Surface Atmosphere Radiation Budget (SARB) working group update

Seiji Kato[1], Fred G. Rose[2], David A. Rutan[2],

Seung Hee Ham[2], Alexander Radkevich[2], Thomas E. Caldwell[2]

Antonio Viudez-Mora[2], Tyler J. Thorsen[1], Ryan C. Scott[2],

David Fillmore[3], and Xianglei Huang[4]

[1]NASA Langley Research Center

[2]Science System & Applications Inc.

[3]NCAR

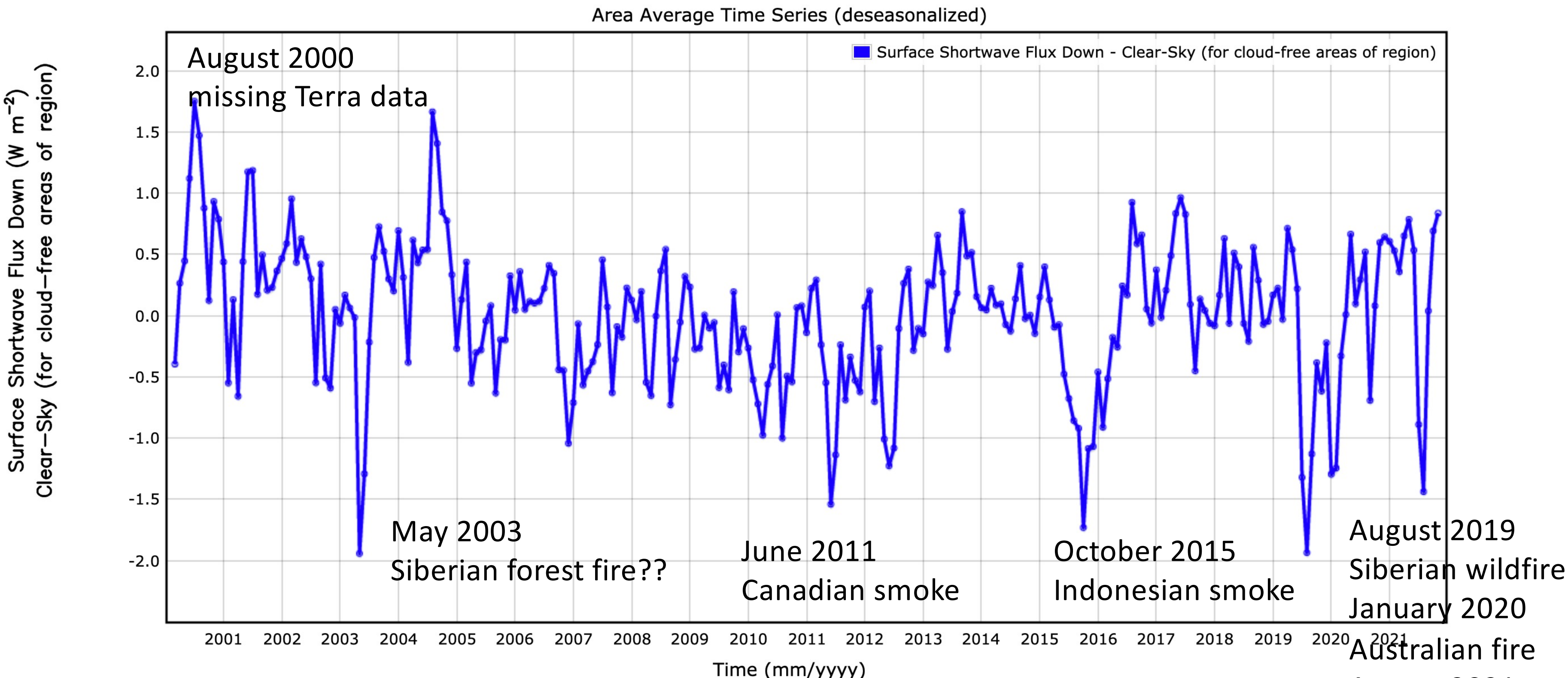
[4]University of Michigan

CERES Science Team Meeting
April 26-28, 2022

Outline of this talk

- Edition 5 plan
  - MATCH aerosol
  - Langley Fu-Liou code update
  - MOA (temperature, specific humidity, and ozone profiles)
- Skin temperature impact on surface irradiance

Global monthly surface clear-sky downward shortwave anomalies



Standard deviation = 0.59 Wm^{-2}

Number of month > 2σ: 14 (out of 261)

8 occurred after 2010

5 occurred after 2019

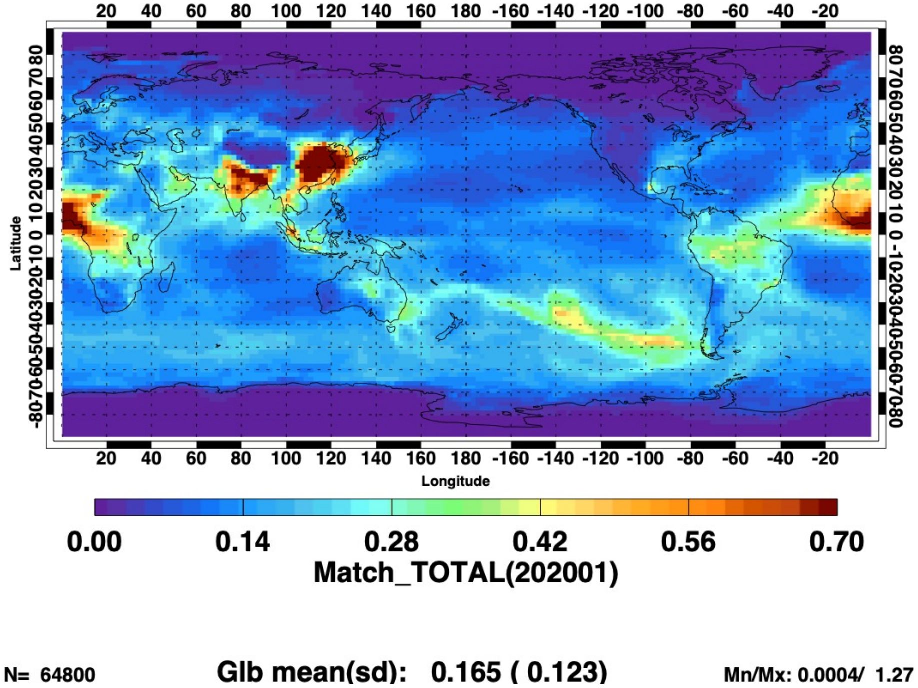
Selected Region: [-90,0 to 90,360]

Edition 4 MATCH

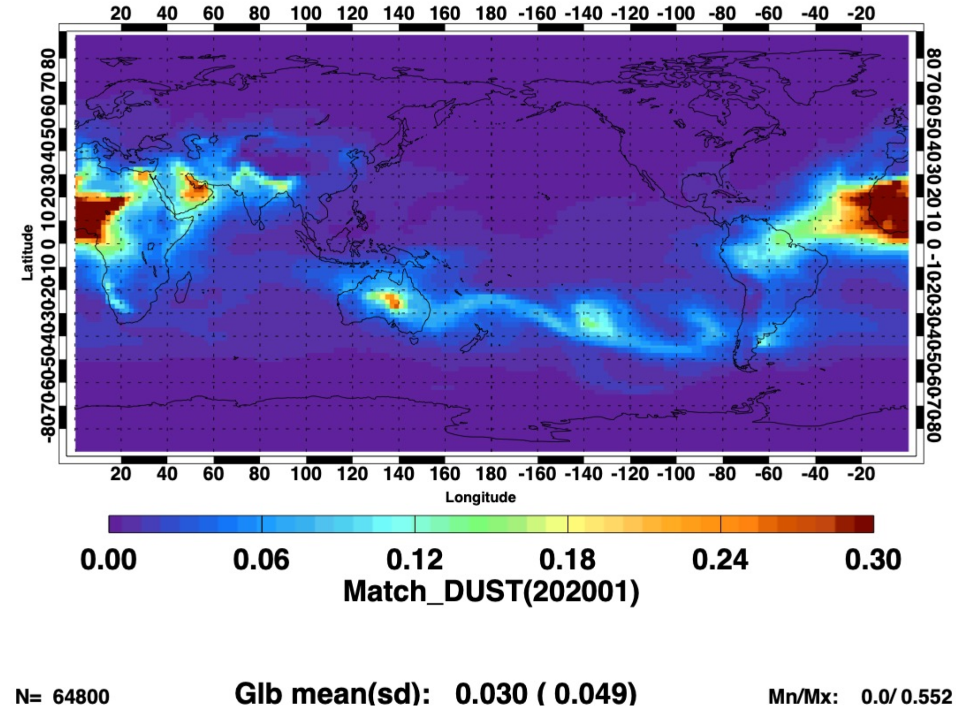
- Clear-sky total aerosol optical thickness is constrained by MODIS derived aerosol optical thickness (dark target and deep blue).
- Modeled dust optical thickness is too large
  - Modeled dust optical thickness is adjusted by MODIS optical thickness when MODIS optical thickness is available
  - Sometimes dust aerosol is used for smoke.
- Large fraction of sulphate and small fraction of sea salt over ocean.
- MATCH provides aerosols over polar regions
  - Transport of aerosol to polar regions is important.
- Aerosol under cloudy conditions largely depend on model but affects clear-sky cloud removed irradiances.

Australian fire event (January 2020)

Total aerosol optical thickness



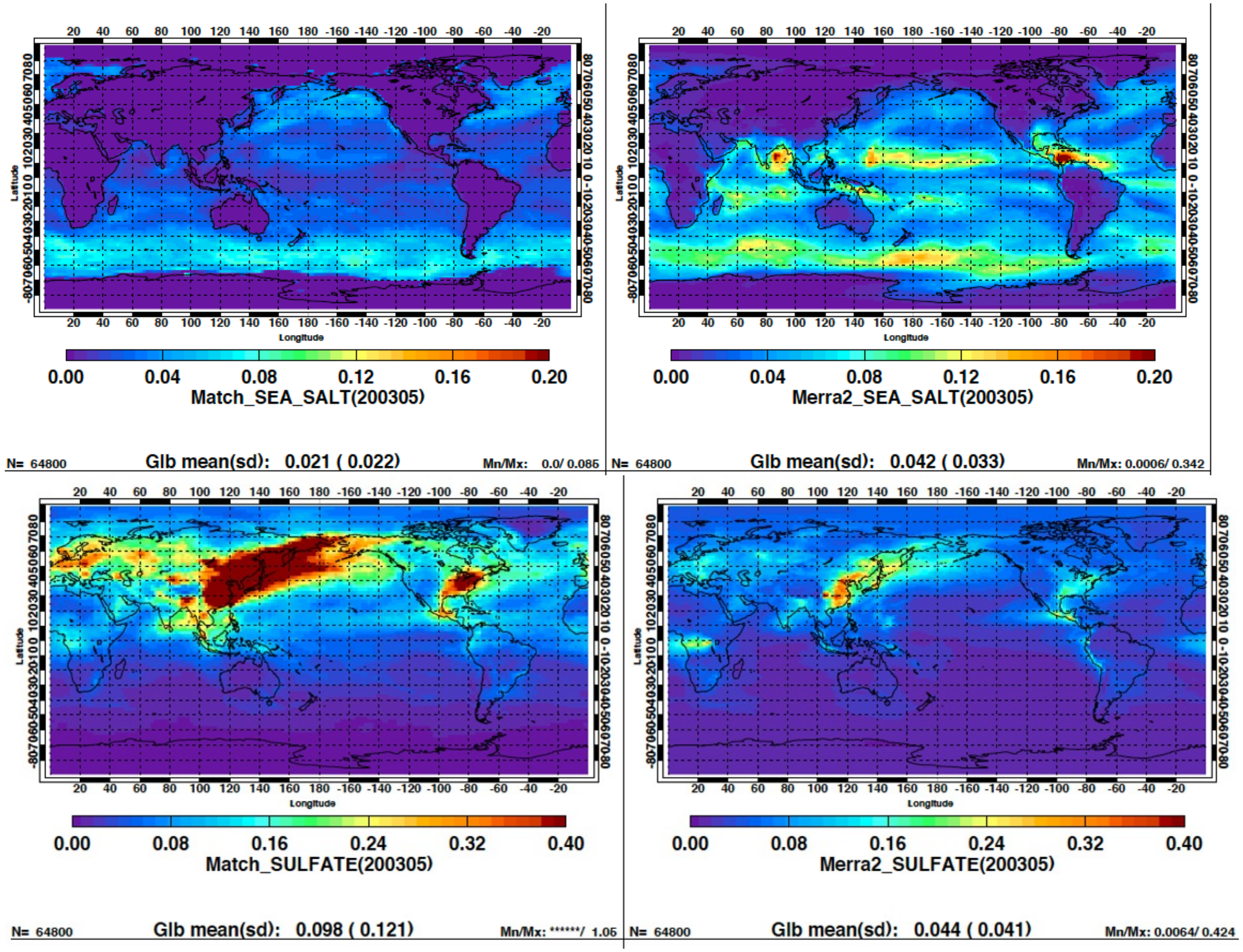
Dust aerosol optical thickness



Edition 4 sea salt and sulfate aerosols

MATCH

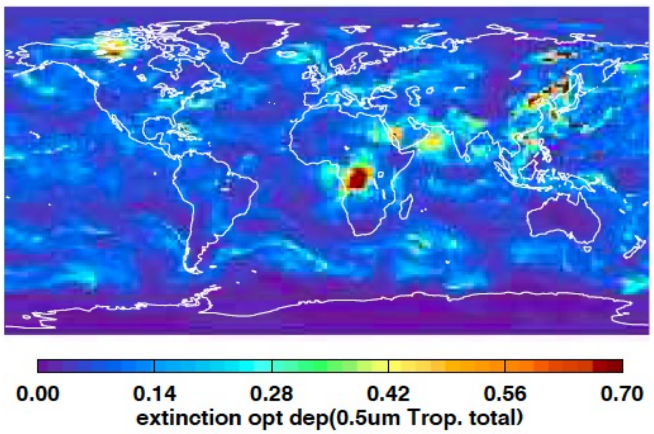
MERRA-2

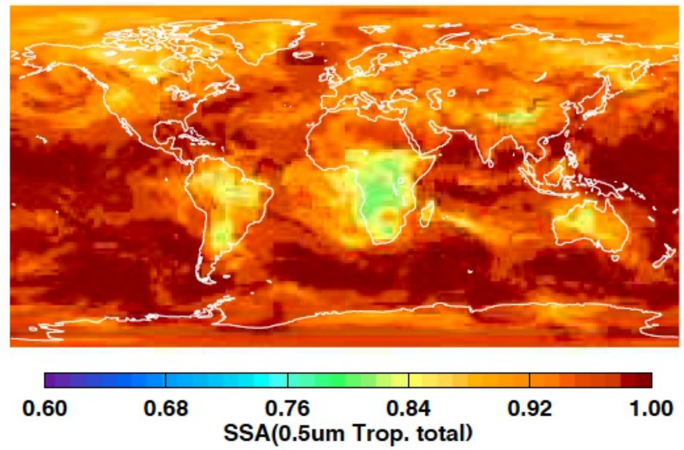


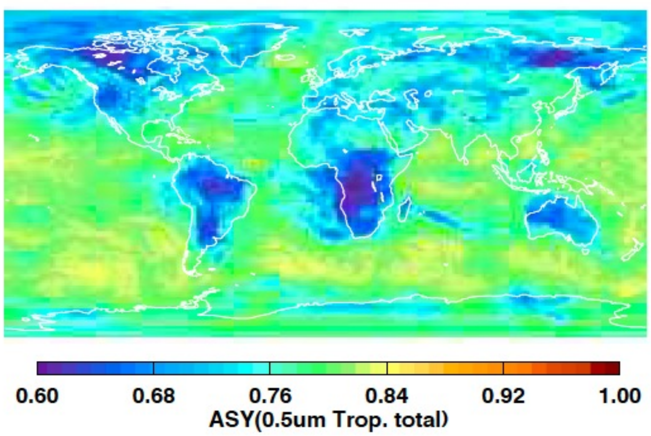
Edition 5 MATCH

- A MODIS/VIIRS aerosol optical thickness assimilation module is going to be developed for NCAR Community Earth System Model (CESM), Community Atmosphere Model (CAM) 6
- Use 3-mode modal aerosol representation (MAM3, internal mixing) in CAM 6
  - Aitkin (SO4, SOA, and SS), accumulation (SO4, POA, SOA, BC, SS, and DST), coarse (SO4, SS, and DST).
  - Species include SO4 sulfate, SOA secondary organic aerosol, SS Sea-salt, POA primary organic aerosol, BC black carbon, and DST mineral dust.
  - Stratospheric aerosol (TBD)
  - Optical property of species in 4D (+ wavelength) are provided by CAM6 and used in Edition 5 Langley Fu-Liou RT model (Changes from Edition 4).
- Winds (u and v components) and T and q are nudged 3 hourly using GEOS.
- Current plan is to assimilate total AOT, fine and coarse mode fractions and/or AOT at multiple wavelengths.
- A Back-up plan is to use 4D aerosol fields and optical property form GEOS

Optical property input to Langley Fu-Liou code







These aerosol properties come from MATCH (CAM6)
But can be replaced by GEOS-IT or R21C

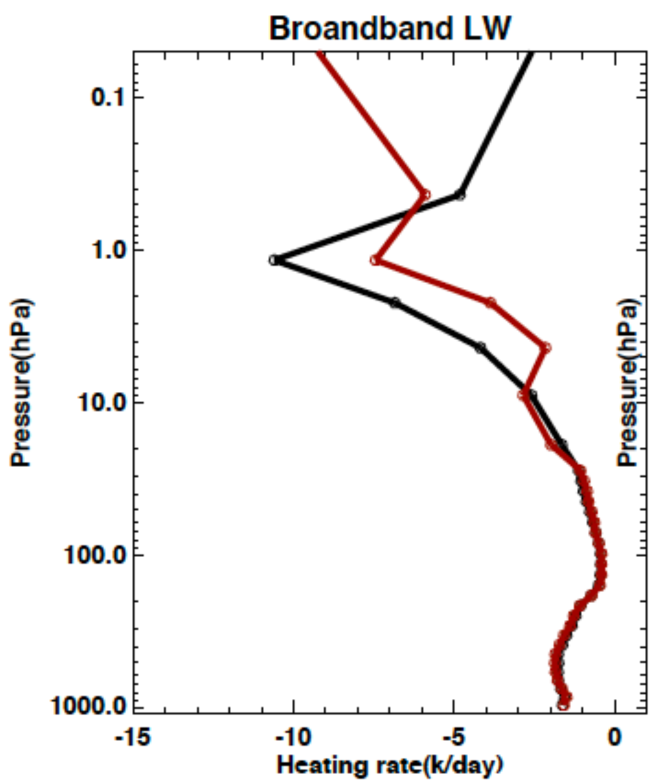
Langley Fu-Liou RT code: gaseous absorption update

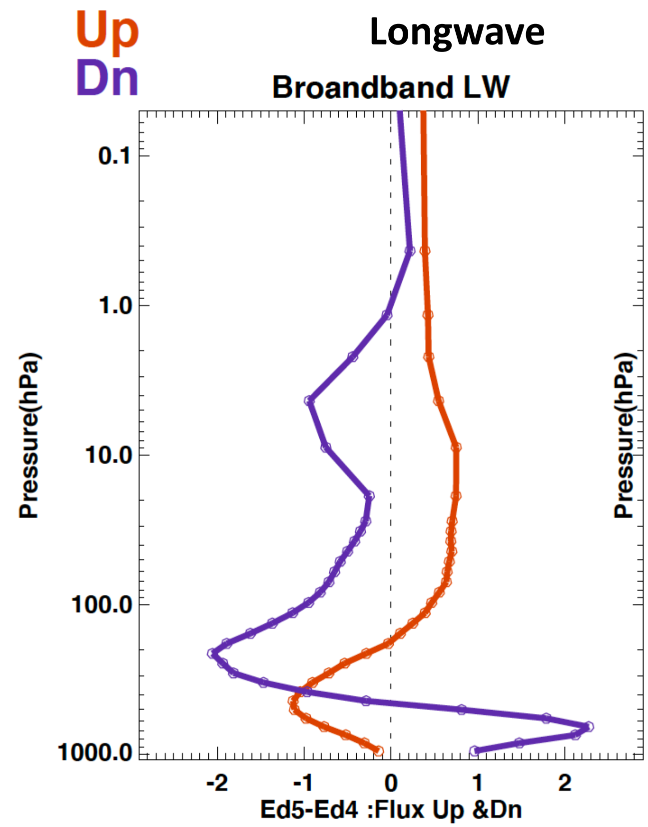
- Absorption cross sections are updated with HITRAN 2012 (line by line code, lblrtm v12.8, outputs were made by Lusheng Liang)
- Includes absorption by H_2O, CO_2, O_3, O_2, and CH_4
  - CO_2 absorption with variable CO_2 concentrations can be computed for both shortwave and longwave
- Current version is participating in Correlated k-Distribution Model Intercomparison (CKDMIP, Hogan and Matricardi 2020)

Longwave Edition 5 vs. Edition 4 n(mean of 5 standard atmospheres)

LW heating rate

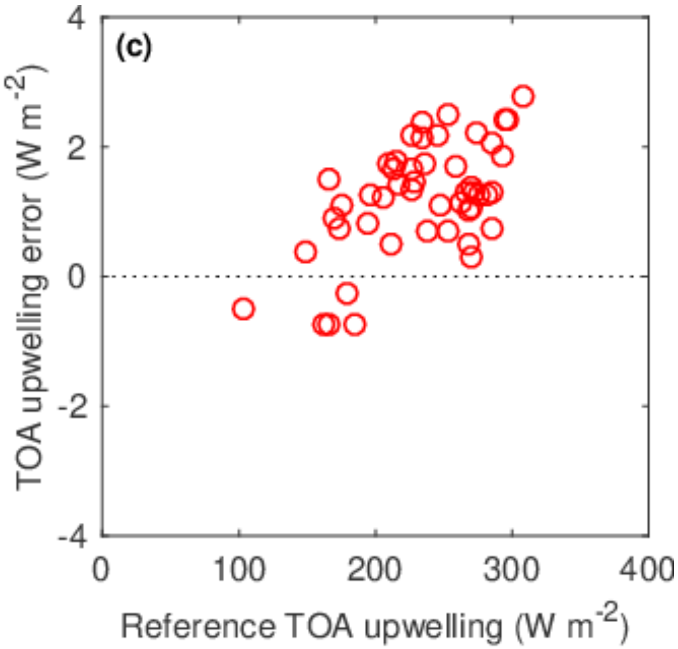
Ed 5: red Ed4 Black





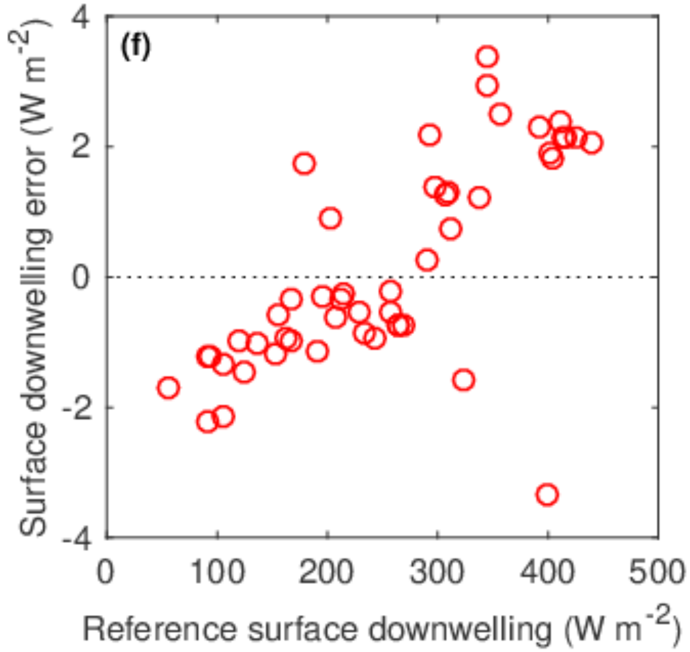
Correlated K-Distribution Model Intercomparison Project (CKDMIP, Hogan and Matricardi 2020)

TOA



Mean bias 1.32 Wm-2
RMS 1.70 Wm-2

Surface



Mean bias 0.23 Wm-2
RMS 1.71 Wm-2

Courtesy of Robin Hogan

Edition 5 MOA plans

- Grid size
  - 1 deg by 1 deg (can be changed later)
- Vertical levels
  - same as GEOS product or same as Edition 4
- Use hourly mean surface skin temperature
  - Retrieved cloud properties are not very sensitive
  - Hourly mean is required to produce hourly mean surface irradiance
- Include GEOS cloud fraction

Surface skin temperature

- Sensitivity of surface irradiance to skin temperature bias
- Retrieved cloud properties are not very sensitive to skin temperature, except for nighttime cloud fraction.
- Sensitivity of upward longwave irradiance

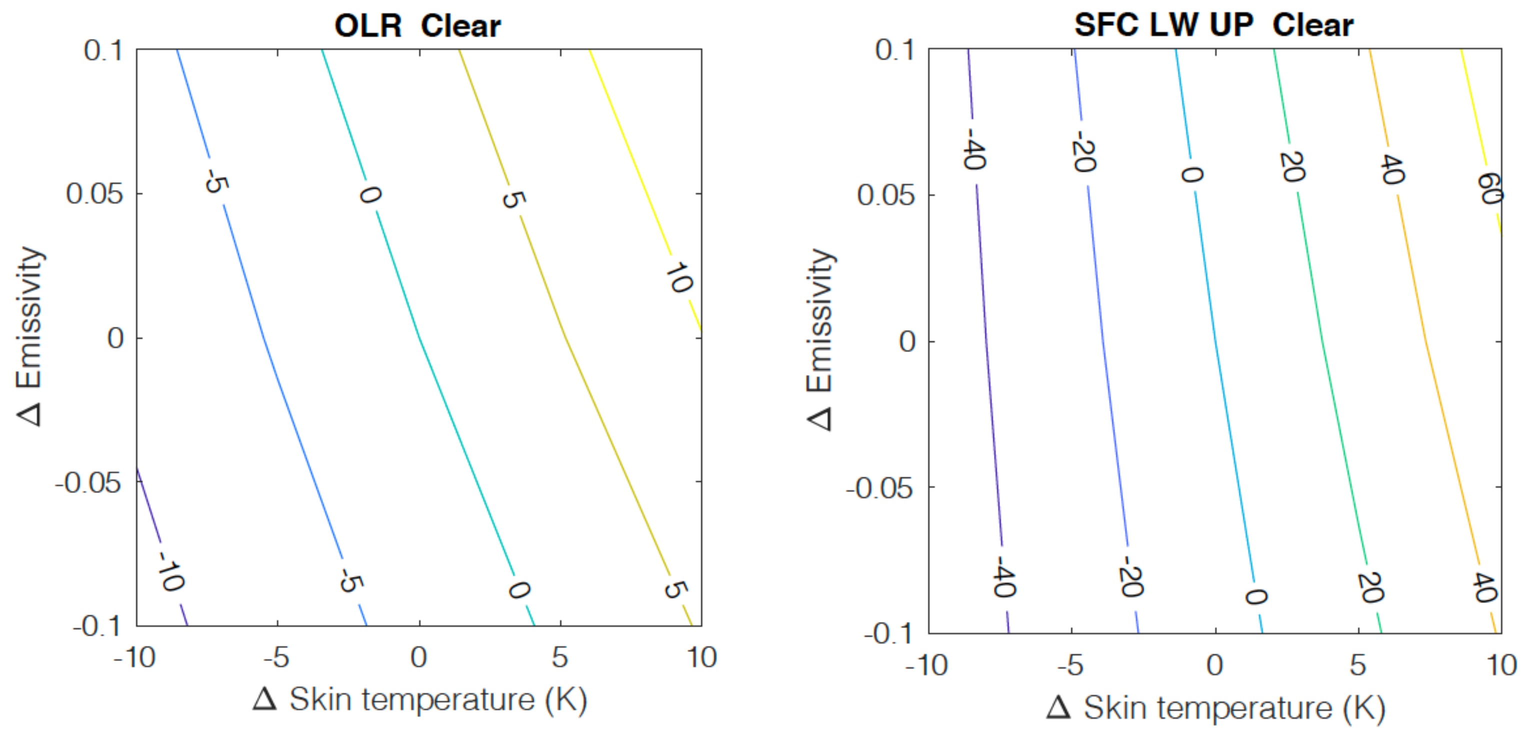
$$\Delta F_{\uparrow} = -F_{net}\frac{\Delta\varepsilon}{\varepsilon} + \varepsilon\left(4\sigma T^4\frac{\Delta T}{T} - F_{\downarrow}\frac{\Delta F_{\downarrow}}{F_{\downarrow}}\right) + \Delta F_{\downarrow}$$

- Sensitivity of net longwave irradiance

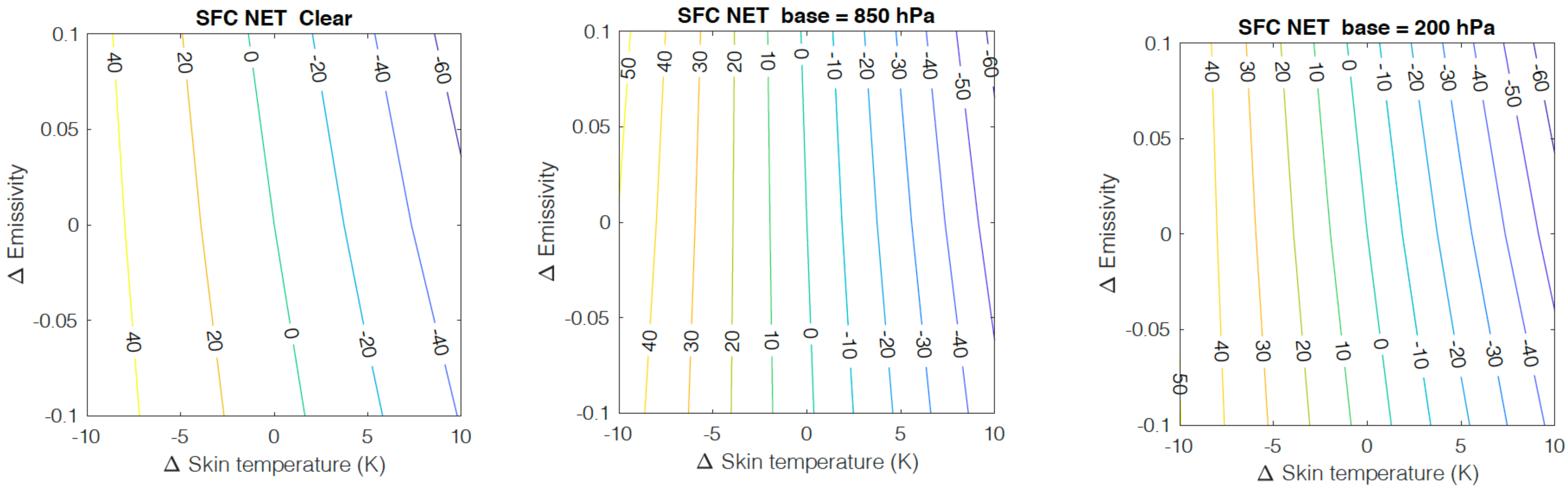
$$\Delta F_{net} = F_{net}\frac{\Delta\varepsilon}{\varepsilon} - \varepsilon\left(4\sigma T^4\frac{\Delta T}{T} - F_{\downarrow}\frac{\Delta F_{\downarrow}}{F_{\downarrow}}\right)$$

TOA and surface upward longwave irradiance

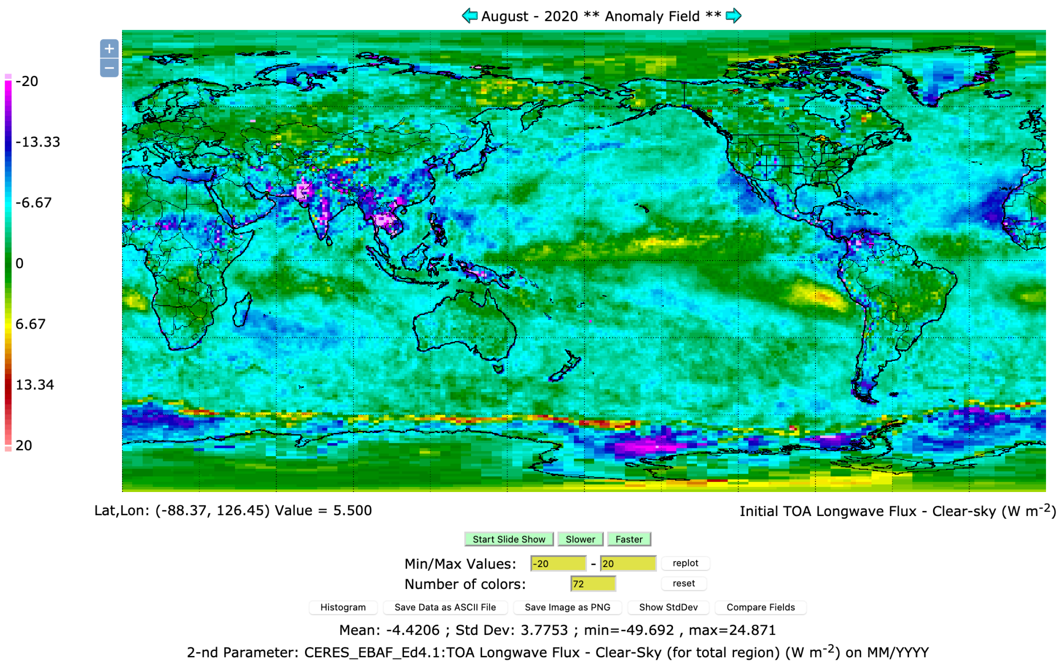
Mid-latitude summer atmosphere
Surface skin temperature = 295 K
Surface emissivity = 0.90



Clear-sky and all-sky surface net longwave irradiance



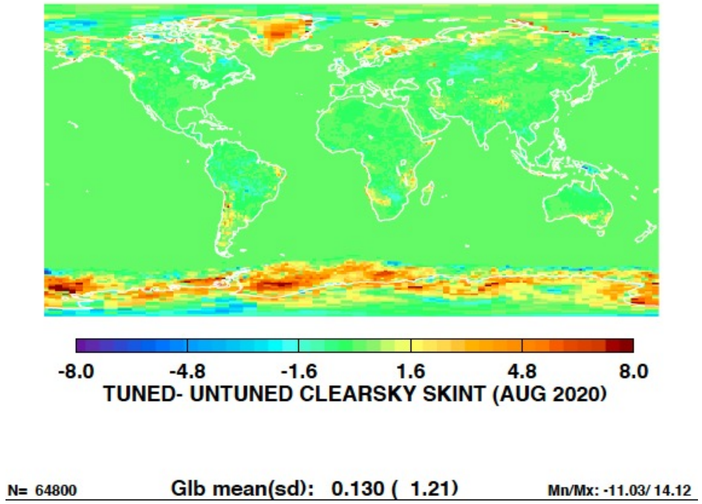
Clear-sky (total area) OLR: Computed (Ed.4 SYN) – Observed (EBAF)



Smaller OLR difference over desert

- Day-night skin temperature bias might partially cancel out
- Humidity bias, GEOS-541 upper tropospheric humidity has a positive bias
- Dust aerosol layer optical thickness and height (negative bias over ocean)

Adjusted skin temperature



Need to determine bias and correct bias error (work with the cloud working group)

Summary

- Treatment of gaseous absorption in Langley Fu-Liou code is updated for Edition 5 production
  - Newer HITRAN database (2016) and SW absorption varies with CO2 concentration.
- One of objectives of Edition 5 MATCH development is to improve aerosol type (fine and coarse mode)
- Importance of aerosols in computing clear-sky radiation budget change is emphasized
  - Large aerosol loading events occur more often
  - Transport of aerosol to polar regions and aerosol under cloudy conditions largely depend on model.
- Work with the cloud group to improve the impact of GEOS surface skin temperature bias to surface irradiance.

Publications

- Ham, S.-H., S. Kato, F. G. Rose, N. G. Loeb, K.-M. Xu, T. Thorsen, M. G. Bosilovich, S. Sun-Mack, Y. Chen, and W. F. Miller, 2021: Examining Cloud Macrophysical Changes over the Pacific for 2007–17 Using CALIPSO, CloudSat, and MODIS Observations, *J. Appl. Meteo. Clim*., 60(8), 1105-1126, DOI: 10.1175/JAMC-D-20-0226.1.
- Fillmore, D. W., D. A. Rutan, S. Kato, F. G. Rose, and T. E. Caldwell, 2021: Evaluation of aerosol optical depths and clear-sky radiative fluxes of the CERES Edition 4.1 SYN1deg data product, submitted to *Atmospheric Chemistry and Physics*.
- Ham, S. H., S. Kato, F. G. Rose, S. Sun-Mack, Y. Chen, W. F. Miller, and R. Scott, 2022: Combining cloud properties from CALIPSO, CloudSat, and MODIS for top-of-atmosphere (TOA) SW broadband irradiance computations: impact of cloud vertical profiles, submitted to J. Applied Meteorology and Climatology.
- Scott, R. C., F. G. Rose, P. W. Stackhouse Jr., N. G. Loeb, S. Kato, D. R. Doelling, D. A. Rutan, and P. C. Tayler, 2022: Clouds and the Earth's Radiant Energy System (CERES) Cloud Radiative Swath (CRS) Edition 4 data product, submitted to Journal of Atmospheric and Oceanic Technology.

Back-ups

Edition 5

- Fu-Liou code
  - Edition 4 versus Edition 5 gaseous absorption
- MATCH
- MOA
  - 1deg by 1deg(?)
  - Cloud also uses hourly mean skin temperature (i.e. not instantaneous skin temperature
- Skin temperature impact on surface irradiance
- D1 CCCM (Seung-Hee Ham)

Recent activities

- Released Edition 4.1 EBAF through November 2021
- Released D1 version (revised from B1) of CCCM (jointly with the cloud working group)
- Generated MOA using GEOS-IT
- Implemented the algorithm and modernized (.pro to .py) to use AFWA ice age product after CLASS ice age product was terminated in August 2021
- Developed the SYN algorithm that uses no geostationary satellite data.
- Developed Edition 4 CRS production code and evaluated instantaneous surface fluxes

Validation

- Evaluated Edition 4 MATCH aerosol optical thickness (paper is under review) using AERONET, MODIS, and MERRA-2 aerosol optical thickness.
- Evaluated twilight cloud properties derived from geostationary satellites and their effects to surface fluxes
- Evaluated time series of surface flux anomalies derived from Aqua only (i.e. no geostationary satellite derived clouds) SYN.
- Validated CRS instantaneous footprint-scale Arctic surface downwelling broadband radiative fluxes against measurements conducted at the MOSAiC drifting observatory.
- Updated surface validation input files from binary files to netCDF files and developed a python code to generate the input files from surface observations.

Aqua only noGEO, Terra only no GEO, and Terra+Aqua noGEO SYN analysis

- Edition 4.2 EBAF uses SYN noGEO product
  - Adjust Terra only and NOAA 20 only climatology based on Terra+Aqua.
  - Use Terra only, NOAA20 only, and Terra+Aqua anomalies.
- Difference in climatology and anomalies
- Difference in surface irradiance trends
- Surface validation

Effect of skin temperature bias on the surface upward longwave irradiance

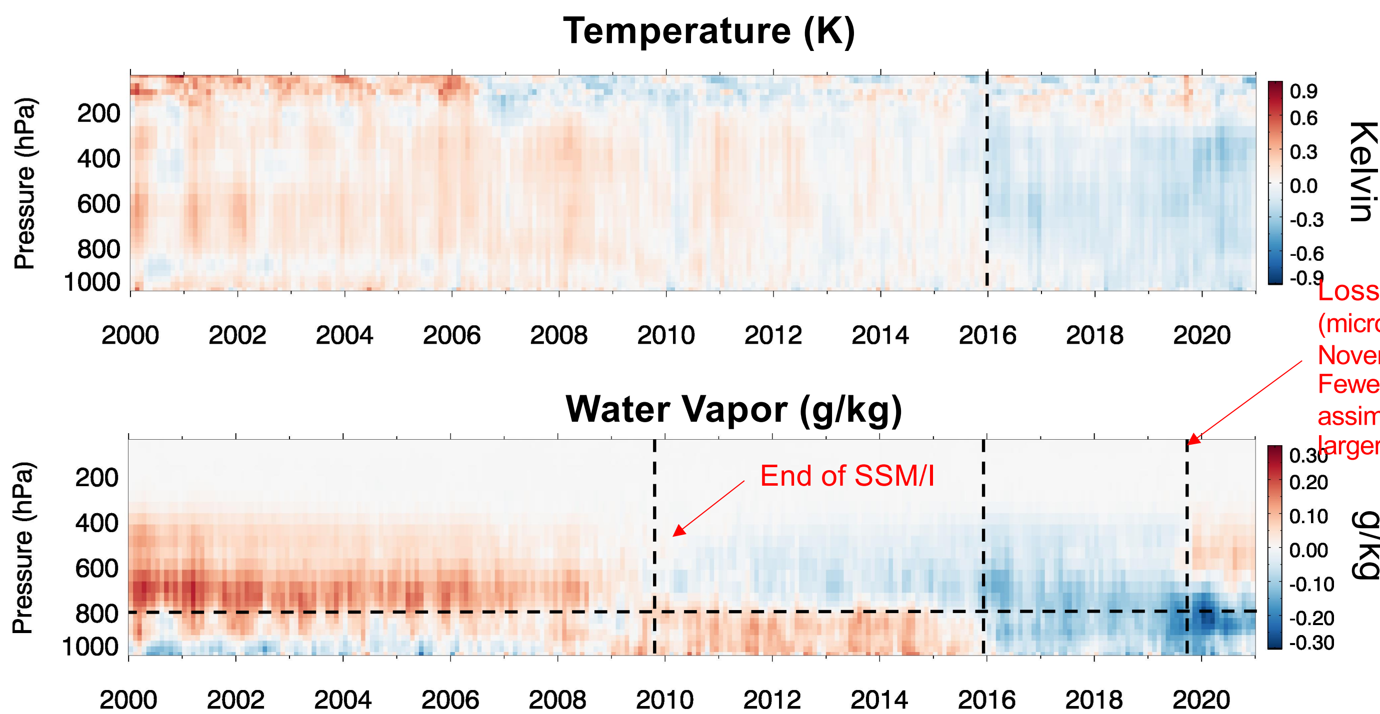
- Sensitivity of skin temperature derived from TOA radiance to surface emissivity
    - $I = T\left[\varepsilon B_\lambda(T_{skin}) + (1-\epsilon)B_\lambda(T_{eff})\right]$
    - $\frac{\partial B_\lambda(T_{skin})}{\partial \varepsilon} = -\frac{B_\lambda(T_{skin}) - B_\lambda\left(T_{eff}\right)}{\varepsilon}$
    - Retrieved skin temperature is sensitive to emissivity under dry, clear, and daytime conditions
- Skin temperature bias gives
    - Cloud mask bias: Cloud mask is not very sensitive to skin temperature (Sunny's result)
    - Cloud property bias (Sunny's result)

- Skin temperature bias directly affects surface upward longwave irradiance
    - Comparison of clear-sky OLR with CERES (C3M or CRS??)
    - Run CRS with Sunny's results??

60S-60N Land+Ocean

Area weighted; climatology is obtained using 2003-2020

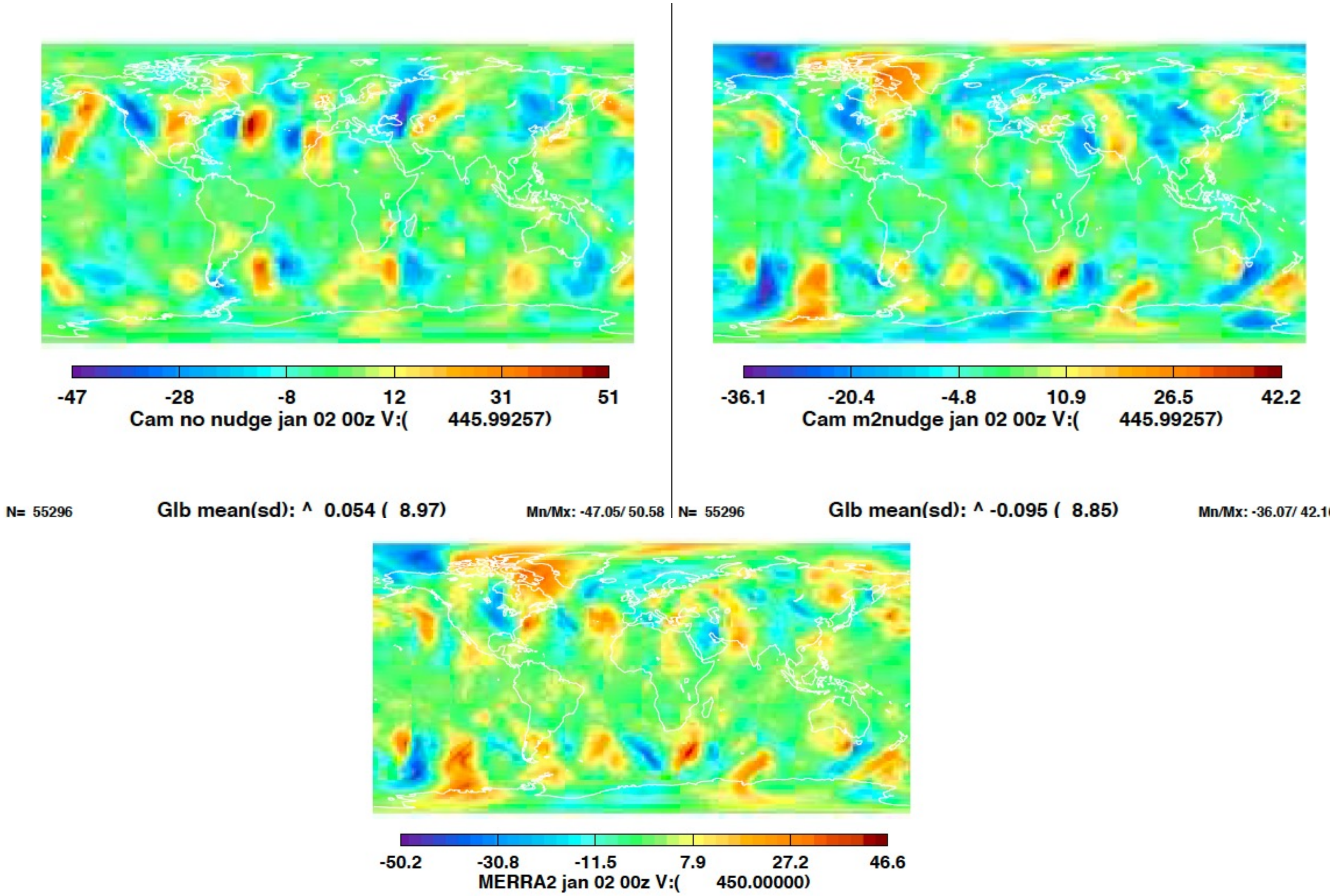
[G-5.4.1 Anomalies] – [ERA-5 Anomalies]



Loss of MHS
(microwave humidity sounder)
November 2019
Fewer instruments are assimilated so that the impact is larger in GEOS-5.4.1

Tropical standard ATM Water vapor mixing ratio @ 400 hPa
~0.6 g/kg
~20 to 30% drift

- The differences between G541 and ERA5 are similar to those between G541 and MERRA-2.
- This implies that the differences are mainly driven by G541 problems.


-47
-28
-8
12
31
51
Cam no nudge jan 02 00z V:(445.99257)
-36.1
-20.4
-4.8
10.9
26.5
42.2
Cam m2nudge jan 02 00z V:(445.99257)
N= 55296
Glb mean(sd): ^ 0.054 (8.97)
Mn/Mx: -47.05/ 50.58
N= 55296
Glb mean(sd): ^ -0.095 (8.85)
Mn/Mx: -36.07/ 42.16
-50.2
-30.8
-11.5
7.9
27.2
46.6
MERRA2 jan 02 00z V:(450.00000)