Surface Atmosphere Radiation Budget (SARB) working group update

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CERES Science team meeting
April. 26-28, 2016
Hampton, VA

Work done after the last CERES meeting

- EBAF-surface Ed4 (Rose, Kato)
  - Spectral irradiance (bogus tuning)
  - Spectral radiance (TBD)
- SYN Ed4
  - 200801 to 201112 were processed
  - Surface validation
  - Himawari 8 testing
- Terra drift study (Rutan)
- C3M
  - Comparison with CloudSat products
  - Planning for the new edition
  - Consistency check between clouds, T, and q for low-level clouds
- Sea ice spectral albedo from ARISE (Radkevich)
- Radiance comparison over Dome C
- Multi-layer cloud comparison (Viudze-Mora)
- Surface validation web site revision

SYN ed4

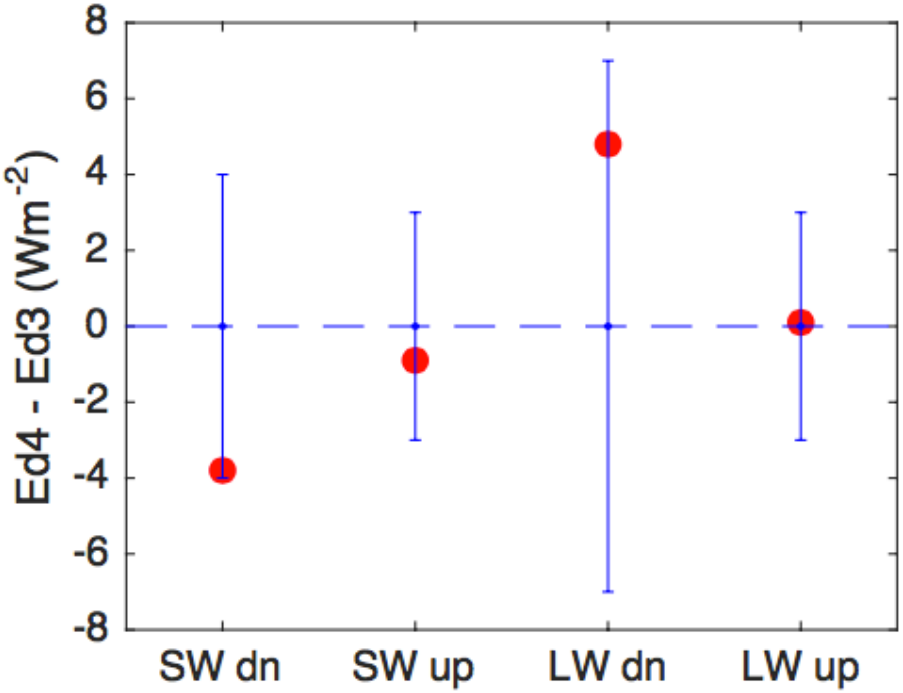
- Ed 3 versus Ed 4
- Comparison with surface data

Ed3 and Ed4 Global annual mean comparison (200607-201112)

	TOA		Surface			
	SW up (Wm-2)	LW up (Wm-2)	SW down (Wm-2)	SW up (Wm-2)	LW down (Wm-2)	LW up (Wm-2)
Ed4 (clear-sky)	101.0 (51.4)	238.1 (262.5)	183.9 (242.4)	22.4 (28.3)	346.8 (317.6)	397.7 (397.0)
Ed3 (clear-sky)	98.7 (52.8)	237.1 (262.2)	187.7 (242.2)	23.3 (28.6)	342.0 (316.0)	397.6 (397.0)
Obs. Ed4 (clear-sky)	97.8 (50.7)	238.7 (268.1)	-	-	-	-
Obs. Ed3 (clear-sky)	97.5 (50.3)	238.9 (265.8)	-	-	-	-

Clear-sky irradiances are computed by removing clouds
Observed clear-sky are from clear-sky scenes only

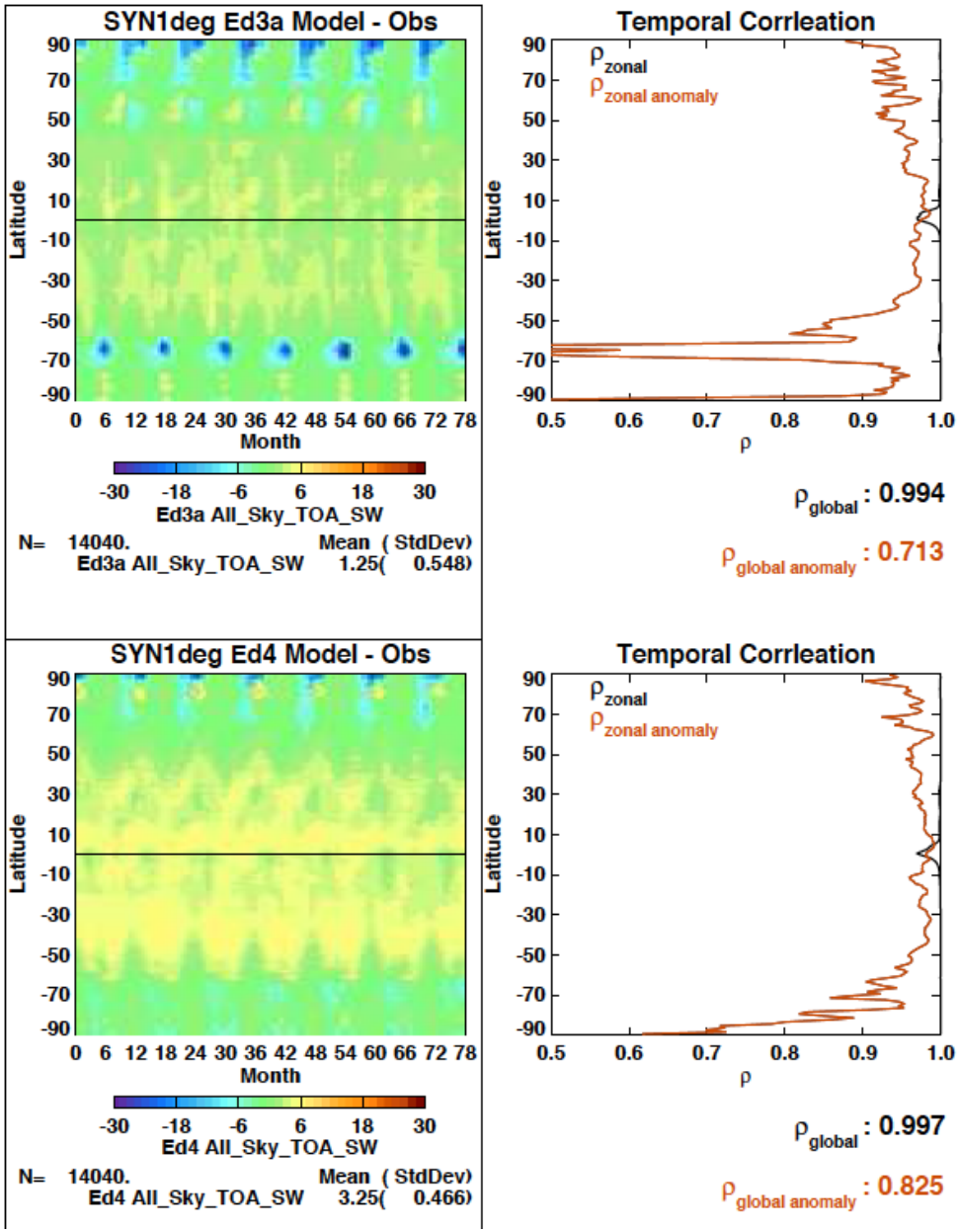
Global annual mean



Error bars are uncertainty from Kato et al. (2013)

- Global mean SW down decreases by 3.8 Wm^{-2} (larger cloud fraction)
- Global annual mean LW down increases by 2 Wm^{-2} from Ed3 SYN to Ed2.8 EBAF-surface
- Ed4 and Ed3 SYN clear-sky LW down difference is 1.6 Wm^{-2} and all-sky difference is 4.8 Wm^{-2} (Clouds contribute more than T and q).
- Ed4 low-level cloud fraction is larger than Ed3 low-level cloud fraction
- Ed4 includes cloud overlap

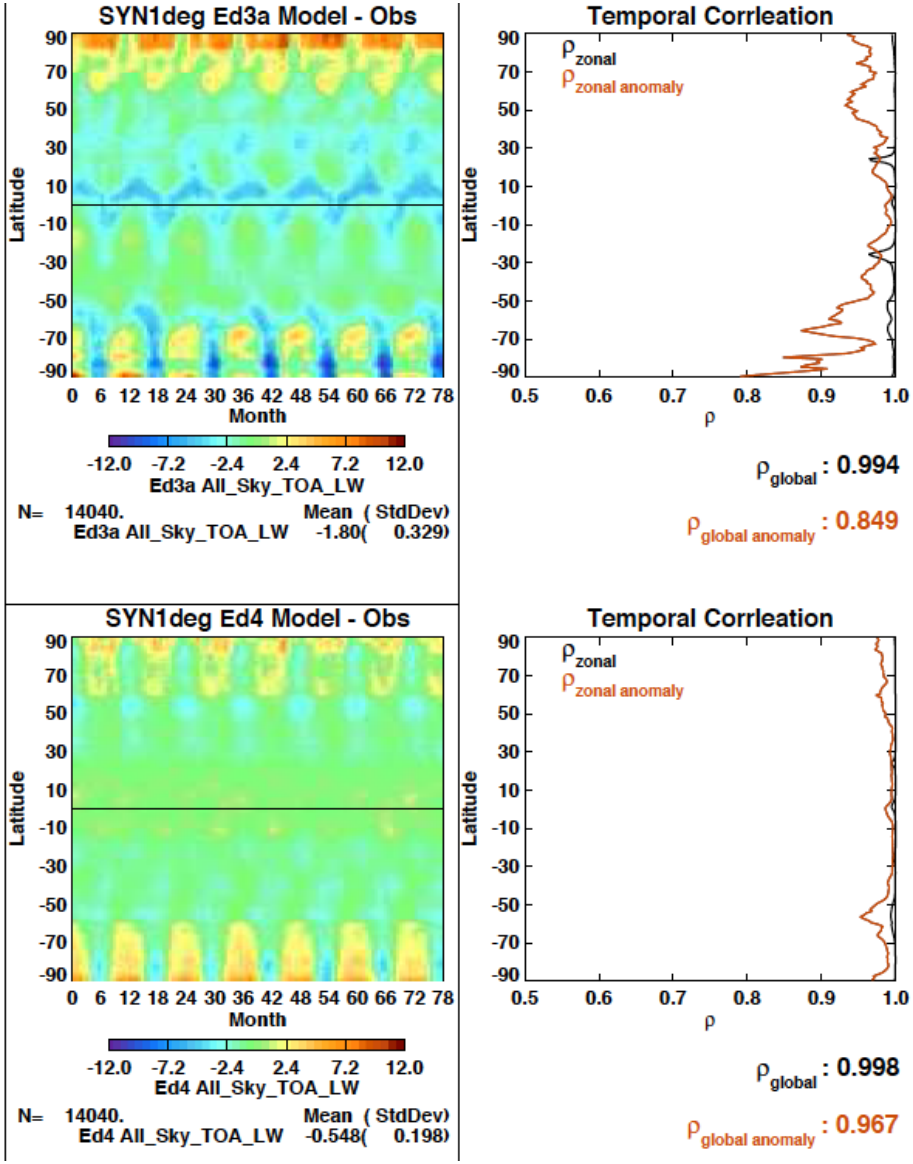
Zonal TOA All Sky (SW)



The difference between computed and observed Ed4 SW TOA is larger than the difference of Ed3

Computed Ed4 is correlated with observed TOA better than Ed3

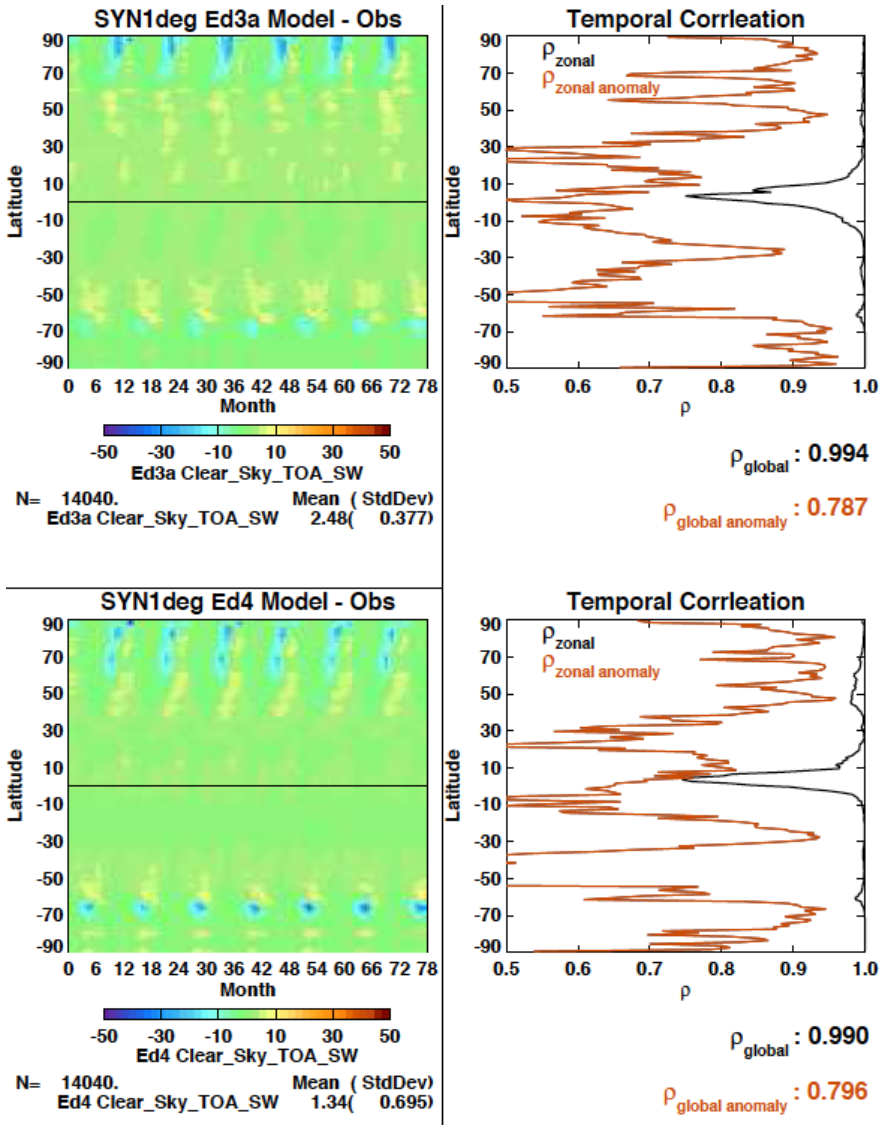
Zonal TOA All Sky (LW)



The difference between computed and observed Ed4 LW TOA is smaller than the difference of Ed3

Computed Ed4 is correlated with observed TOA better than Ed3

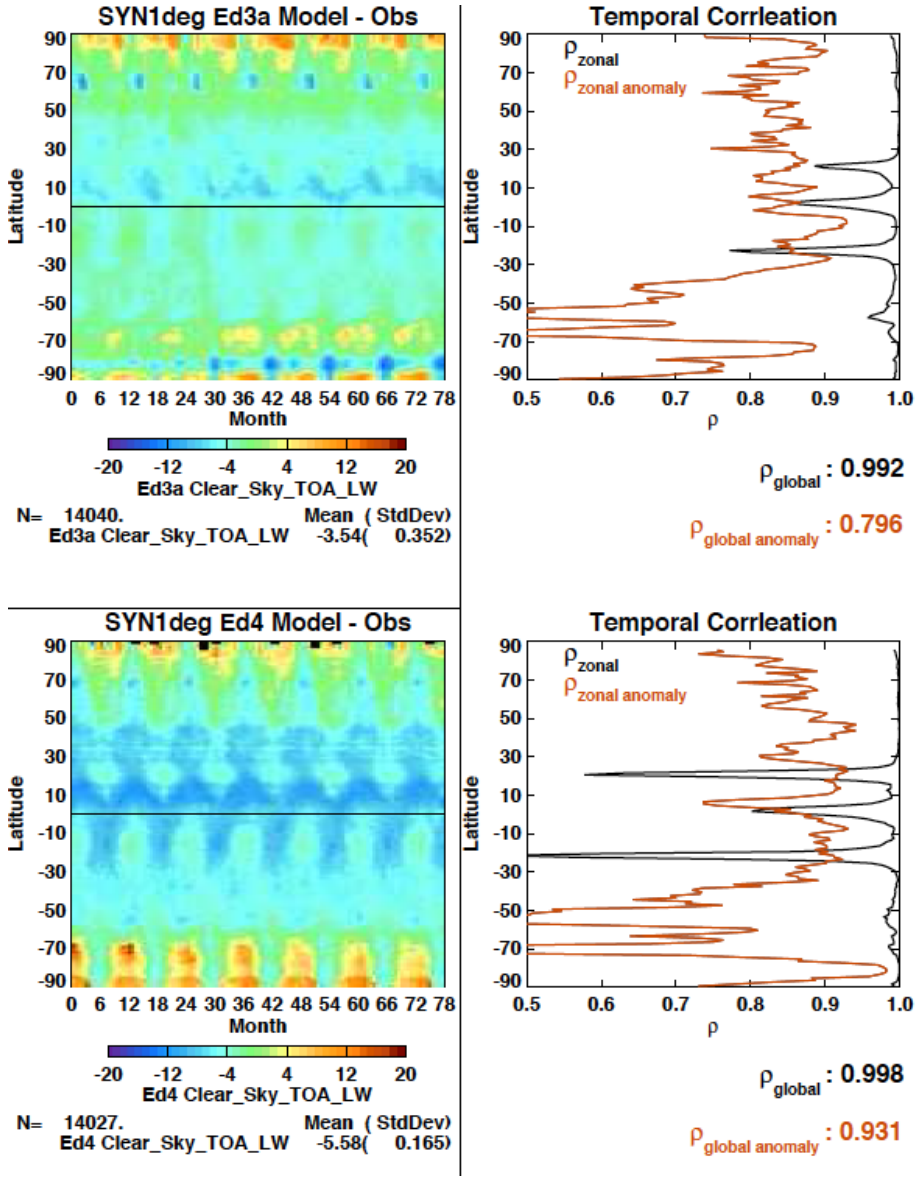
Zonal TOA Clear Sky (SW)



The difference between computed and observed Ed4 SW TOA is smaller than the difference of Ed3

Computed Ed4 is correlated with observed TOA better than Ed3

Zonal TOA Clear Sky (LW)

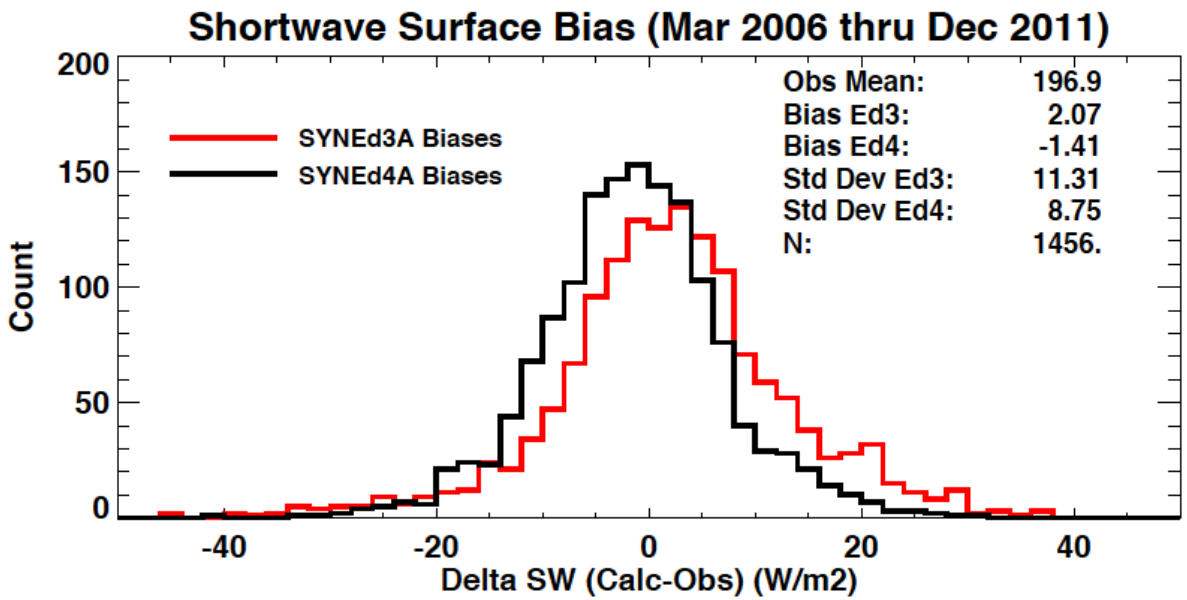


The difference between computed and observed Ed4 LW TOA is larger than the difference of Ed3

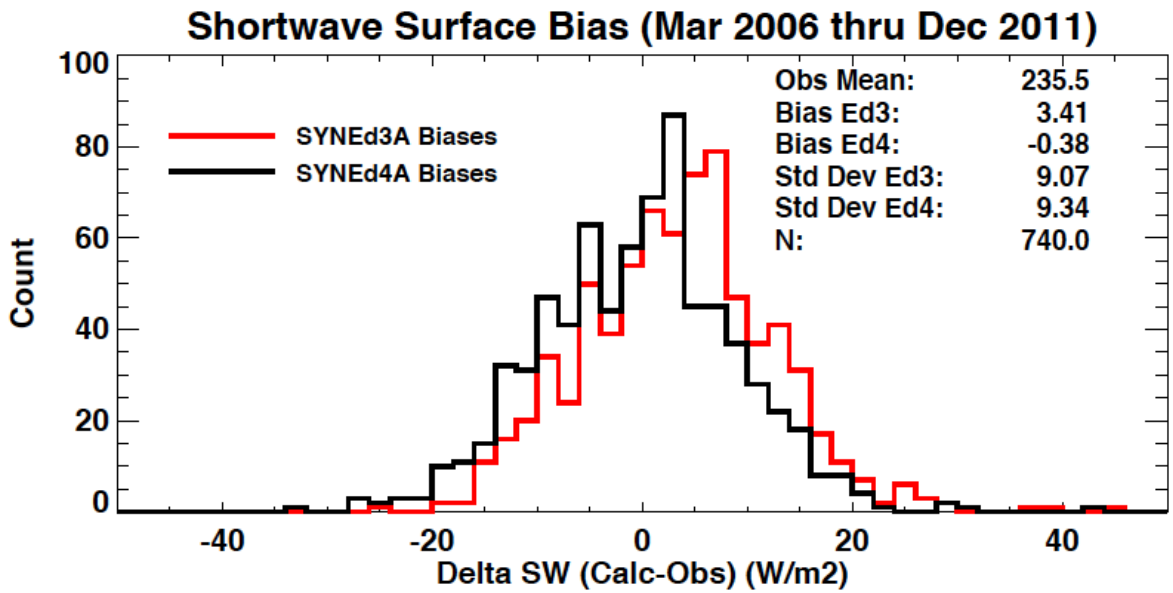
Computed Ed4 is correlated with observed TOA better than Ed3

Comparison with surface observations (SW)

Land

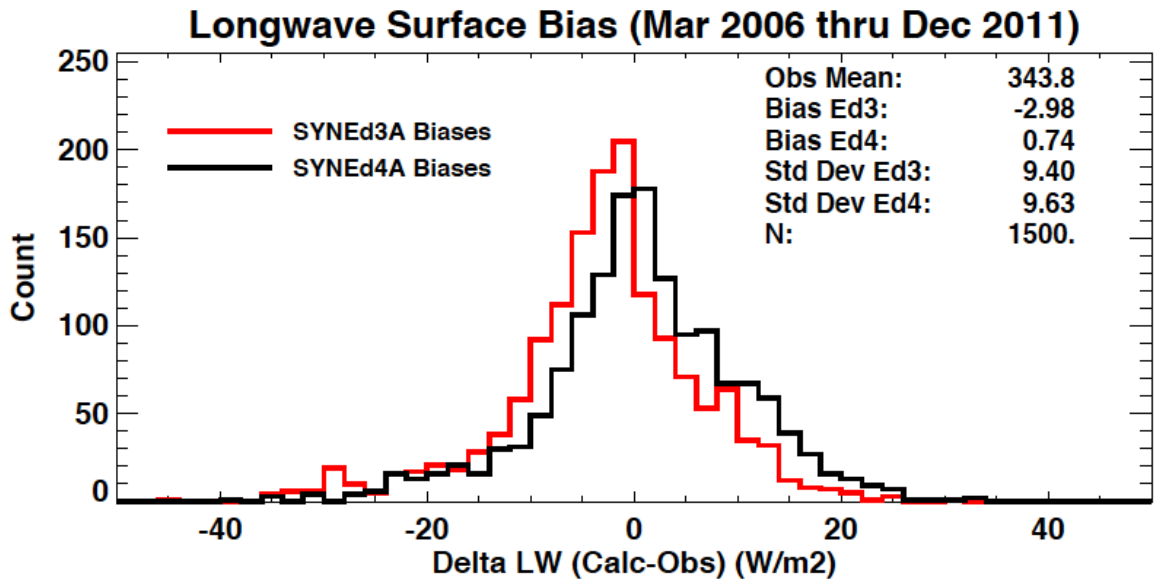


Ocean

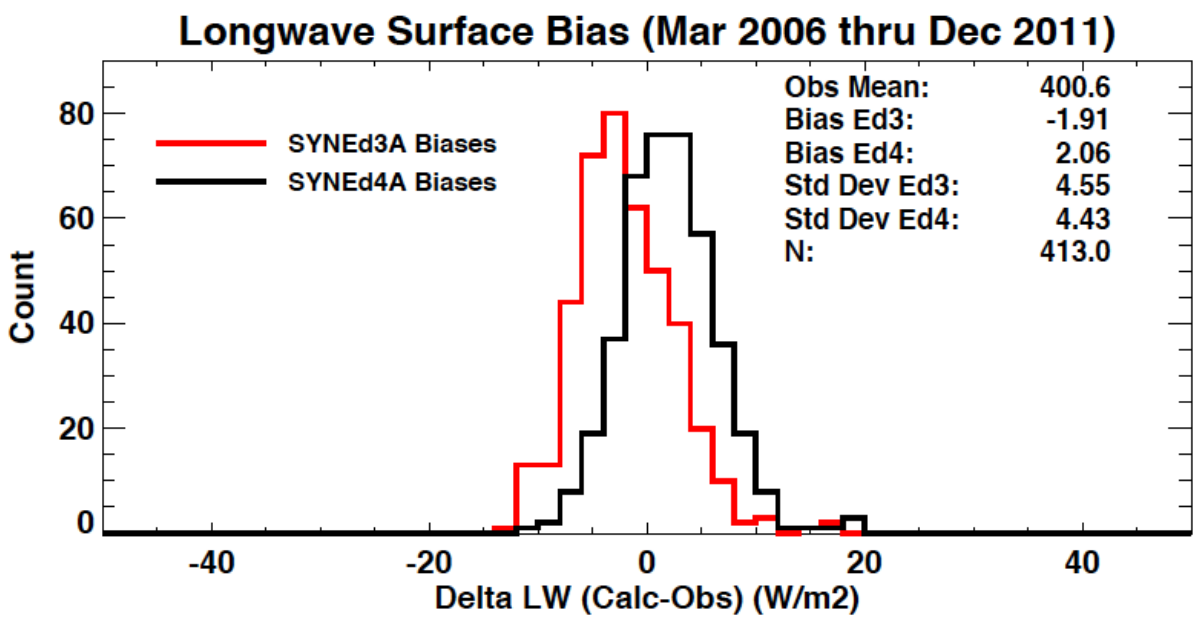


Comparison with surface observations (LW)

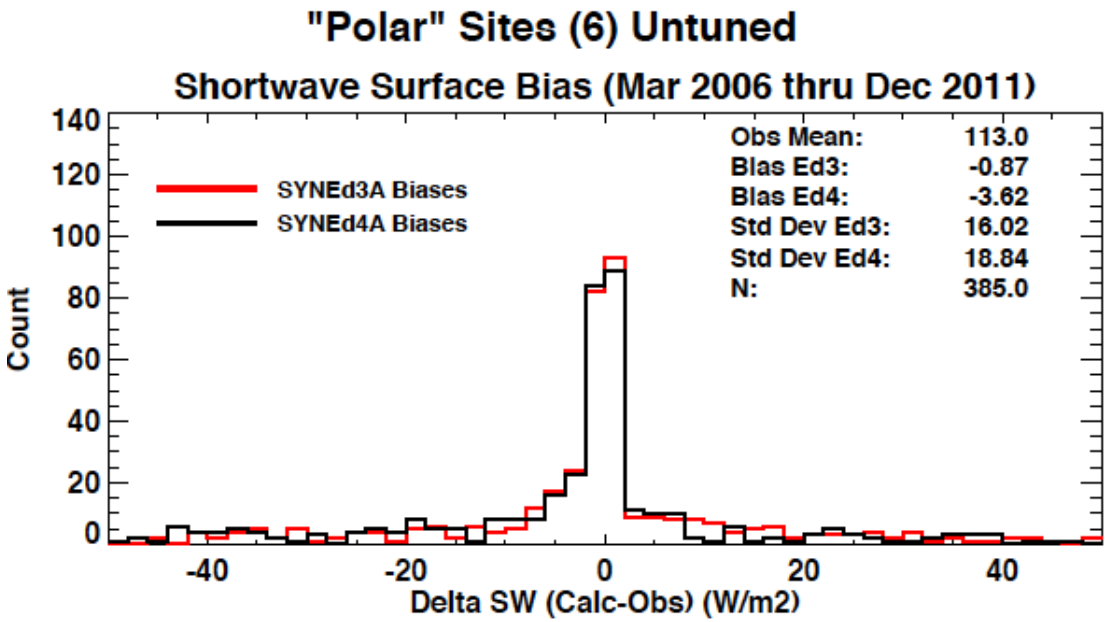
Land

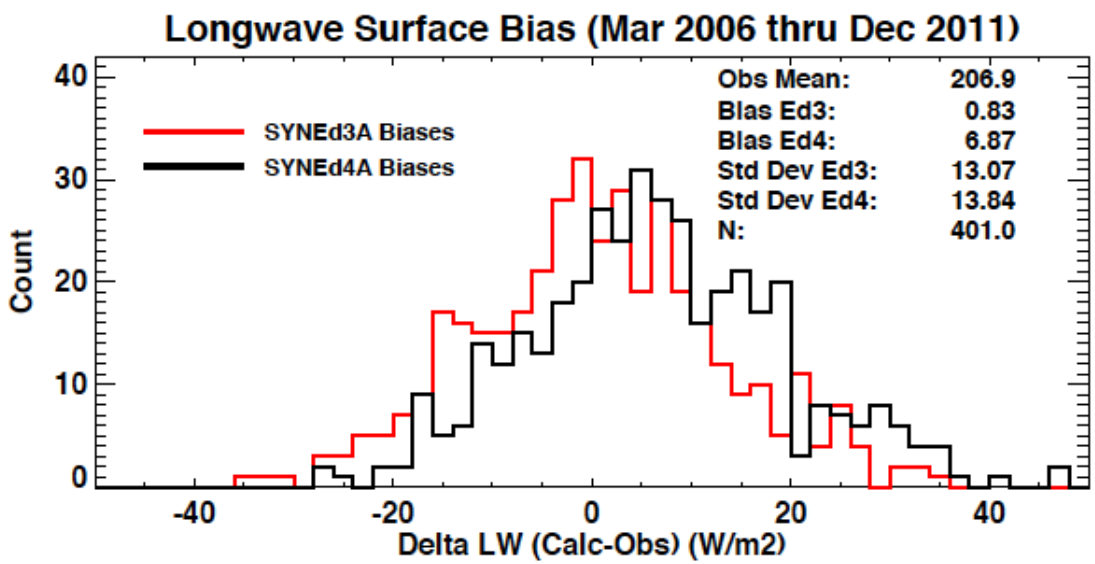


Ocean



Comparison with surface observations (Polar)

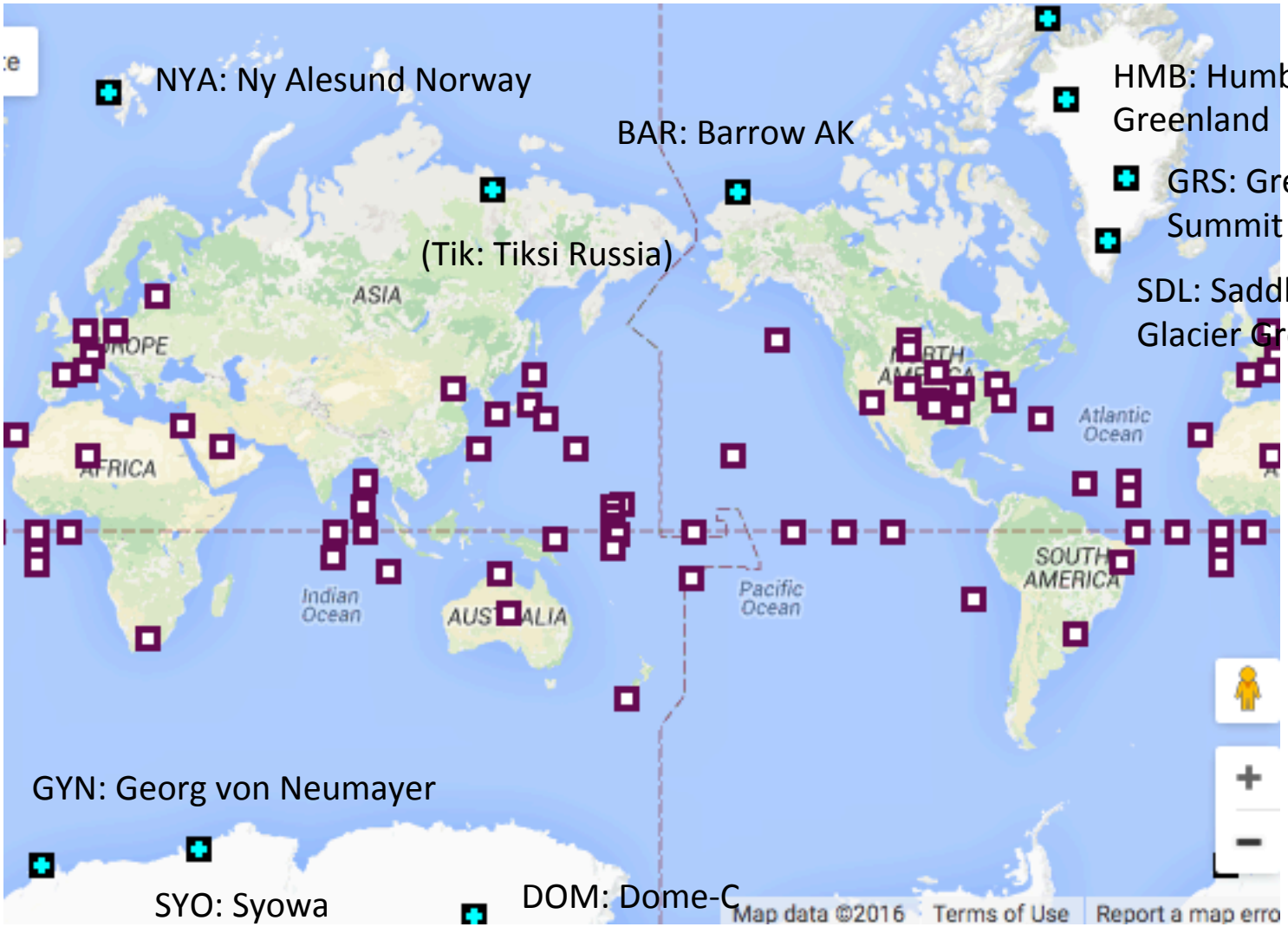




Ed4 difference is larger than the Ed3 difference for both SW and LW

Polar sites

ALE: Alert Canada



NYA: Ny Alesund Norway

BAR: Barrow AK

HMB: Humboldt Glacier Greenland

GRS: Greenland Summit

(Tik: Tiksi Russia)

SDL: Saddle Glacier Greenland

GYN: Georg von Neumayer

SYO: Syowa

DOM: Dome-C

SPO: South pole

Comparison at polar sites

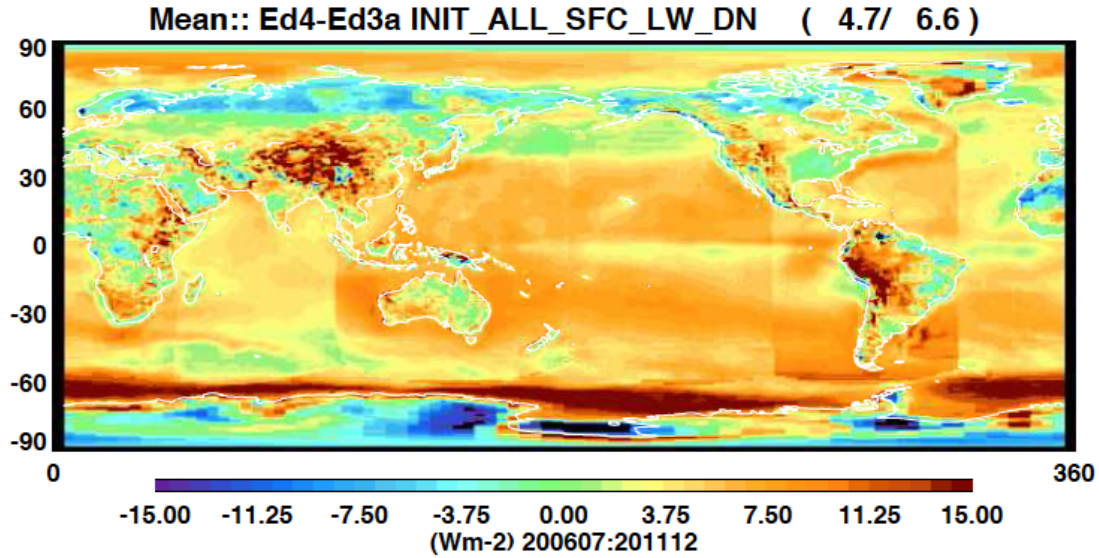
	ALE	NYA	BAR	GRS	HMB	SDL	GVN	SYO	DOM	SPO
SW diff.										
Ed3	5.11 (11.42)	-7.29 (14.03)	5.97 (13.29)	6,67 (11.03)	7.42 (9.41)	11.60 (8.63)	-12.3 (15.91)	11.90 (15.29)	-4.03 (4.74)	-4.93 (9.27)
Ed4	1.02 (9.31)	-10.0 (15.90)	3.31 (10.51)	0.80 (11.72)	6.60 (8.60)	5.51 (11.08)	-19.5 (20.97)	13.85 (18.04)	-7.29 (11.68)	-6.41 (11.78)
LW diff.										
Ed3	-0.82 (14.60)	7.88 (9.91)	-0.92 (9.19)	-	-	-	1.33 (11.60)	-11.8 (7.79)	12.60 (4.63)	8.35 (12.24)
Ed4	5.14 (16.54)	17.19 (13.58)	1.39 (9.63)	-	-	-	12.27 (11.49)	-0.85 (13.29)	10.08 (8.54)	3.73 (7.75)
Ed4-Ed3										
All-sky LW	6.5	9.4	1.1		4.5		12.3	10.8	-2.7	4.8
Clear-sky LW	1.5	3.9	2.8		3.1		3.8	5.6	0.1	2.6

SW tends to improve over the Arctic and LW tends to improve over the Antarctica

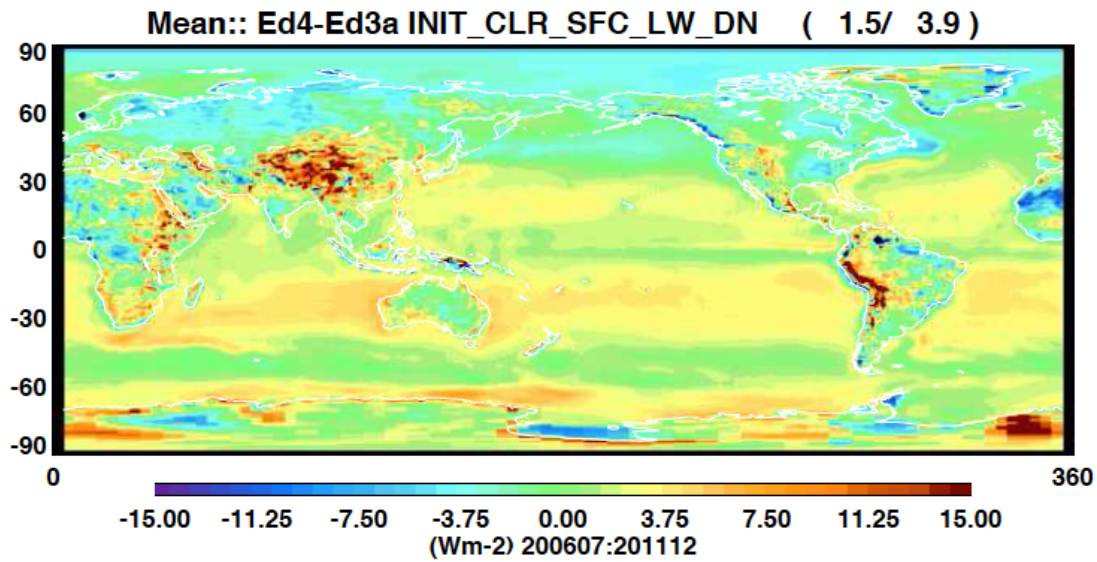
Downward longwave difference (200607 to 201112 mean)

(Mean/RMS)

All-sky



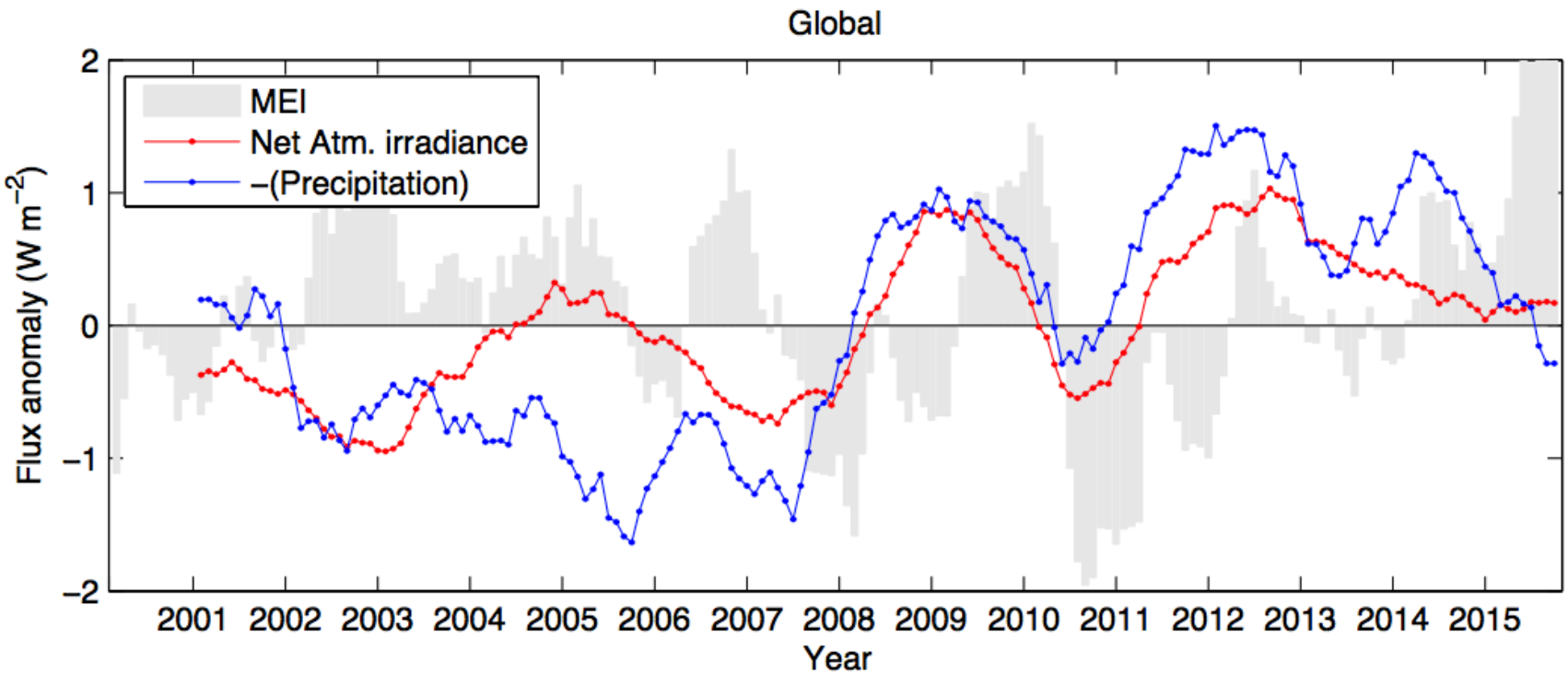
Clear-sky



Larger LW down over the Arctic is primarily due to clouds (more low-level clouds)
Larger LW down over Southern Ocean is due to clouds and GEOS (T and q)

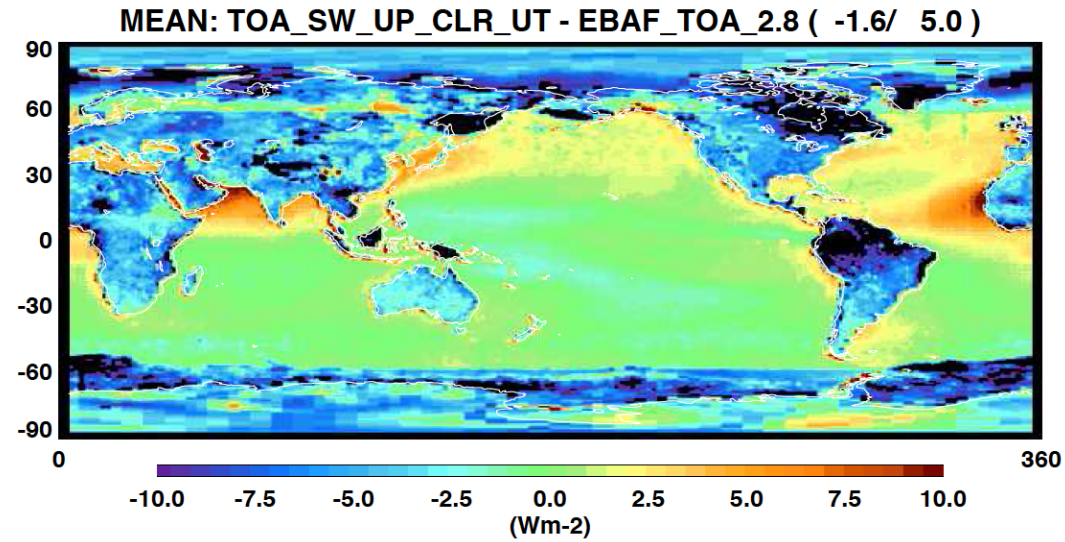
Ed 2.8 EBAF-surface

Currently data from March 2000 through June 2015 are available
Will be extended through November 2015 soon

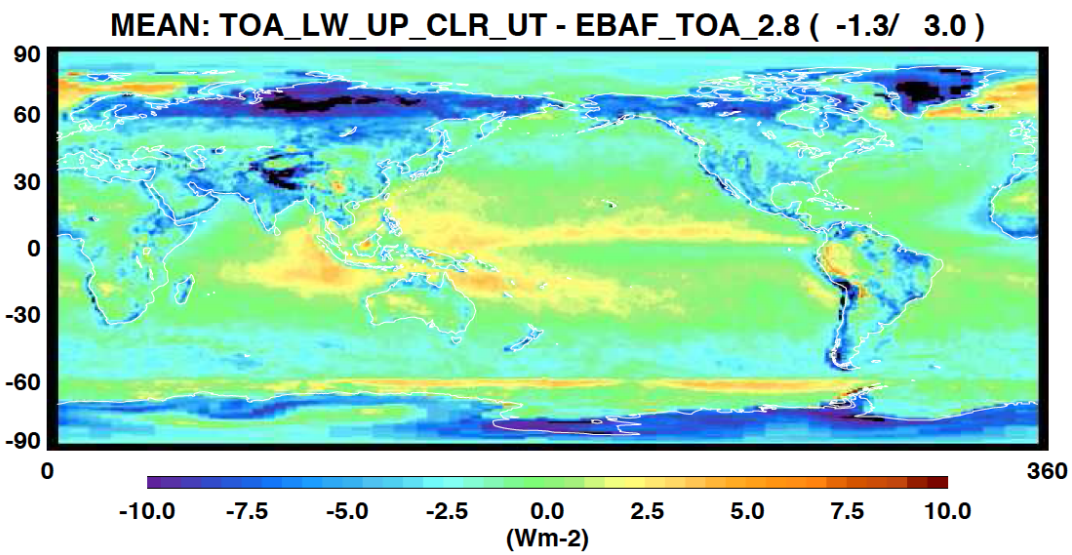


Wirth 12 month running mean

Clear-sky Ed4 SYN computed untuned – Ed2.8 EBAF-TOA (2008-2011 mean)

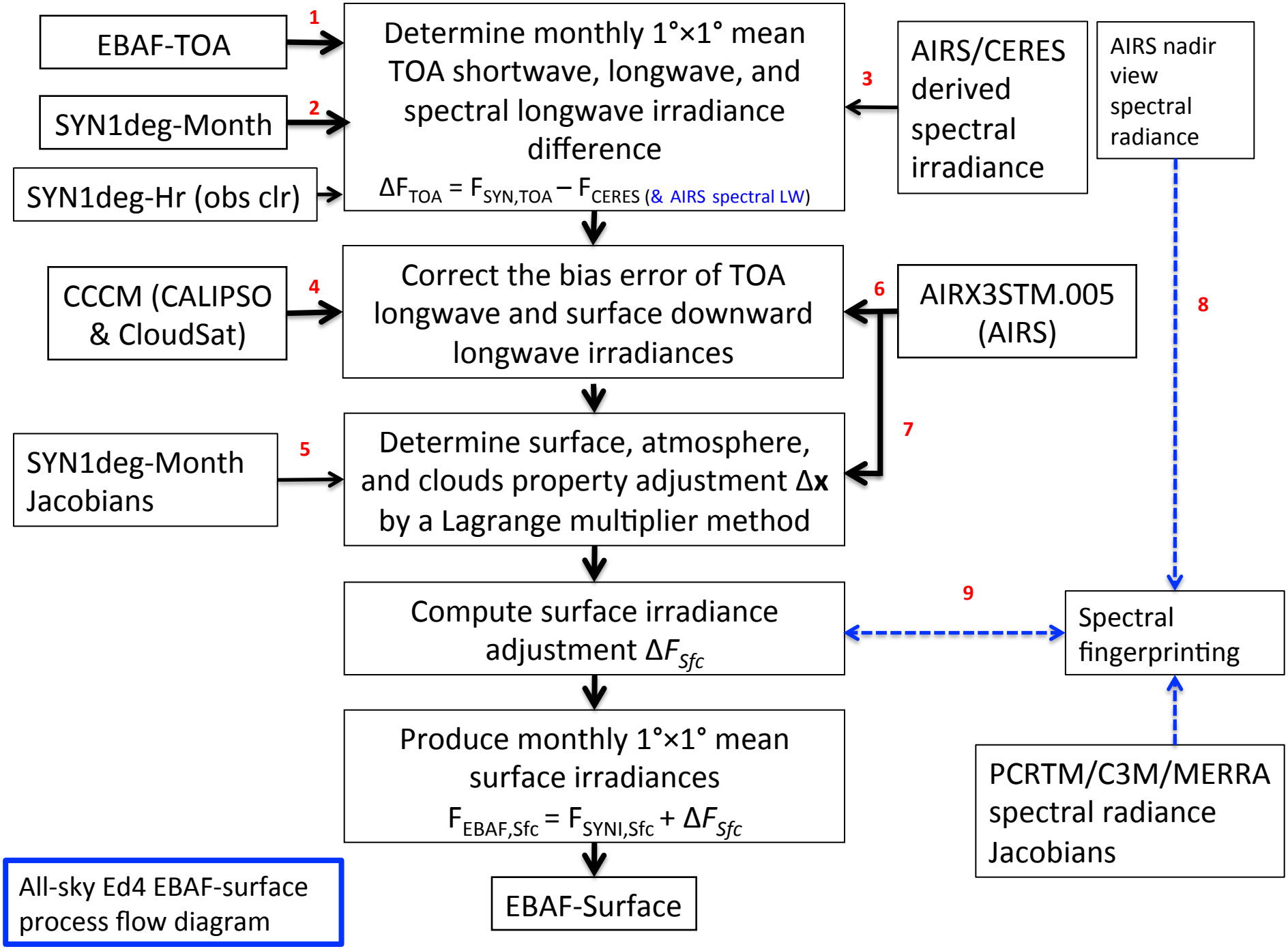


Increasing clear-sky SW over northern hemisphere ocean reduces the EBAF clear-sky tuning



Increasing OLR over tropical ocean (< $5Wm^{-2}$) reduces the EBAF clear-sky tuning

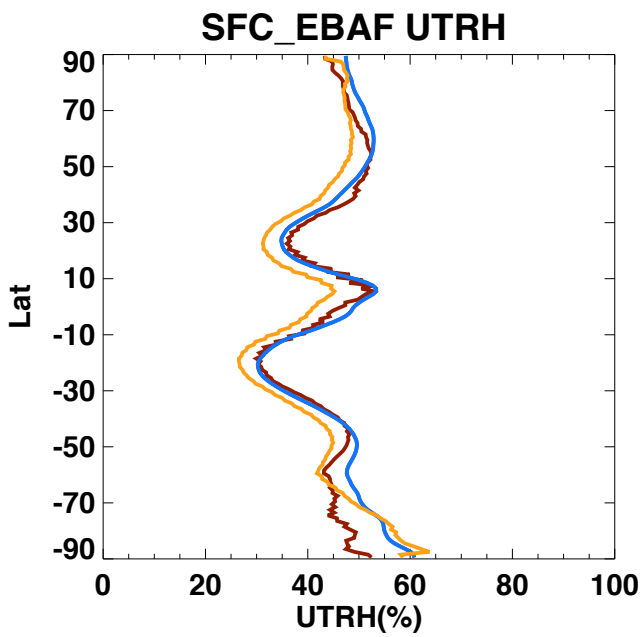
EBAF surface ed4

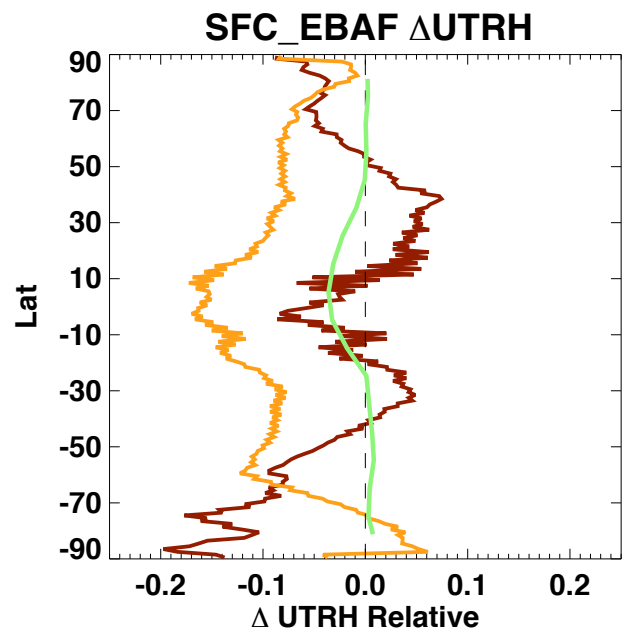


All-sky Ed4 EBAF-surface process flow diagram

UTRH Adjustment

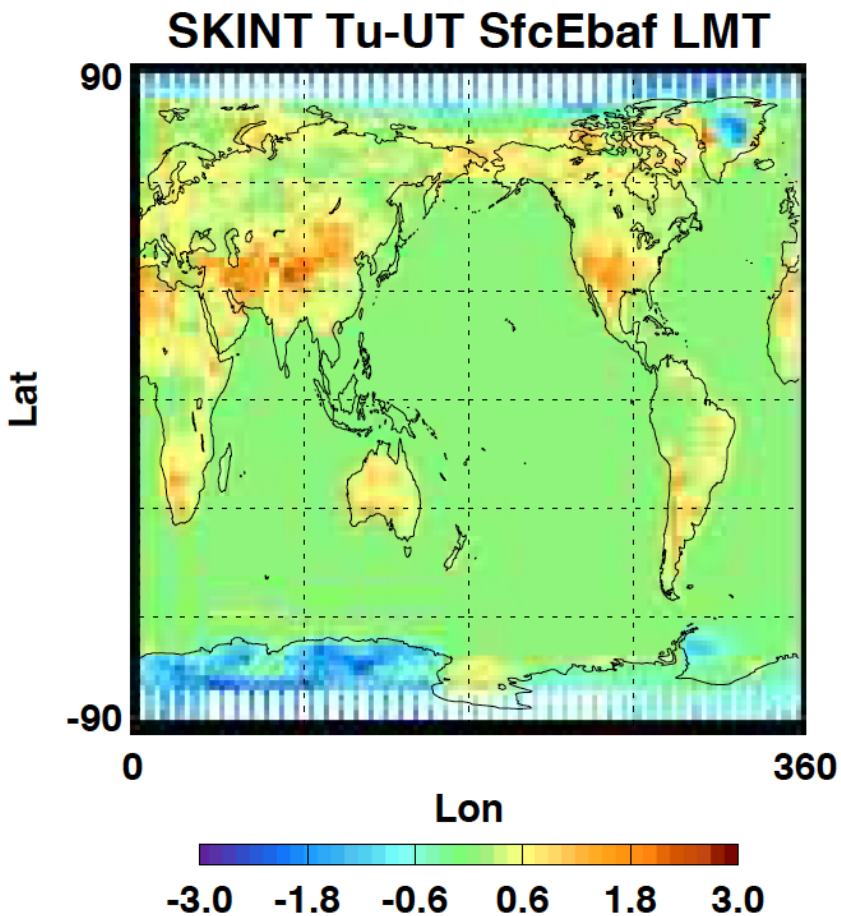
- Unadjusted MOA Geos5.4.1
- Pre-tuning to Modified AIRSL3 Product UTRH
- Lagrange Multiplier solution Airs Spectral Flux
- Fingerprinting to AIRS Radiances using PCRTM spectral model &C3M data



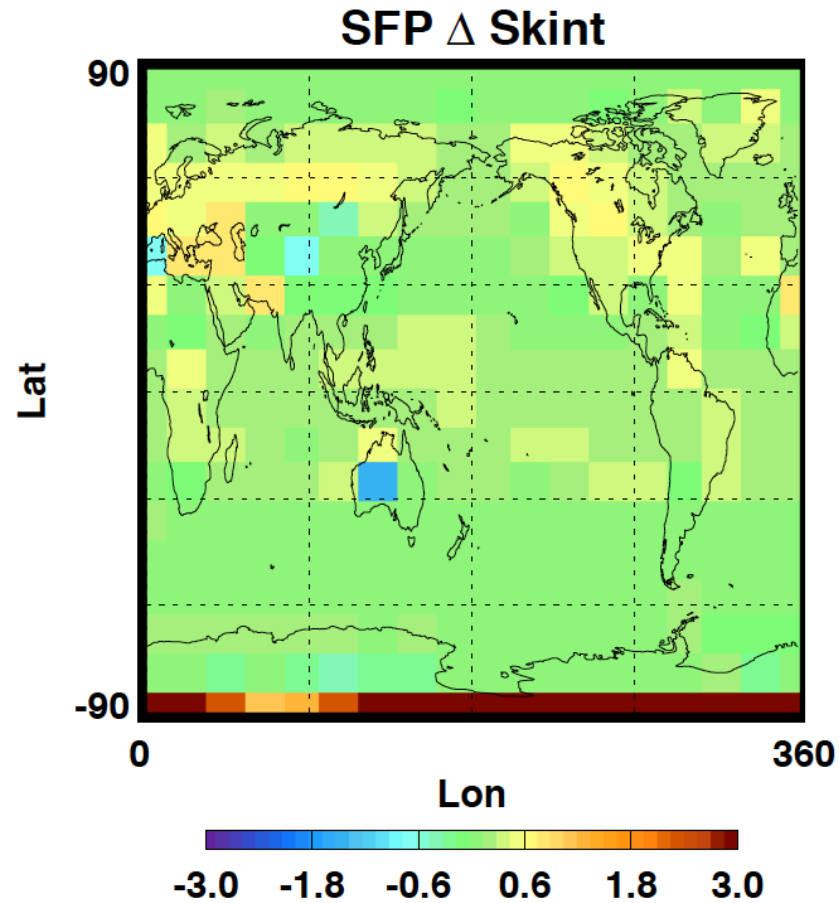


Skin temperature adjustment

Adjustment by Lagrange multiplier



Adjustment by radiance fingerprinting



Land height is not properly handled in the current algorithm

Remaining work for Ed4 EBAF-surface

- LW down irradiance bias correction
  - Use Ed3 – Ed4 SYN difference to correct bias correction derived from C3M
  - Evaluation over polar regions
- Upper tropospheric relative humidity bias correction (vs. use of AIRS spectral irradiance in Lagrange multiplier).
- Comparison of Jacobians (coarse and high temporal resolutions).
- Refinement of the uncertainty used in Lagrange multiplier
- Consistency check with spectral radiance fingerprinting
- Clear-sky fraction weighted average of T, precipitable water, aerosol optical thickness, etc.

Assessment of boundary T and q from GEOS

- Boundary layer temperature and relative humidity comparison by cloud type
  - Shallow cumulus
  - Stratocumulus
  - Stratus
- Consistency check of cloud base height derived from CALIPSO/CloudSat/MODIS and lifting condensation level (LCL) computed from GEOS

Cloud object type definitions

Table 2: Cloud object type and selection criteria. Note that cloud objects are derived using only daytime data. Note also that 440 hPa and 680 hPa pressure levels are approximately 7 km and 3.4 km above the sea level in the tropics, respectively.

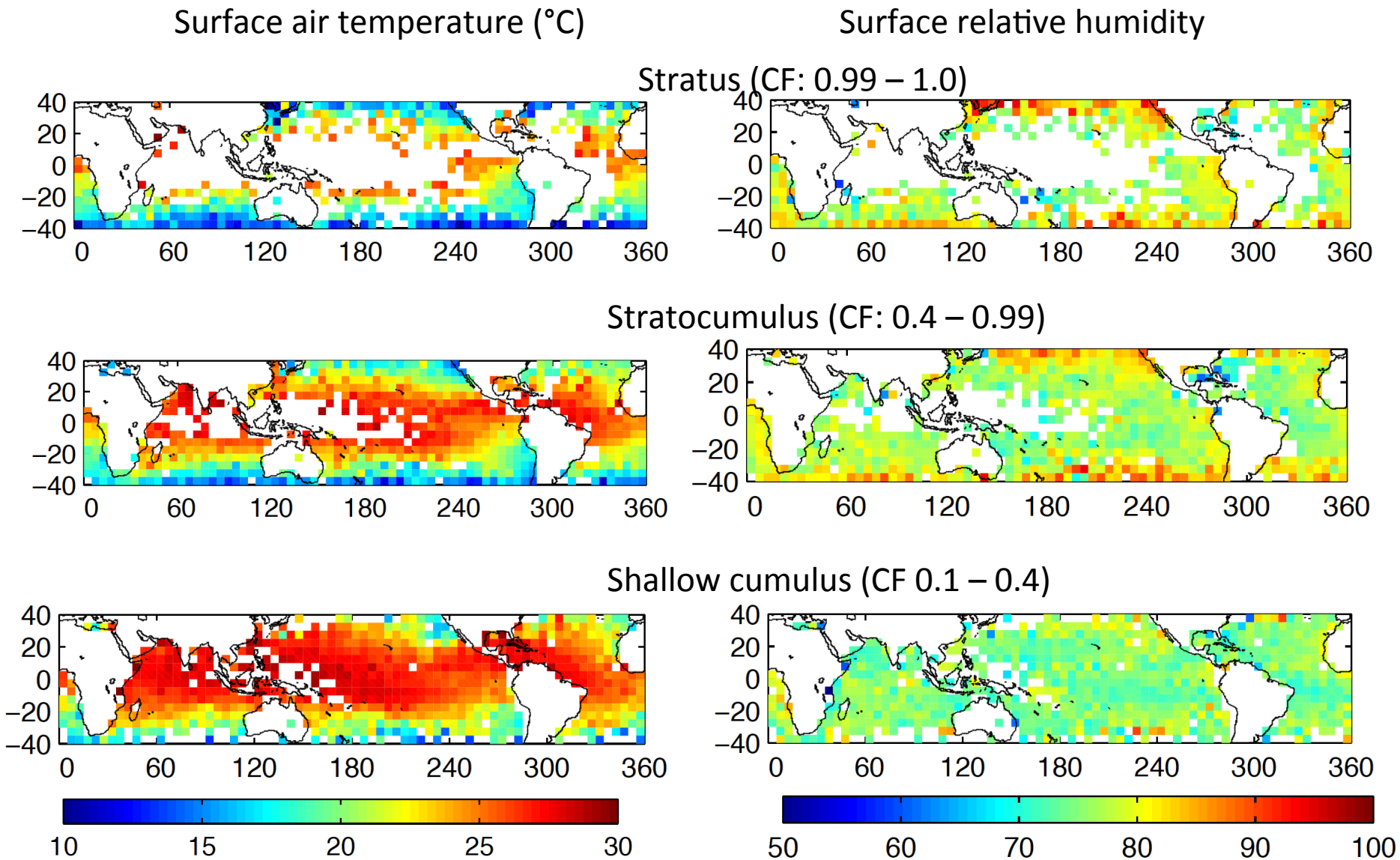
Cloud object type*	Cloud top height	Cloud optical depth	Cloud fraction	Current Latitude band
Tropical deep convection	< 440 (hPa)	> 10	1.0	25°S-25°N
Trade/shallow cumulus	> 680 hPa	—	0.1 – 0.4	40°N-40°S
Transition stratocumulus	> 680 hPa	—	0.4 – 0.99	40°N-40°S
Solid stratus	>680 hPa	—	0.99 – 1.0	40°N-40°S
Altocumulus	440 hPa < h < 680 hPa	—	0.1 – 0.4	40°N-40°S
Transition altocumulus	440 hPa < h < 680 hPa	—	0.4 – 0.99	40°N-40°S
Solid altocumulus	440 hPa < h < 680 hPa	—	0.99 - 1.0	40°N-40°S
Cirrus	< 440hPa	< 10	0.1 – 0.4	40°N-40°S
Cirrocumulus	< 440 hPa	< 10	0.4 – 0.99	40°N-40°S
Cirrostratus	< 440 hPa	< 10	0.99 – 1.0	40°N-40°S

* All cloud object types of given type are grouped into three size categories, 100 km to 150 km, 150 km to 300 km, and greater than 300 km.

Method

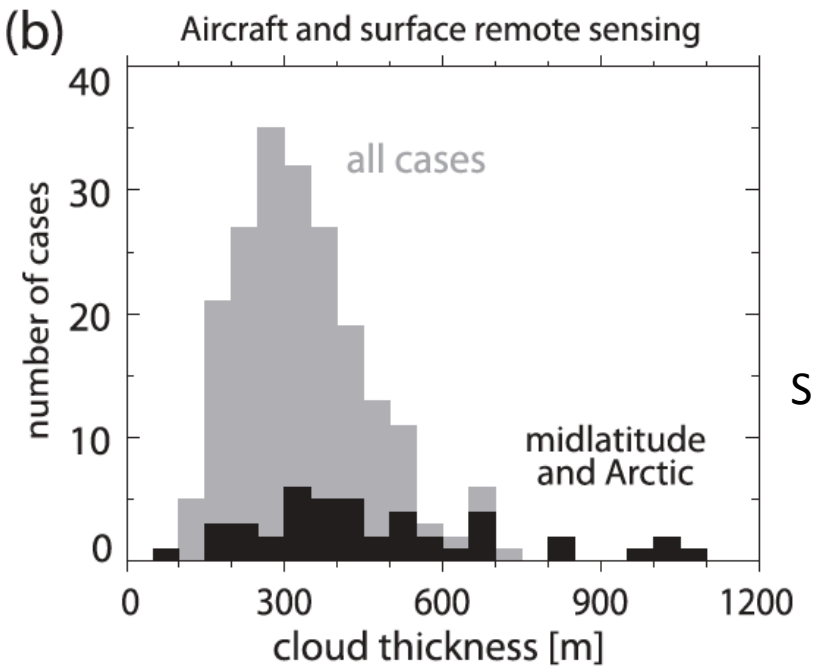
- Use one year (2009) of CALIPSO, CloudSat, MODIS from C3M
- Collocate CALIPSO CloudSat data with cloud objects determined by MODIS
- Subset CALIPSO CloudSat derived cloud properties and GEOS-5.2 temperature and water vapor mixing ratio by cloud object type (daytime only).
- Average temperature, water vapor mixing ratio, and cloud properties in 5°×5° grids.
- 6 hourly temperature and humidity profiles are spatially and temporally interpolated for CERES footprint location and time

Surface temperature and RH



Stratus and stratocumulus thickness

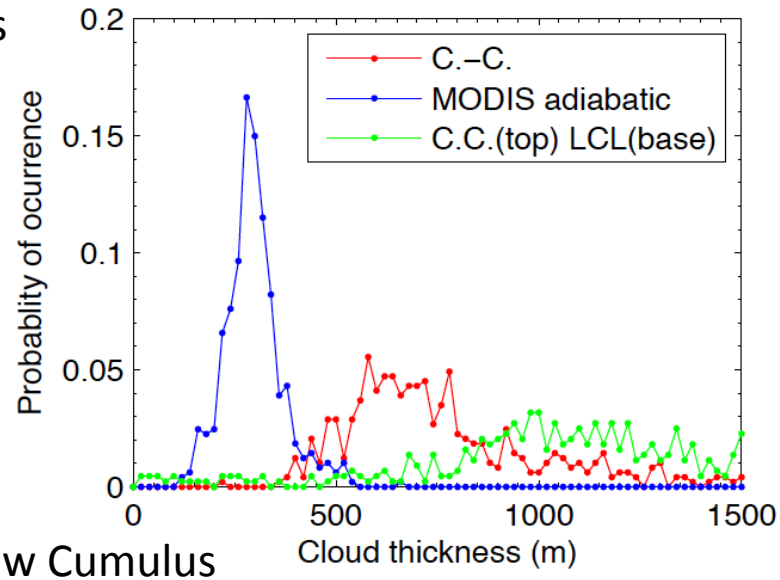
Cloud thickness computed with different cloud base heights.
Top: CALIPSO



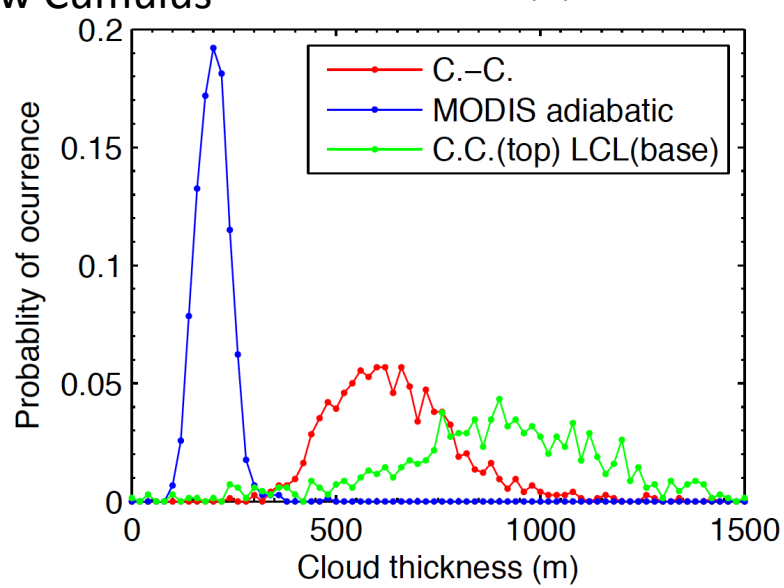
Wood (2012, Monthly Weather Review)

MODIS adiabatic: thickness ≈ SQRT(αLWP)
(i.e. LWC linearly increases with height)

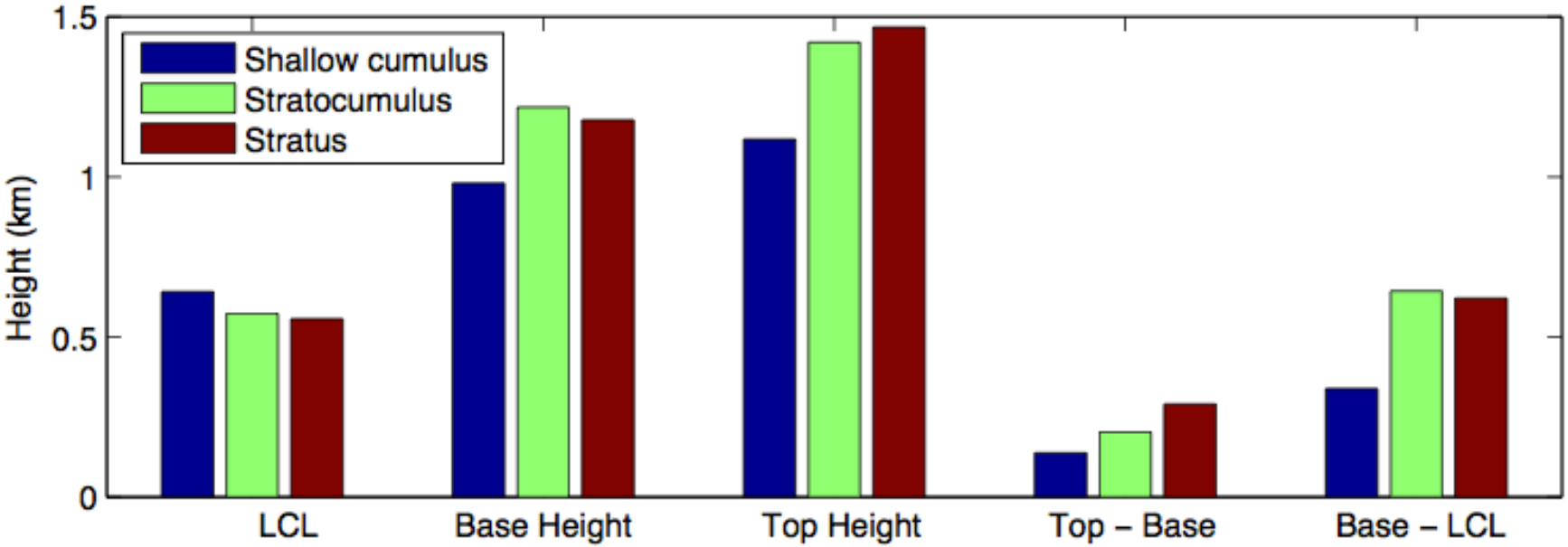
Stratus



Shallow Cumulus



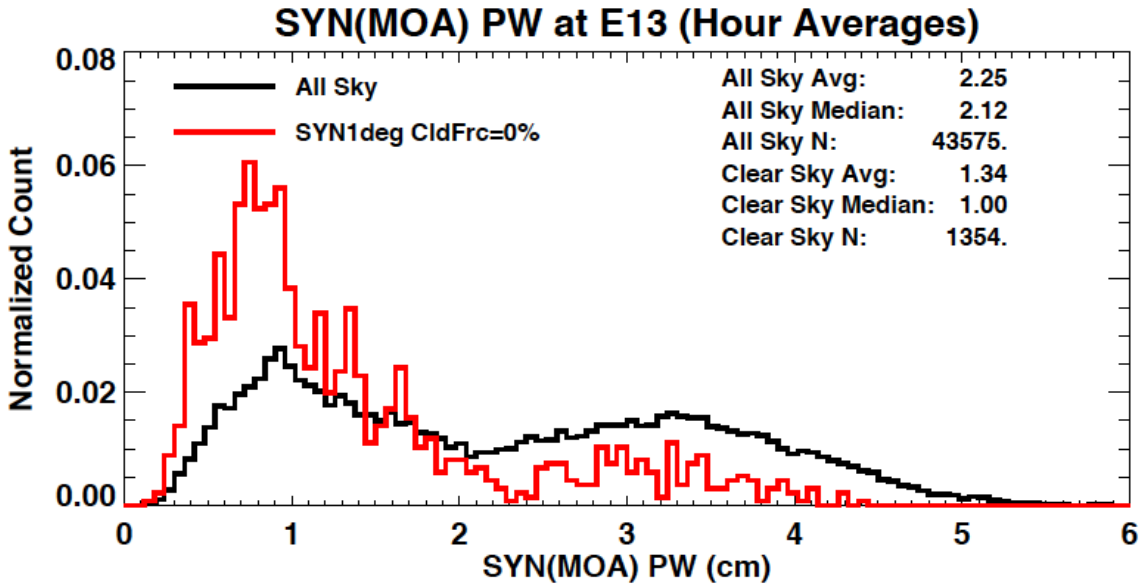
Cloud top and base heights and LCL by cloud type



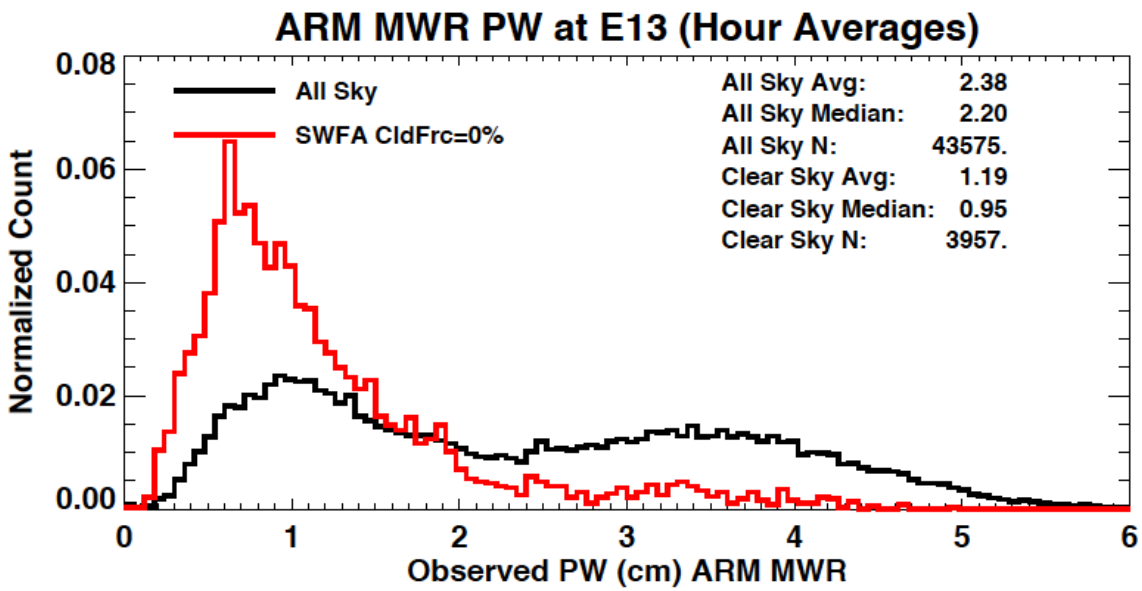
Shallow cumulus: Cloud fraction 0 to 0.4
Stratocumulus: Cloud fraction 0.4 to 0.99
Stratus : Cloud fraction 0.99 to 1.0

Clear-sky vs. all-sky precipitable water over SGP

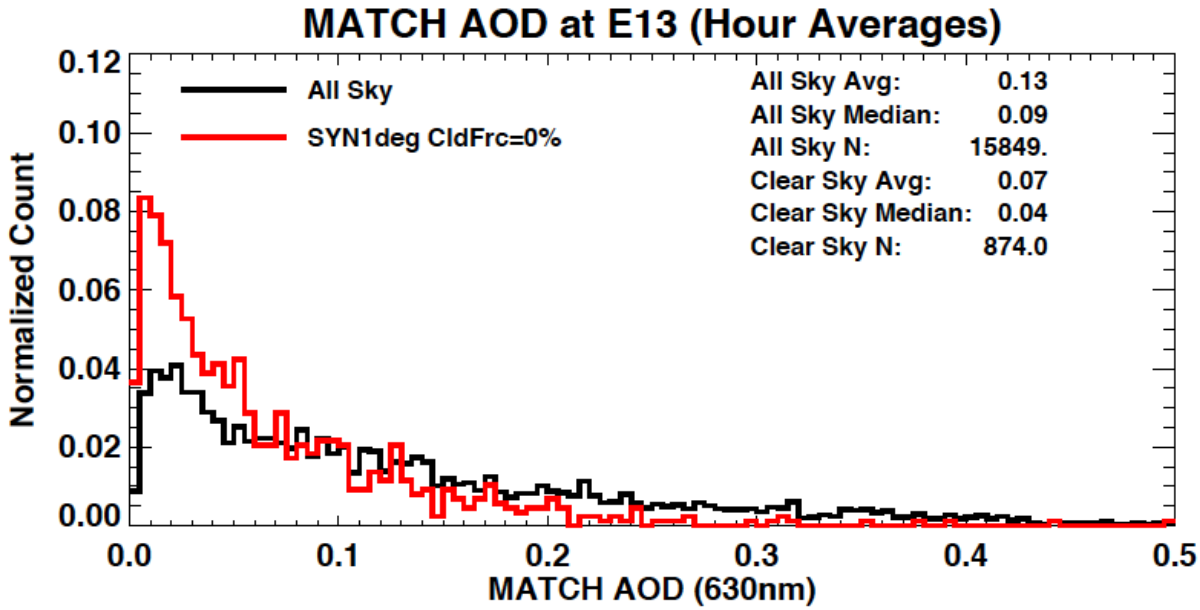
GEOS with MODIS clear-sky ID

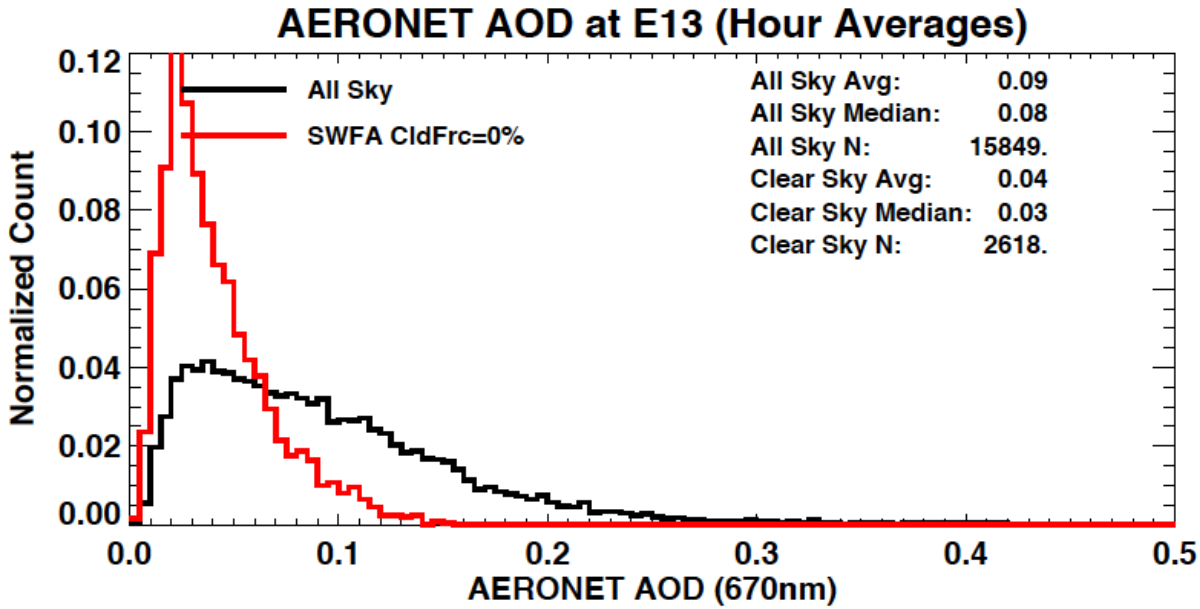


Ground-based microwave radiometer with ground based clear-sky ID



Clear-sky vs. all-sky aerosol tau water





Summary

- Ed4 SW down is smaller and LW down is larger primarily due to larger low-level cloud fraction.
- In general, Ed4 surface irradiances are improved from Ed3 surface irradiance (need to look polar regions more closely).
- Ed4 EBAF-surface development is on schedule.
- GEOS-5.4.1 boundary layer T, and RH over tropics are consistent with low-level cloud types.

Publications

- Ham, S.-H, S. Kato, and F. G. Rose, 2016: Correction of ocean hemispherical spectral reflectivity for longwave irradiance computations, JQSRT, 171, 57-65, http://dx.doi.org/10.1016/j.jqsrt.2015.12.003
- Smith, L. et al. 2016: Arctic Radiation-IceBridge Sea and Ice Experiment (ARISE): the arctic radiant energy system during the critical icen transition, submitted to BAMS
- Kato, S., K. M. Xu, T. Wong, N. G. Loeb, F. G. Rose, K. E. Trenberth, and T. J. Thorsen, 2016: Investigation of the residual in column integrated atmospheric energy balance using cloud objecgts, submitted to J. Climate.

Back-ups

Sea ice albedo

- Derive spectral albedo (shape) for various sea ice types

Notes on the flow diagram

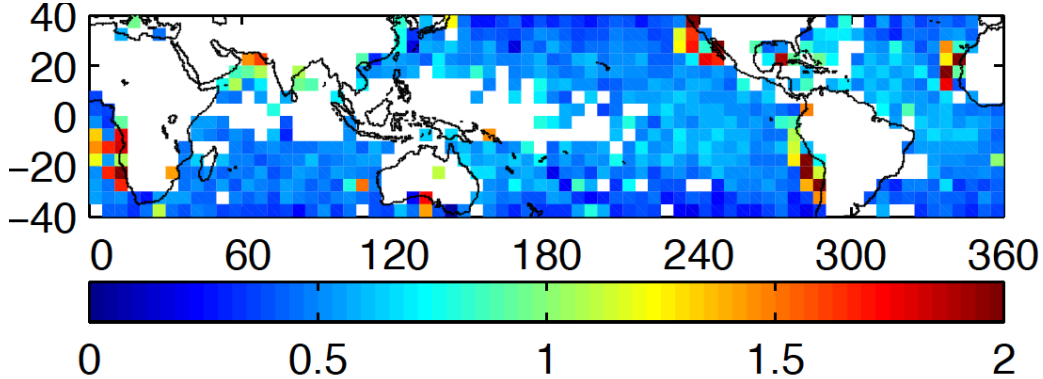
1. All-sky irradiances from Ed4 EBAF-TOA
2. Monthly 1deg by 1deg All-sky untune computed irradiance from Ed4 SYN1deg
3. Spectral IR irradiances derived from collocated CERES and AIRS observations (Huang et al. ??)
4. Surface downward longwave irradiance bias correction is derived for Ed3. But use Ed4 and Ed3 downward longwave irradiance difference to adjust the downward longwave bias correction for Ed4.
5. CALIPSO/CloduSat derived cloud fraction, height and optical thickness are used to determine the uncertainty.
6. Upper tropospheric relative humidity bias correction using Level 3 AIRS data. The bias correction is derived by regressing the difference of UTRH from GEOS (MOA) and AIRS level 3 with the difference of AIRS and SYN1deg spectral irradiances. This process might not be needed because IR spectral irradiance is directly used in 3.
7. AIRS level 3 data are used to determine the uncertainty in skin temperature, air temperature, and humidity.
8. Retrieval of skin temperature, air temperature, and water vapor mixing ratio biases in GEOS using IR spectral radiance difference between computed with GEOS thermodynamic variables and CALIPSO/CloudSat clouds (C3M) and observed nadir view AIRS spectral radiances.
9. Consistency check between skin temperature, air temperature, and humidity adjustments and those derived from process 8.

SARB accomplishments since April 2015

- Delivered Ed4 SYN code (Oct. 2015) and made initial evaluation of Ed4 SYN
- Assessed the effect of the surface emissivity on the surface longwave irradiance
  - Ham, S.-H, S. Kato, and F. G. Rose, 2016:, *JQSRT*, 171, 57-65, http://dx.doi.org/10.1016/j.jqsrt.2015.12.003
- Assessed regional surface energy balance residual and submitetd a paper
  - Kato, S., K. M. Xu, T. Wong, N. G. Loeb, F. G. Rose, K. E. Trenberth, and T. J. Thorsen, 2016: submitted to *J. Climate*.
- Contributed to Australian surface energy budget analysis
  - Loeb, N. G, H. Wang, L. Liang, S. Kato, F. G. Rose, 2016; *Int. J. Climatology*, in press.
- Contributed to U.S. CLIVAR eastern tropical oceans synthesis working group white paper and its BAMS paper led by P. Zuidema
- Published a paper on the use of CERES data for climate research
  - Kato, S., N. G. Loeb, D. A. Rutan, and F. G. Rose, 2016; *J. Meteorol. Soc. Japan*, DOI:10.2151/jmsj.2015-048.
- Evaluated Ed3 SYN1deg surface irradiances with surface gourbnd sites, buoys and ship observations
- Evaluated multi-layer cloud retrieval with CALIPSO/CloduSat data
- Started analyzing ARISE data and cobtributed to the ARISE BAMS paper
  - Smith, W. L. and co-authors, 2016: submitted to BAMS.
- Made plan for the revision of C3M
- Produced Ed2.8 EBAF-surface through June 2015
- Made progress on Ed4 EBAF-surface
- Presented results of CERES data analyses at a Gordon conference, an AGU fall meeting, a CLIVAR workshop, and a radiation science workshop.

Cloud base vs. LCL

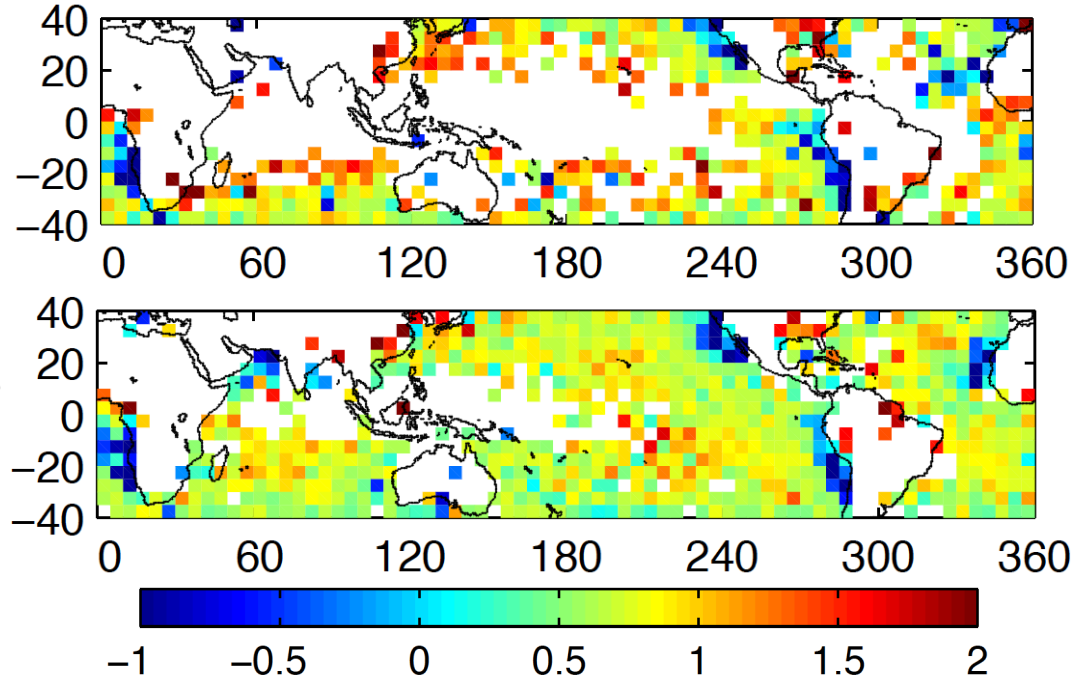
Lifting condensation level computed with GEOS5.2 surface, T, w, and p when stratocumulus are present



Distance between LCL and cloud base derived from MODIS LWP with adiabatic assumption in km

Stratus

Stratocumulus

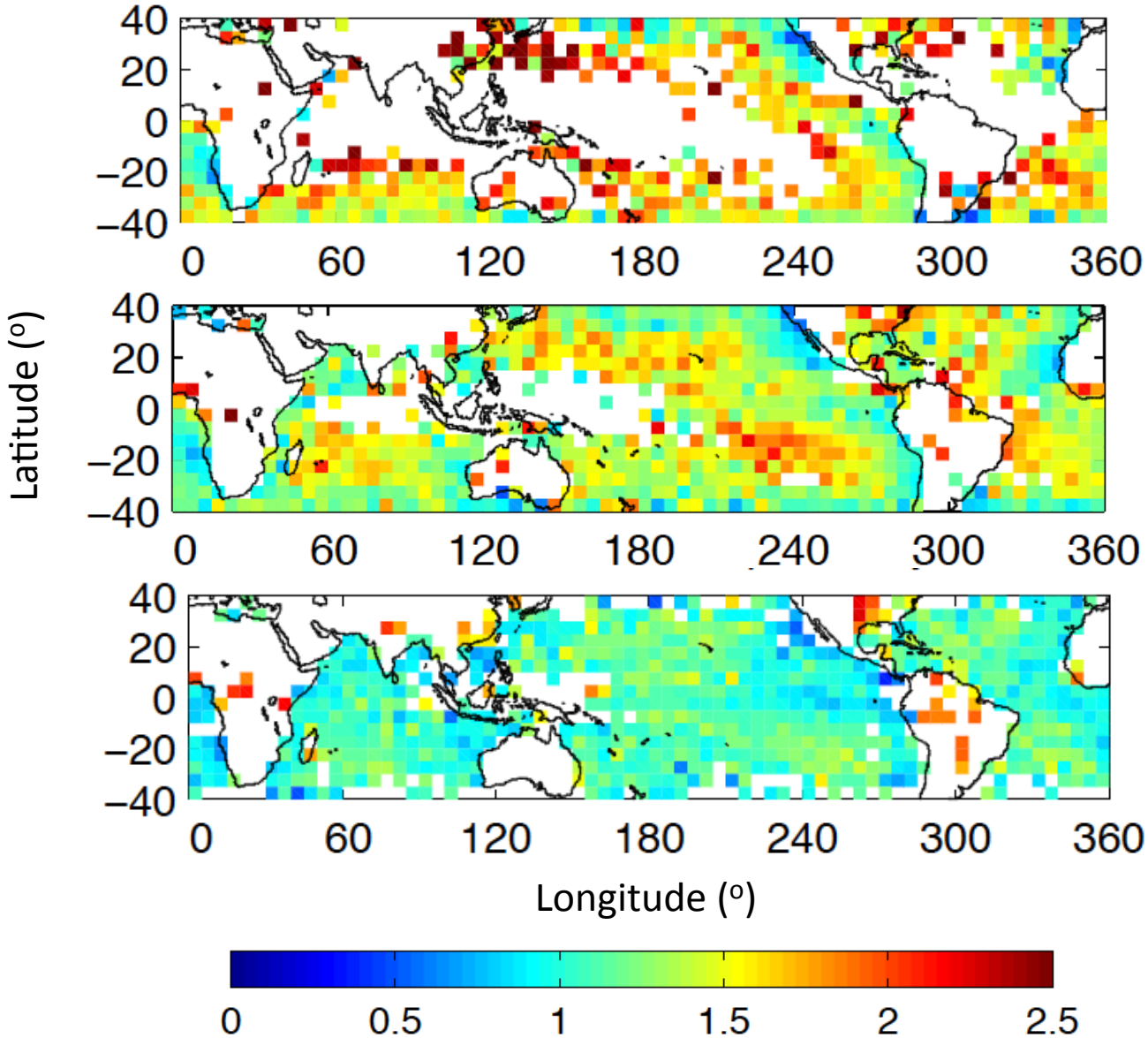


Ed4 Validation plots (monthly)

File name	Plot description	Notes
Syni.ed4-ed3.*.v3.Apr22.pdf	comparison with Ed3	
CER_TSI_SYNI_ABS.ed4.*.v3.*.pdf	TOA flux comparison separated by Terra, Aqua, and GEO	
Syni_Tsi.*.stats_by_sat.*.pdf Barplt.4seasonal.pdf	OLR comparison by MODIS and GEO	
Zonal_geo_modis_cloud.*.pdf	GEO cloud fraction vs. MODIS cloud fraction	Need special TSI and not for all months
Bylayer.v4.pdf	Cloud overlap	Not for all months
SW-sfc-dn.*.pdf, LW-sfc-dn.*.pdf	Surface validation of hourly irradiancs	
Skint_check.*.pdf, olr_check.*.pdf	Monthly time series of skin temperature and OLR for a grid	Only for grids with problems
lw.dc.LND.pdf, sw.dc.LND.pdf, lw.dc.OCN.pdf, sw.dc.OCN.pdf	Monthly mean diurnal cycle comparison	

These plots will be made separate from internal subsetter

Single layer cloud top height (km)



Stratus
CF 0.99 – 1.0

Stratocumulus
CF 0.4 – 0.99

Shallow cumulus
CF 0.1 – 0.4