Liou model can easily incorporate the modified band structure through a single configuration file.

Total-Sky TOA/SFC Flux Available for Each Cloud Type within a CERES Footprint

"Sub-footprint scale fluxes"



"Footprint-scale fluxes"

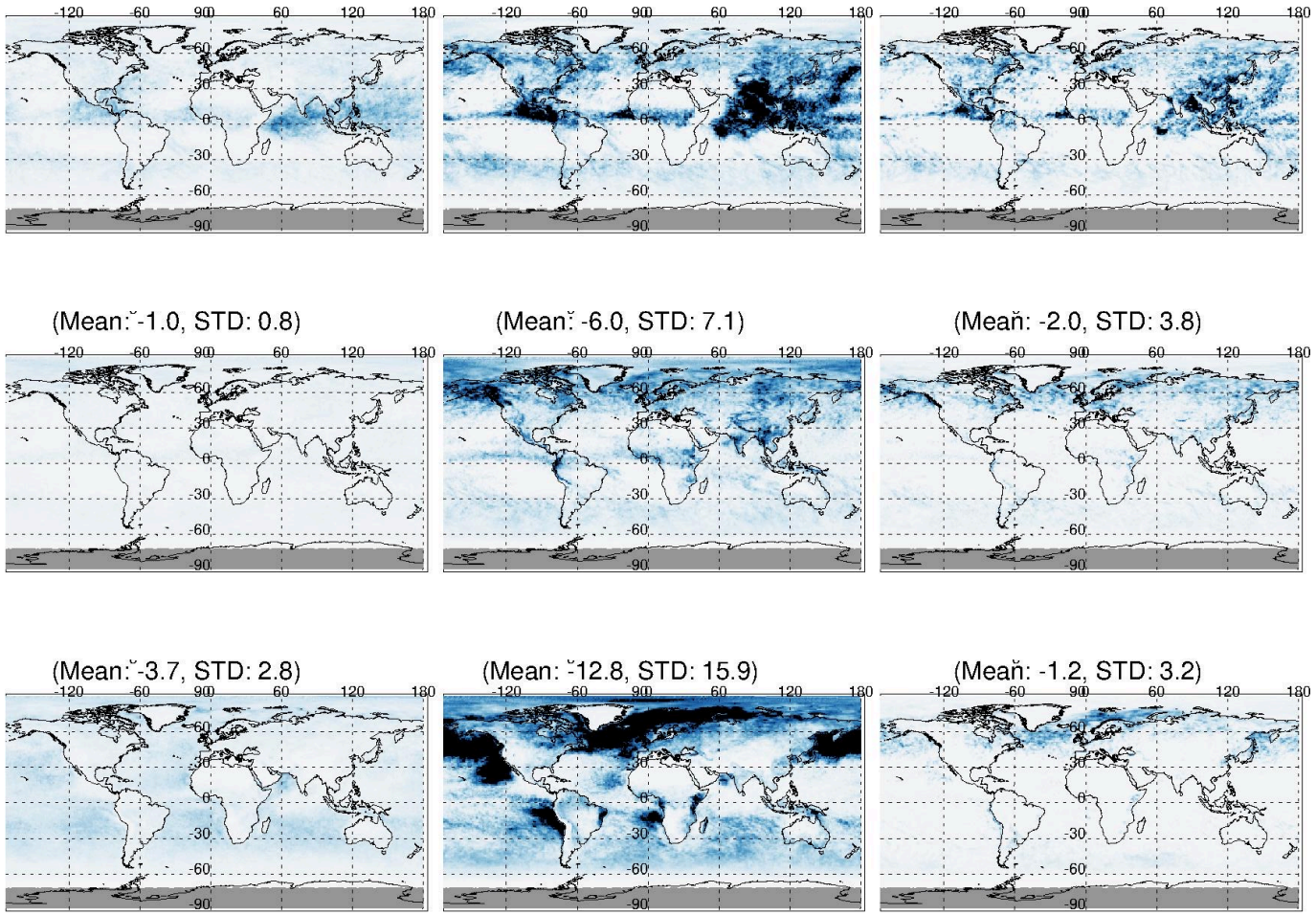
$F(FOV)=f_{c1}F_{cld1} + f_{c2}F_{cld2} + f_{clr}F_{clr}$

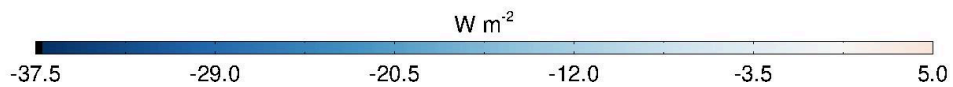
- CRS fluxes are provided for footprint scales for i) total, ii) clear, iii) no-aerosol, and iv) pristine skies.
- When there are two cloud types within a CERES footprint, it is difficult to link the cloud radiative effect (CRE) for the given cloud optical depth (τ) and cloud top pressure (p_c) from the footprint scale of fluxes.
- In Ed5, we additionally provide total-sky flux for each cloud type (sub-footprint scale), and thus CRE can be estimated for the specific cloud optical depth (τ) and cloud top pressure (p_c).

Applications of Sub-Footprint Scales of Cloud Fluxes

Cloud Radiative Effect (CRE) on SW TOA Net by Cloud Type

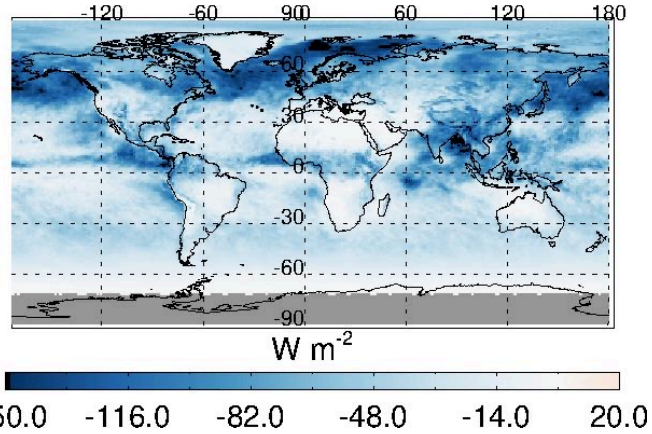
	Thin (τ < 3.5)	Medium (τ: 3.5-22.6)	Thick (τ>22.6)
High (10-440 hPa)	(Mean: -3.3, STD: 4.0)	(Mean: -9.9, STD: 13.0)	(Mean: -5.2, STD: 8.7)
Mid (440-680 hPa)	(Mean: -1.0, STD: 0.8)	(Mean: -6.0, STD: 7.1)	(Mean: -2.0, STD: 3.8)
Low (> 680 hPa)	(Mean: -3.7, STD: 2.8)	(Mean: -12.8, STD: 15.9)	(Mean: -1.2, STD: 3.2)





Total CRE on TOA SW Net

Sum of 3x3 Types
(Mean: -43.9, STD: 33.6)



Summary and conclusions

- Edition 5 3 by 3 cloud classification maintains optically thick clouds.
- Four-layer classification provides generally higher mean cloud top height and 3 by 3 cloud classification provides lower cloud base height.
- Global mean aerosol optical thickness derived from CAM7 nudged by MODIS aerosol optical thickness agrees with MODIS aerosol optical thickness better than GEOS-IT aerosol optical thickness.
  - Global mean GEOS-IT aerosol optical thickness decreases after ~2024 especially over land.
- Computed CRS SW TOA upward fluxes are reduced in Ed5 due to the change in aerosol source from MATCH to GEOS-IT and changes in cloud properties from Ed4 to Ed5.
- Computed CRS LW TOA upward fluxes are generally increased in Ed5 due to the reduced upper tropospheric humidity in ERA5. Positive LW TOA biases for deep convective clouds shown in Ed4 are largely eliminated in Ed5 through the improved cloud boundaries.
- The SW band structure of the Ed5 Fu-Liou model was revised to estimate UVA and UVB directly without additional parameterization.
- Sub-footprint-scale of CRS flux will be available for each cloud type under total-sky conditions. This will enable us to link cloud radiative effect (CRE) to the specific cloud optical depths and cloud top pressures.

Publications (since spring 2026)

- 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, *J. Atom. Ocean. Technol*. 43, 1043–1057, https://doi.org/10.1175/JTECH-D-25-0118.1.
- 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*.

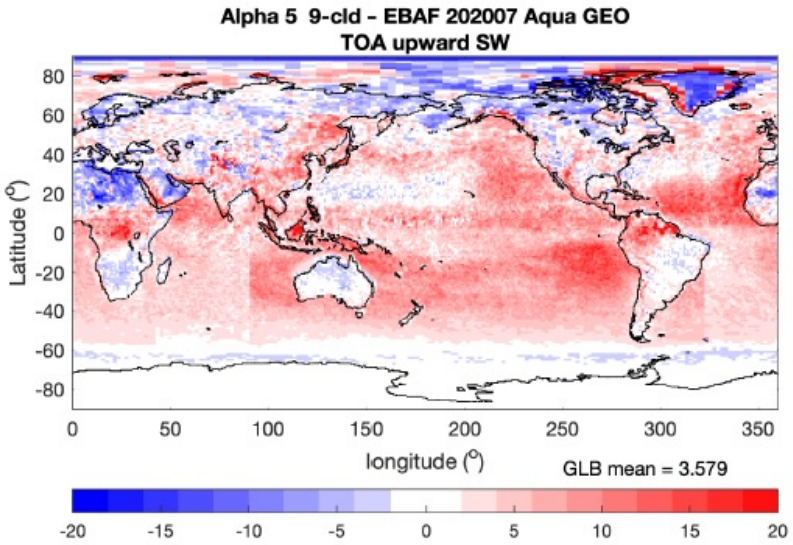
Back Ups

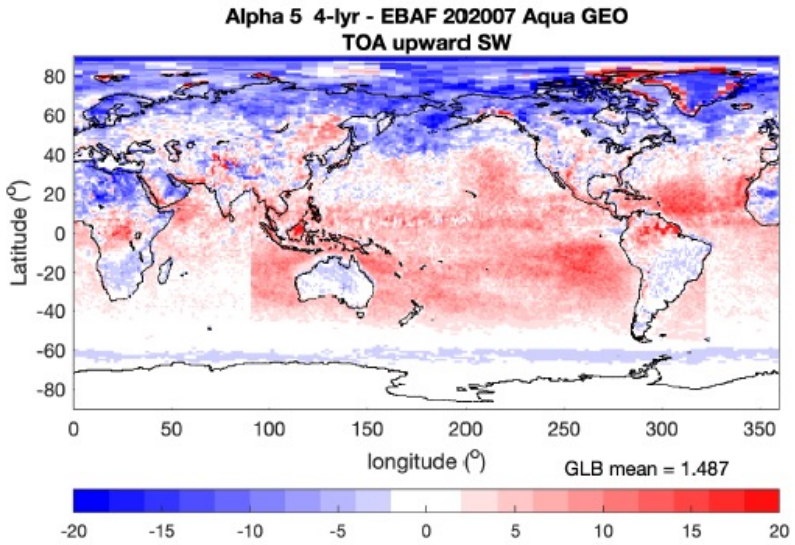
TOA irradiance comparison: July 2020

3 by 3

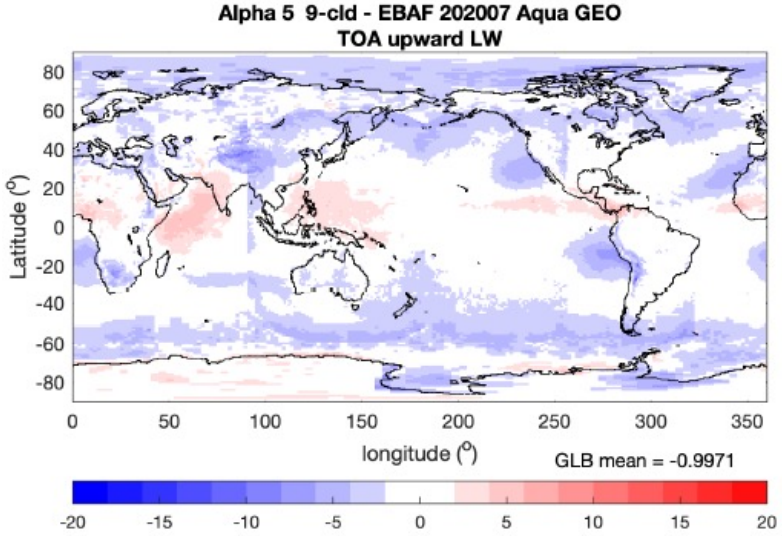
4-layer

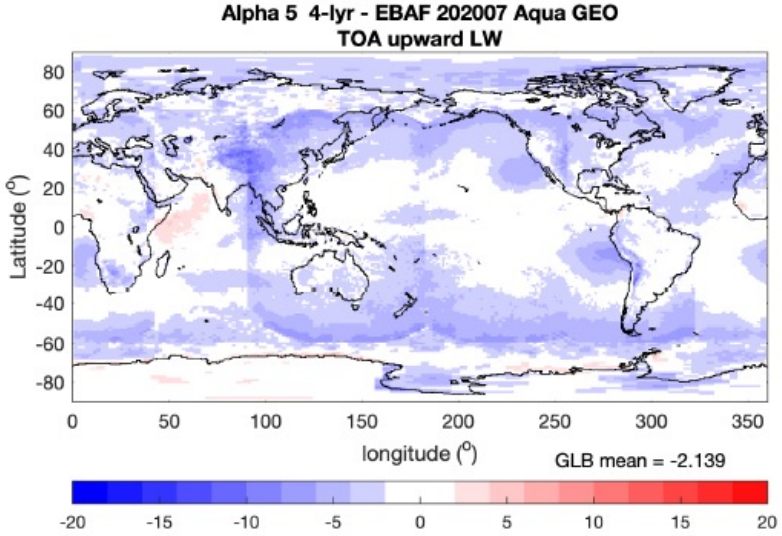
Shortwave





Longwave





Summary

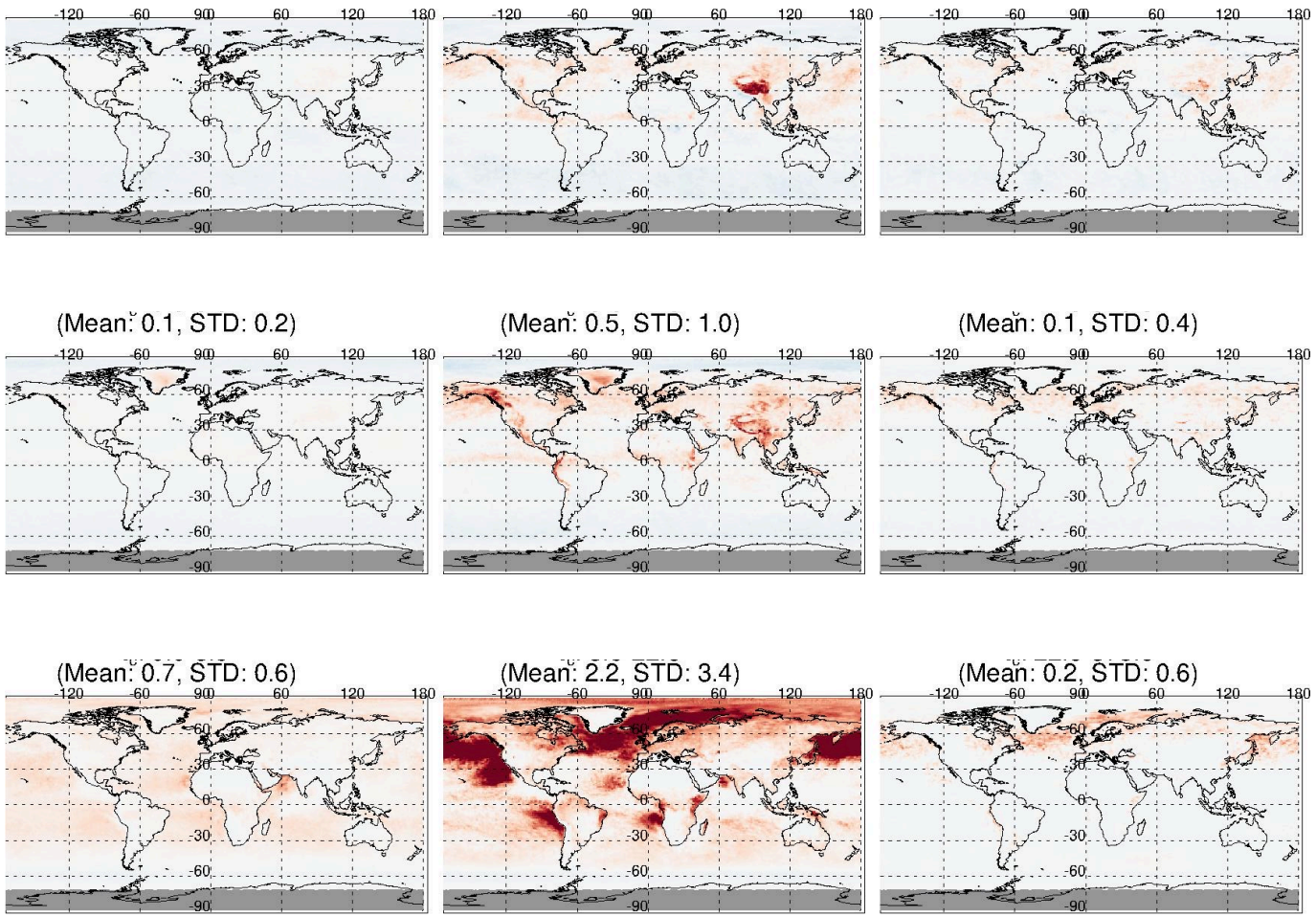
- Computed CRS SW TOA upward fluxes are reduced in Ed5 due to the change in aerosol source from MATCH to GEOS-IT and changes in cloud properties from Ed4 to Ed5.
- Computed CRS LW TOA upward fluxes are generally increased in Ed5 due to the reduced upper tropospheric humidity in ERA5. Positive LW TOA biases for deep convective clouds shown in Ed4 are largely eliminated in Ed5 through the improved cloud boundaries.
- The SW band structure of the Ed5 Fu-Liou model was revised to estimate UVA and UVB directly without additional parameterization.
- Sub-footprint-scale of CRS flux will be available for each cloud type under total-sky conditions. This will enable us to link cloud radiative effect (CRE) to the specific cloud optical depths and cloud top pressures.

Applications of Sub-Footprint Scales of Cloud Fluxes

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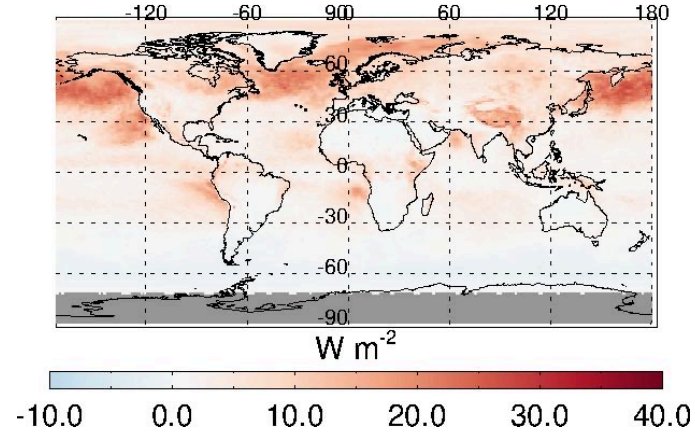
Cloud Radiative Effect (CRE) on SW ATM Net by Cloud Type

	Thin (τ < 3.5)	Medium (τ: 3.5-22.6)	Thick (τ>22.6)
High (10-440 hPa)	(Mean: -0.0, STD: 0.2)	(Mean: 0.2, STD: 0.9)	(Mean: 0.1, STD: 0.4)
Mid (440-680 hPa)	(Mean: 0.1, STD: 0.2)	(Mean: 0.5, STD: 1.0)	(Mean: 0.1, STD: 0.4)
Low (> 680 hPa)	(Mean: 0.7, STD: 0.6)	(Mean: 2.2, STD: 3.4)	(Mean: 0.2, STD: 0.6)



Total CRE on TOA SW ATM

Sum of 3x3 Types
(Mean: 4.0, STD: 4.9)

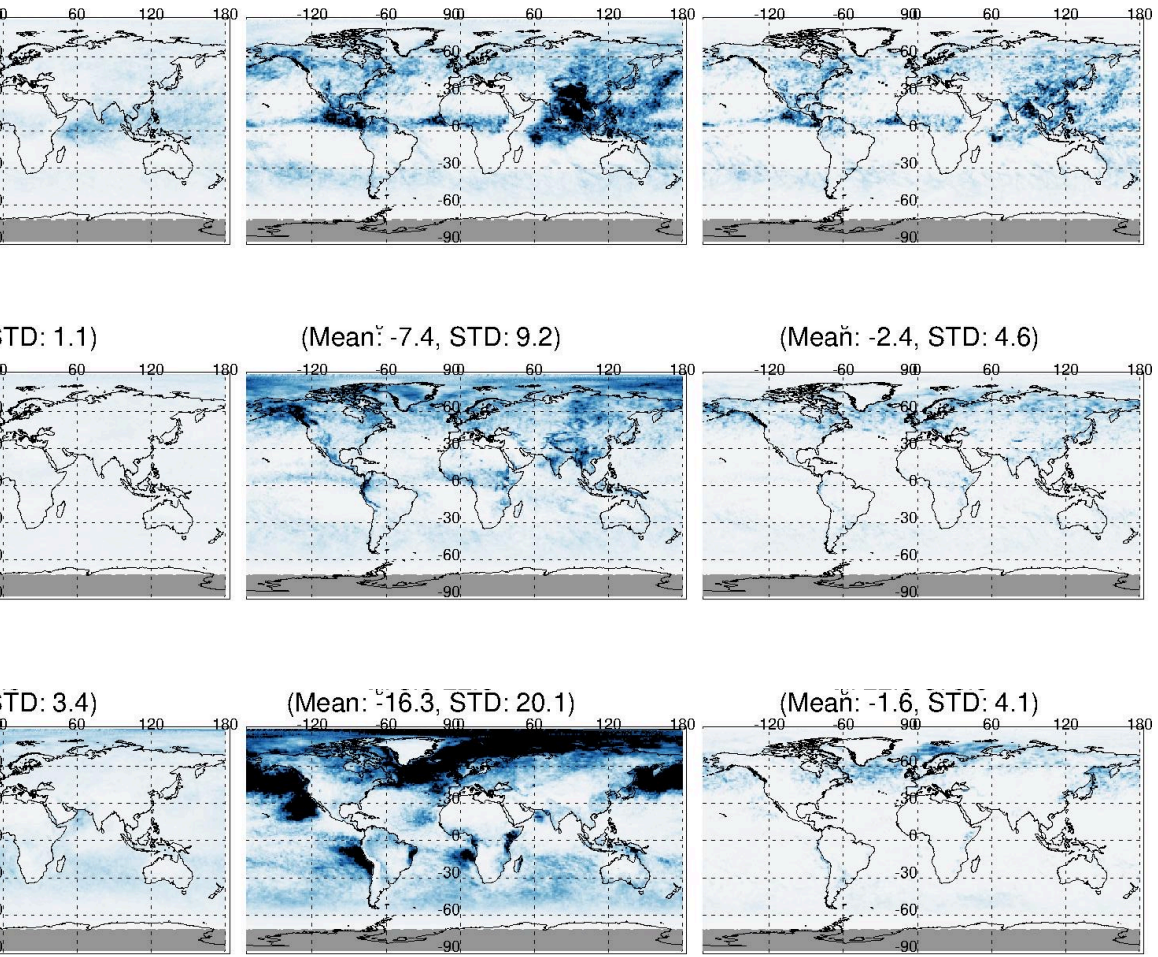


Applications of Sub-Footprint Scales of Cloud Fluxes

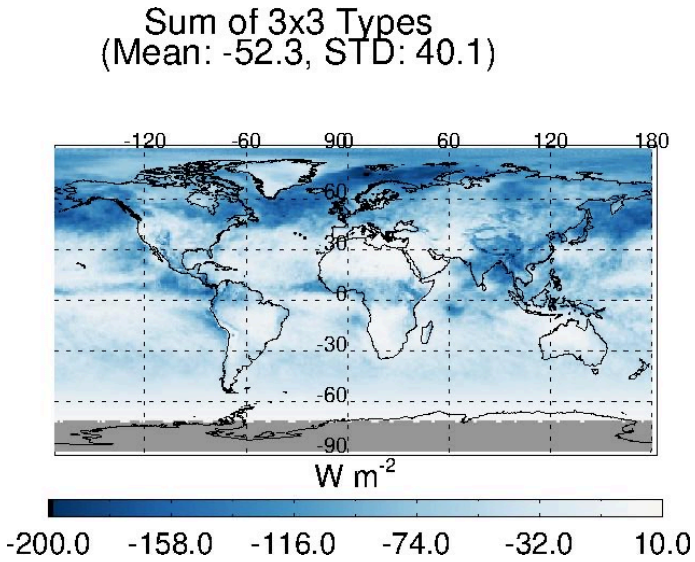
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Cloud Radiative Effect (CRE) on SW SFCDN by Cloud Type

	Thin (τ < 3.5)	Medium (τ: 3.5-22.6)	Thick (τ>22.6)
High (10-440 hPa)	(Mean: -3.4, STD: 4.0)	(Mean: -11.0, STD: 14.4)	(Mean: -5.8, STD: 9.6)
Mid (440-680 hPa)	(Mean: -1.2, STD: 1.1)	(Mean: -7.4, STD: 9.2)	(Mean: -2.4, STD: 4.6)
Low (> 680 hPa)	(Mean: -4.6, STD: 3.4)	(Mean: -16.3, STD: 20.1)	(Mean: -1.6, STD: 4.1)



Total CRE on TOA SW SFCDN

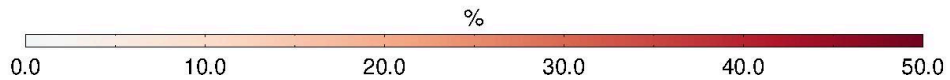


Applications of Sub-Footprint Scales of Cloud Fluxes

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Occurrence (%) by Cloud Type

	Thin (τ < 3.5)	Medium (τ: 3.5-22.6)	Thick (τ>22.6)
High (10-440 hPa)	(Mean: 9.4, STD: 10.1)	(Mean: 7.4, STD: 8.2)	(Mean: 2.5, STD: 3.6)
Mid (440-680 hPa)	(Mean: 3.8, STD: 3.6)	(Mean: 6.7, STD: 6.7)	(Mean: 1.2, STD: 1.9)
Low (> 680 hPa)	(Mean: 12.3, STD: 8.4)	(Mean: 16.9, STD: 15.3)	(Mean: 0.9, STD: 2.0)



Total Occurrence (%)

Sum of 3x3 Types
(Mean: 61.1, STD: 25.0)

