CERES Cloud Radiative Swath (CRS) Update

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Collaboration with:

SARB group: David Rutan, and Emily Monroe (Surface validation)

David Fillmore and Antonio Viudez-Mora (MATCH aerosol)

TISA Group: David Doelling and Pamela Mlynczak (TISA gridding for CRS1deg product)

Data Management: Walter Miller, Victor Sothcott, and Kathleen Dejwakh

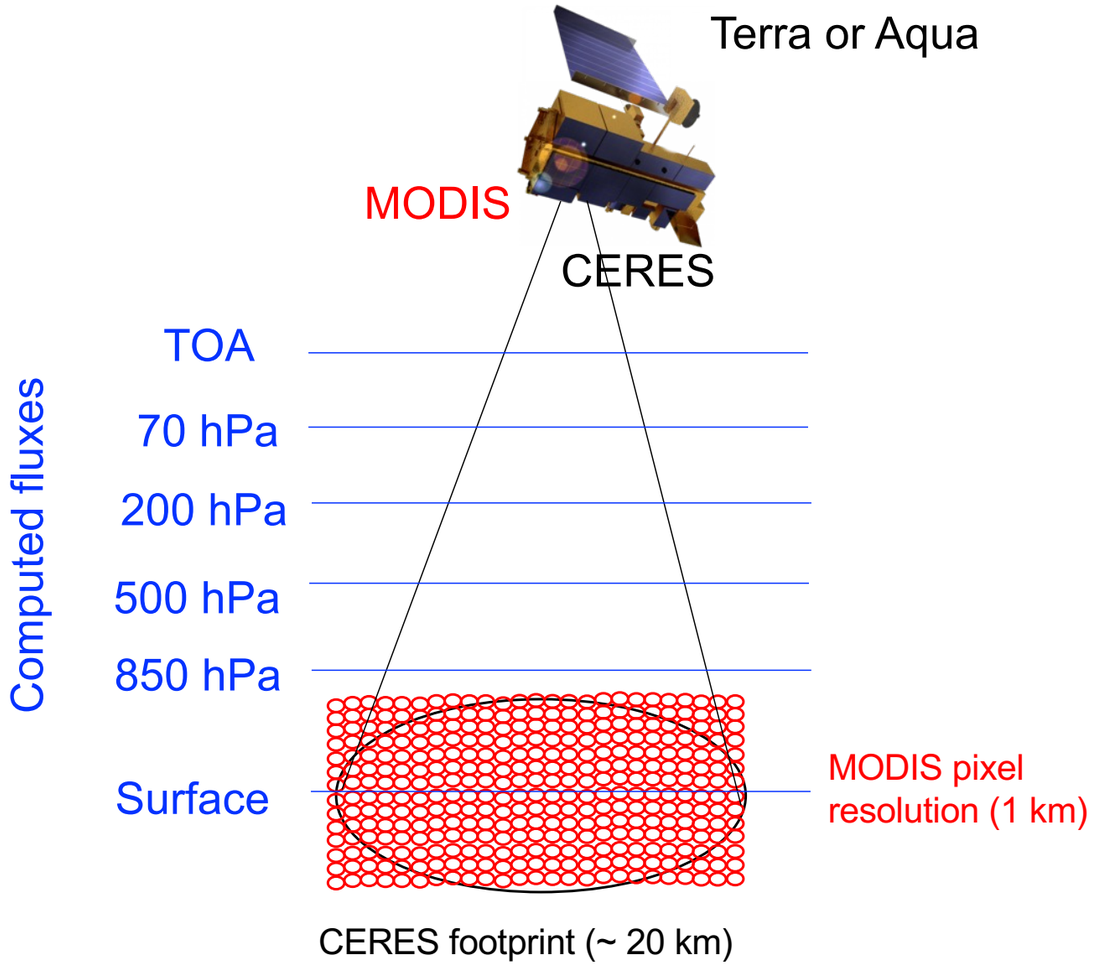
ADM Group: Wenying Su (TOA fluxes)

Cloud group: Bill Smith Jr and Sunny Sun-Mack (Cloud retrievals)

FLASHFLUX group: Paul Stackhouse (Parameterized surface fluxes in FLASHFLUX)

Brief Introduction of Cloud Radiative Swath (CRS) Product

- CERES instrument provides an estimation of TOA fluxes, but not fluxes at atmosphere or surface levels.
- CRS algorithm provides instantaneous computed fluxes at 6 vertical levels – TOA, 70 hPa, 200 hPa, 500 hPa, 850 hPa, and surface for every CERES footprint. The fluxes are computed in four different conditions – total, clear (no cloud but with aerosol), no aerosol (but with clouds), and pristine skies, to estimate cloud and aerosol radiative effects.
- NASA Langley Fu-Liou model is used for simulations (4str SW/2str LW).
- The model inputs are from satellite or reanalysis datasets.
- One of the main factors to determine fluxes is the clouds. This information comes from cloud retrievals by Cloud Group using MODIS narrowband radiance measurements, which occur on the same satellite platform with CERES (Terra or Aqua).



CRS Data Processing

- Due to the computational costs, earlier versions (Ed2B and Ed2C) of CRS processing was ceased to prioritize the development of L3 CERES products. We resumed Ed4 CRS processing and the data was just released for the 5-year period (2018-2022).
- An hourly CRS HDF file contains ~ 99,000 CERES footprints from cross-track scanning. The data file size for one month is 21-22 GB. Processing time for one hourly data is about 2 hours. Note that Ed4 processing time is shorter, compared to the earlier versions since the tunning option is turned off in Ed4, and we have better computer resources now.
- Temporal coverages of each edition:

Ed2B (MOD C4 radiances)	Terra CERES-FM1 or FM2 Aqua CERES-FM3 or FM4	Mar 2000 – June 2006 July 2002 – May 2006	
Ed2C (MOD C5 radiances)	Aqua CERES-FM3	May 2006 – Dec 2007	
Ed4 (MOD C6 radiances)	Terra CERES-FM1 Aqua CERES-FM3	2018-2022 2018-2022	”5 years”

- If there is a certain period related to research projects (e.g., field campaigns), please reach out to the CERES team so we can discuss the possibility of expanding the data period!

Fu-Liou Model Inputs for CRS Flux Simulations

	Ed4 (Current Version) (Released in May 5th, 2023)	Ed5 (Ongoing Development) (Target release date: 2025-2026)
$T(z)/q(z)/O_3(z)$ profiles & wind speed	GEOS-5.4.1 (MOA-5.4.1 1° grid)	GEOS-IT (MOA-IT 0.5° grid)
Skin Temperature	• MODIS 11μm-derived T_{skin} for clear skies • GEOS-5.4.1 T_{skin}	• MODIS 11μm-derived T_{skin} for clear skies • GEOS-IT T_{skin}
Surface Albedo	▪ Parameterized albedo model from Jin (2004) ▪ MODIS BRDF Spectral albedo ▪ Surface albedo history (SAH) Ed4 map derived from clear-sky CERES measurements	▪ Theoretical albedo model from Jin (2004) ▪ MODIS BRDF Spectral albedo ▪ Surface albedo history (SAH) Ed5 map derived from clear-sky CERES measurements
Cloud properties	MODIS clouds from Ed4 Cloud Algorithm	MODIS clouds from Ed5 Cloud Algorithm
Aerosol Properties	• Ed4 Hourly MATCH (Fillmore et al., 2022) • MODIS C6 multi-channel aerosol optical depths	• Ed5 Hourly MATCH: MODIS/VIIRS aerosol with CAM6 aerosol scheme (David Fillmore's talk during CERES STM) • MODIS C7 multi-channel aerosol optical depths
RTM	Langley Fu-Liou model	Langley Fu-Liou model with updated correlated k gas absorption features

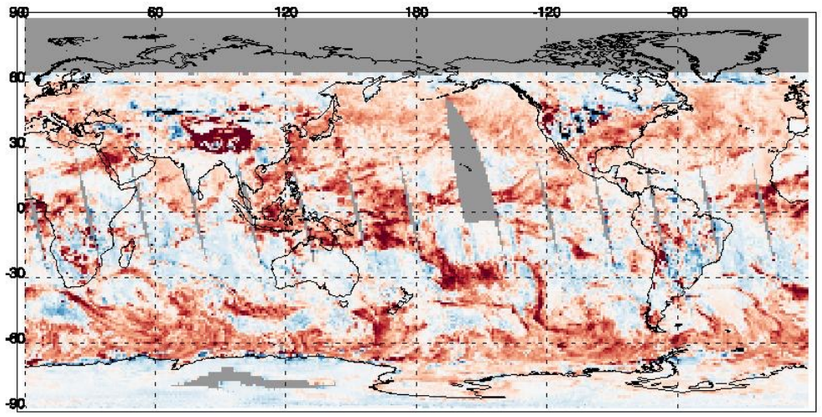
Ed4 CRS algorithm paper: Scott, R. C., F. G. Rose, P. W. Stackhouse, N. G. Loeb, S. Kato, D. R. Doelling, D. A. Rutan, P. C. Taylor, W. L. Smith, 2022: Clouds and the Earth's Radiant Energy System (CERES) Cloud Radiative Swath (CRS) Edition 4 Data Product. J. Atmos. Oceanic Technol., 39(11), 1781-1797. doi: 10.1175/JTECH-D-22-0021.1

SW TOA Biases (W m^{-2}) of CRS Computed Fluxes to Observations

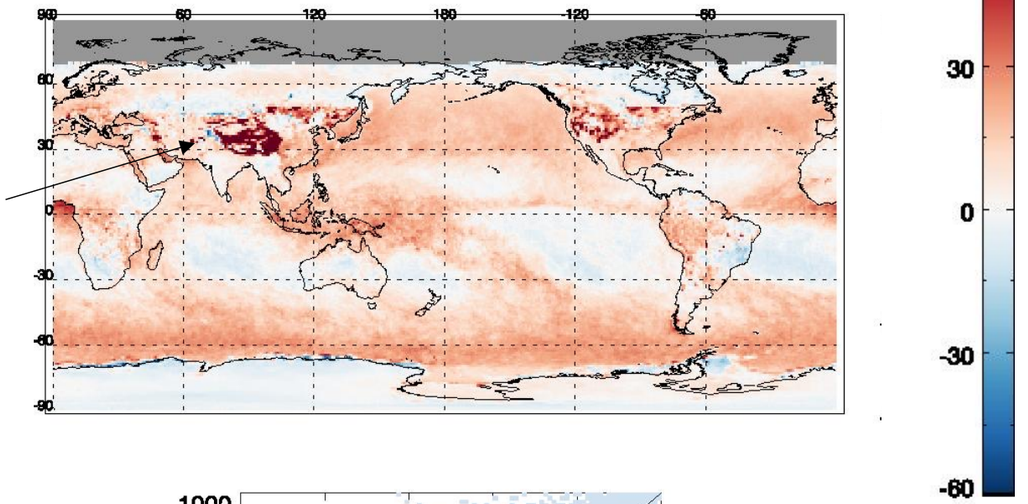
Aqua FM3

(Sampling available footprints; no diurnal/temporal integration)

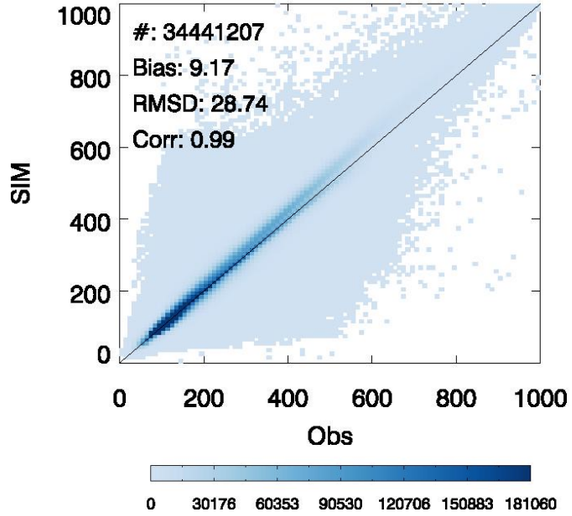
One Day (January 1st, 2019)



One Month (January 2019)



- Nice spatial coverage even from daily cross-track sampling!
- Cloudy regions (ITCZ and storm track regions) have positive SW biases. This might be related to 1) plane-parallel biases (e.g., broken clouds, or inhomogeneity within a cloud type) 2) underestimated ice particle size in MODIS retrievals (Ham et al., 2021) → Investigation plans for Ed5
- High elevation regions (e.g., Himalaya) show large uncertainties in cloud detections (seems to be much improved in cloud Ed4B algorithm).

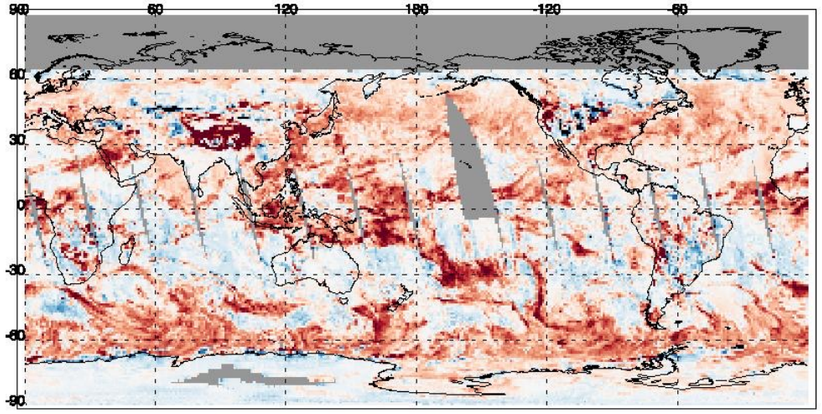


SW TOA Biases (W m^{-2}) of CRS Computed Fluxes to Observations

(Sampling available footprints; no diurnal/temporal integration)

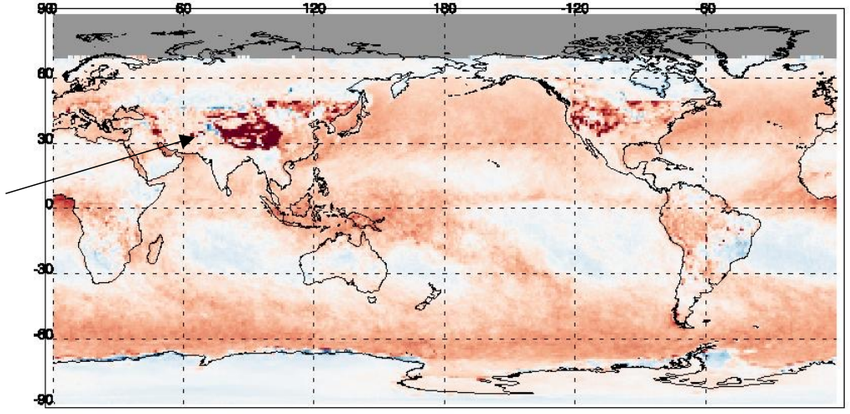
One Day (January 1st, 2019)

SW SIM - OBS (Mean: 10.22, RMSD: 23.78, #: 53250)



One Month (January 2019)

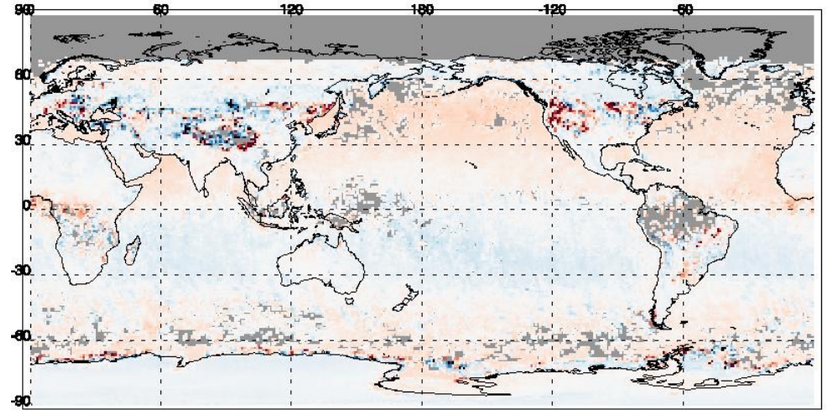
SW SIM - OBS (Mean: 10.07, RMSD: 16.60, #: 57355)

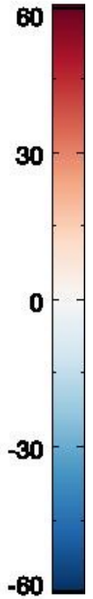


Snow region

One Month (Jan 2019) – Cloud-Free Cases

SW SIM - OBS (Mean: 0.22, RMSD: 10.84, #: 52978)

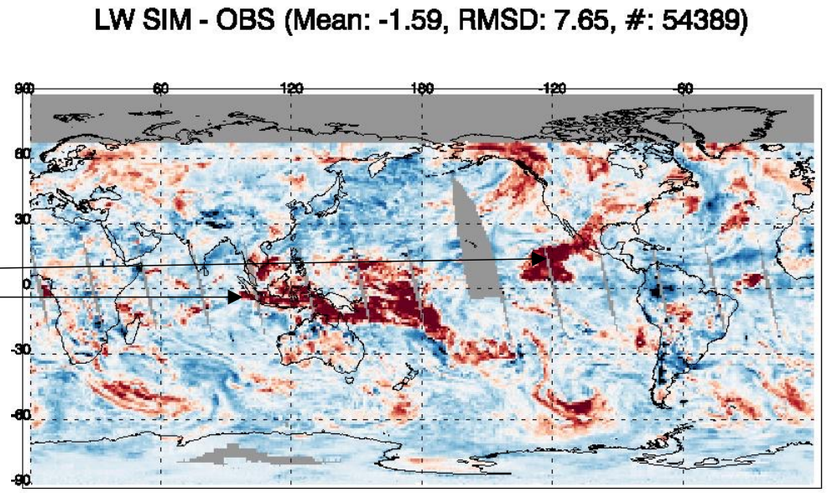




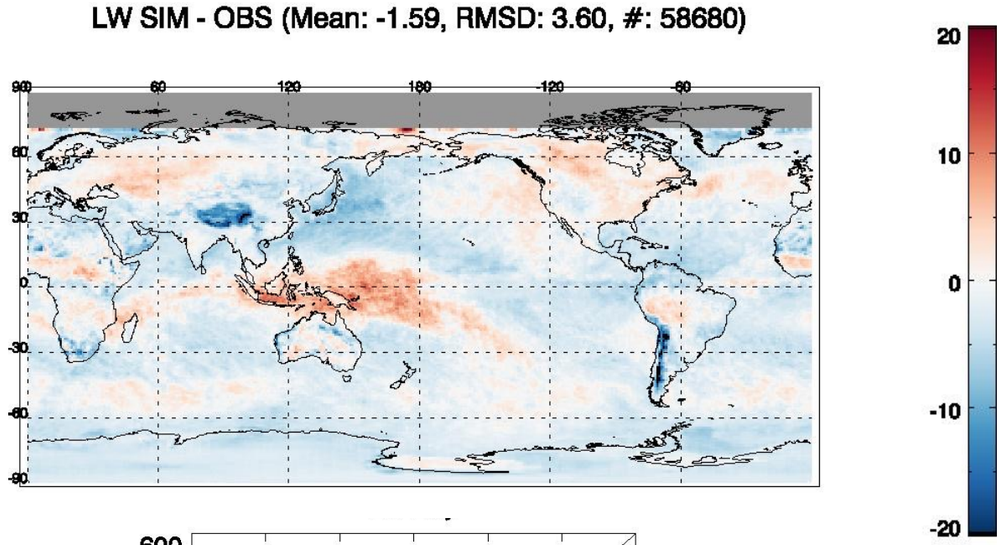
- Clear-sky shows good agreement between simulations and observations.

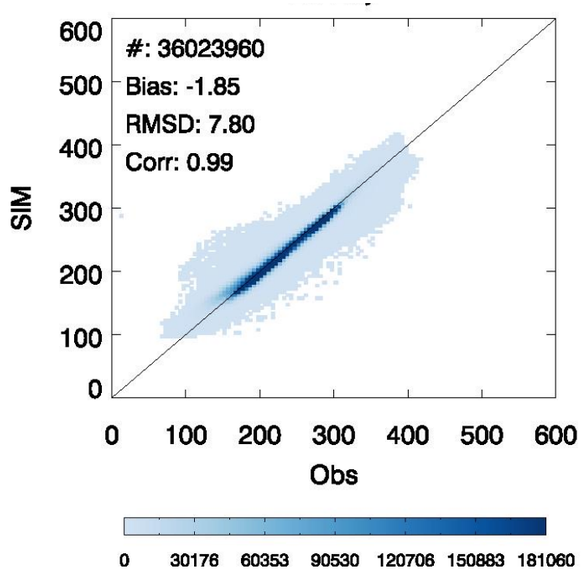
Daytime LW TOA Biases of CRS Computed Fluxes to Observations

One Day (January 1st, 2019)



One Month (January 2019)





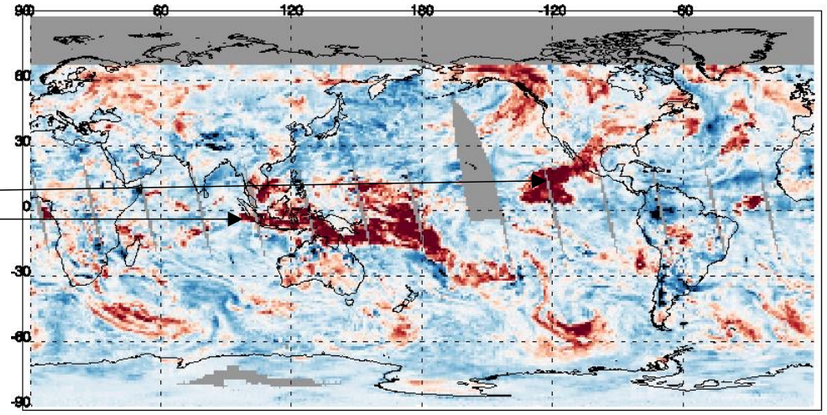
- The positive daytime LW biases over high cloud regions might be related to the assumption of cloud boundaries (top & base). The cloud top/base pressures are calculated from the retrieved cloud effective pressure and assumed layer thickness. For the given cloud top and base boundaries, homogeneous cloud profiles also can cause the simulation biases.

Daytime LW TOA Biases of CRS Computed Fluxes to Observations

Aqua FM3

One Day (January 1st, 2019)

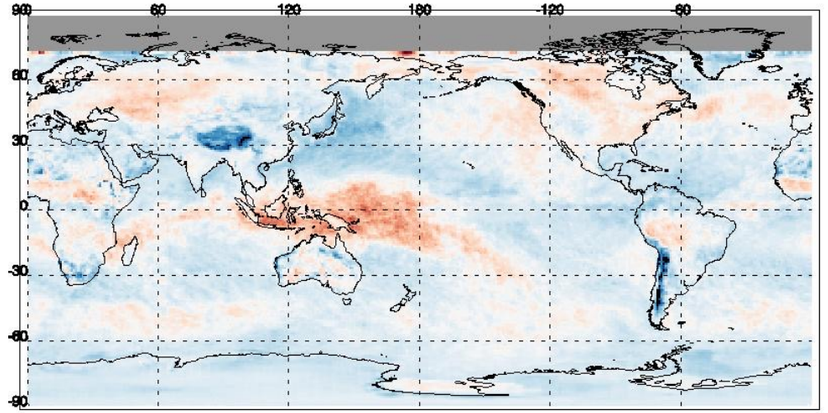
LW SIM - OBS (Mean: -1.59, RMSD: 7.65, #: 54389)



Low cloud top pressure retrieved

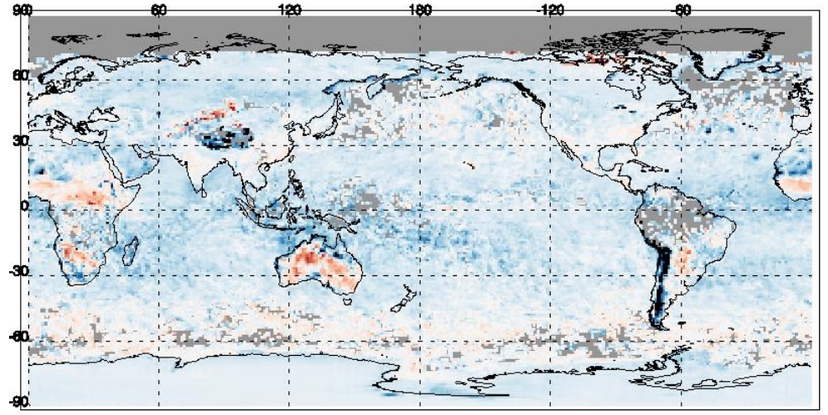
One Month (January 2019)

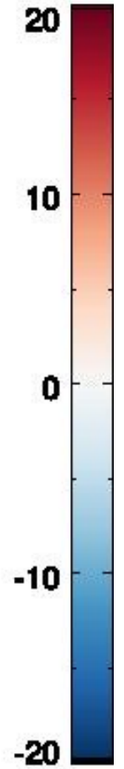
LW SIM - OBS (Mean: -1.59, RMSD: 3.60, #: 58680)



One Month (Jan 2019) – Cloud-Free Cases

LW SIM - OBS (Mean: -2.99, RMSD: 4.56, #: 54327)



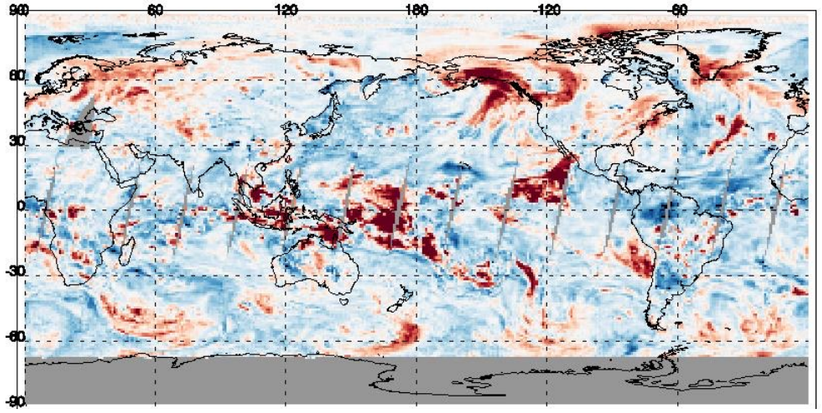


- For cloud-free cases, negative LW biases over ocean, implying wet biases or cold biases in GEOS-5.4.1 T(z) & q(z) profiles → Better reanalysis dataset (GEOS-IT) is coming!

Nighttime LW TOA Biases of CRS Computed Fluxes to Observations

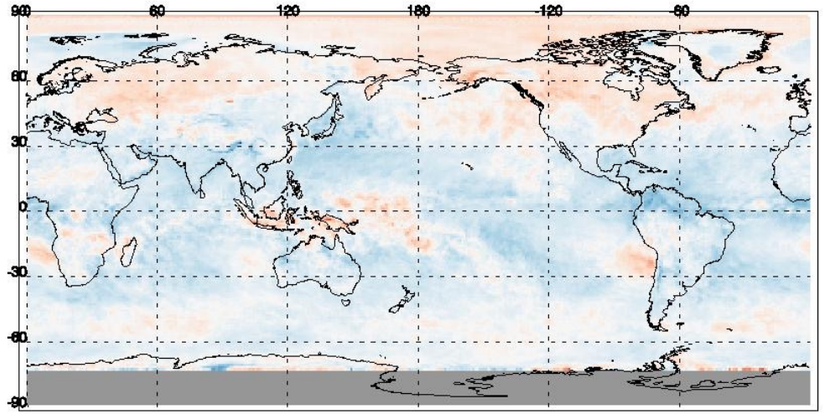
One Day (January 1st, 2019)

LW SIM - OBS (Mean: -1.57, RMSD: 6.91, #: 55187)



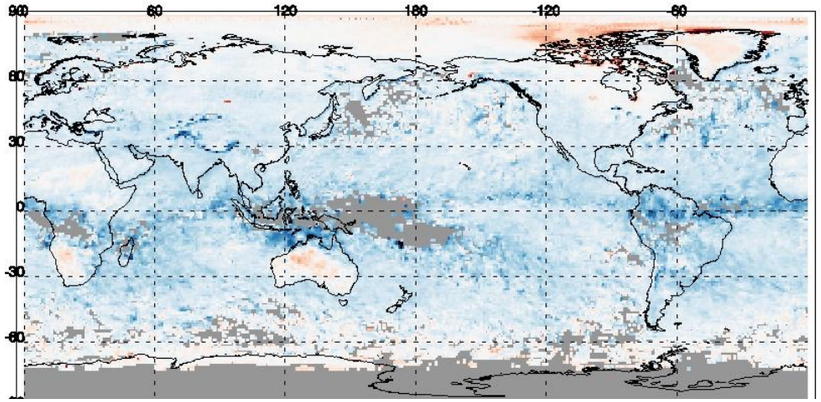
One Month (January 2019)

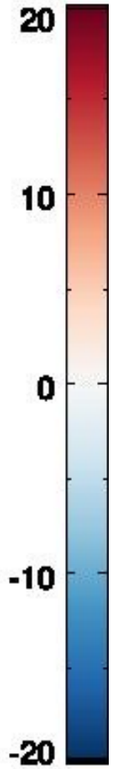
LW SIM - OBS (Mean: -1.75, RMSD: 3.06, #: 58680)



One Month (Jan 2019) – Cloud-Free Cases

LW SIM - OBS (Mean: -3.64, RMSD: 4.71, #: 52484)





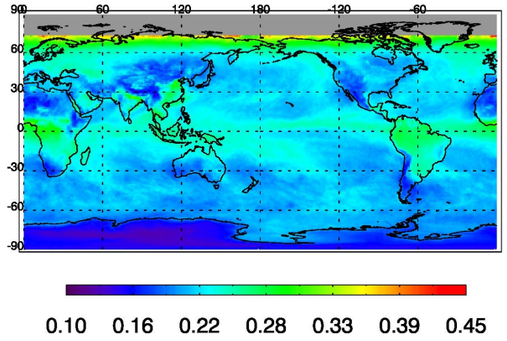
- Similar nighttime LW biases are shown to the daytime LW biases.

CRS Spectral Band Fluxes

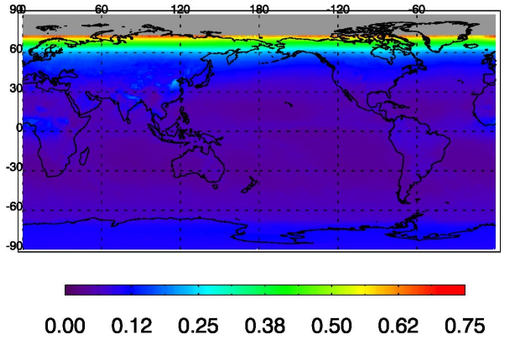
- Besides SW and LW broadband fluxes, computed fluxes are also available for **14 SW spectral bands and 12 LW spectral bands** in the CRS Ed4 product.
- The spectral fluxes are available for total skies at TOA and surface levels.

SW Atmos Absorptance = (SW Atmos Abs)/($F_0 \cos\theta_s$)

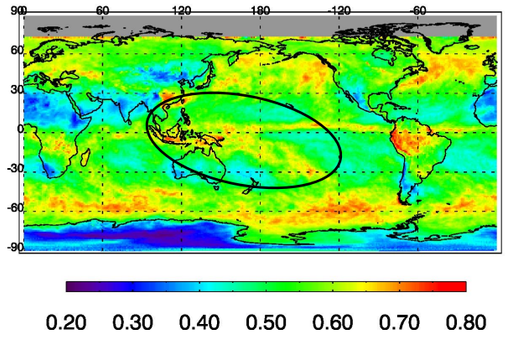
SW broadband
0.18-4.00 μm (0.22±STD: 0.03)



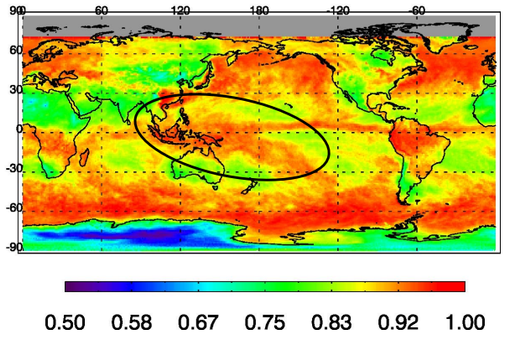
Non-cloud-absorbing visible channel
0.59-0.69 μm (0.08±STD: 0.08)



Weak cloud-absorbing channel
1.90-2.50 μm (0.54±STD: 0.09)

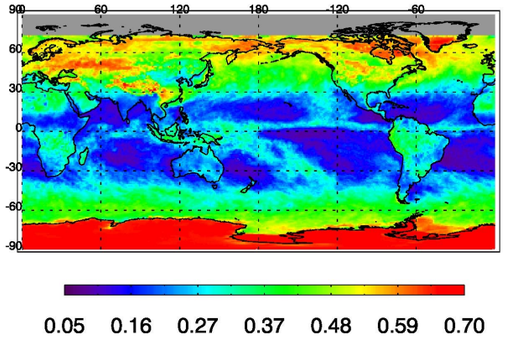


Strong cloud/gas-absorbing channel
2.50-4.00 μm (0.88±STD: 0.06)

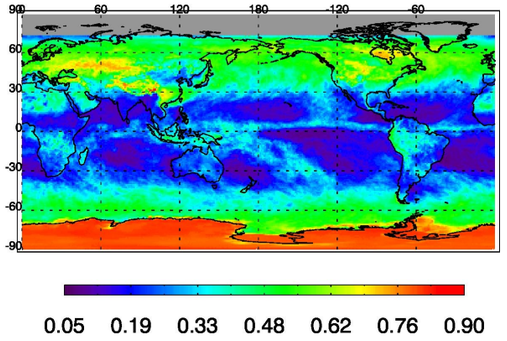


SW TOA Reflectivity = (SW TOAUp)/($F_0 \cos\theta_s$)

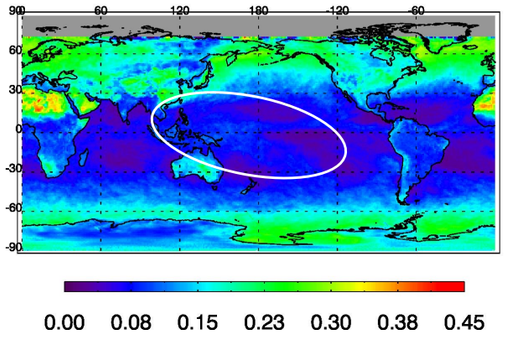
SW broadband
0.18-4.00 μm (0.31±STD: 0.14)



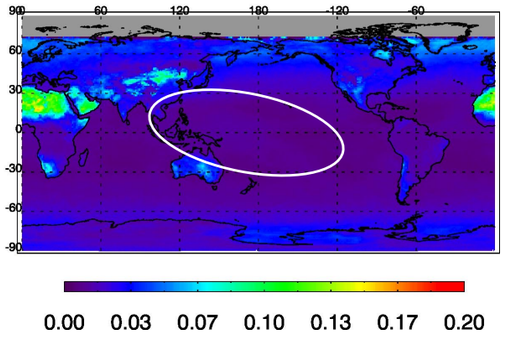
Non-cloud-absorbing visible channel
0.59-0.69 μm (0.33±STD: 0.17)



Weak cloud-absorbing channel
1.90-2.50 μm (0.11±STD: 0.07)



Strong cloud/gas-absorbing channel
2.50-4.00 μm (0.02±STD: 0.02)

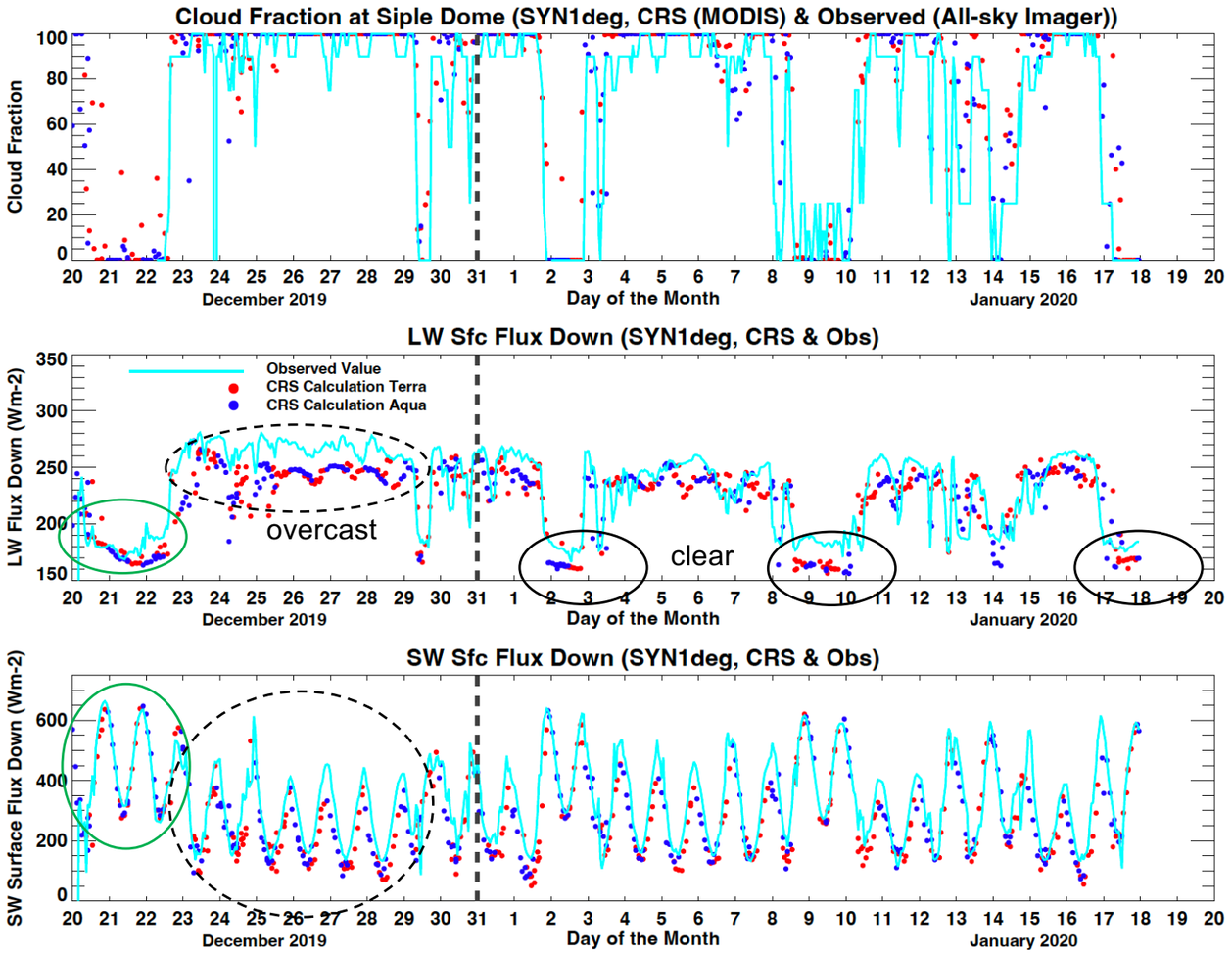


Strong cloud absorbing channels (1.9-2.5 μm) show large atmospheric absorption and small TOA reflectance.
Weak cloud absorbing channels (0.59-0.69 μm) show small atmospheric absorption and large TOA reflectance.
The spectral dependency can be examined using CRS product.

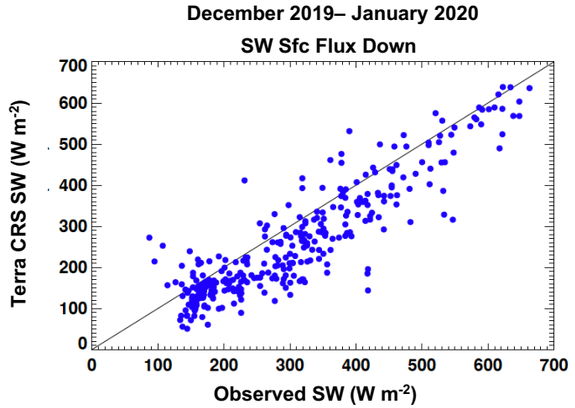
https://www.usap-dc.org/view/dataset/601540

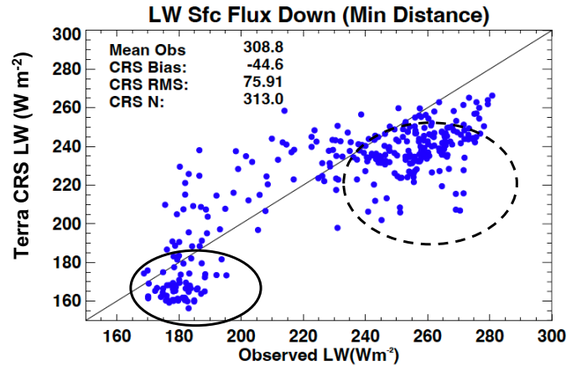
Ongoing Surface Validation Work – Siple Dome (SDM)

- Surface energy balance measurement in 2019-2020 at Siple Dome, which is located in West Antarctica on the Siple Coast (Lat 81.65°S, Lon 148.81°W, Elevation 720 m).



Ed5 cloud τ algorithm will add 1.6 μm in addition to 1.24 μm over snow/ice surface types, which will greatly reduce the τ positive biases.





(David Rutan)

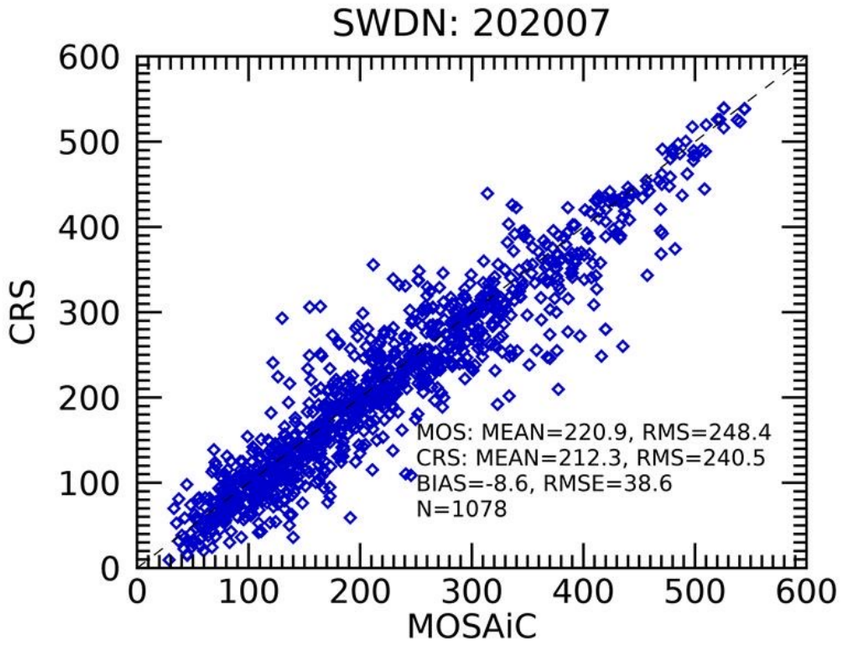
Clr/Broken — CRS T(z) is too cold, or q(z) is too dry near surface.

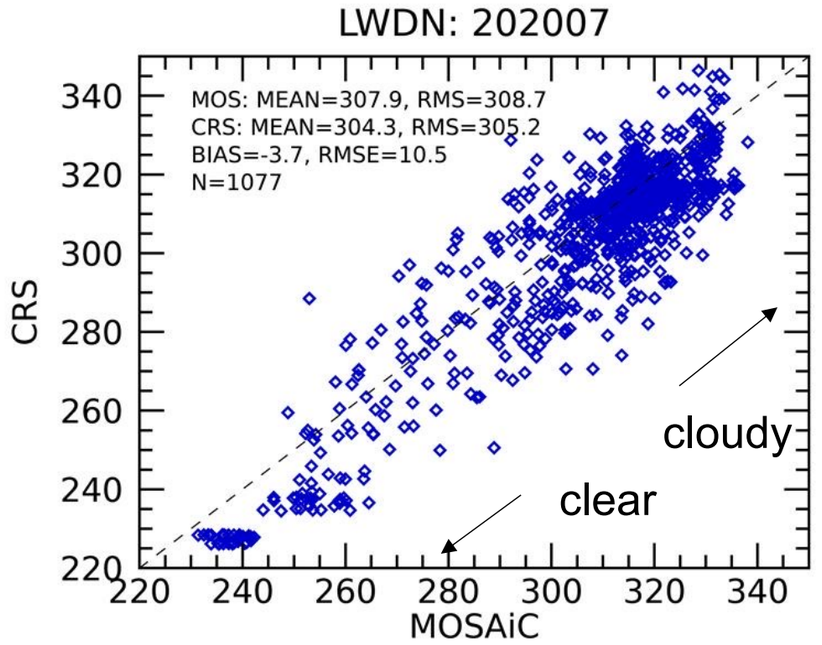
Overcast — CRS cloud base temperature cold biases. CRS cloud optical depth might be too large.

CRS inputs might be close to truth.

Ongoing Surface Validation Work – MOSAiC Ship Campaign

- Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) observed the Artic area from September 2019 to October 2020. The campaign includes surface broadband flux measurements, which can be used for the validation of CRS computed surface fluxes.





(Emily Monroe)

- Overall, computed surface fluxes are well correlated with observations.
- Both computed surface downward SW and LW fluxes are slightly negatively biased to observations (similar results were shown in Scott et al. (2022) but a different month was used in that study).
- CRS SW surface downward fluxes are negatively biased to observations, but not as much in Siple Dome.
- CRS LW surface downward fluxes are negatively biased, which are similar to Siple Dome comparison results.

Level 3 CRS1deg-Hour Product (In Progress with TISA group)

- Level 3 hourly averaged gridded (1°) product of instantaneous computed and observed fluxes
- CRS1deg product are aligned with SSF1deg product. Both products contain the same number of CERES footprints. CRS1deg contains computed fluxes, and SSF1deg product includes cloud/aerosol properties and CERES-observed fluxes.
- The relationship between cloud/aerosol with radiative fluxes can be examined on a grid scale.
- The L3 product can be more easily collocated with other satellite product (e.g., AIRS) and climate model results.
- Note that CRS1deg-Hour product is derived from a certain local time (10:30AM for Terra and 1:30PM for Aqua) and when comparing with other products, the time differences across datasets should be taken into account.

Summary

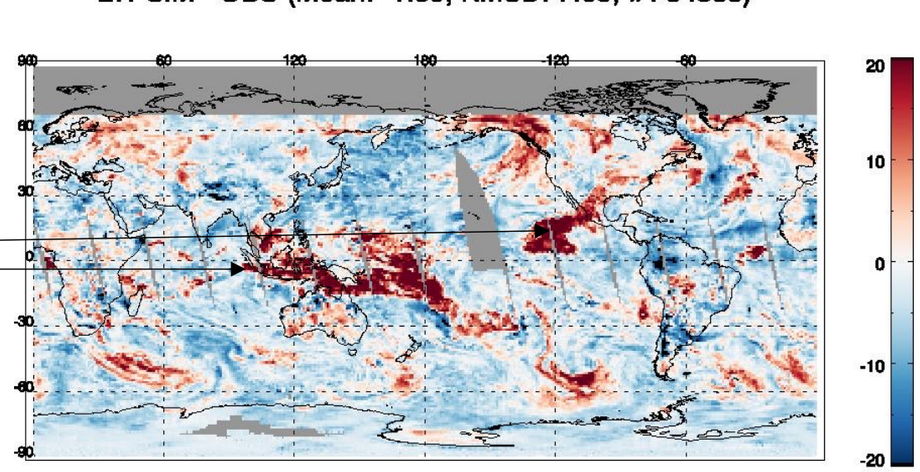
- Terra and Aqua CRS Ed4 products were released for the five-year period (2018-2022).
- The product will include computed fluxes at six vertical levels and for four different conditions (total, clear, no-aerosol, and pristine conditions), at a CERES footprint resolution.
- Spectrally resolved fluxes will be also available at TOA and surface for all-sky (total) conditions, enabling examination of spectral features of aerosol and clouds.
- The surface validation work is ongoing.
- CRS1deg-Hour product will be available soon, and this L3 product can be more easily collocated with other products.

Thank you for your attention!

Please contact to seung-hee.ham@nasa.gov if you have any questions.

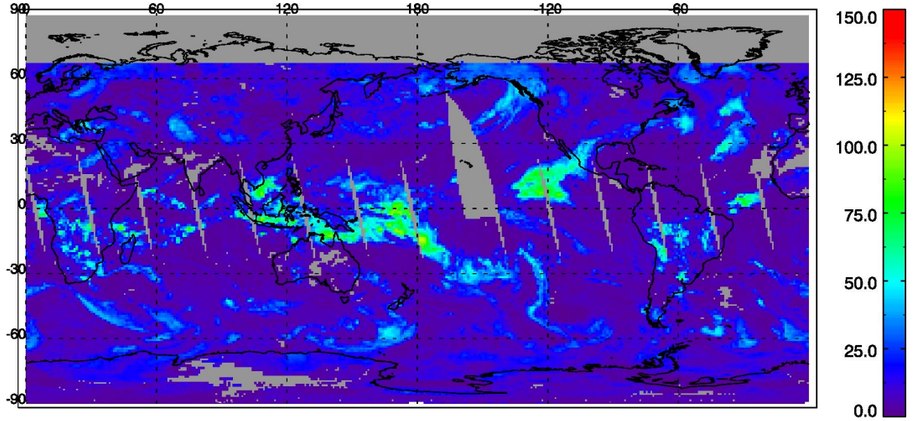
Daytime LW TOA Biases of CRS Computed Fluxes to Observations

One Day (January 1st, 2019)

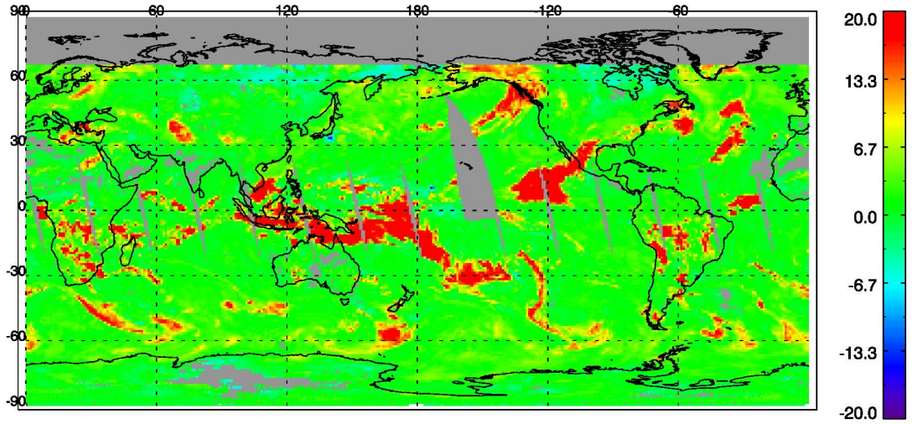


Low cloud top pressure retrieved

CBT – CTT (K)
CBT: Cloud Base Temp, CTT: Cloud Top Temp



MidTemp – Teff (K)
where MidTemp = 0.5(CTT+CBT)



- The positive daytime LW biases over high cloud regions might be related to the assumption of cloud boundaries (top & base). The cloud top/base pressures are calculated from the retrieved cloud effective pressure and assumed layer thickness. For the given cloud top and base boundaries, homogeneous cloud profiles also can cause the simulation biases.