Surface Atmosphere Radiation Budget (SARB) working group update

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CEERES Science Team Meeting
October 29-31, 2019

Work done after the Spring 2019 CERES science team meeting

- Extended Edition 4.1 SYN1deg through May 2019
- Extended EBAF-surface through January 2019 (will be released through May 2019 after this meeting).
- Estimated the error in diurnally averaged TOA and surface irradiances computed by 2- and 4-stream models.
- Evaluated clear-sky surface irradiances
- Evaluated surface irradiances at two surface sites
  - McMurdo (complex surface types) and Macquarie Island
- Continue collaborating with GMAO in developing a new version of GEOS reanalysis for Ed5 CERES products.
- Continue updating Fu-Liou radiative transfer code
  - Revising shortwave and longwave k-distribution coefficient with HITRAN 2016 (work in progress)

Outline of this talk

- Edition 4.1 related
  - SYN surface downward shortwave and longwave irradiance evaluation over southern ocean with ship data (revised)
    - EBAF adjustment over southern ocean
    - Nighttime cloud issue
  - Entropy production estimates included in Edition 4.1 SYN1deg
  - Errors in diurnally averaged shortwave irradiances by 2- and 4-stream models.
- Edition 5 related (work in progress)
  - Revision of shortwave correlated-k
    - Longwave correlated-k will be revised using a similar approach.
  - Longwave fingerprinting to correct bias errors in temperature and humidity
- Publications

Edition 4.1 SYN1deg

- SYN1deg provides hourly computed surface irradiances at a 1°×1° grid resolution
- Edition 4.1 SYN1deg has been processed from March 2000 through Nay 2019 with
  - MATCH with Collection 6.1 Terra and Aqua (from July 2002)
  - Collection 5 MODIS from March 2000 through February 2016 and Collection 6.1 MODIS after March 2016 for cloud retrieval
  - GEOS-5.4.1 temperature and humidity
  - New surface albedo history map with Collection 6 (not 6.1) MODIS BRDF product

Edition 4.1 EBAF-surface

- EBAF-surface provides monthly computed surface irradiances that are consistent with CERES-derived TOA irradiance (i.e. computed TOA irradiances agree with EBAF-TOA irradiances) at a 1°×1° grid resolution.
- Temperature, humidity, surface, cloud and aerosol properties are adjusted to match CERES-derived TOA irradiances (input adjustments)
- SYN1deg Surface irradiances are adjusted based on input adjustments.
- Available through January 2019
- 4 more months (through May 2019) will be available after this meeting.
- Two types of clear-sky irradiances are included
  - Monthly mean weighted by observed hourly 1°×1° clear-sky fraction
  - Monthly mean (clear-sky occurs every hour over all grids)

Surface irradiance over Southern ocean

Surface downward **shortwave** irradiance
CMIP5 mean - EBAF

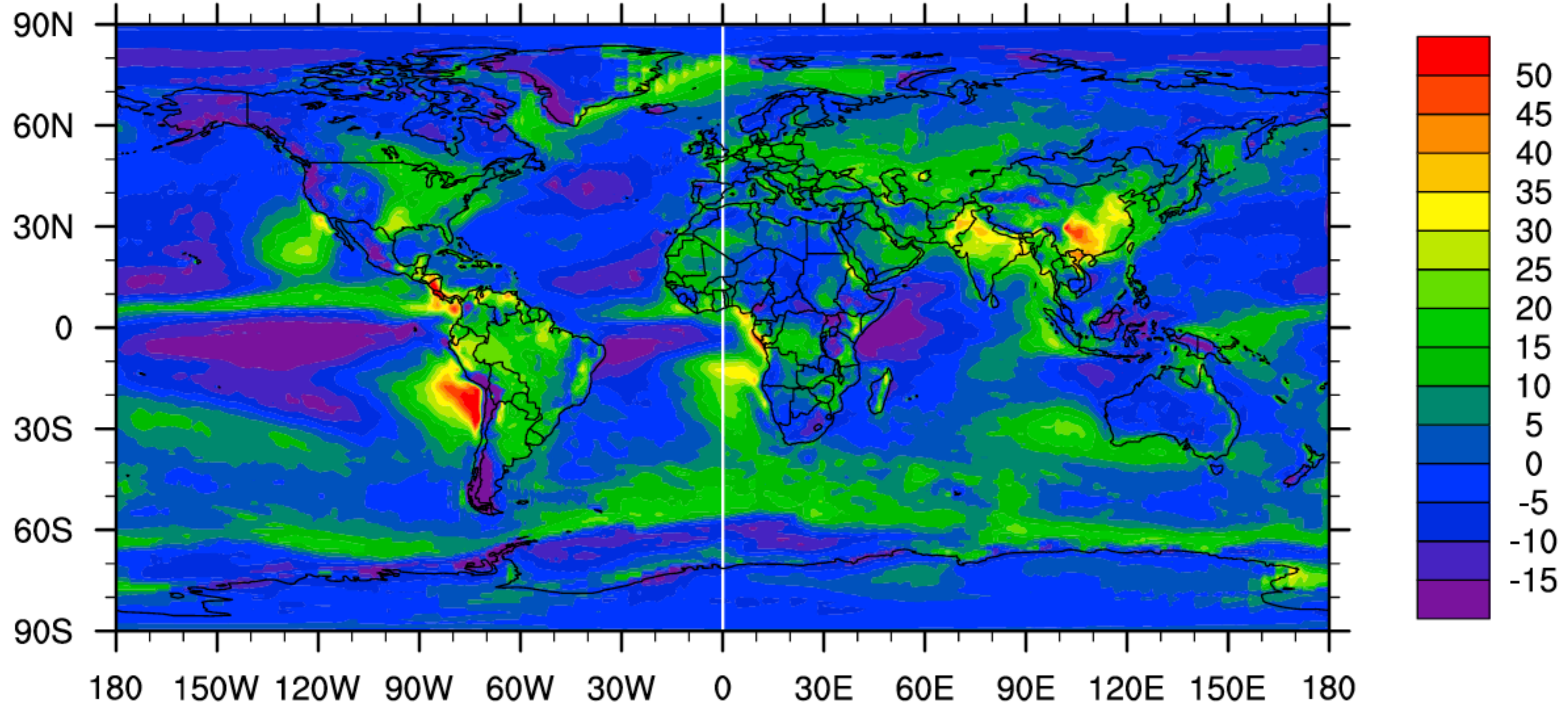
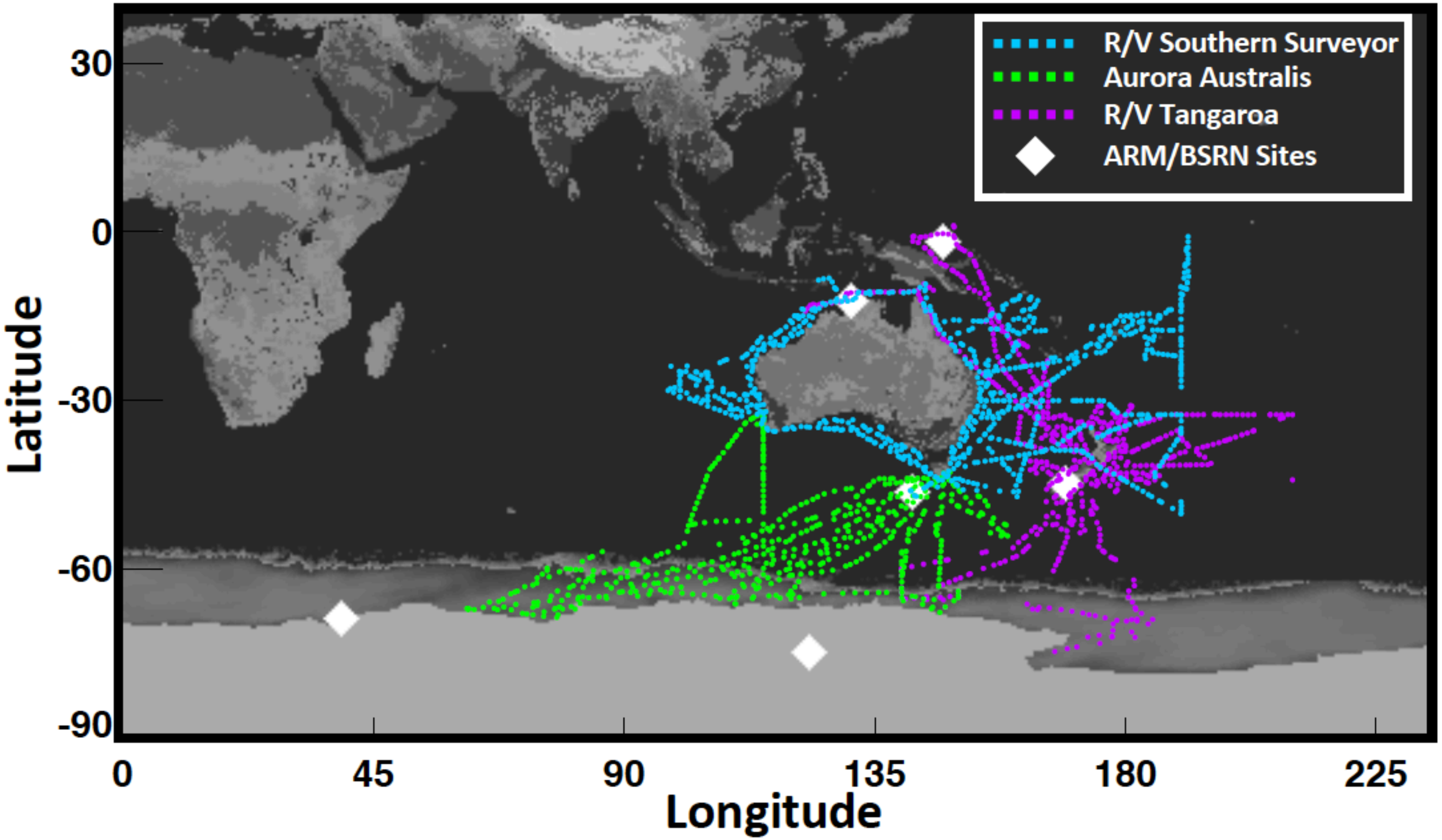


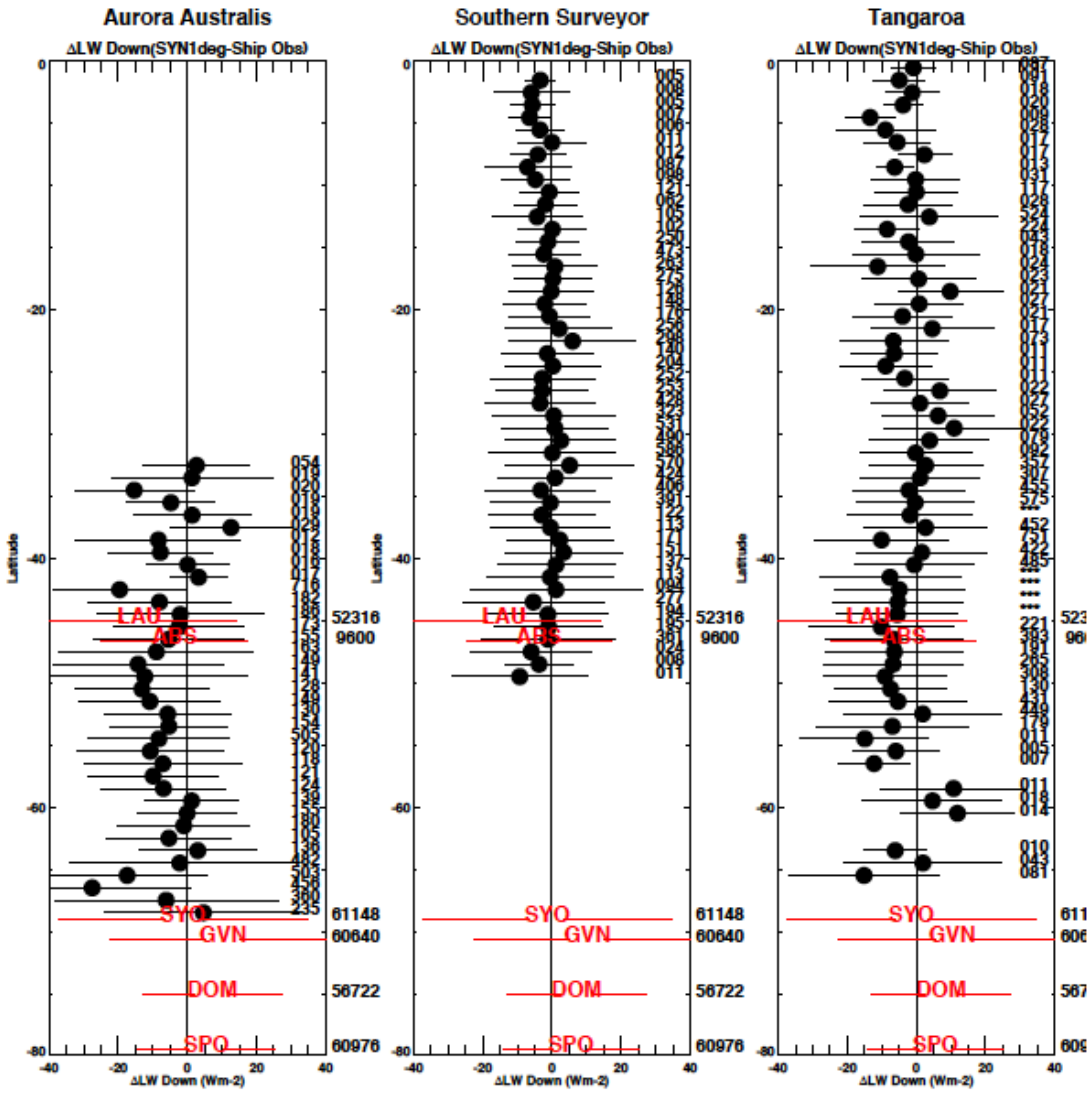
Figure 5. Biases between multimodel mean of surface incident shortwave radiation under all sky (R_S) from 48 CMIP5 ESMs and CERES EBAF R_S for 2000–2005 (CMIP5-CERES EBAF, units: W m^{-2}). All of the CMIP5 models were resampled to a 1° × 1° grid scale, which is the same size as that of CERES EBAF.

Ma et al. 2015 JGR

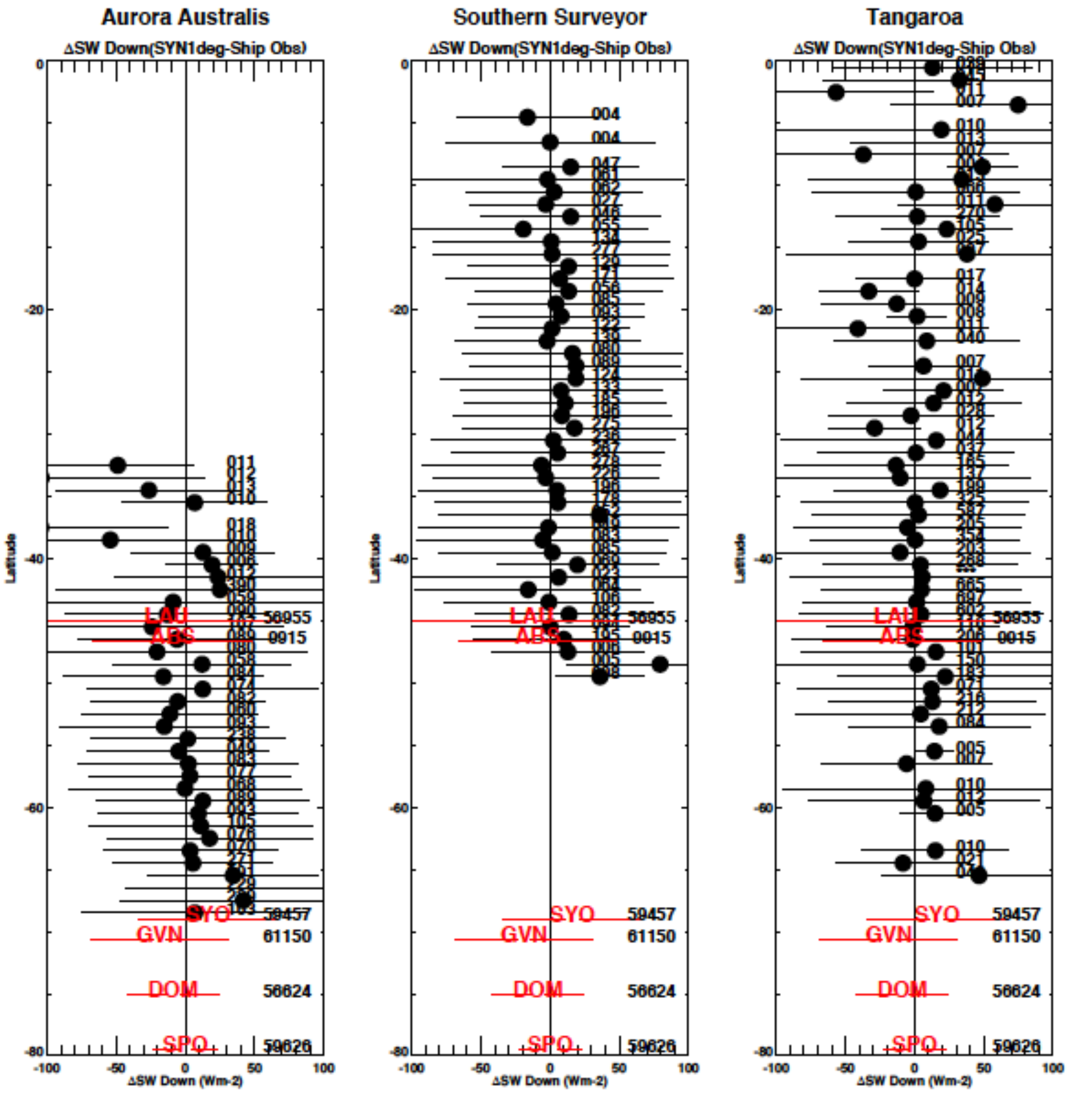
Evaluation of surface irradiances with ship data (revised)



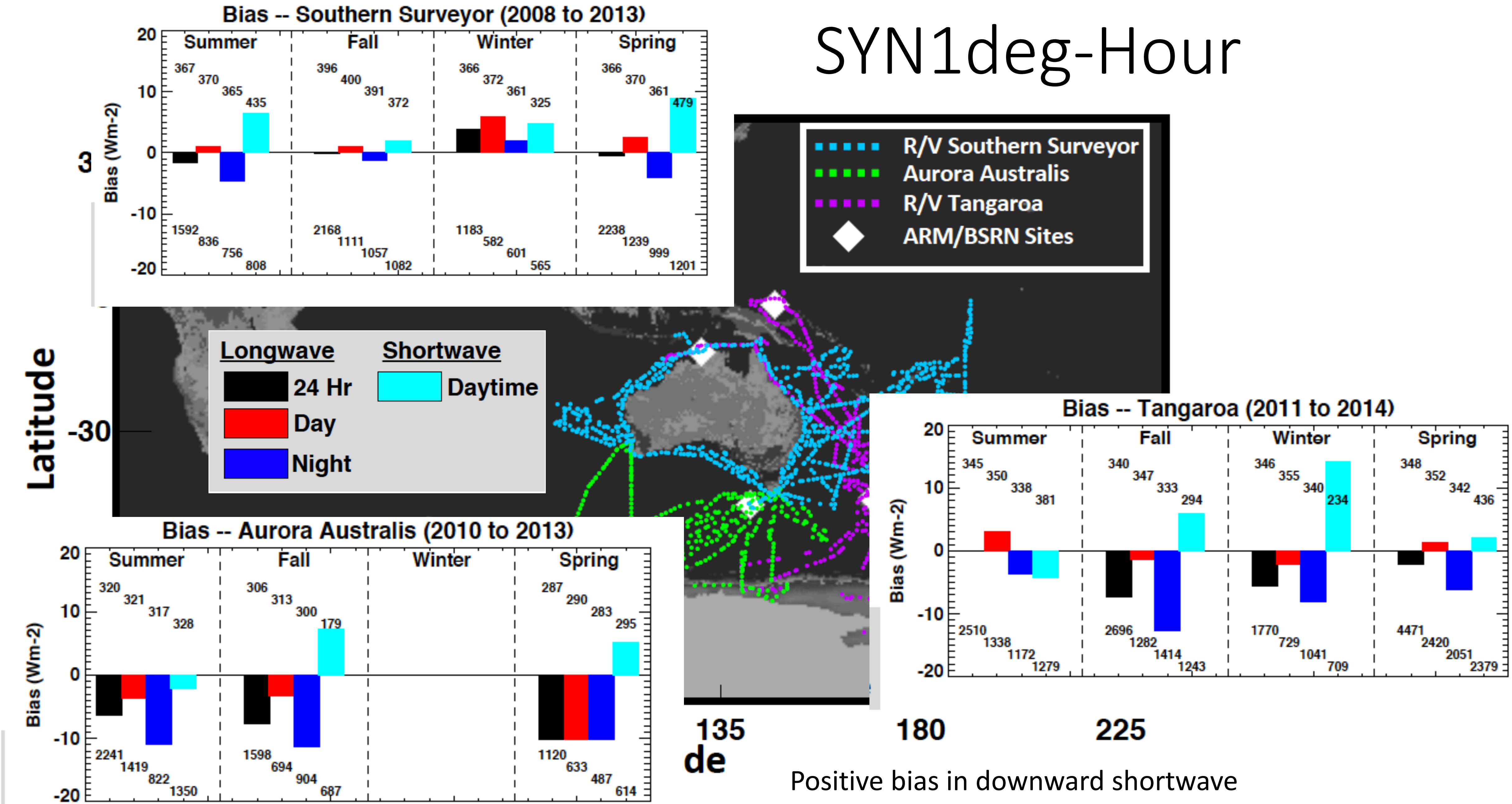
Longwave



Shortwave



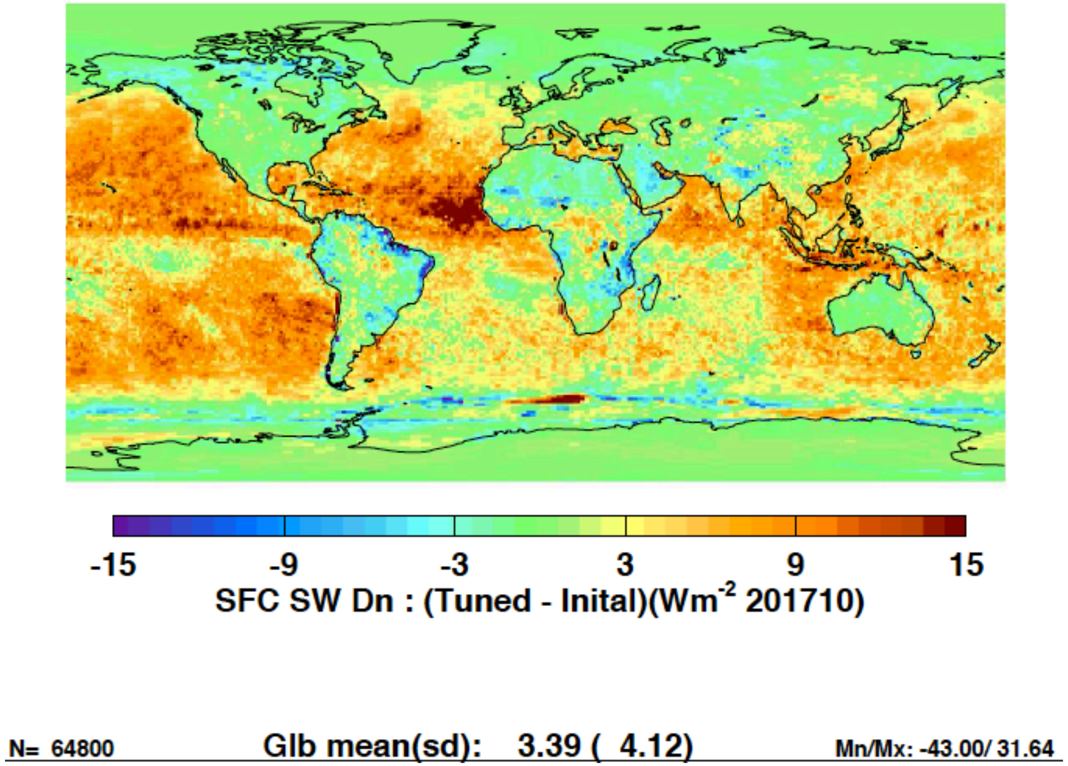
SYN1deg-Hour

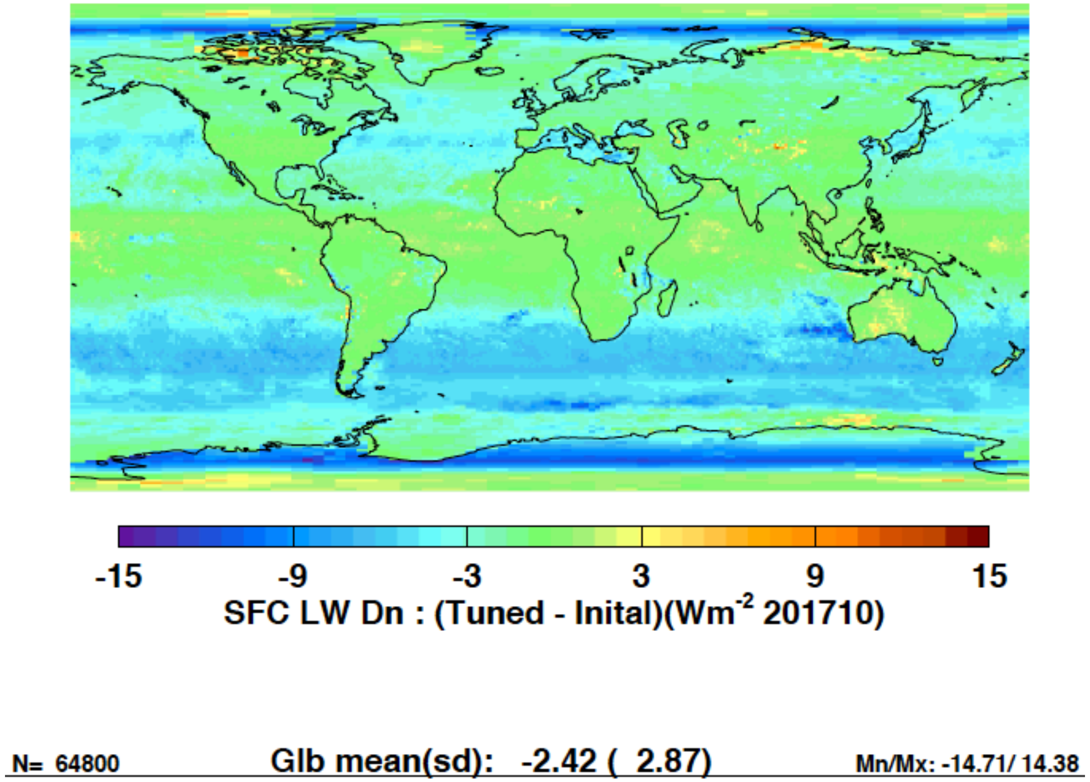


Positive bias in downward shortwave

Negative bias in downward longwave especially during night

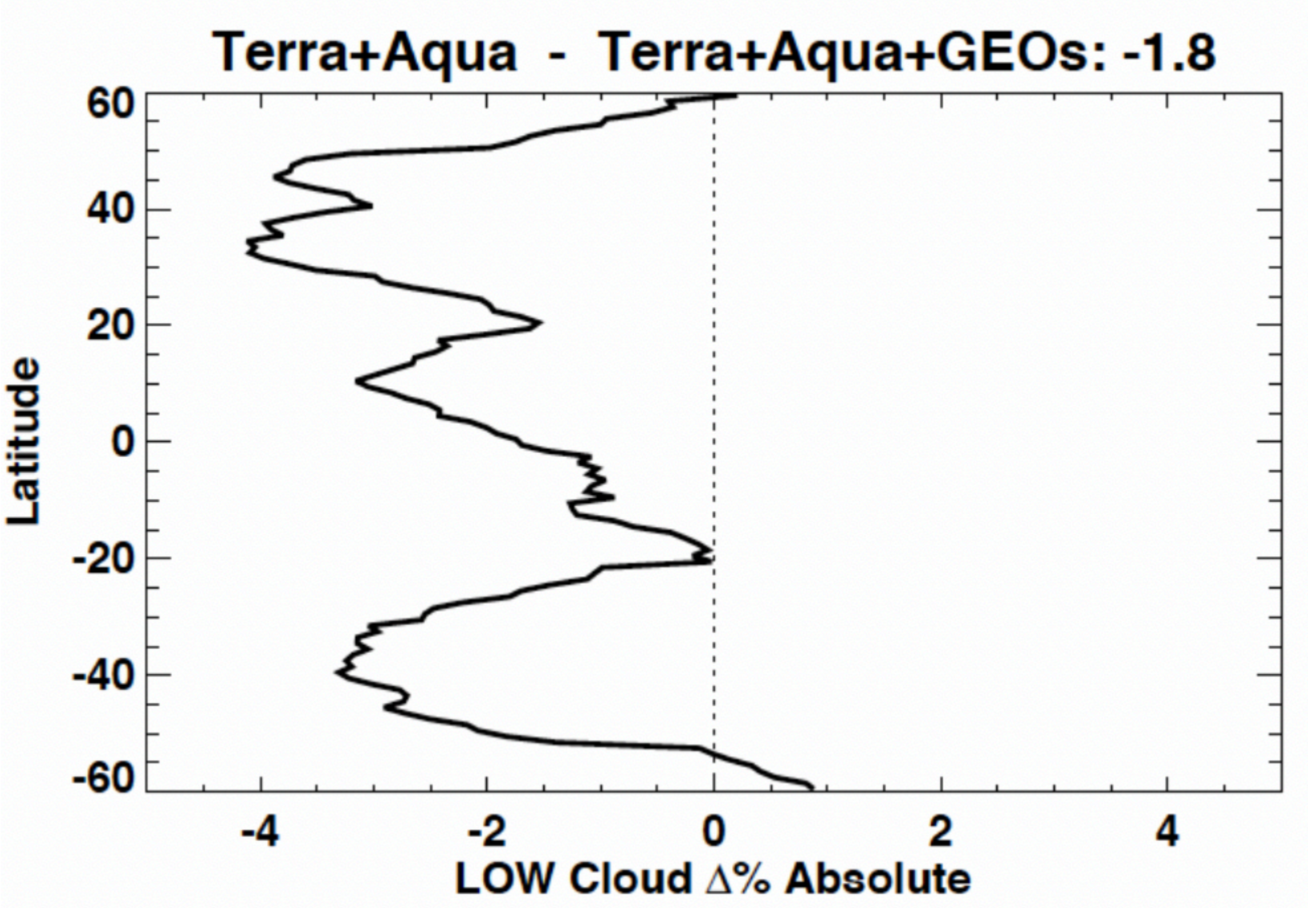
EBAF adjustments (Southern hemisphere Spring)





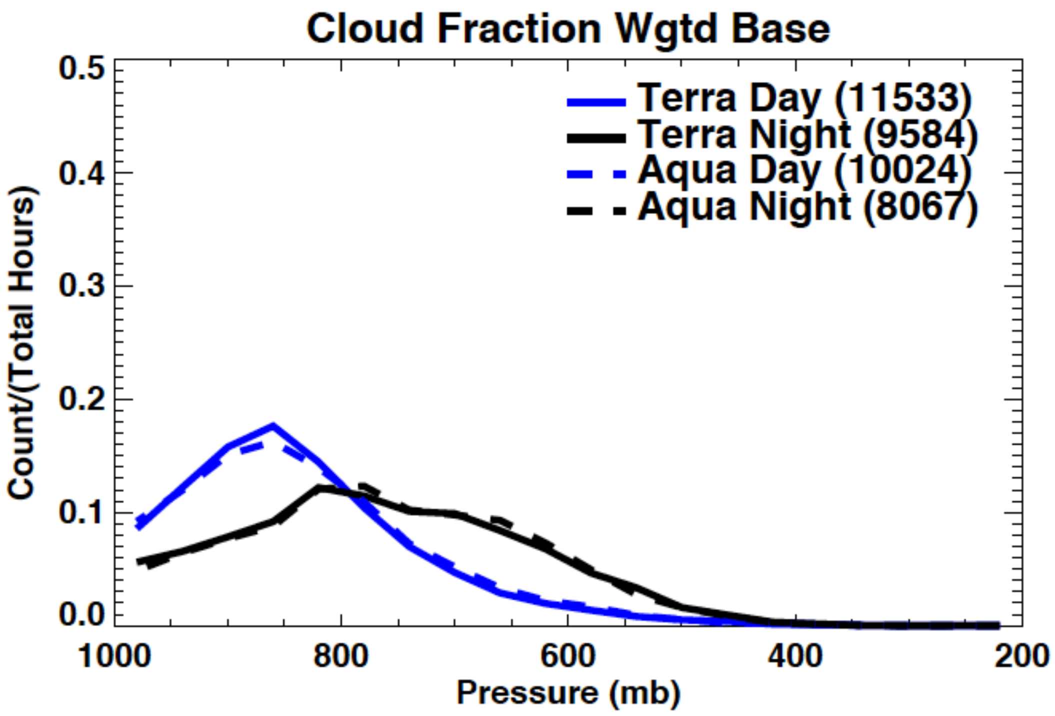
Downward shortwave is further increased and downward longwave is reduced in the EBAF adjustment process

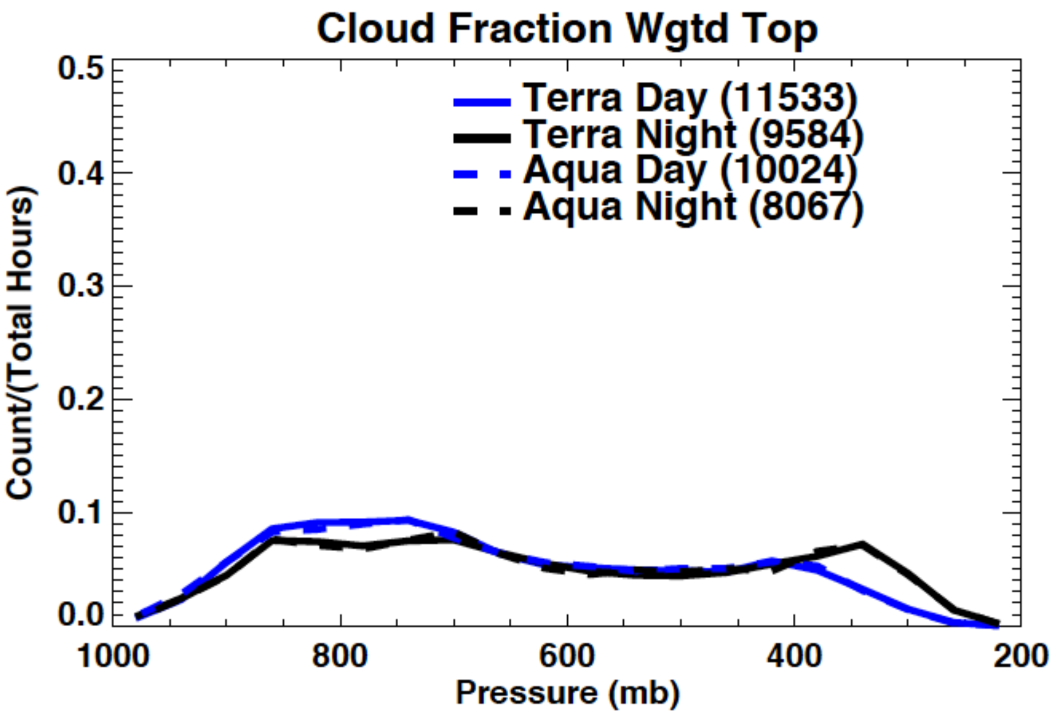
Cloud fraction



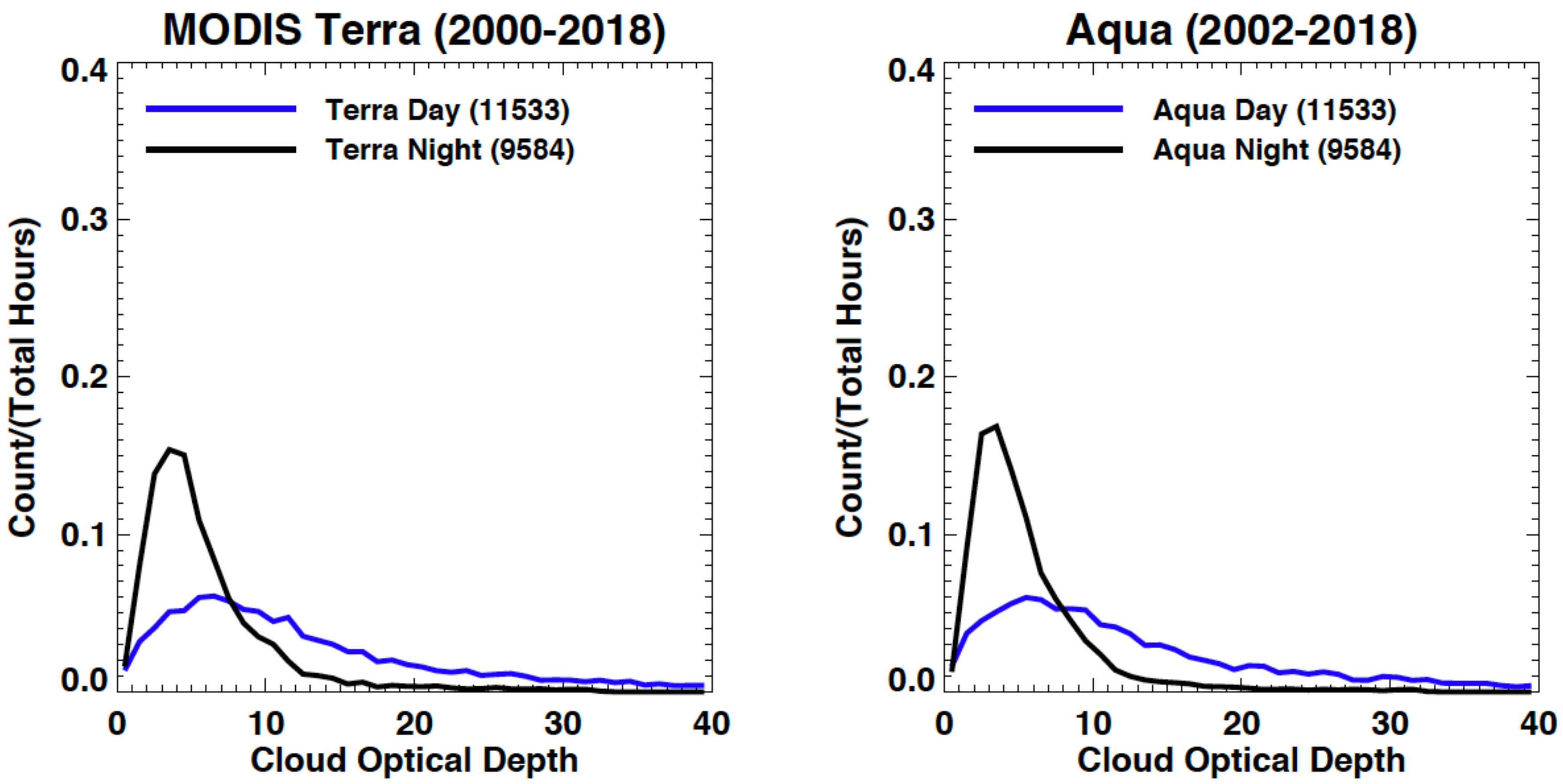
Geo derived cloud fraction is generally larger than MODIS or CALIPSO-CloudSat derived cloud fraction

Daytime and nighttime cloud heights





Cloud optical thickness



This issue will be addressed in Edition 5

Entropy production by radiative processes

- Entropy production estimated from net irradiance and temperature is included in Edition 4.1 SYN1deg

Entropy production by irreversible processes

Diabatic heating due to frictional dissipation is often ignored

Entropy production

$$F_{TOA}^{net} = (1-\alpha)F_0 - F_{atm} - (1-\varepsilon)F_{sfc} \quad (1)$$

$$F_{sfc}^{net} = (1-\alpha-\beta)F_0 + F_{atm} - F_{sfc} - F_{tur} \quad (2)$$

and

$$F_{atm}^{net} = \beta F_0 + \varepsilon F_{sfc} + F_{tur} - 2F_{atm} \quad (3)$$

ip among these net energy fluxes is

$$F_{TOA}^{net} = F_{sfc}^{net} + F_{atm}^{net} \quad (4)$$

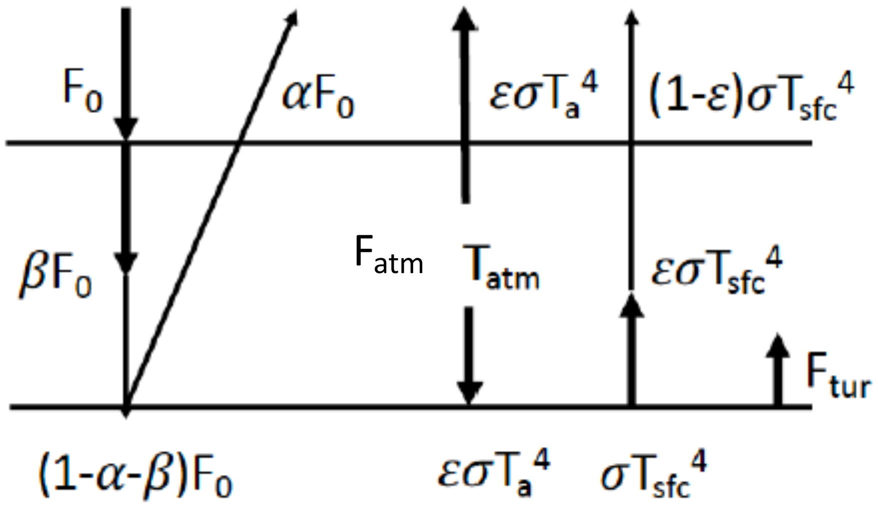


Figure 1: One-dimensional isothermal atmosphere model. F_0 is solar irradiance at top-of-atmosphere, β is the absorptivity of the atmosphere, α is the reflectivity of the surface, T_{sfc} is the surface temperature, T_{atm} is the temperature of the atmosphere, ε is the emissivity of the atmosphere, and F_{tur} is the energy flux by turbulence.

$$\frac{dS}{dt} = \frac{\dot{Q}_a}{T_a} - \frac{\dot{Q}_e}{T_e} + \dot{\Sigma}_{irr} \quad (14)$$

Where

$$\dot{Q}_a = (1-\alpha)F_0 \quad (15)$$

$$\dot{Q}_e = (1-\varepsilon)F_{sfc} + F_{atm} \quad (16)$$

$$\dot{\Sigma}_{tur} = -\left[\frac{F_{sfc,SW}^{net}}{T_{sfc}} + \frac{F_{atm,SW}^{net}}{T_{atm}} + \frac{F_{sfc,LW}^{net}}{T_{sfc}} + \frac{F_{atm,LW}^{net}}{T_{atm}}\right]$$

Kato and Rose 2019

Production of entropy by Irreversible processes

	Entropy production ($Wm^{-2}K^{-1}$)	Estimated from radiation ($Wm^{-2}K^{-1}$)
Frictional dissipation of turbulence (Goody 2000)	**0.0100**	
Frictional dissipation of falling rain drops (Pauluis and Dias 2012)	**0.0100**	
Water phase change (Goody 2000)	**0.0188**	
Turbulent enthalpy transport (Goody 2000)	**0.0024**	
Ocean (Bannon and Najjar 2019)	**0.0016**	
Total	**0.0428**	**0.049**

Entropy production by irreversible process estimated in CMIP5 models

Table 2. Annual mean values of a 20-year subset of control runs from 12 models participating in CMIP5 for TOA and surface energy budgets (B_t and B_s, respectively), maximal and minimal peaks of atmospheric and oceanic meridional enthalpy transports (with peak locations in latitude degrees specified in brackets) (T_a^{max}, T_a^{min}, T_o^{max}, T_o^{min}), water mass budget ($\overline{E} - \overline{P}$), latent energy budget ($\overline{R_L}$), mechanical work by the Lorenz energy cycle, and material entropy production computed with the direct and indirect methods ($\overline{\Sigma_{dir}^{mat}}$ and $\overline{\Sigma_{ind}^{mat}}$, respectively).

	R_t (W m^{-2})	F_s (W m^{-2})	T_a^{max} (PW)	T_a^{min} (PW)	T_o^{max} (PW)	T_o^{min} (PW)	$\overline{E} - \overline{P}$ (kg m^{-2}s^{-1} $\times 10^{-8}$)	$\overline{R_L}$ (W m^{-2})	W (W m^{-2})	$\overline{\Sigma_{dir}^{mat}}$ (mW m^{-2} K^{-1})	$\overline{\Sigma_{ind}^{mat}}$ (mW m^{-2} K^{-1})
BNU	2.37	0.79	4.9 (42)	−5.1 (−39)	1.9 (19)	−0.9 (−17)	−207.1	−5.89	2.0	64.9	58.7
Can2	0.08	0.19	4.7 (41)	−5.1 (−39)	1.5 (20)	−1.1 (−13)	5.32	−0.55	2.2	42.7	56.6
IPSL-M	0.33	0.32	4.6 (40)	−5.2 (−39)	1.5 (19)	−1.4 (−14)	11.1	−0.48	1.6	38.7	57.9
MIR-C	−3.16	1.50	4.8 (42)	−5.7 (−37)	1.4 (19)	−0.4 (−9)	−1.24	−0.70	1.3	39.8	56.5
MIR5	1.06	1.13	4.2 (42)	−4.6 (−40)	1.3 (18)	−0.6 (−10)	−2.94	−0.71	1.4	43.4	60.3
MPI-LR	0.36	0.58	5.0 (42)	−5.5 (−38)	1.9 (19)	−1.3 (−12)	−4.58	−0.88	1.8	43.4	58.7
MPI-MR	0.45	0.60	5.1 (42)	−5.6 (−39)	1.8 (19)	−1.3 (−11)	−4.03	−0.86	1.7	43.4	58.9

Lembo et al. 2019

CERES estimate = 49 mWm^{-2}

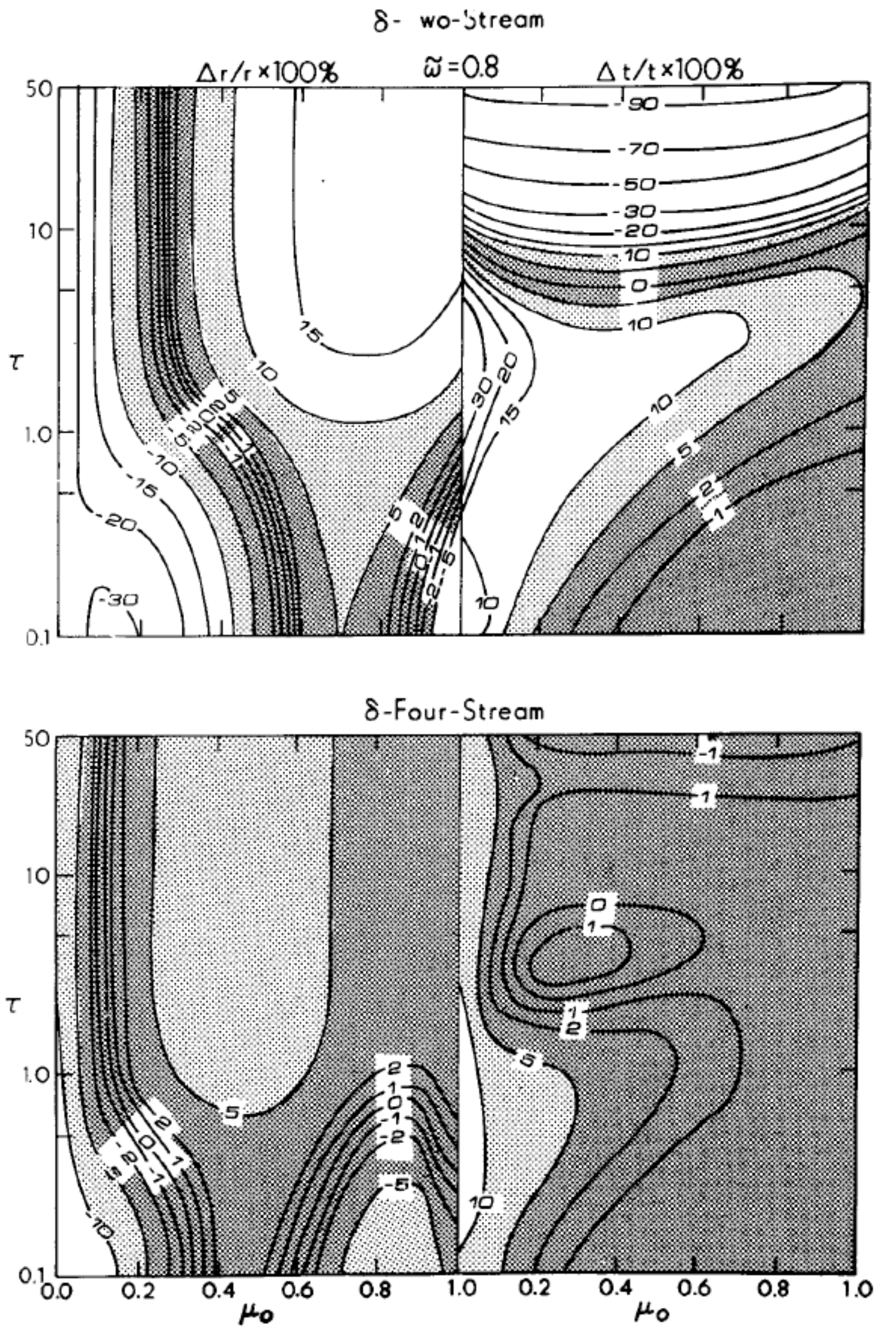
Errors in diurnally averaged shortwave irradiances by 2- and 4-stream models

Modeling error due to 2- and 4-stream approximations

Edition 4 uses:

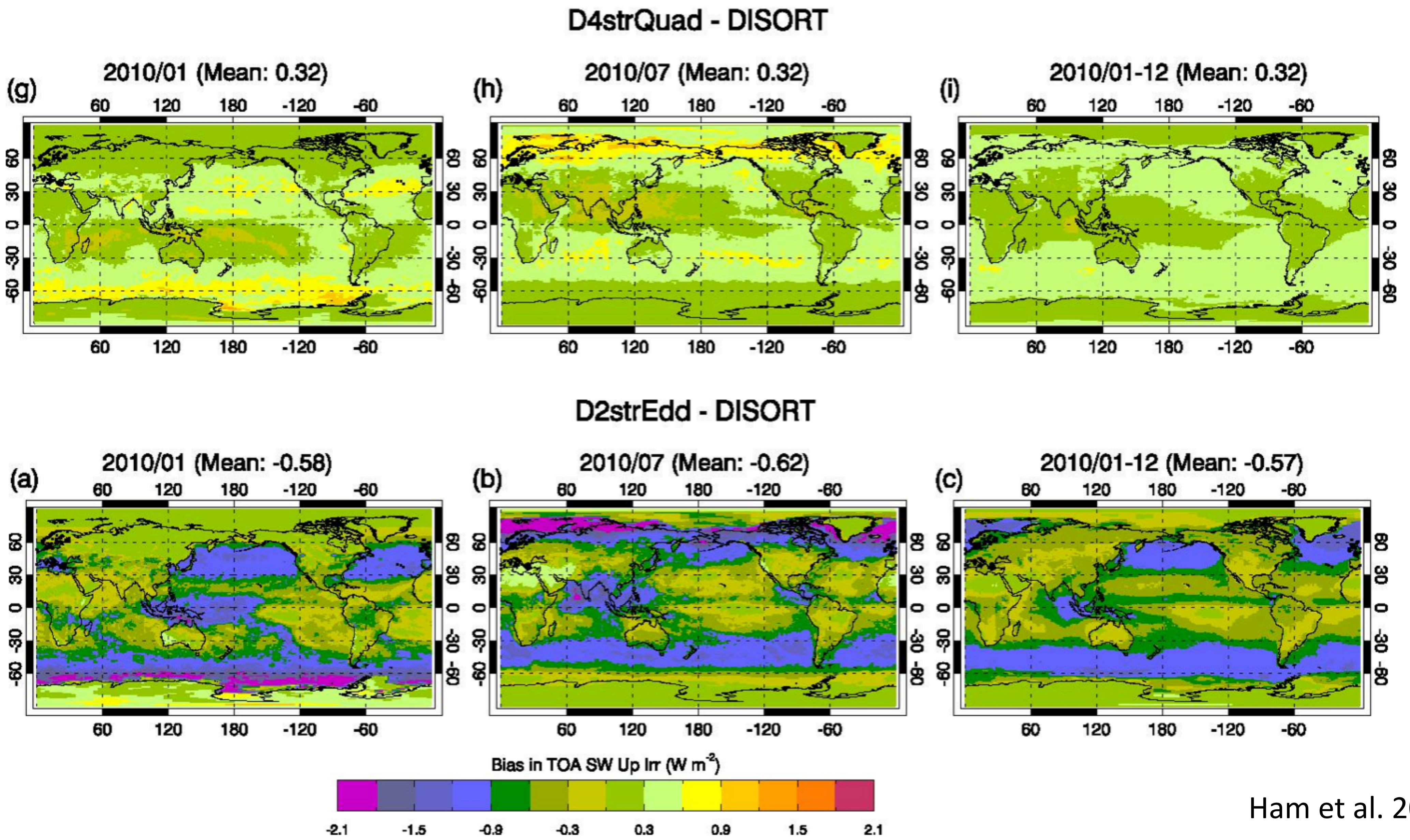
- a 2-stream model for horizontally inhomogeneous clouds (gamma-weighted-two-stream) and
- a 4-stream model for homogeneous clouds and clear-sky

Although the error in instantaneous irradiances are known, the error in diurnally averaged irradiances is unknown



Liou et al. 1988

Diurnally averaged Irradiance error computed with 2-stream and 4-stream models



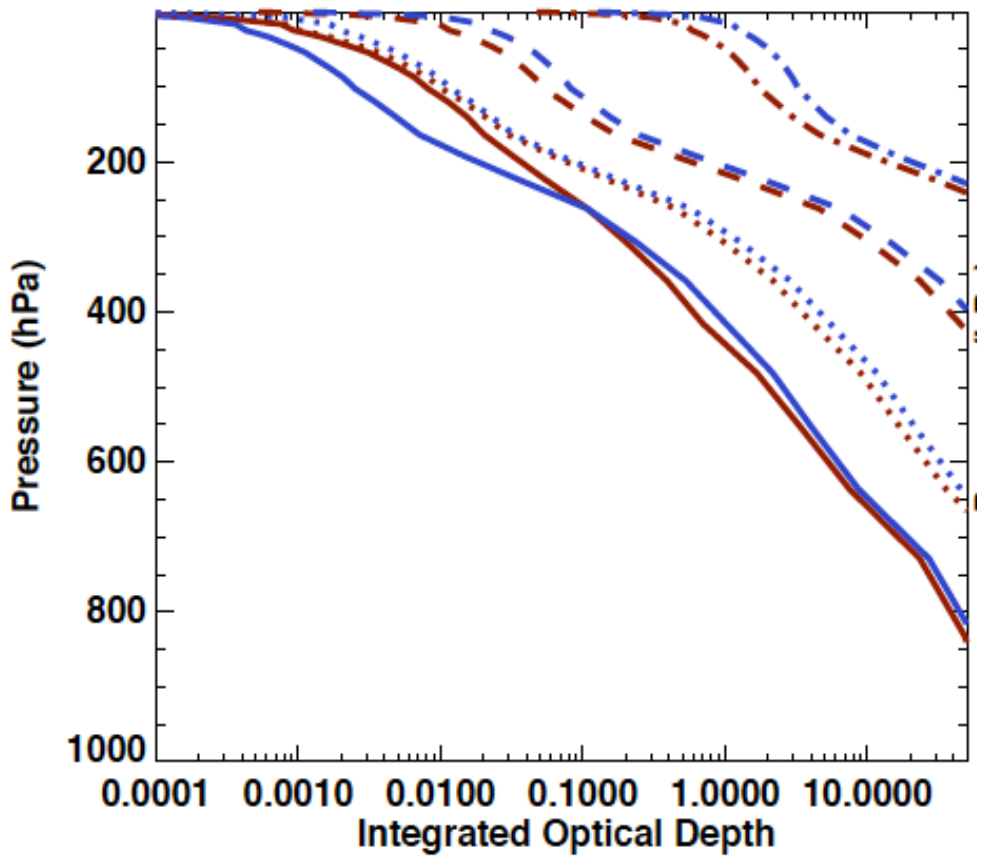
Ham et al. 2019 JAS

Fu-Liou correlated-*k* update

- Shortwave and Longwave
    - LBLRTM 2018 package with HITRAN 2012 and MT_CKD_3.2 continuum
    - Correlated *k*s are generated by the method described in Kato et al. (1999)

Optical thickness by *k*

Tropical standard atmosphere



Edition 5 approach

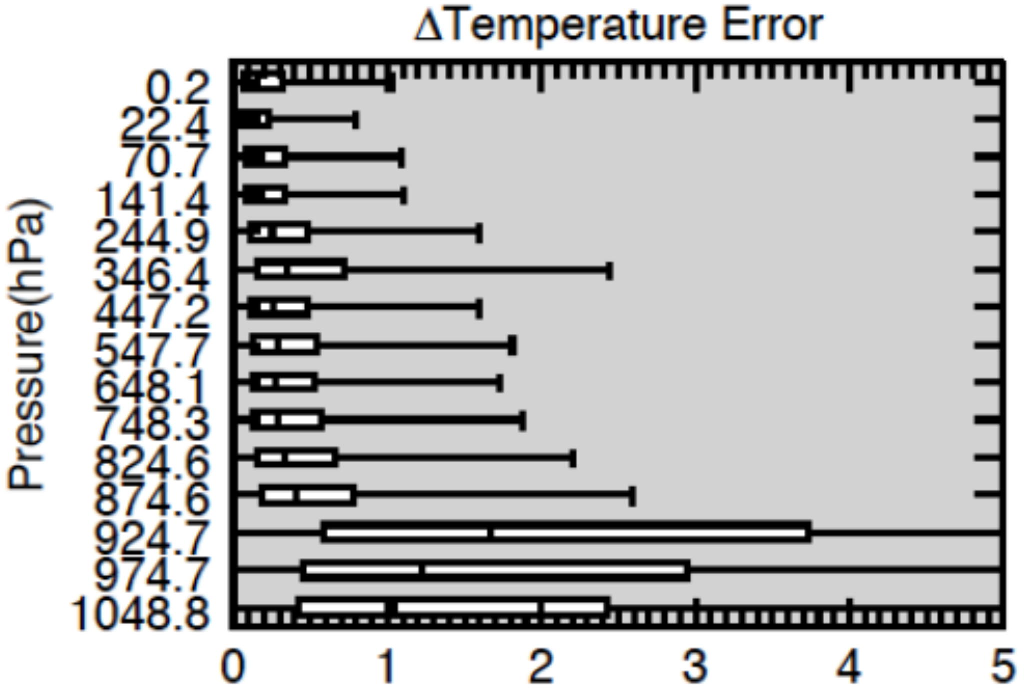
Edition 4 approach

K1@ 22.0%: Solid
K2@ 51.0%: Dotted
K3@ 22.0%: Dashed
K4@ 5.0%: DotDash

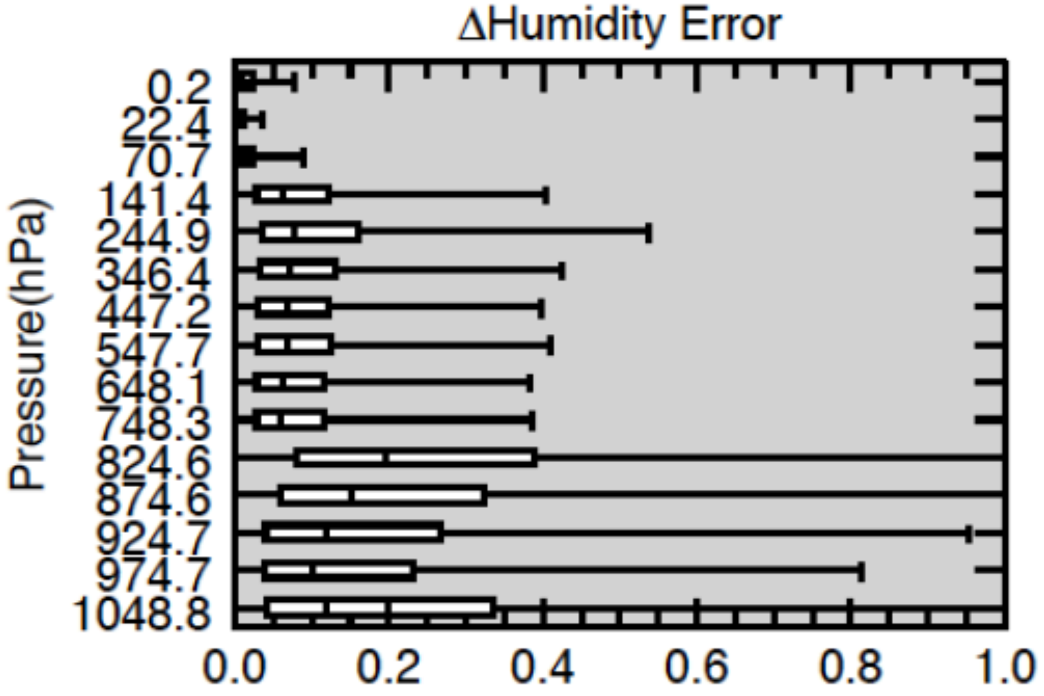
- Edition 4 treats water vapor continuum as an independent gas.
- Effect of the optical depth differences on flux computations need to be tested.

Use spectral radiance to correct monthly mean temperature and humidity

Theoretical estimate of the error in correcting mean temperature and humidity
Next step is to use observed spectral radiances by AIRS



Error in temperature correction (K)



Relative error in specific humidity correction

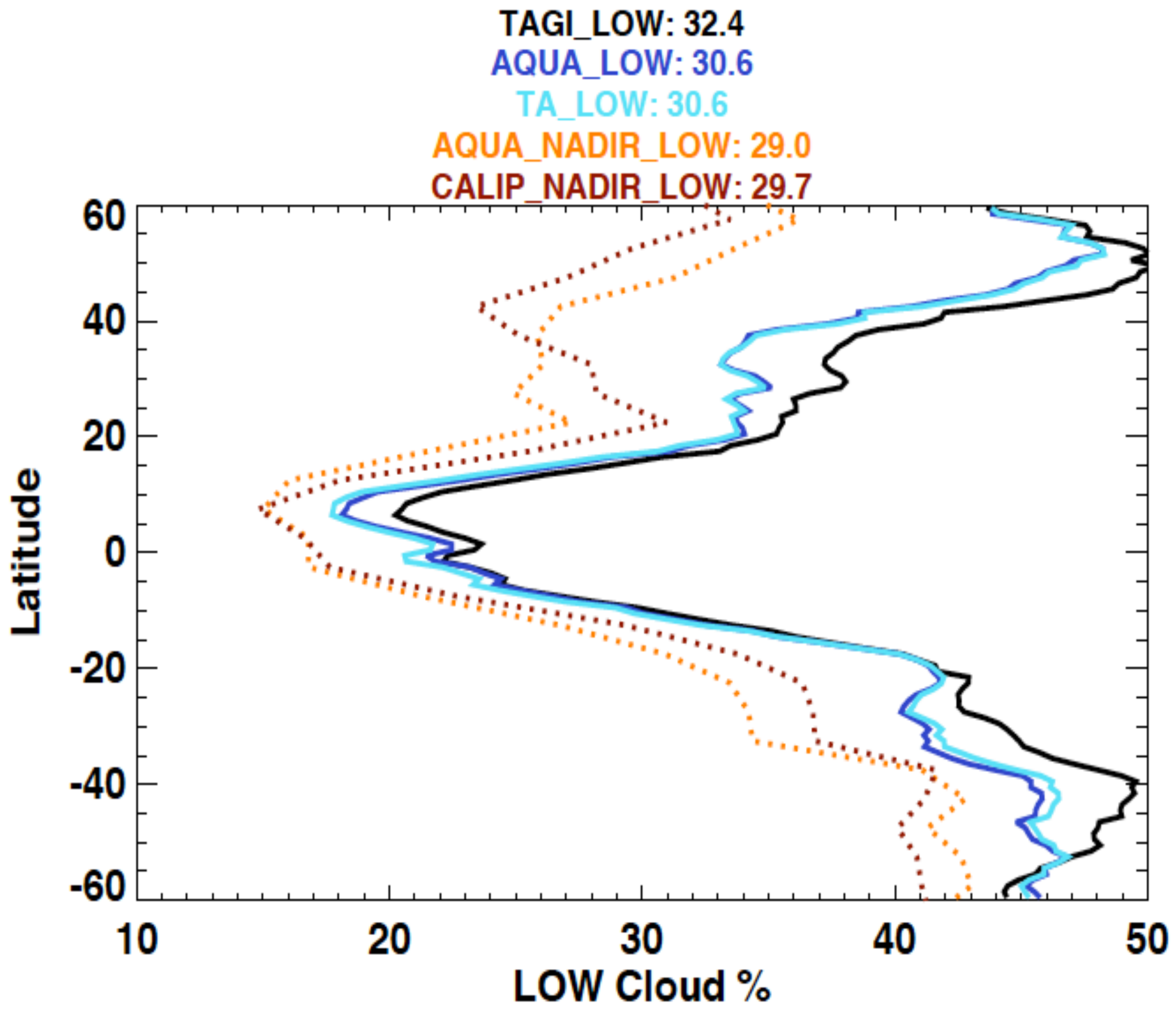
Publications

- Hogilyan, A., Cronin, M. F., D. Zhang, and S. Kato, 2019: Uncertainty in net surface heat flux due to differences in commonly used albedo products, *J. Climate*. In press.
- Meyssignac B, Boyer T, Zhao Z, Hakuba MZ, Landerer FW, Stammer D, Köhl A, Kato S, L'Ecuyer T, Ablain M, Abraham JP, Blazquez A, Cazenave A, Church JA, Cowley R, Cheng L, Domingues CM, Giglio D, Gouretski V, Ishii M, Johnson GC, Killick RE, Legler D, Llovel W, Lyman J, Palmer MD, Piotrowicz S, Purkey SG, Roemmich D, Roca R, Savita A, von Schuckmann K, Speich S, Stephens G, Wang G, Wijffels SE and Zilberman N, 2019: Measuring Global Ocean Heat Content to Estimate the Earth Energy Imbalance. *Front. Mar. Sci*. 6:432. doi: 10.3389/fmars.2019.00432
- Cronin MF, Gentemann CL, Edson J, Ueki I, Bourassa M, Brown S, Clayson CA, Fairall CW, Farrar JT, Gille ST, Gulev S, Josey SA, Kato S, Katsumata M, Kent E, Krug M, Minnett PJ, Parfitt R, Pinker RT, Stackhouse PW Jr, Swart S, Tomita H, Vandemark D, Weller RA, Yoneyama K, Yu L and Zhang D, 2019: Air-Sea Fluxes With a Focus on Heat and Momentum. *Front. Mar. Sci.* 6:430. doi: 10.3389/fmars.2019.00430
- Pan, F., S. Kato, F. G. Rose, A. Radkevich, and X. Liu, 2019: An algorithm to derive temperature and humidity profile changes from highly spatially and temporally averaged spectral radiance differences, submitted to *J. Atmos. Ocean. Technol*.
- Kato, S., N. G. Loeb, D. A. Rutan, and F. G. Rose, 2019: Effects of electromagnetic wave interference on observations of Earth radiation budget, submitted to *J. Quant. Spec. Radiant. Trans.*
- Kato, S. and F. G. Rose, 2019: Global and regional entropy production by radiation estimated from satellite observations, submitted to *J. Climate*.
- Ham, S.-H., S. Kato, and F. G. Rose, 2019: Biases in diurnally-integrated shortwave irradiances dur to two- and four-stream approximations in comparison to Monte Carlo method, submitted to *J. Atmos. Sci*.

Summary

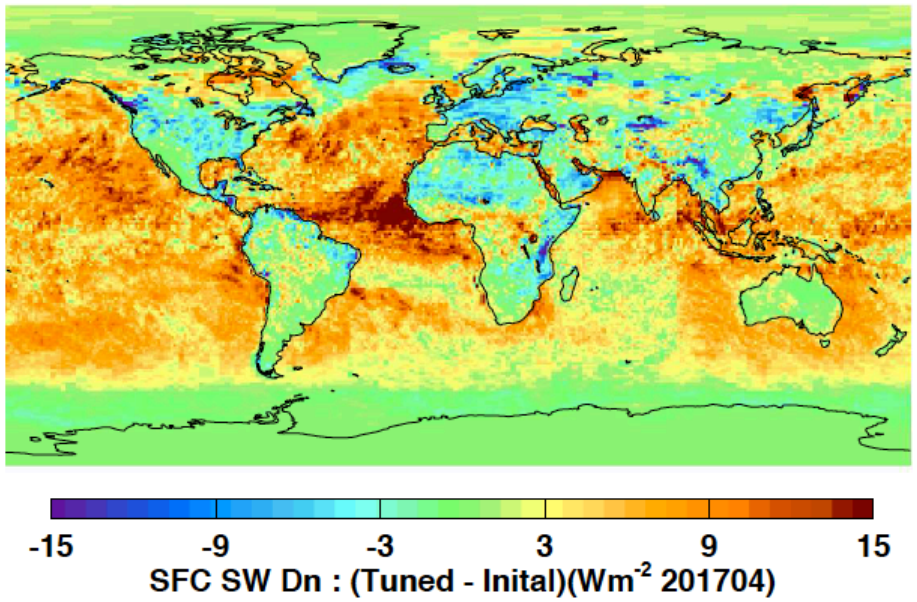
- Evaluation of Edition 4.1 SYN and EBAF downward surface irradiances over southern ocean is revised
  - Downward shortwave irradiances are overestimated by up to 10 Wm^{-2} depending on season
  - Downward longwave irradiances are underestimated especially during night
- Entropy production derived from radiation is included in Edition 4.1 SYN.
- Fu-Liou shortwave and longwave radiative transfer code will be revised for Edition 5.

Cloud fraction bias

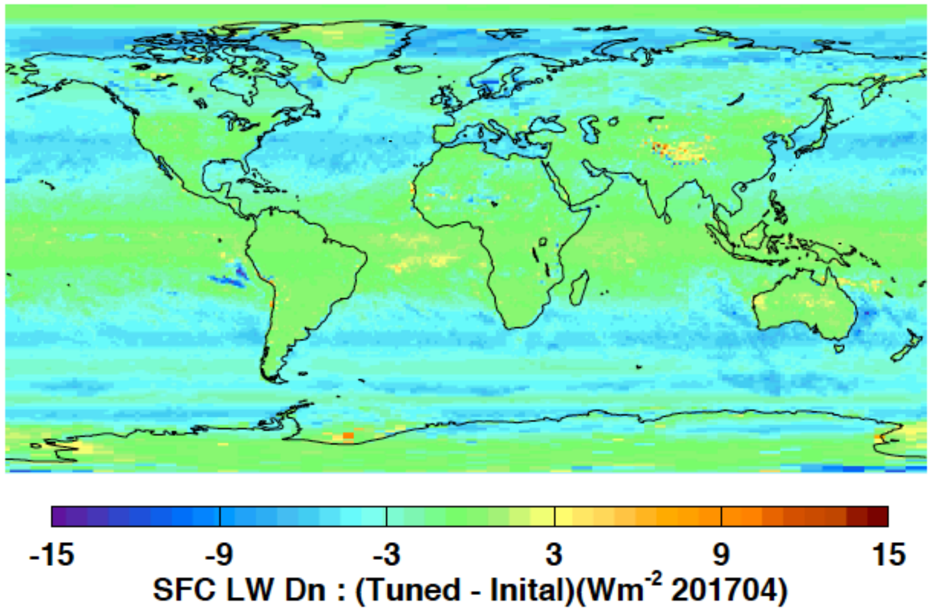


Geo derived cloud fraction is generally larger than MODIS or CALIPSO-CloudSat derived cloud fraction

EBAF adjustments (Southern hemisphere Fall)



N= 64800 Glb mean(sd): 3.62 (4.31) Mn/Mx: -37.81/ 30.86



N= 64800 Glb mean(sd): -2.31 (2.12) Mn/Mx: -14.31/ 17.25

Carnot efficiency of the Earth system

Ta = Shortwave irradiance absorbed by Earth / Entropy production by shortwave = 282 K (9 °C)
Te = Longwave irradiance emitted by Earth / Entropy production by longwave = 259 K (-14 °C)

$$\eta = \frac{T_a - T_e}{T_a} = 0.085$$

Carnot efficiency of a gasoline engine ~ (1089 K – 300 K) / 1089 K = 0.725

Theoretical upper limit of thermal efficiency