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CERES Cloud Radiative Swath (CRS) Update

Seung-Hee Ham[1], Seiji Kato[2], Fred Rose[1], Norman Loeb[2], David Doelling[2],
David Rutan[1], Emily Monroe[1], Walter Miller[1], and Paul Stackhouse[2]

[1]Science Systems and Applications, Inc. (SSAI), Hampton, Virginia, USA
[2]NASA Langley Research Center, Hampton, Virginia, USA

Collaboration with:

SARB group: David Rutan, and Emily Monroe (Surface validation)
Antonio and David Fillmore (MATCH aerosol)

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

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

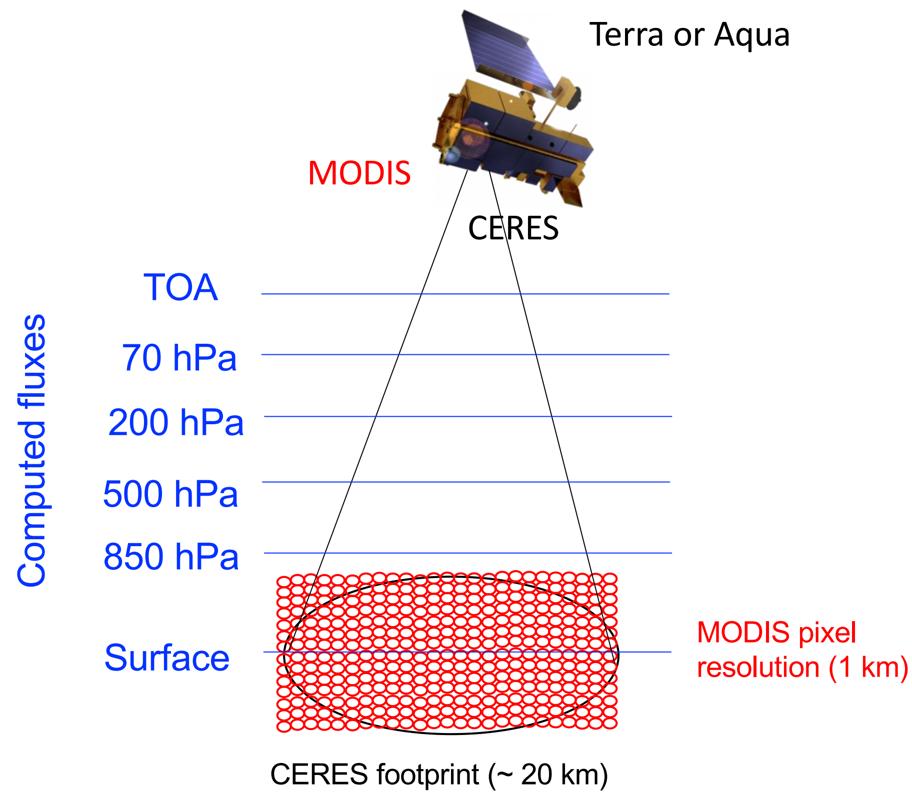
ADM Group: Wenying Su (TOA fluxes)

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 measurements provide estimation of TOA fluxes, but not at atmosphere or surface levels.
- CRS algorithm provides instantaneous (CERES footprint resolution) computed fluxes at 6 vertical levels – TOA, 70 hPa, 200 hPa, 500 hPa, 850 hPa, and surface. The fluxes are computed four different conditions - all, clear, no-aerosol, and pristine skies, in order to estimate cloud and aerosol radiative effects.
- NASA Langley Fu-Liou model is used for simulations.
- The model inputs are from satellite or reanalysis datasets.
- One of main factor to determine the fluxes is clouds. These information comes form MODIS narrowband radiance measurements, which is aboard on the same satellite platform (Terra or Aqua).



CRS Data Processing

- Due to the computational costs, earlier versions (Ed2B and Ed2C) processing was ceased to prioritize the development of L3 CERES products. The resumed Ed4 CRS product targets 5-year period (2018-2022).
- An hourly CRS HDF file contains ~ 99,000 CERES footprints from cross-track scanning. 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 tunning option is turned off in Ed4 and better we have computer resource 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 project (e.g., field campaign), 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) (Target release date: May 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 spectral aerosol optical depths	• Ed5 Hourly MATCH with CAM6 (David Fillmore's talk during CERES STM) • MODIS C7 spectral 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

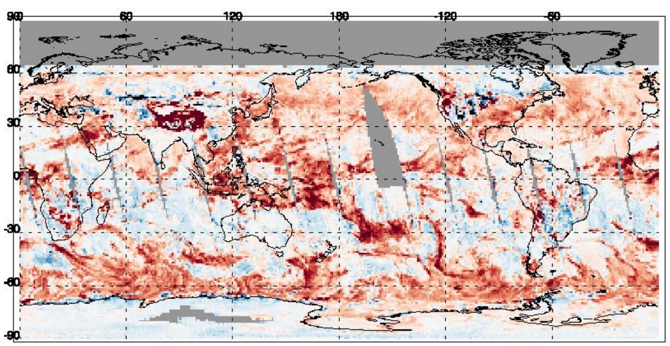
Aqua FM3

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

(Sampling available footprints; no diurnal/temporal integration)

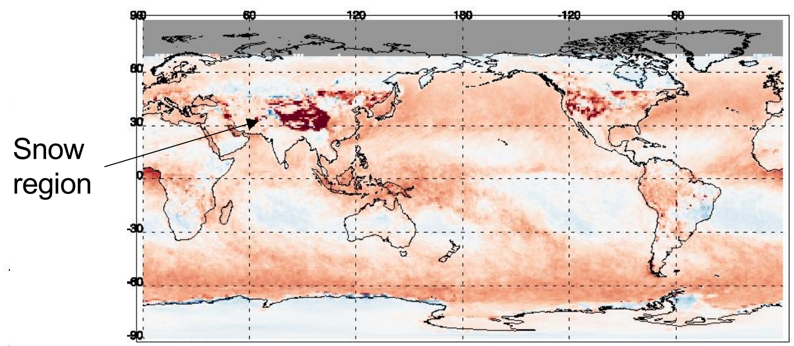
One Day (January 1st, 2019)

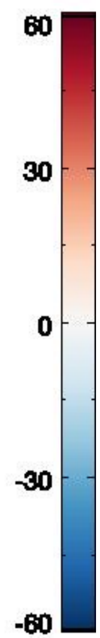
SW SIM - OBS (Mean: 10.22, RMSD: 23.78, #: 53250)



One Month (January 2019)

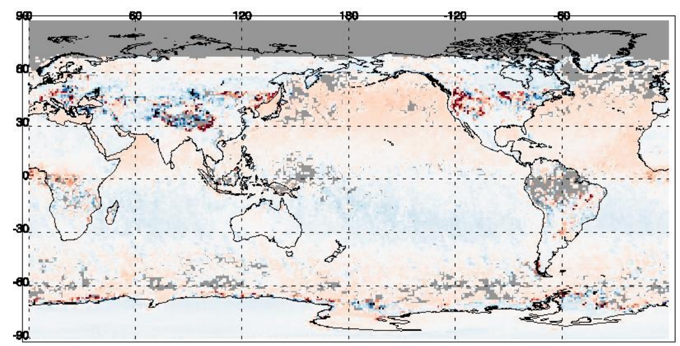
SW SIM - OBS (Mean: 10.07, RMSD: 16.60, #: 57355)





One Month (Jan 2019) – Clear Sky Composites

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



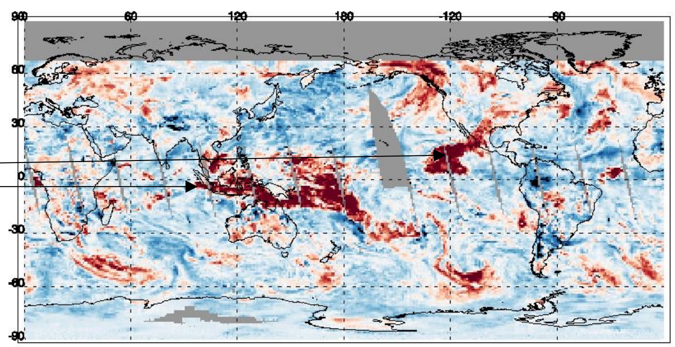
- Nice spatial coverage even from daily cross-track sampling!
- Cloudy regions (ITCZ and storm track regions) have positive SW biases. This might be related to 1) plane-parallel biases (e.g., broken clouds, or inhomogeneity within a cloud type), 2) underestimated ice particle size in MODIS retrievals (Ham et al., 2021), 3) uncertainties in cloud altitude (determine WV absorption above clouds) → 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).
- Clear-sky shows good agreement between simulations and observations.

Aqua FM3

Daytime LW TOA Biases of CRS Computed Fluxes to Observations

One Day (January 1st, 2019)

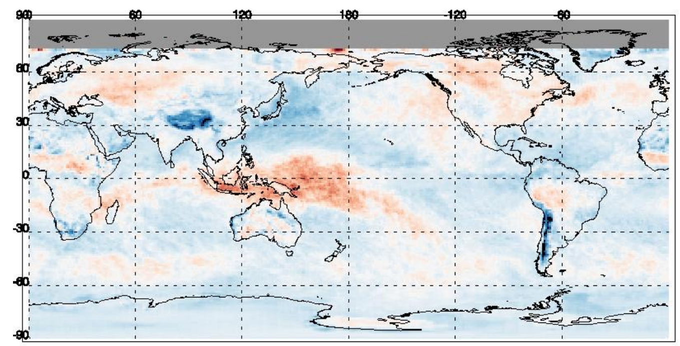
LW SIM - OBS (Mean: -1.59, RMSD: 7.65, #: 54389)



Low cloud top pressure retrieved

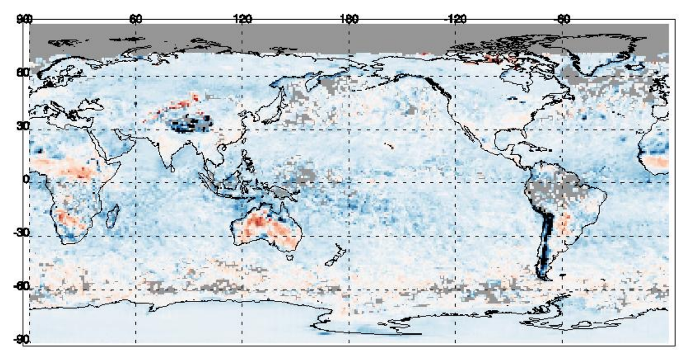
One Month (January 2019)

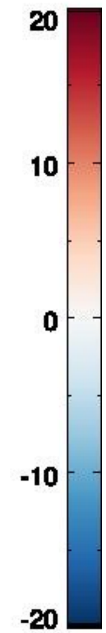
LW SIM - OBS (Mean: -1.59, RMSD: 3.60, #: 58680)



One Month (Jan 2019) – Clear Sky Composites

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





- Positive daytime LW biases over high cloud regions.
- Overall negative LW biases over ocean for clear skies, implying wet biases or cold biases in GEOS-5.4.1 T(z) & q(z) profiles → Better reanalysis dataset (GEOS-IT) is coming!

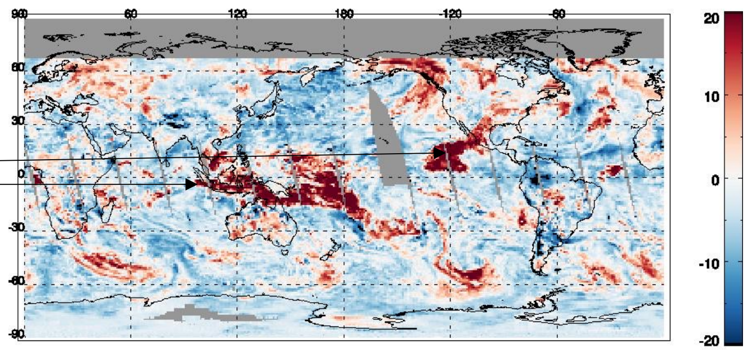
Aqua FM3

Daytime LW TOA Biases of CRS Computed Fluxes to Observations

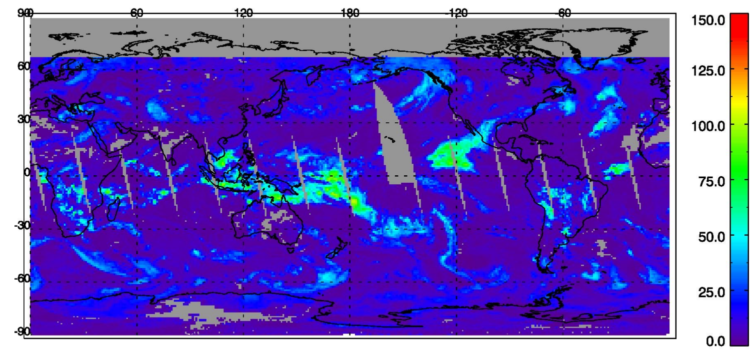
One Day (January 1st, 2019)

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

Low
cloud top
pressure
retrieved

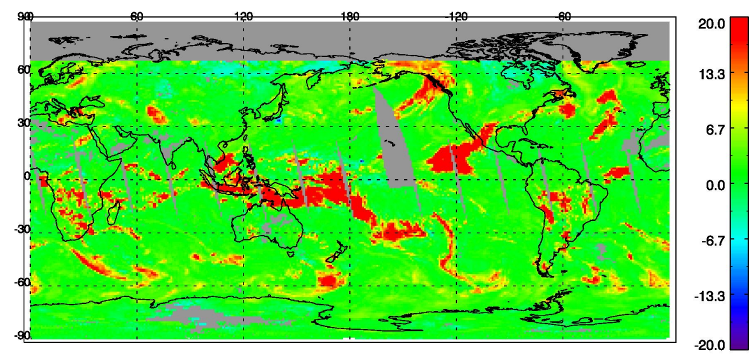


CBT – CTT (K)
CBT: Cloud Base Temp, CTT: Cloud Top Temp



- 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.

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

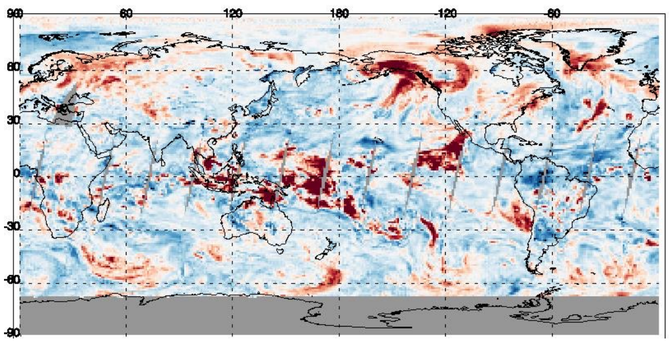


Aqua FM3

Nighttime LW TOA Biases of CRS Computed Fluxes to Observations

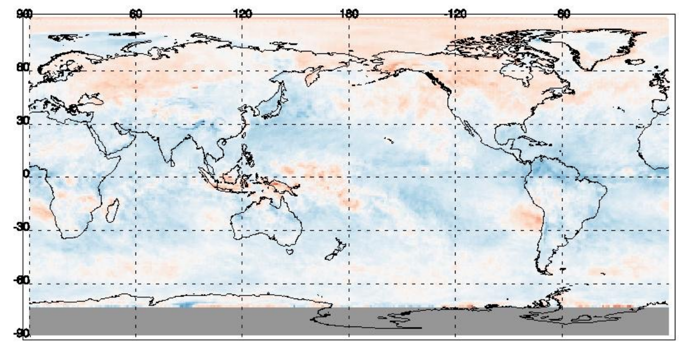
One Day (January 1st, 2019)

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



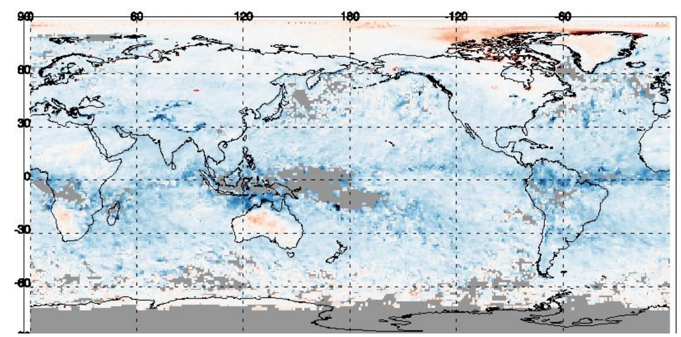
One Month (January 2019)

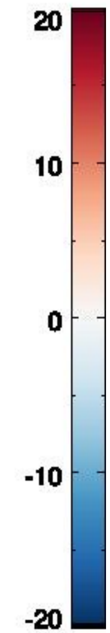
LW SIM - OBS (Mean: -1.75, RMSD: 3.06, #: 58680)



One Month (Jan 2019) – Clear Sky Composites

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

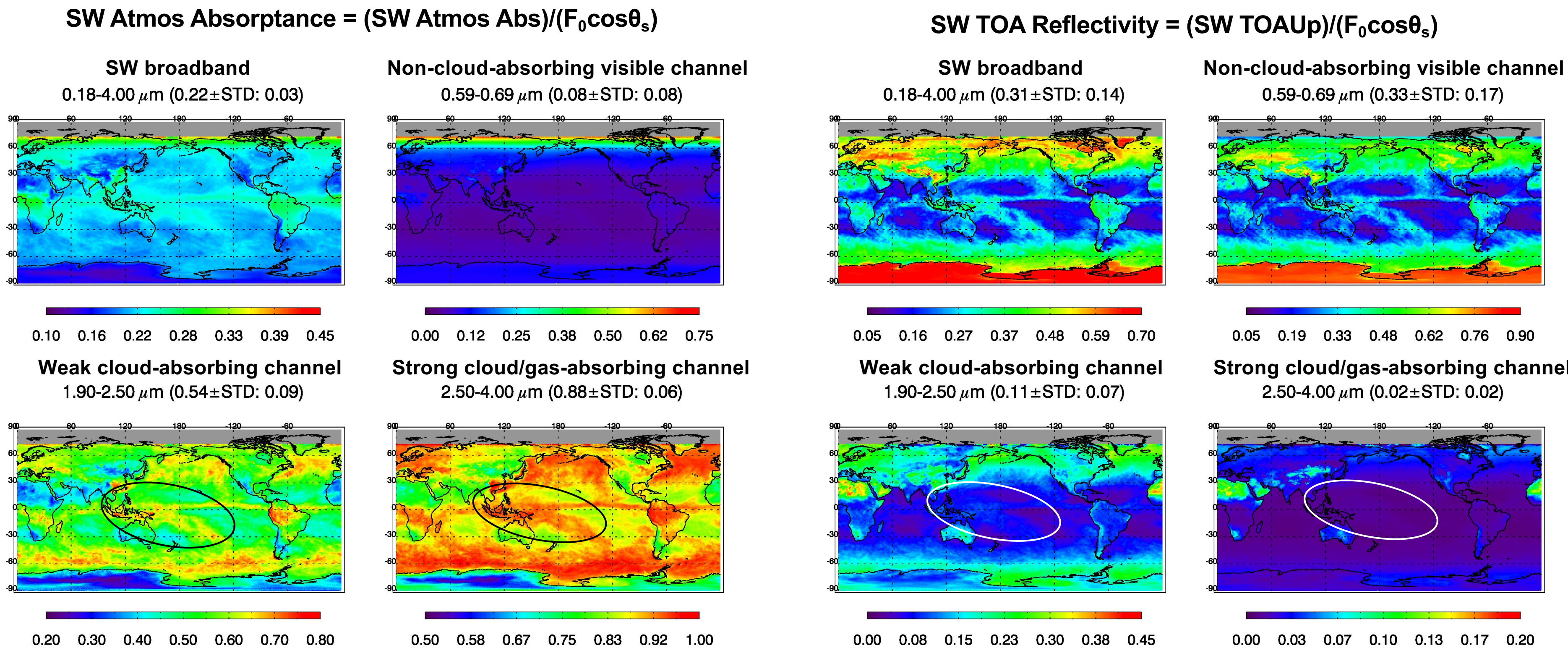




- Positive LW biases for high clouds.
- Positive LW biases appear over stratus regions (consistent use of T(z) between cloud retrieval and RT calculation will help) → Improvement plan for Ed5
- Overall negative LW biases for clear skies

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 CRS Ed4 product.
- The spectral fluxes are available for total skies at TOA and surface levels.



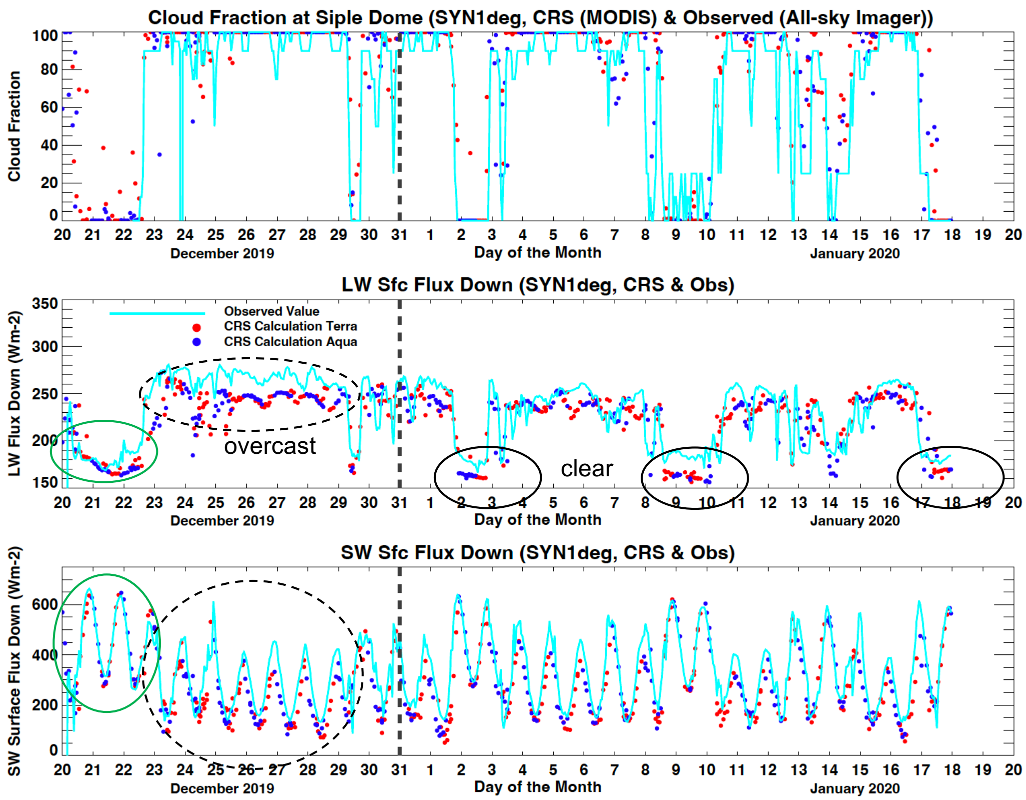
Strong cloud absorbing channels (1.9-2.5 μm) show large atmospheric absorption and small TOA reflectance.
Weak cloud absorbing channels (0.59-0.69 μm) show small atmospheric absorption and large TOA reflectance.
The spectral dependency can be examined using CRS product.

January 2019, Aqua FM3

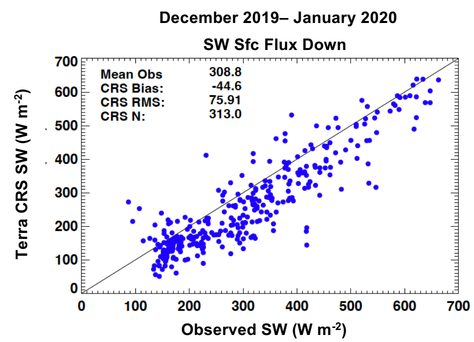
Ongoing Surface Validation Work – Siple Dome (SDM)

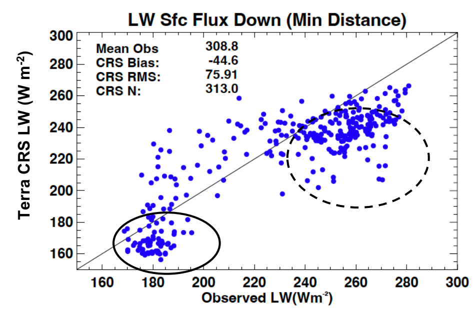
https://www.usap-dc.org/view/dataset/601540

- 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).

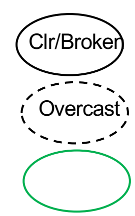


Ed5 cloud τ algorithm will add 1.6 µm in addition to 1.24 µm over snow/ice surface types, which will greatly reduce the τ positive biases.





(David Rutan)



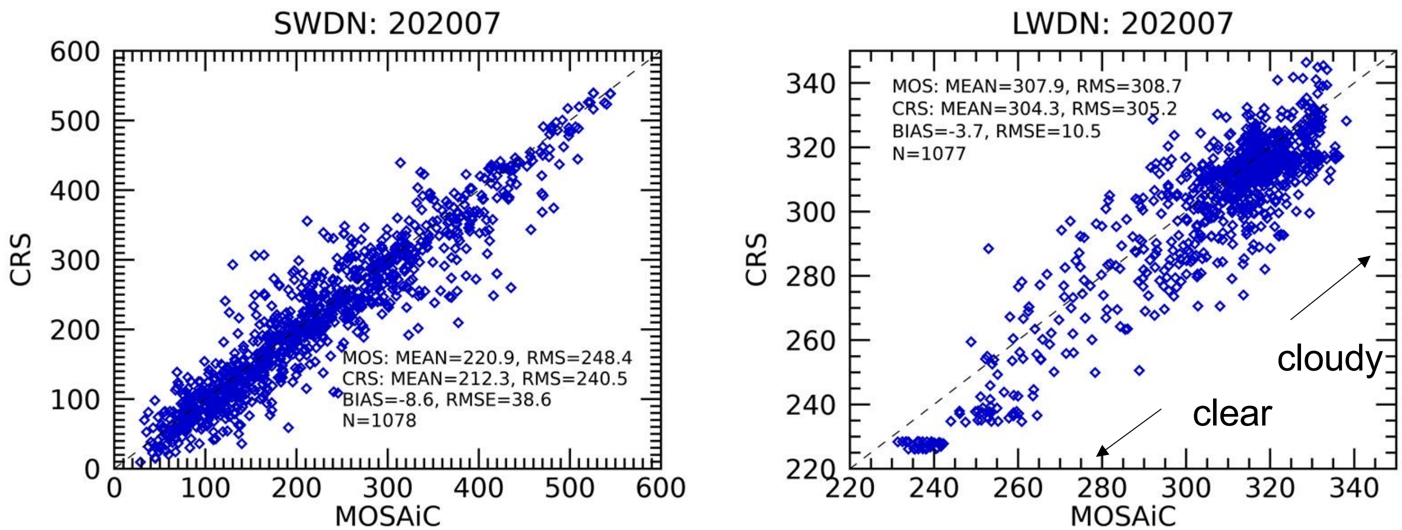
CRS T(z) is too cold, or q(z) is too dry near surface.

CRS cloud base temperature (height) 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 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).
- Negative SW biases appear for cloudy regions (not shown), implying overestimation of cloud optical depth.
- Negative LW biases appear as in Siple Dome, which could be due to 1) T(z) and q(z) biases near surface 2) cloud base temperature biases.

CRS1deg-Hour Product (In Progress with TISA group)

- Level 3 hourly averaged gridded (1°) product providing computed and observed fluxes
- The product includes instantaneous fluxes (not hourly integrated fluxes).
- The L3 product can be more easily collocated with other product, compared to level 2 (L2) CRS product.
- The CRS1deg-Hour product can be used as alternatives of flux simulators to validate climate models (Eitzen et al. 2017). The product includes fluxes for the given cloud, aerosol, surface, and atmospheric condition.

Summary

- Terra and Aqua CRS Ed4 product will be released soon for the five-year period (2018-2022).
- The product will include computed fluxes at five vertical levels and for four different conditions (all, clear, no-aerosol, and pristine conditions), at a CERES footprint resolution.
- The product also contains CERES-observed TOA fluxes, and the biases of computed fluxes can be easily estimated.
- Spectral fluxes will be also available at TOA and surface for all-sky conditions, enabling examination of spectral dependency depending on aerosol and clouds.
- The surface validation over snow/ice surface suggests the overestimation of MODIS cloud optical depth, and we will work with the cloud team for future Ed5 algorithm.
- CRS1deg-Hour product will be available, and this L3 product can be more easily collocated with other products. Also, this product can be used as an alternative tool of GCM simulators.

Thank you for your attention!

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