Surface Atmosphere Radiation Budget (SARB) working group update

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CERES Science team meeting

October 18-21, 2016

Reading, UK

SARB update outline

- Surface Atmosphere Radiation Budget working group
  - Surface irradiance in SYN1deg
  - EBAF-surface
  - C3M (CALIPSO CloudSat CERES MODIS) atmospheric hearting rate
- Work done after last meeting
- Changes in Ed4 SYN1deg from Ed3 SYN1deg
- Ed4 SYN time series (from 07 2002 through 12 2014)
- Polar, land, ocean surface irradiance validation
- Surface irradiance uncertainty estimate

Work done after the last CERES science team meeting

- Development of Ed 4 EBAF-surface
- Evaluation of Ed4 SYN1deg
  - Ship data
  - Ice buoys
- Plan for C3M revision
- Sea ice spectral surface albedo derived from ARISE
- Comparison between Ed4 MATCH and MERRA2 aerosol optical thicknesses
- NPP SYN
  - plan to test transition from Terra/Aqua SYN to NPP SYN (waiting for NPP TSI).
- Plan for parallelizing SYNI code

Ed4 SYN1deg

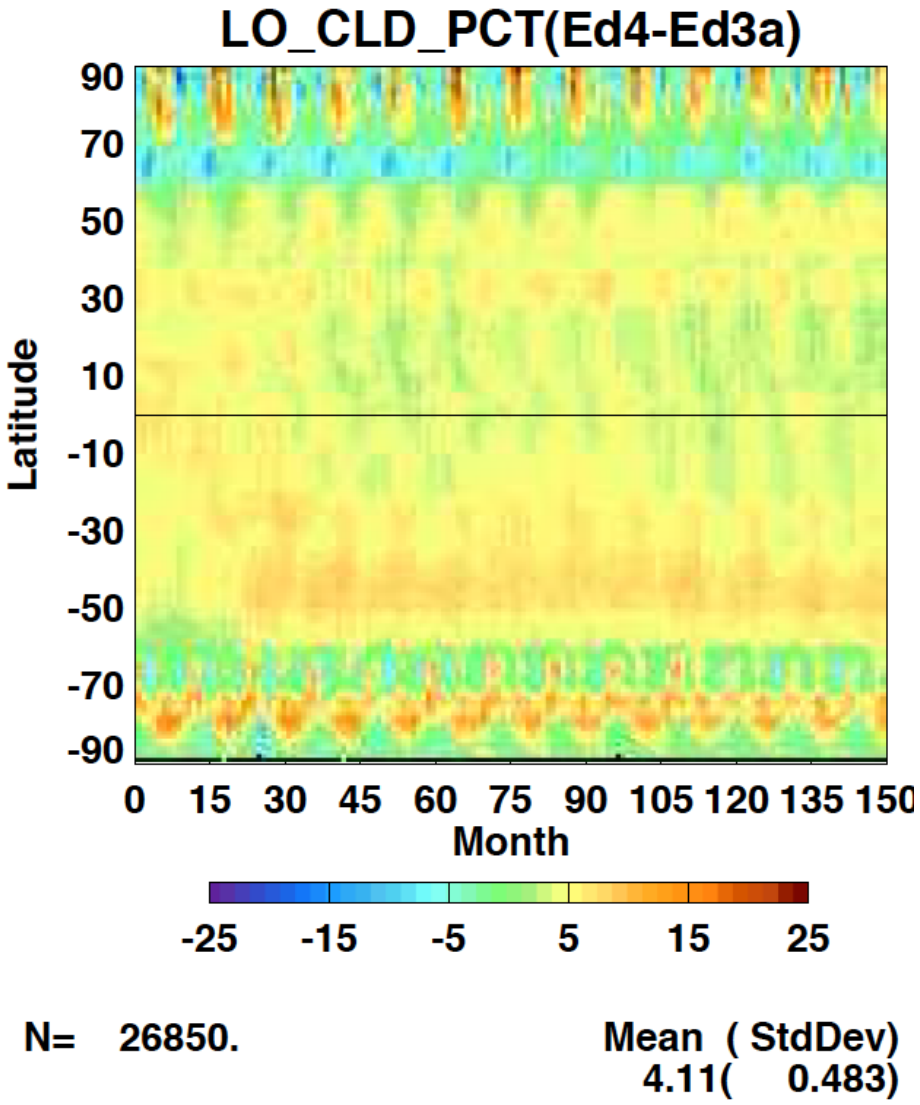
Ed3 and Ed4 Global annual mean comparison (mean from 200207 through 201214)

	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 All-sky (clear-sky)	101.1 (51.4)	238.0 (262.4)	184.0 (242.6)	22.5 (28.4)	347.1 (317.6)	397.8 (397.1)
Ed3 All-sky (clear-sky)	98.7 (52.8)	237.0 (262.2)	187.9 (242.3)	23.3 (28.7)	341.9 (315.8)	397.7 (397.1)
Obs. Ed4 All-sky (clear-sky)	97.9 (50.1)	238.6 (268.0)	-	-	-	-
Obs. Ed3 All-sky (clear-sky)	97.6 (50.4)	238.8 (265.8)	-	-	-	-

Clear-sky irradiances are computed by removing clouds
Observed clear-sky are from clear-sky scenes only
Surface net irradiance is changes from 108.8 Wm^{-2} with Ed3 to 110.8 Wm^{-2} with Ed4

Ed4 and Ed3 global annual mean cloud cover

	Ed 4	Ed3	Ed4 – Ed3
Total	66.6	60.9	5.7
High (<300 hPa)	8.2	9.6	-1.4
Mid-high (500-300 hPa)	16.0	14.7	1.3
Mid-low (700-500 hPa)	11.6	9.6	2.0
Low (Sfc-700 hPa)	31.1	27.0	4.1



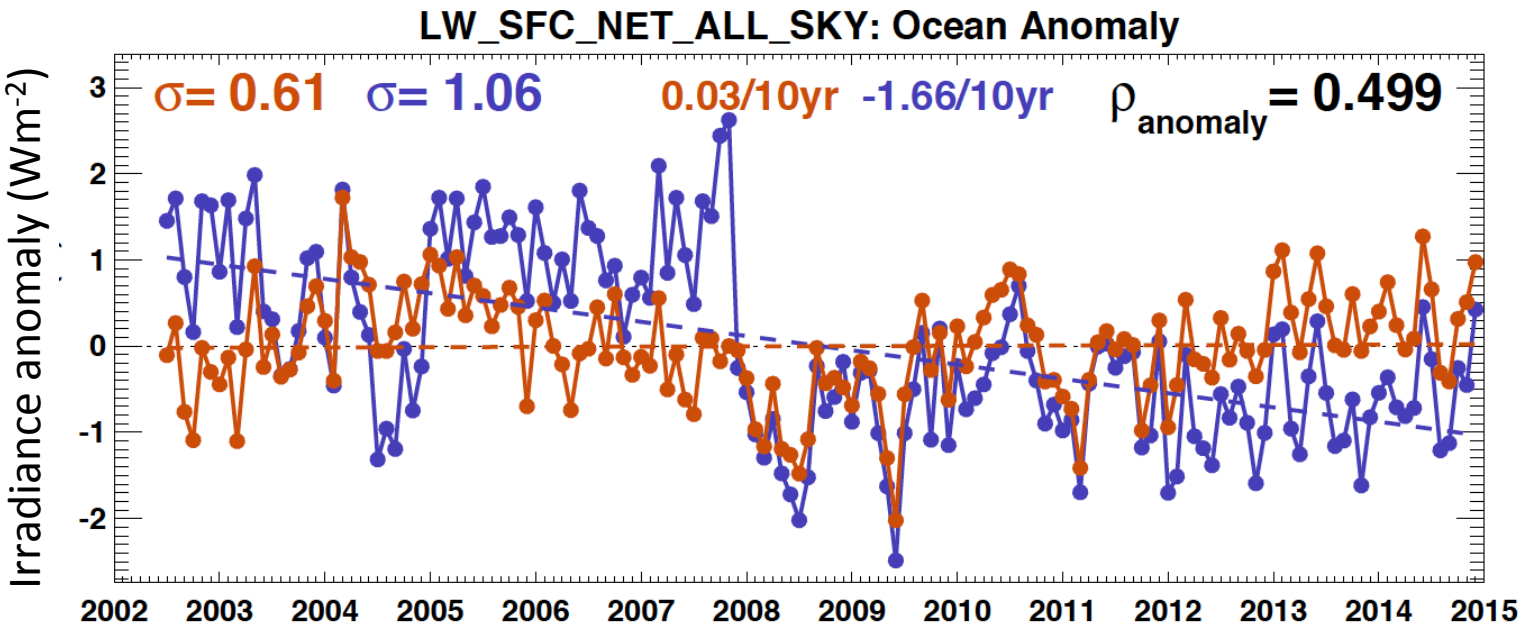
Low-level clouds are increased at almost all latitudes

Ed4 SYN main differences from Ed3 SYN

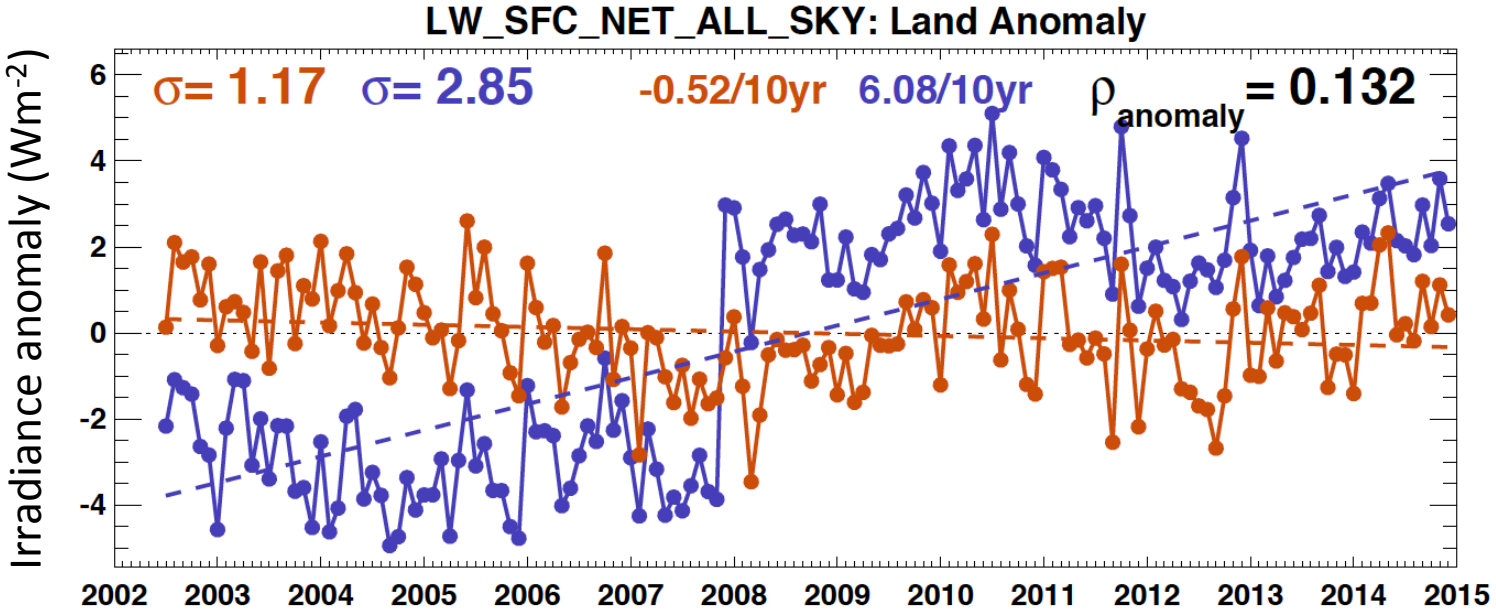
- Generally, Ed4 has more clouds than Ed3 especially low-level clouds
  - Global mean all-sky surface downward shortwave is decreased by 3.9 Wm^{-2}
- Cloud overlap treatment in Ed4 further increasing surface downward longwave irradiance
  - Global mean all-sky surface downward longwave is increased by 5.2 Wm^{-2}
- Boundary layer temperature is generally higher in Ed4 than in Ed3
  - Global mean clear-sky surface downward longwave is increased by 1.8 Wm^{-2}

Trend in net LW, ocean and land

Red: Ed4
Blue: Ed3



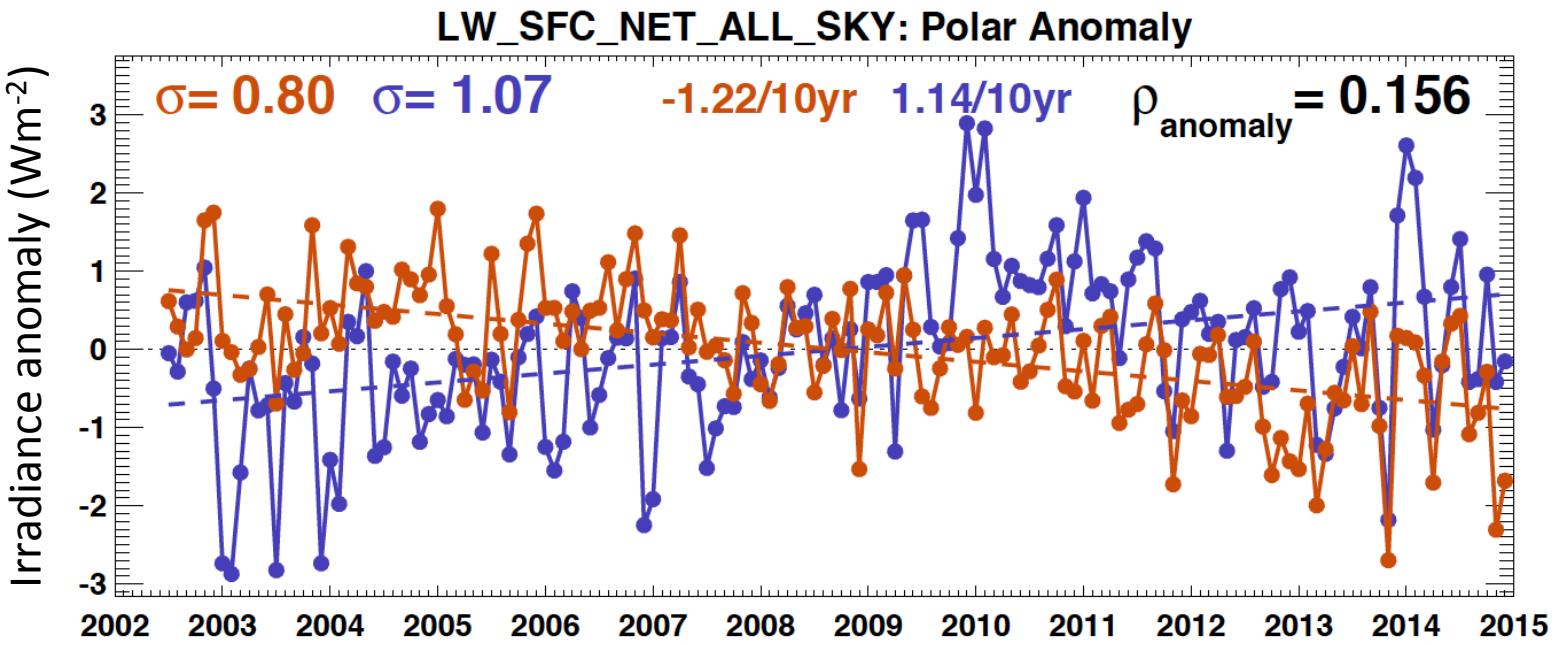
Discontinuity introduced by GEOS (reanalysis) switch at the end of 2007 in Ed3 are eliminated in Ed4

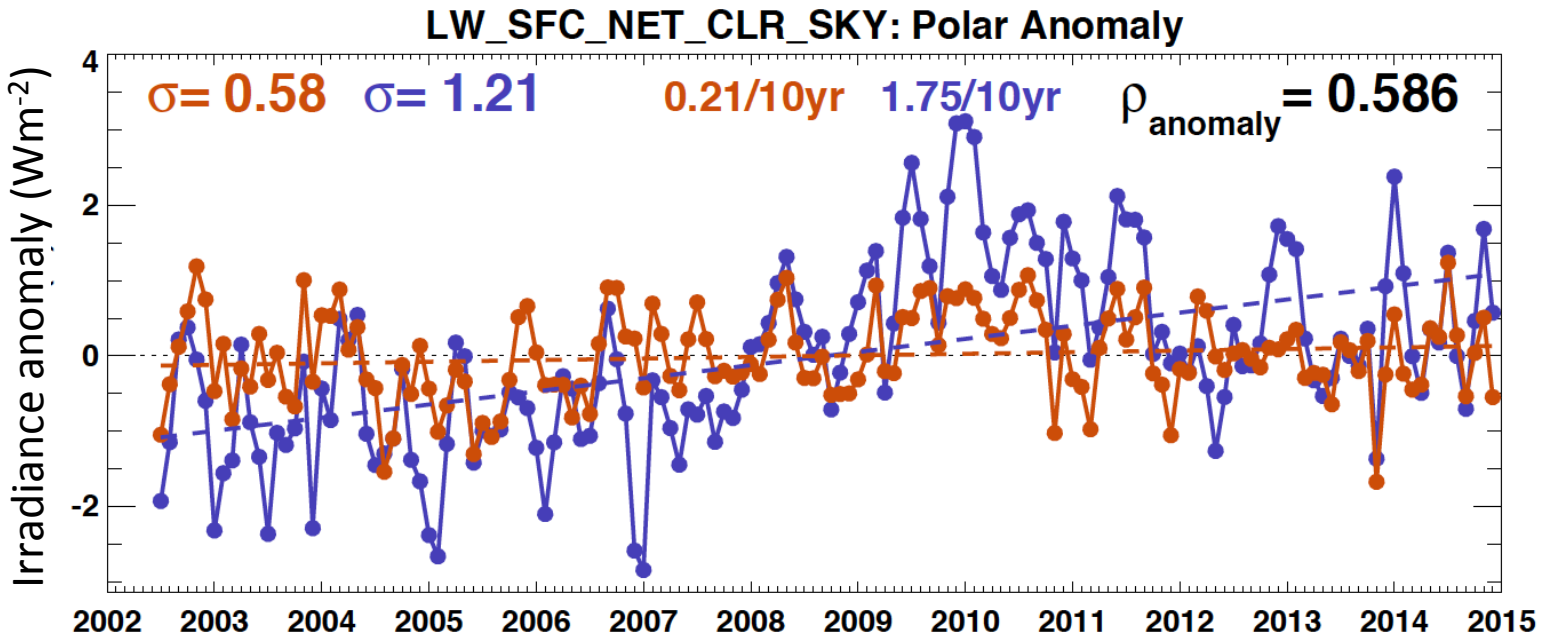


Trend in surface net LW net, polar

Red: Ed4
Blue: Ed3

Apparent shift from negative anomalies before 2008 to positive anomalies after 2008 is not present in Ed4

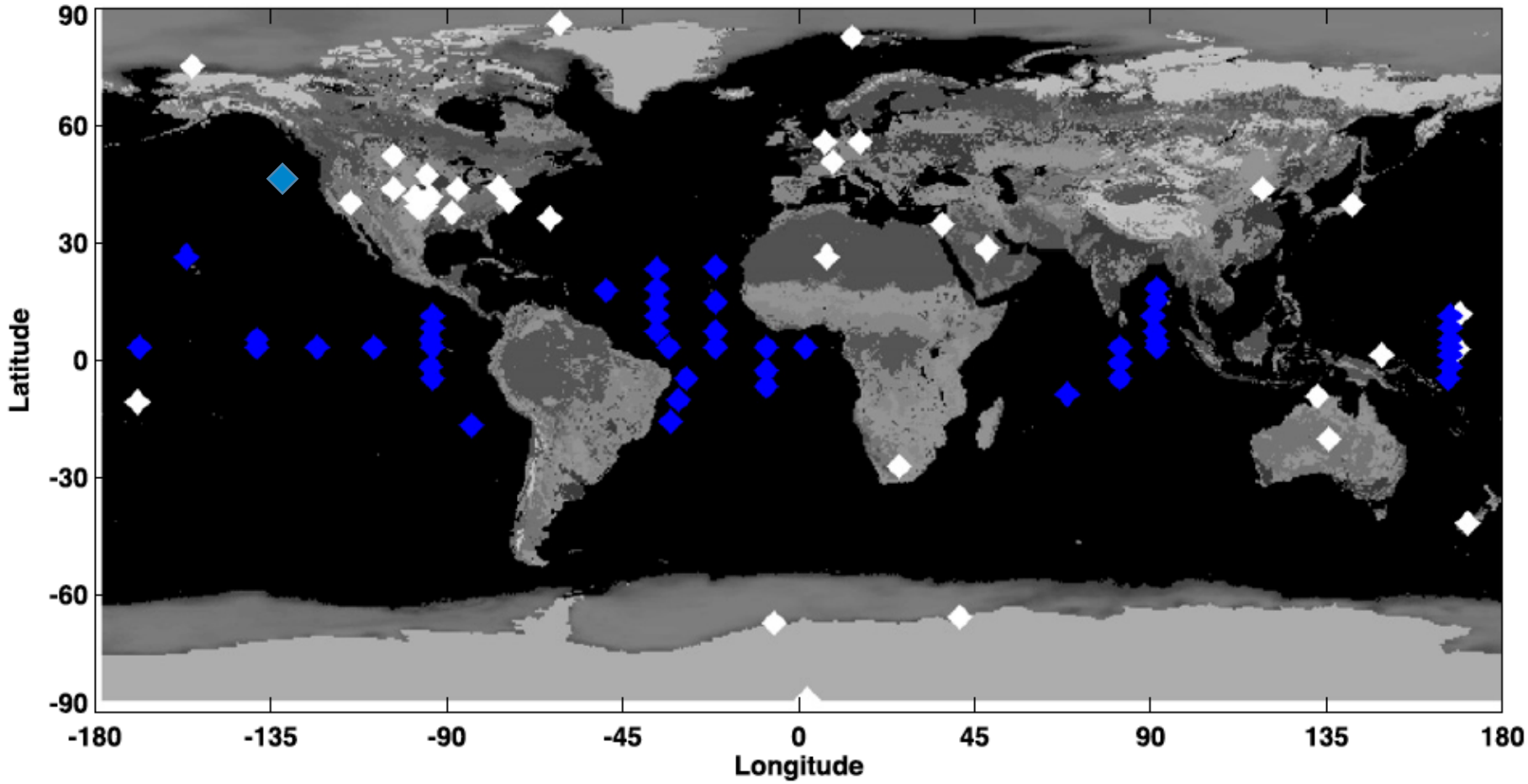




Surface irradiance uncertainty

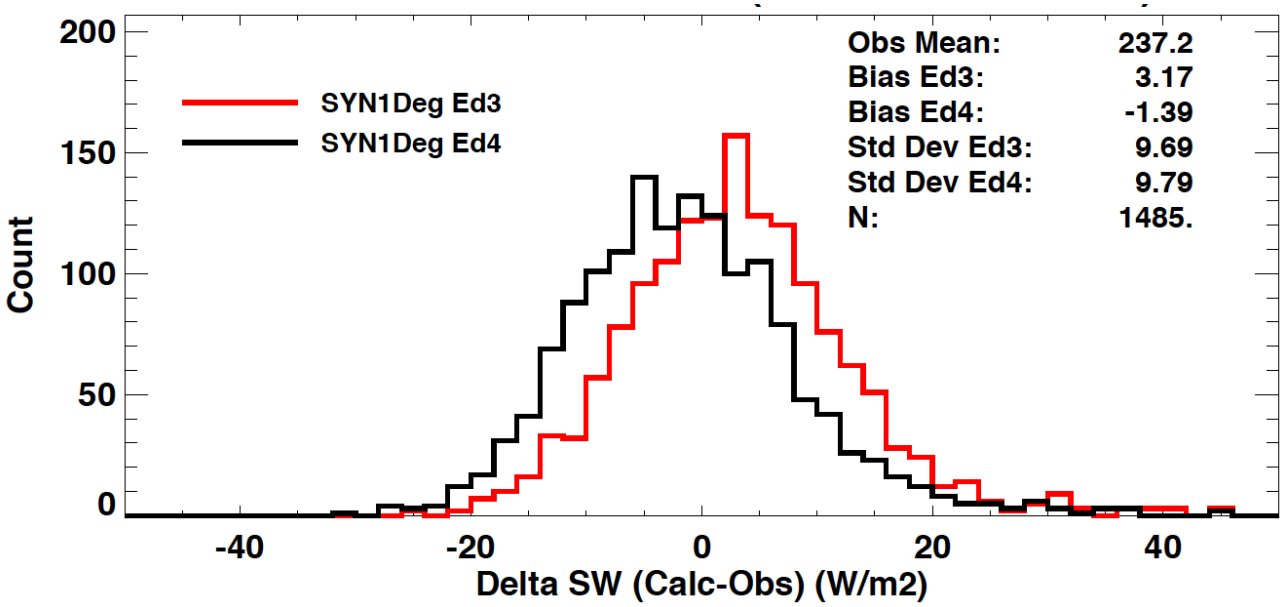
- Uncertainty in surface irradiances for different temporal and spatial scale is published in Kato et al. (2013 *J. Climate*)
- If we estimate the uncertainty in all inputs used for irradiance computations and perturb individually, compute corresponding surface irradiance change, sum-up all changes, resulting irradiance change is almost always larger than the RMS difference between computed and observed downward surface irradiances
- Instead of taking into correlations among all input variables, we used selected inputs that affect the surface irradiance most (e.g. cloud fraction, T and Q) to estimate the uncertainty in the surface irradiance
- Resulting uncertainty tends to agree with the RMS difference between computed and observed downward surface irradiances.

Ed4 SYN surface validation

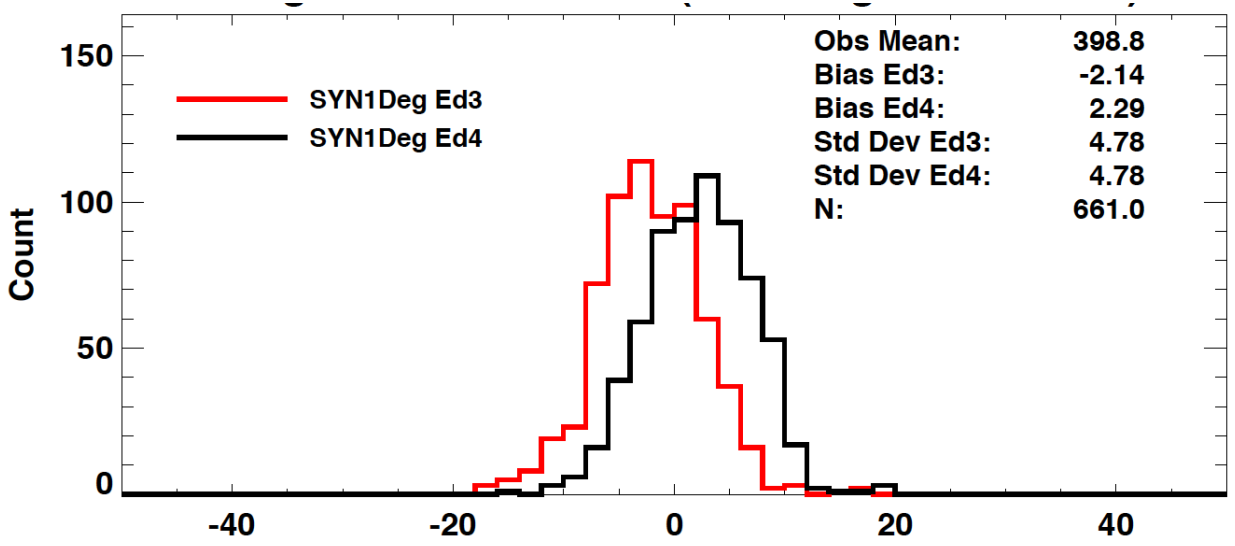


Comparison with ocean buoy data (tropical ocean)

Downward shortwave



Downward Longwave



Downward SW and LW uncertainty in Wm^{-2}

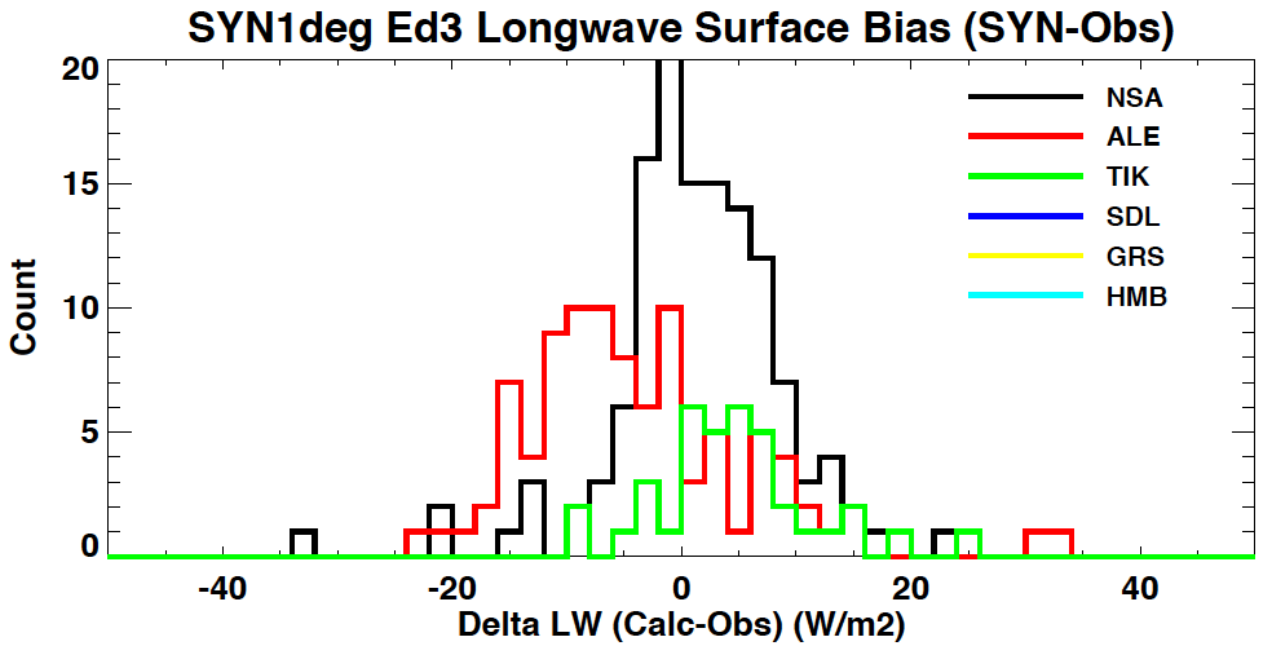
		Estimated uncertainty	Surface validation			
	Mean value	Monthly gridded	Mean value	RMS	Mean ratio	Mean ratio × RMS
Ocean						
Longwave	354	12	399	5.3	0.89	4.7
Shortwave	190	9	237	9.9	0.80	7.9
Land						
Longwave	329	17	316	10.0	1.04	10.4
Shortwave	203	12	184	11.5	1.10	12.7

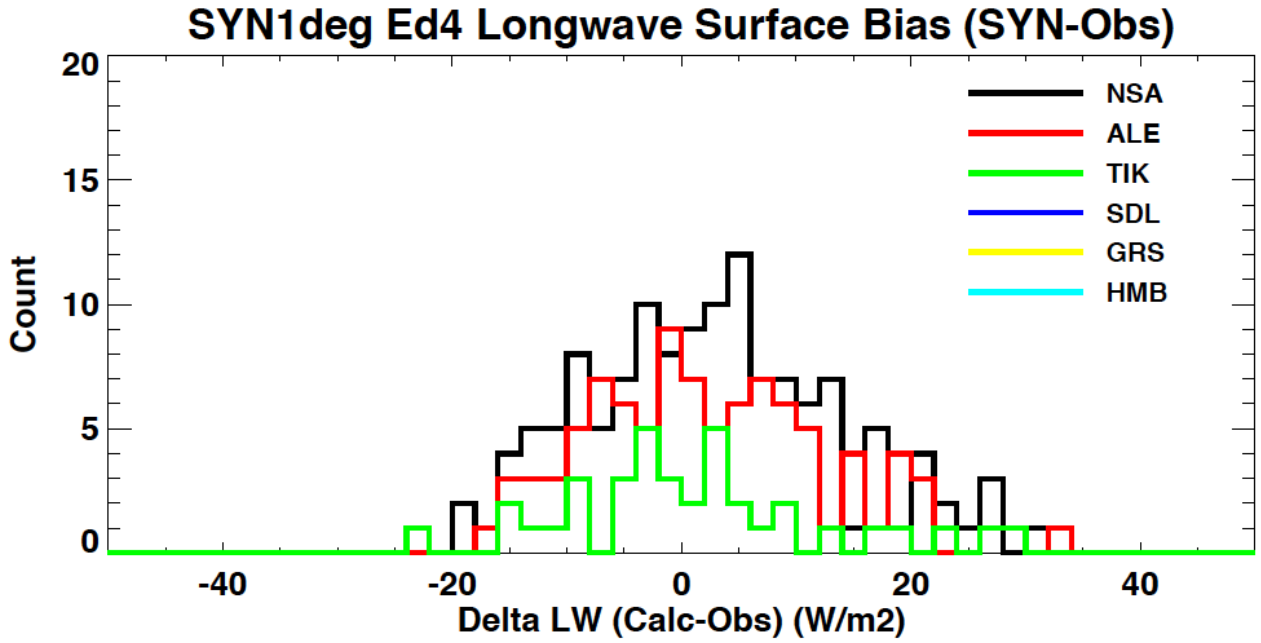
Estimated uncertainty given in Kato et al. (2013) is larger or close to the RMS difference

Uncertainty in downward surface irradiance over polar regions

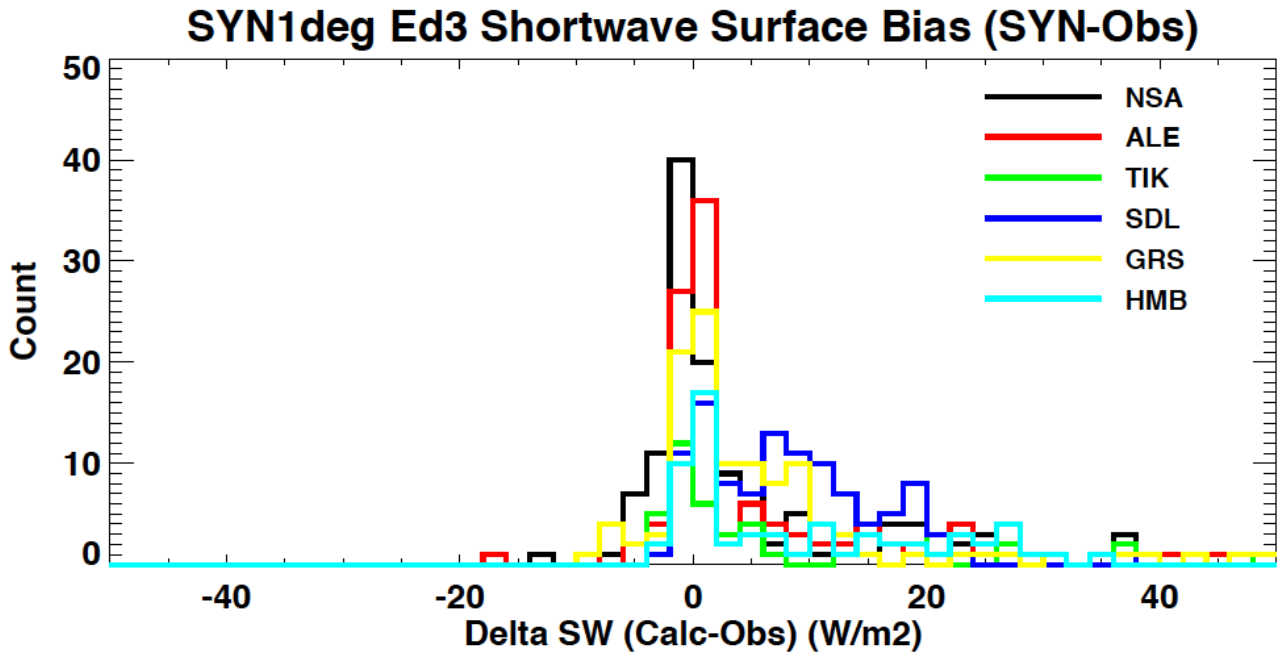
Arctic LW

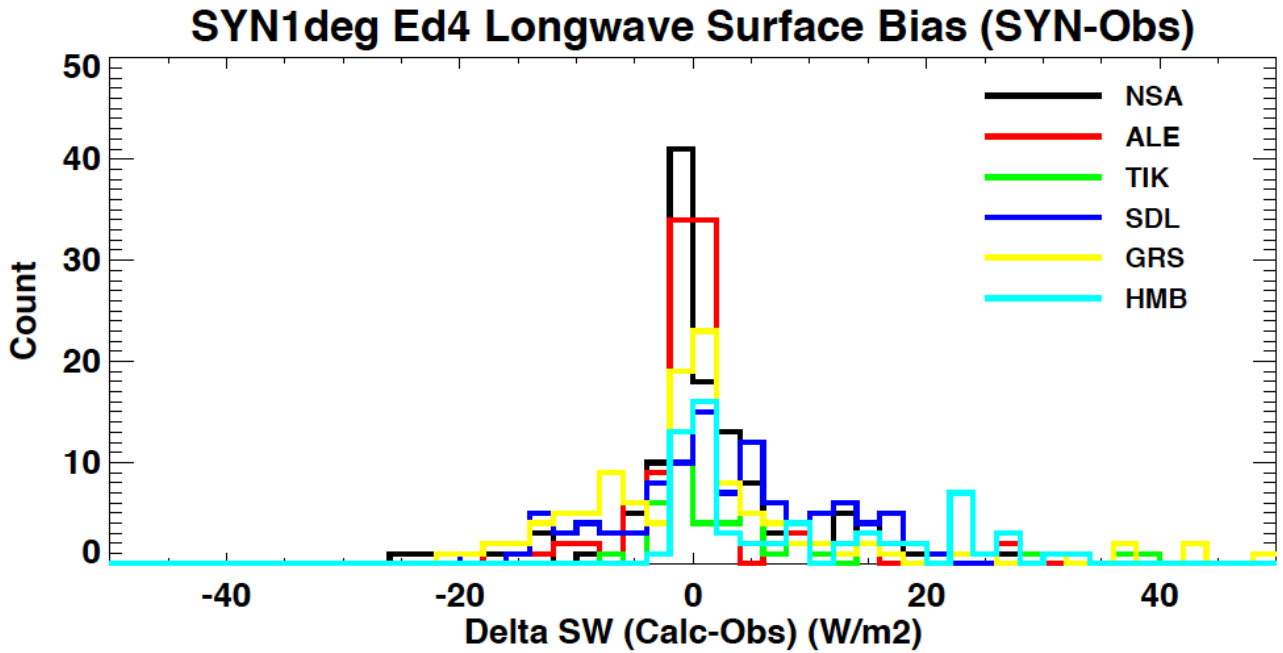
Distribution is less dependent on site with Ed4





Arctic SW


SYN1deg Ed3 Shortwave Surface Bias (SYN-Obs)
Count
Delta SW (Calc-Obs) (W/m2)
NSA
ALE
TIK
SDL
GRS
HMB
50
40
30
20
10
0
-40
-20
0
20
40


SYN1deg Ed4 Longwave Surface Bias (SYN-Obs)
Count
Delta SW (Calc-Obs) (W/m2)
NSA
ALE
TIK
SDL
GRS
HMB
50
40
30
20
10
0
-40
-20
0
20
40

Uncertainty estimate (monthly gridded)

	Non-polar	Arctic RMS (mean)	Greenland RMS (mean)	Antarctica RMS (mean)
Downward longwave (Wm^{-2})	14 (345)	22 (241)	----	13 (167)
Downward shortwave (Wm^{-2})	10 (192)	12 (116)	12 (135)	21 (136)

Ed4 RMS difference is used for the uncertainty

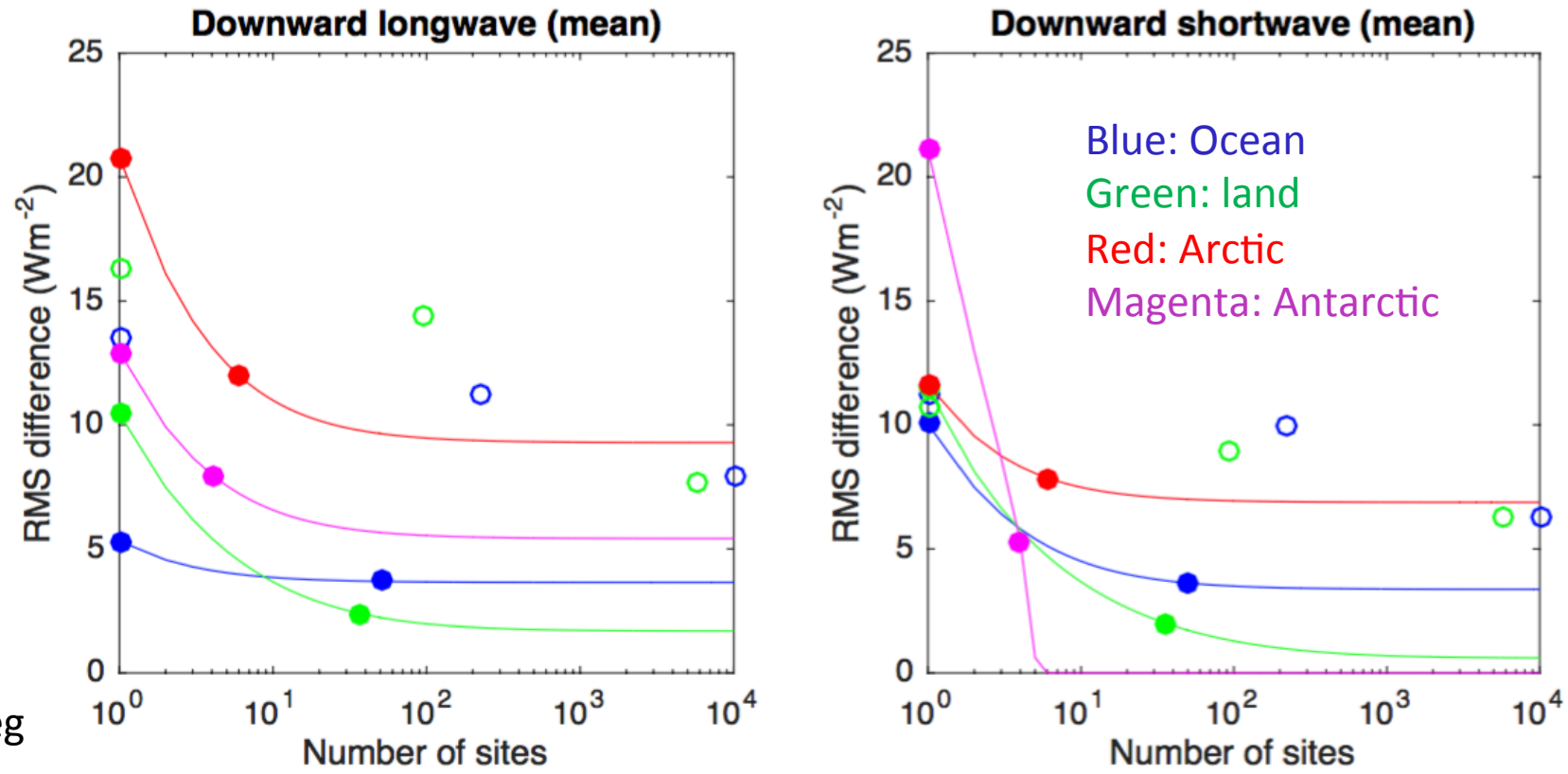
Uncertainty at different spatial scales can be estimated by computing the RMS difference of computed and observed irradiances averaged over all sites

Uncertainty in monthly regional mean irradiances

Assumption:
$RMS^2 = bias^2 + random^2/N$

N: number of surface sites

Uncertainties given by Kato et al (2013) are shown by open circles



Regional: 60 deg-90 deg

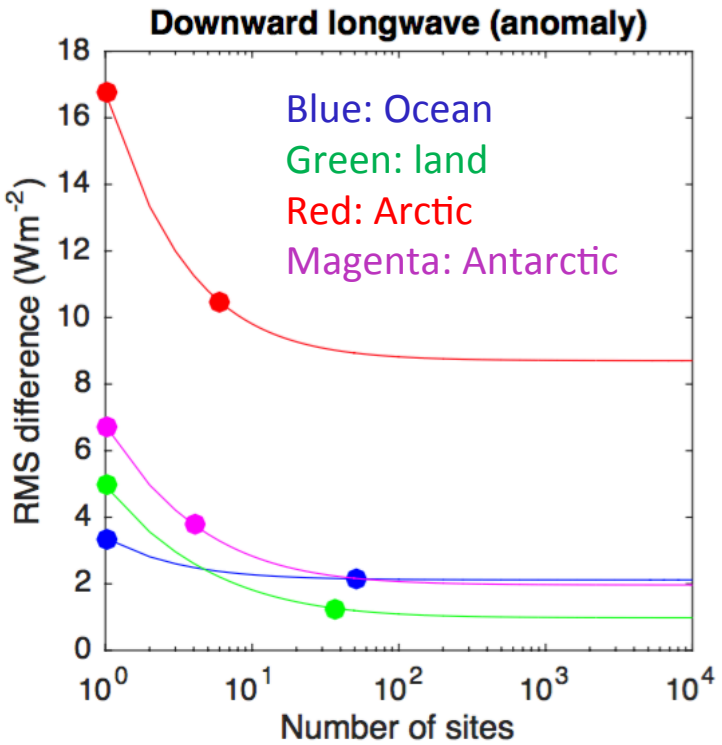
	Downward Longwave				Downward Shortwave			
	Ocean	Land	Arctic	Antarctic	Ocean	Land	Arctic	Antarctic
Monthly gridded (Wm^{-2})	12	17	21 (232*)	13 (166*)	9	12	12 (113*)	21 (166*)
Monthly zonal (Wm^{-2})	10	15			8	10		
Monthly regional (Wm^{-2})			9	5			7	-----
Monthly global (Wm^{-2})	7	8			5	7		

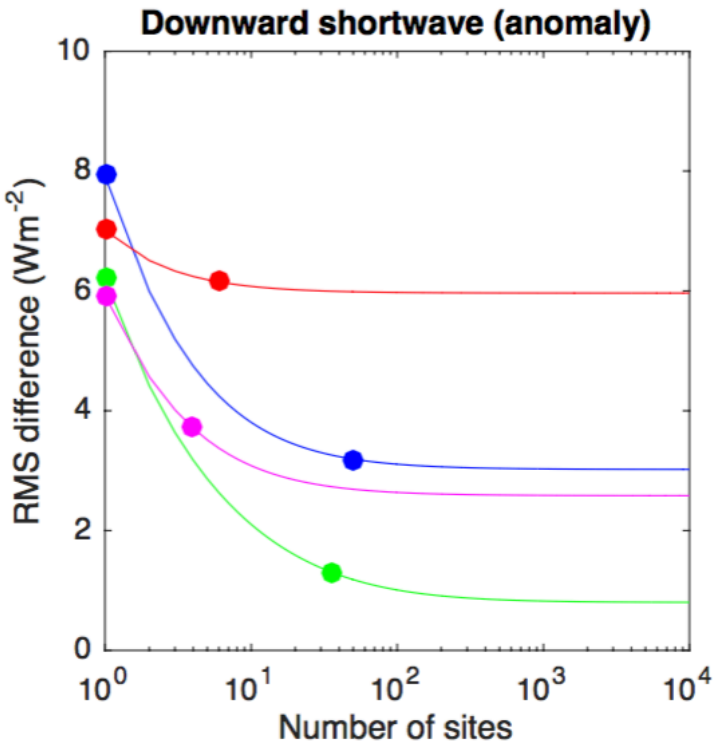
* mean

Uncertainty in anomalies

- First RMS difference
  1. Compute desesonalized monthly anomalies for each sites.
  2. Compute the RMS difference between computed and observed monthly anomalies
- Second RMS difference
  1. Average irradiances over all sites within a group (ocean, land, Arctic, and Antarctic)
  2. Compute the deseasonalized anomalies for each gorup
  3. Compute the RMS difference between computed and observed monthly anomalies

Uncertainty in monthly regional irradiance anomalies





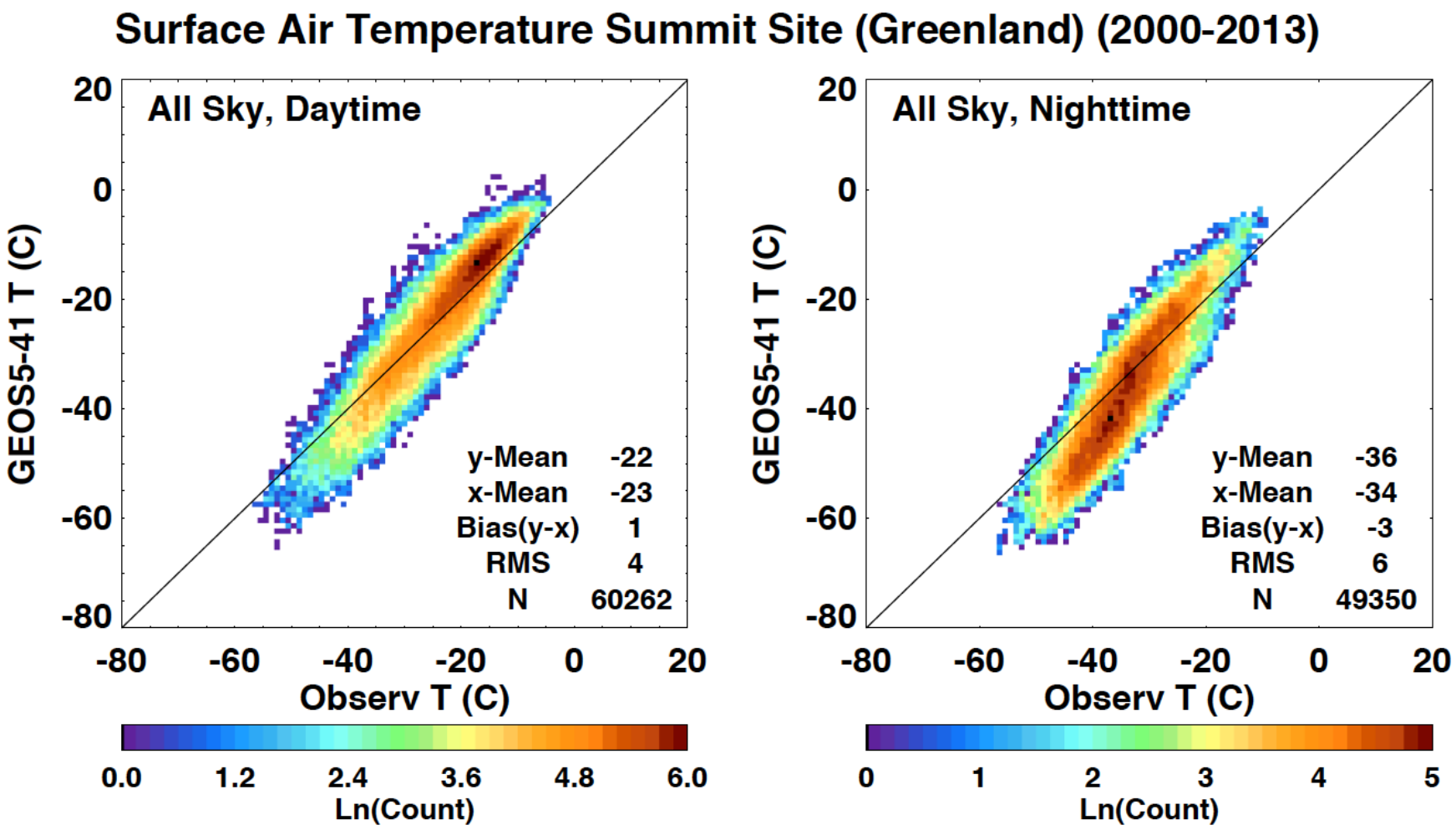
The reason for a larger RMS for the Arctic is unknown

	Downward Longwave				Downward Shortwave			
	Ocean	Land	Arctic	Antarctic	Ocean	Land	Arctic	Antarctic
Monthly gridded (Wm^{-2})	3	5	17	7	8	6	7	6
Monthly zonal (Wm^{-2})	2	1			3	1		
Monthly regional (Wm^{-2})			9	2			6	3
Monthly global (Wm^{-2})	2	1			3	1		

Downward LW over Greenland (over snow surface)

- RMS differences for Arctic are larger than RMS differences from other regions.
- Seasonal dependent bias error

Surface air temperature at Summit site



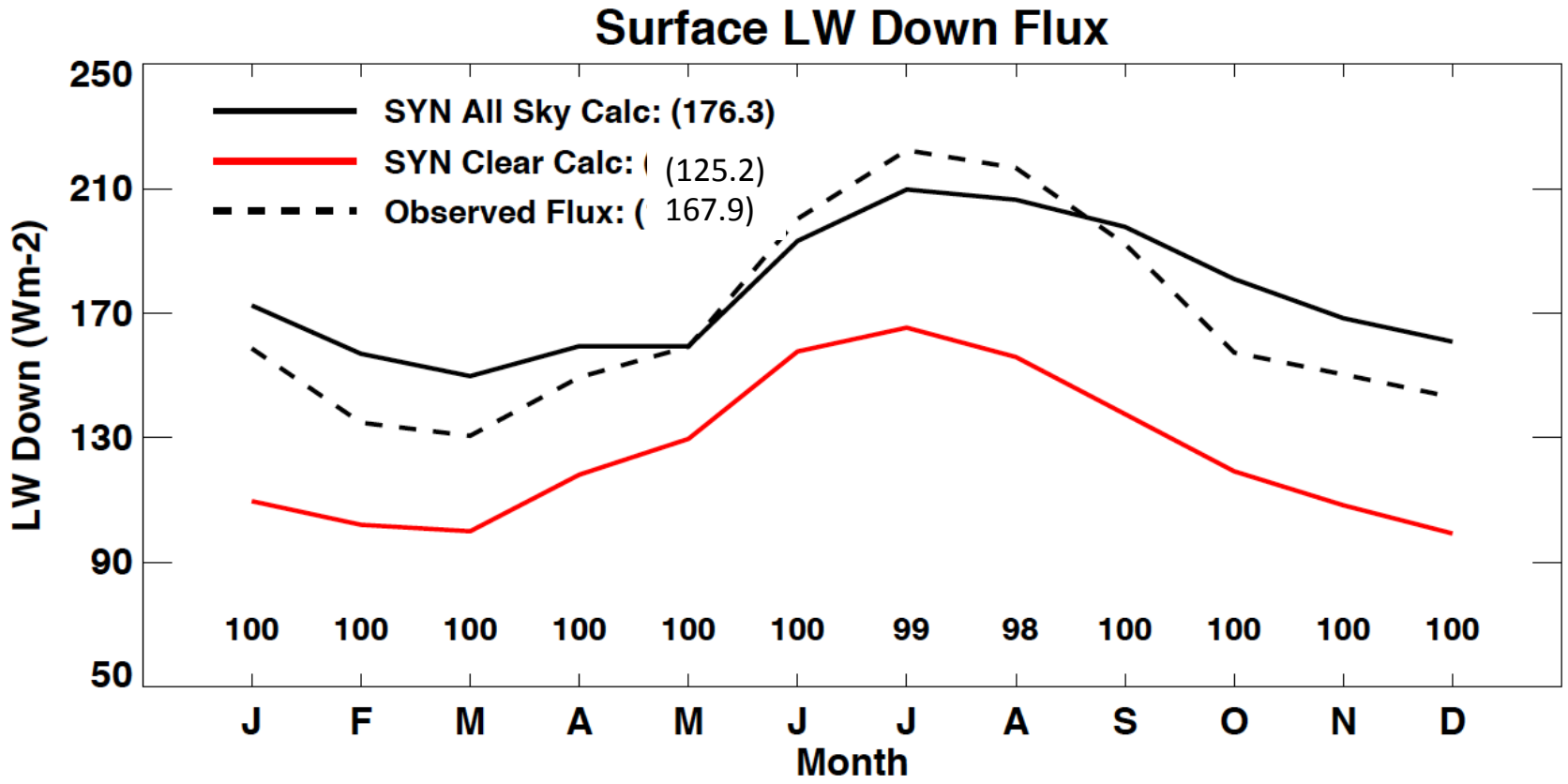
GEOS-5.4.1 is biased high when surface air temperature is high and biased low when surface air temperature is low

Biases at other Greenland sites Humboldt Glacier and Saddle Glacier are similar

Downward longwave irradiance changes about 1 Wm-2 by changing near surface air temperature by 1 K

Cold snow surfaces are misidentified as clouds (then irradiance errors due to temperature and clouds partly cancel).

Greenland LW down

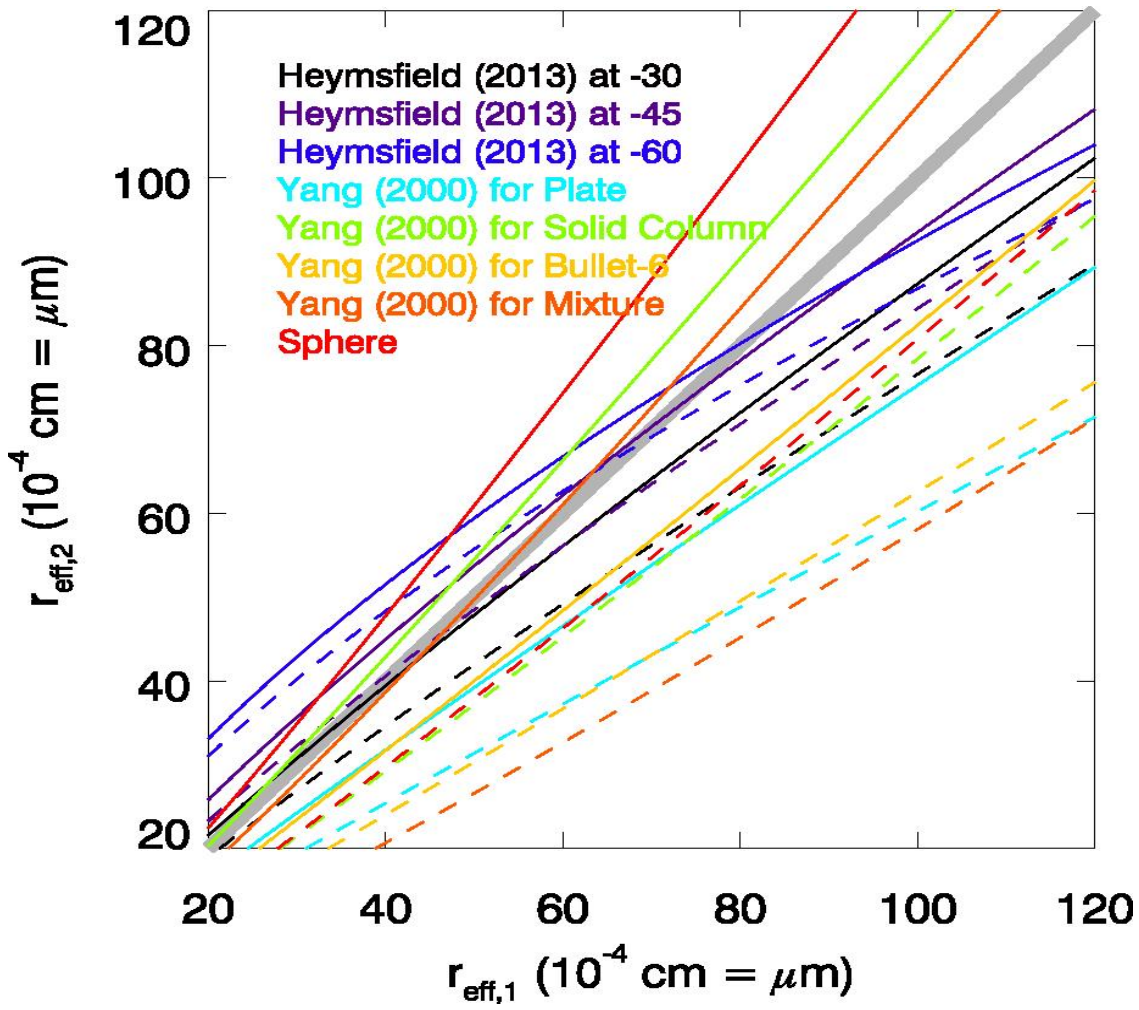


Cold snow surfaces are misidentified as clouds (then irradiance errors due to temperature and clouds partly cancel).

Publications

- 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 lcoud objects, *J. Climate*. DOI: 10.1175/JCLI-D-15-0782.1.
- Ham, S.-H., S. Kato, F. G. Rose, 2016: Examining Impacts of Mass-Diameter (m-D) and Area-Diameter (A-D) Relationships of Ice Particles on Retrievals of Effective Radius and Ice Water Content from Radar and Lidar Measurements, Submitted to J. Geophys. Res.

Example of Effective Radius Conversion (2/2)



$r_{eff,1}$: Effective radius from gamma PSD and a, b, γ, and δ of Brown and Francis (1998).

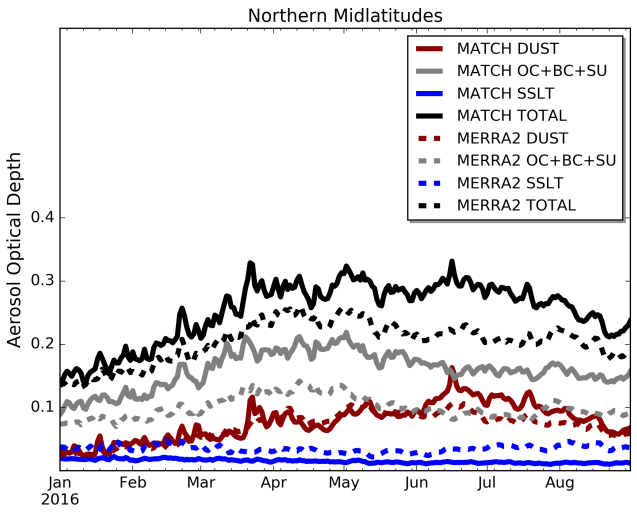
$r_{eff,2}$: Effective radius from lognormal PSD and a, b, γ, and δ of different methods in the legend

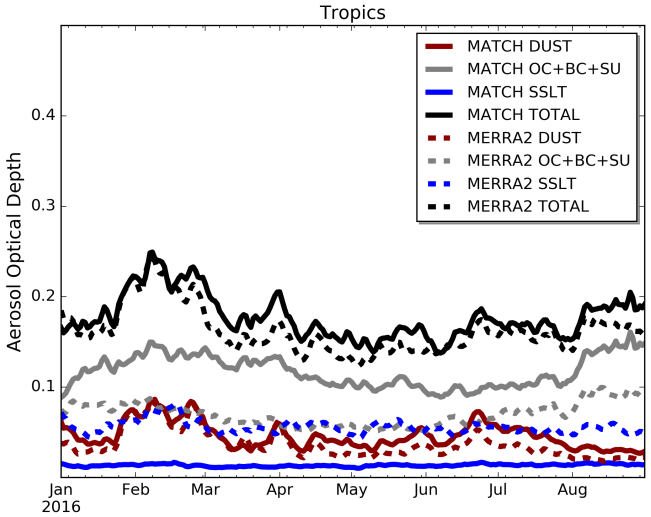
Ham et al. 2016 submitted JGR

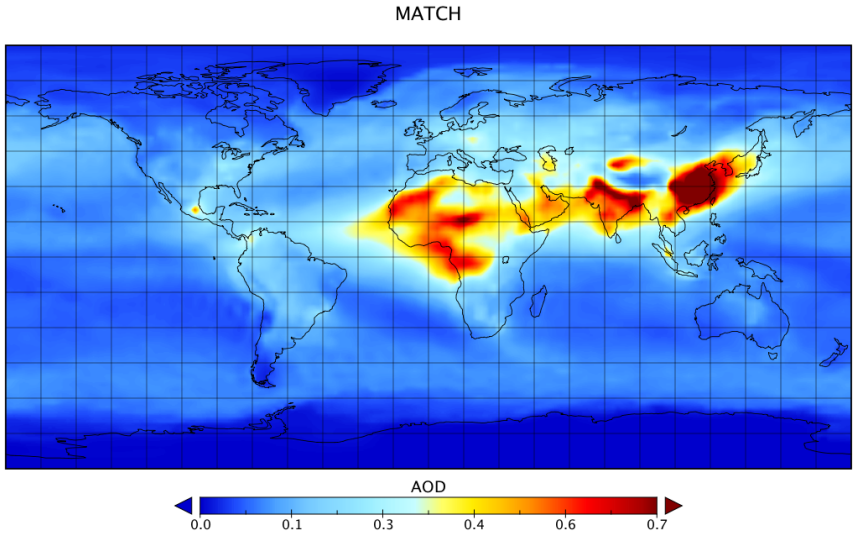
Solid line: μ and ω are assumed with temperature = -75℃
Dashed line: μ and ω are assumed with temperature = -5℃

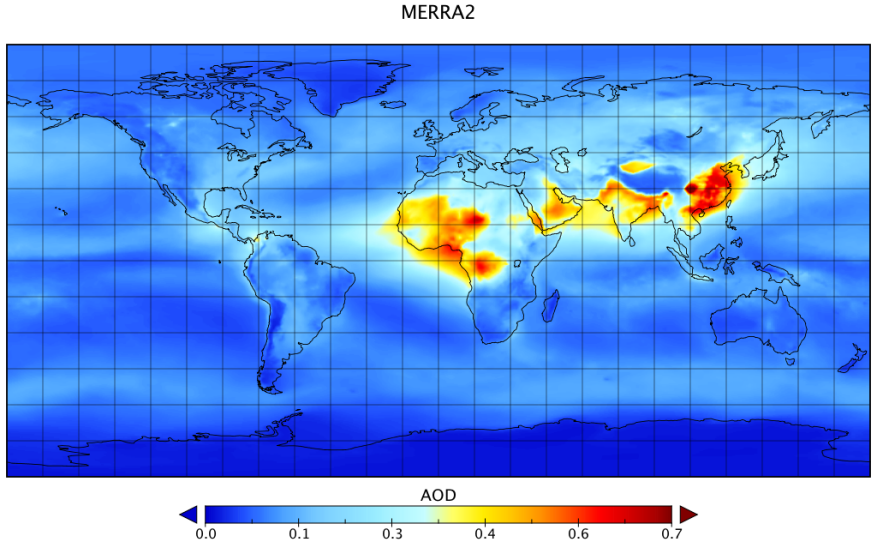
MATCH Ed4

- Continued comparison of MATCH Ed4 versus MERRA2







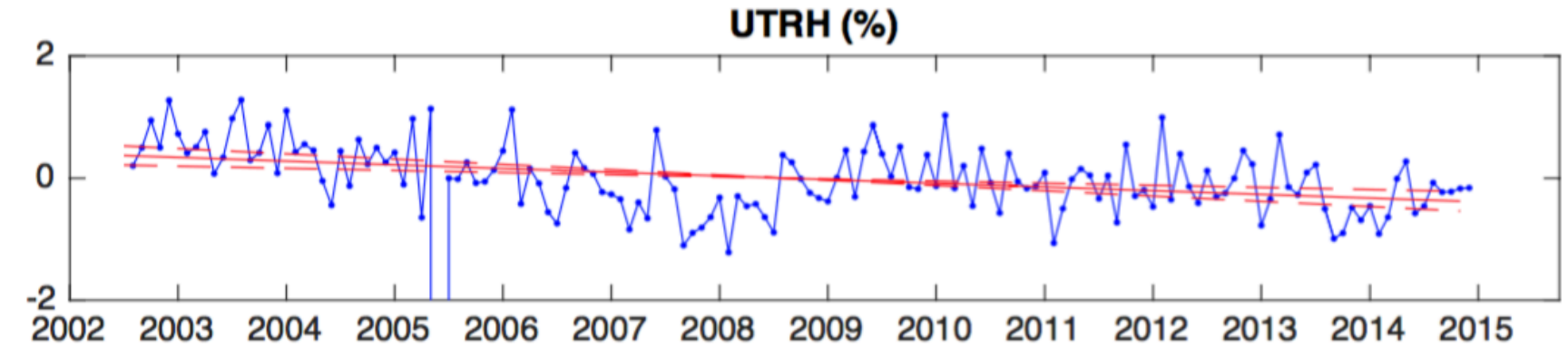


- Shown are the daily time series for spatial mean AOD (Northern Mid-latitudes 15N – 45N and Tropics 15S – 15N)
- January 2016 through August 2016 (current data availability)
- Differences in optical depth by species are generally large than differences in total AOD

Summary

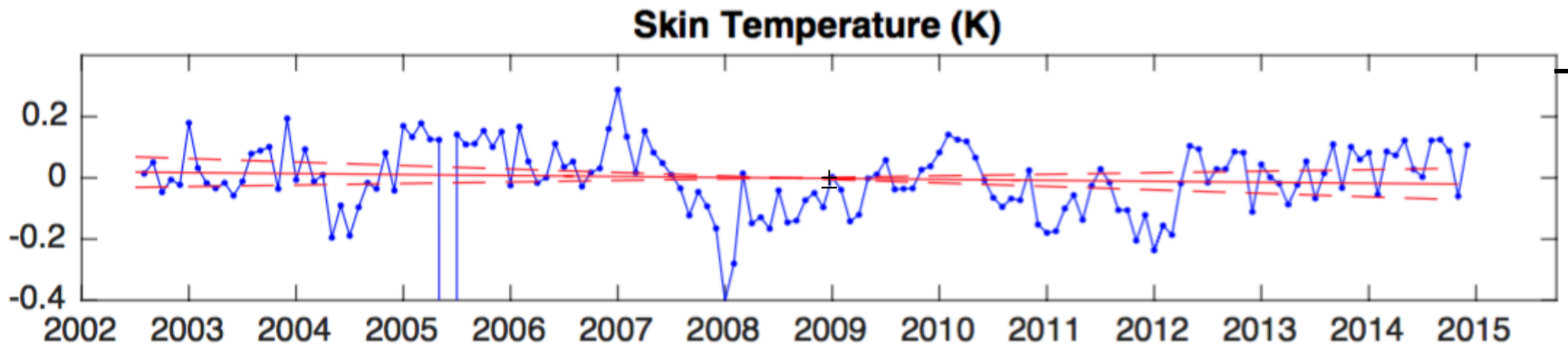
- Ed4 surface downward longwave is increased and downward shortwave is decreased from Ed3 because larger cloud fraction especially for low-level clouds and temperature in boundary layer
- Surface net irradiance increases by ~2 Wm^{-2} from Ed3
- Discontinuity due to GEOS switch in Ed3 is eliminated in Ed4
- Uncertainty in downward surface irradiance over Arctic appears to be larger than the uncertainty from other regions. The reason for the larger uncertainty is unknown.

Back-ups



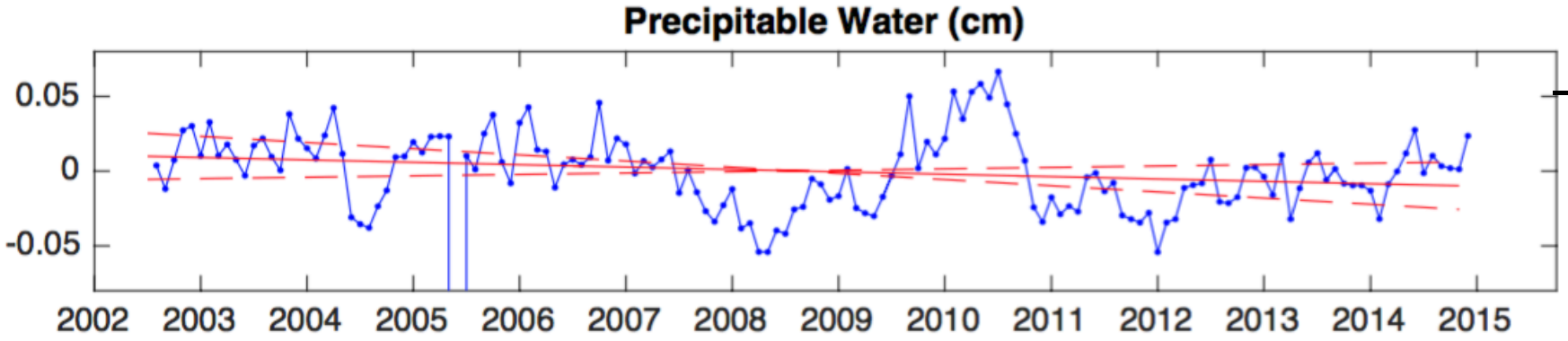
-0.61 ± 0.26

% per decade



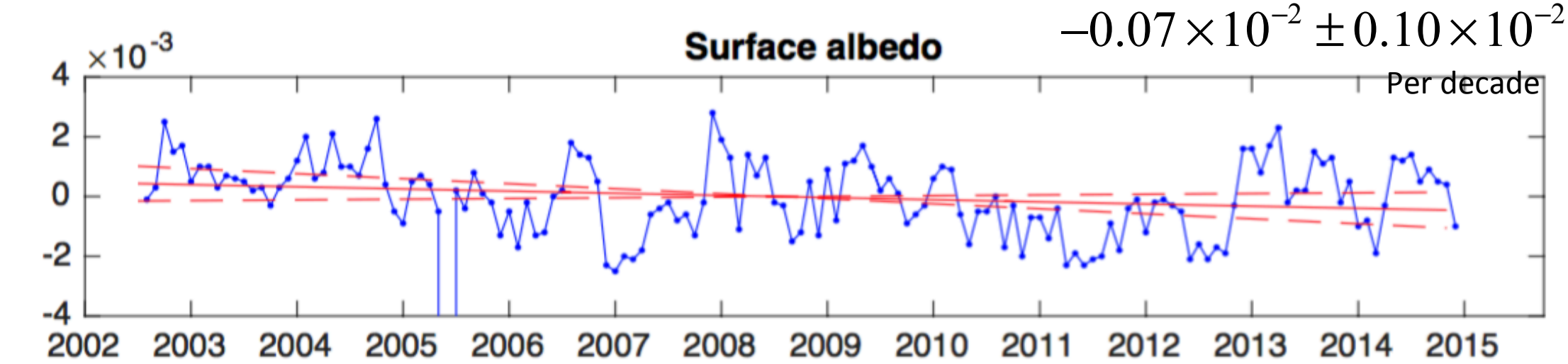
-0.03 ± 0.08

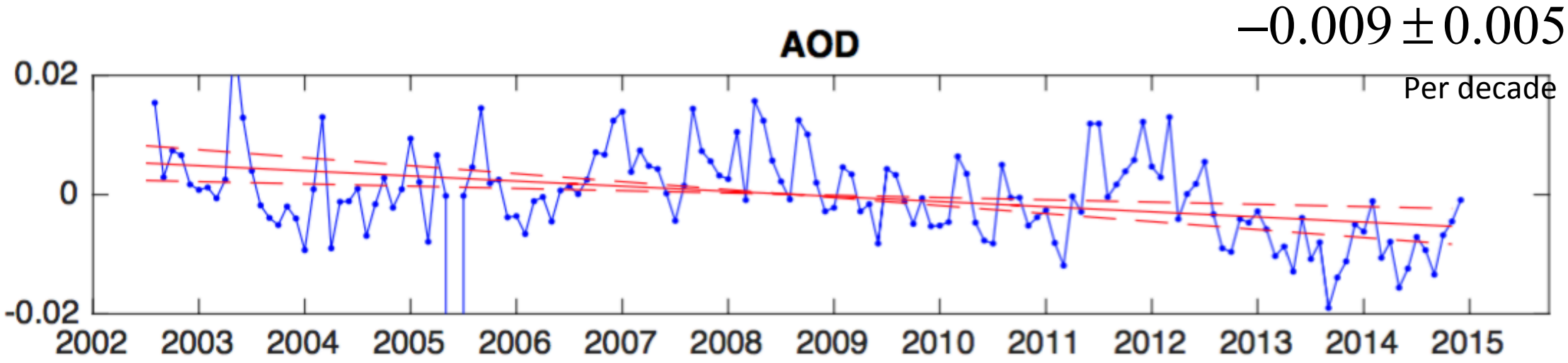
K per decade



-0.02 ± 0.03

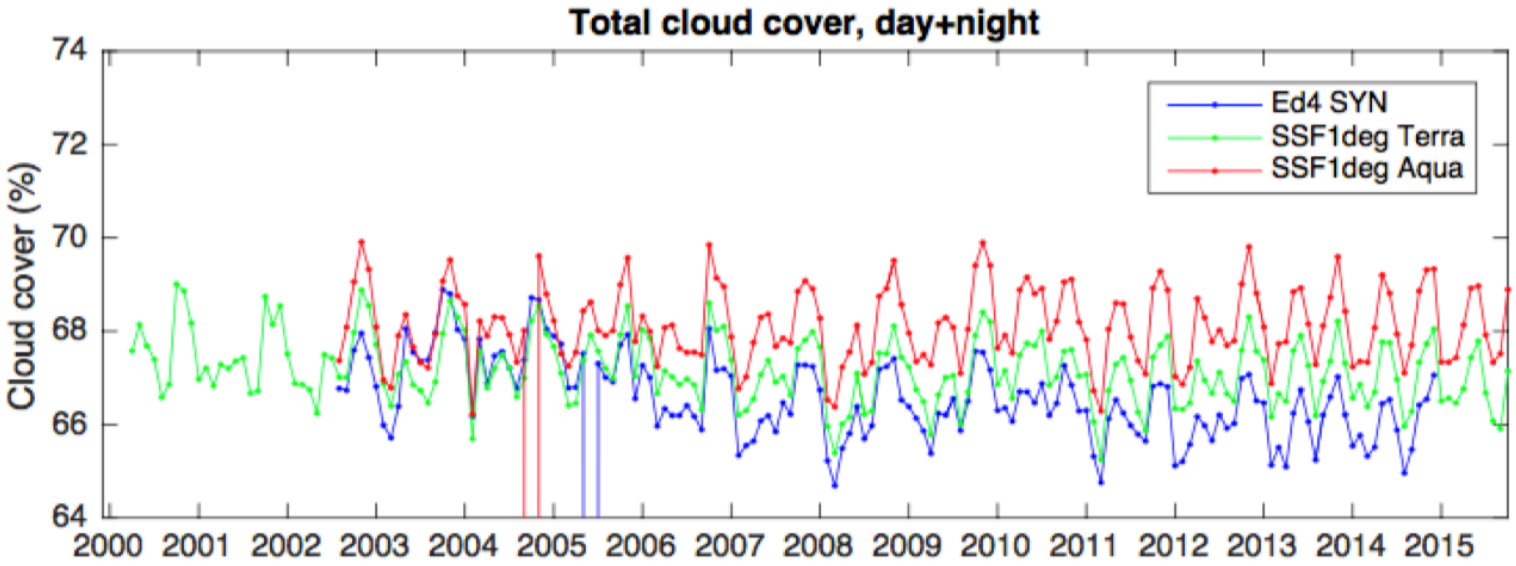
Cm per decade

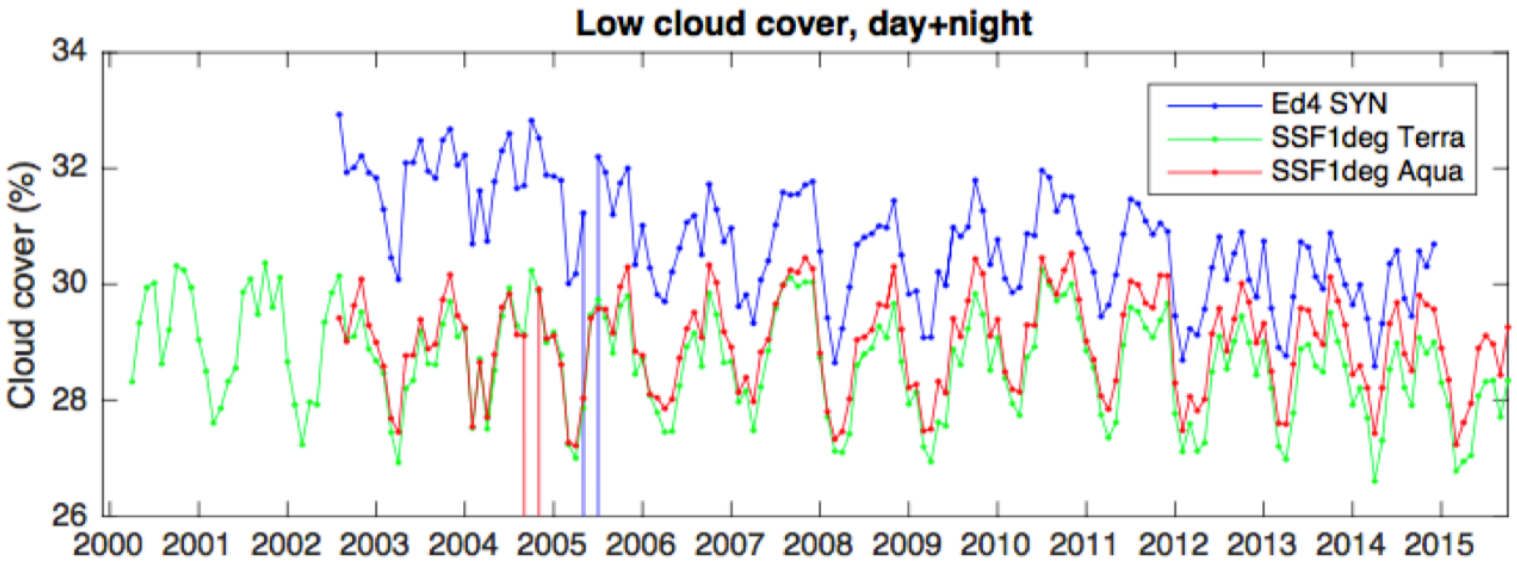

Surface albedo
$-0.07\times10^{-2}\pm0.10\times10^{-2}$
Per decade
×10^-3
4
2
0
-2
-4
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015


AOD
-0.009 ± 0.005
Per decade
0.02
0
-0.02
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015

Ed4 SYN cloud cover

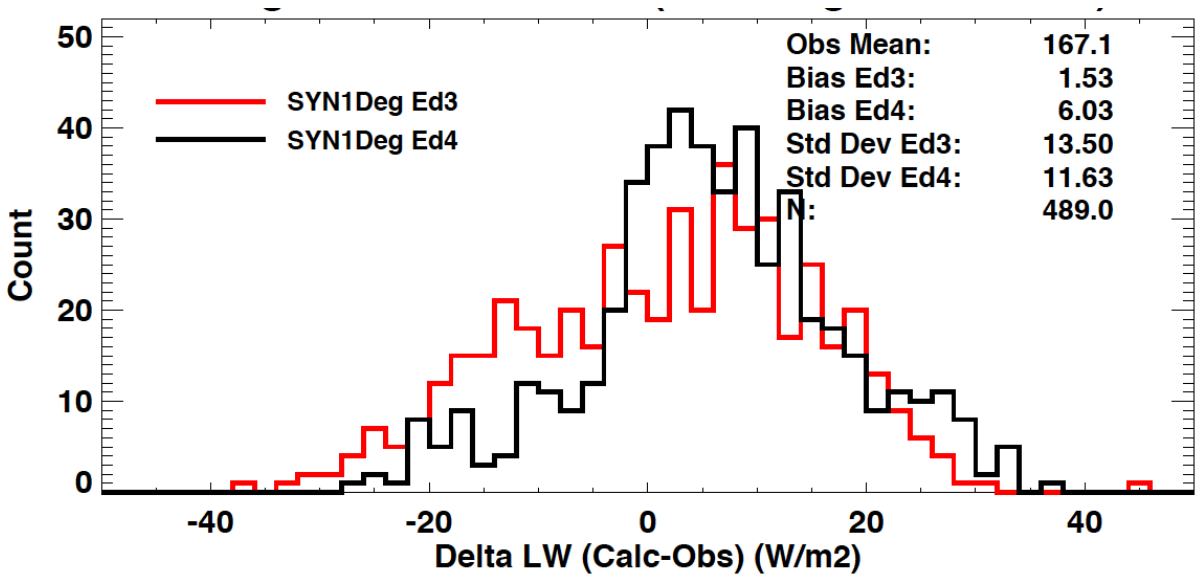
Make sure that the effect of artificial cloud fraction trend will be taken out in EBAF-surface



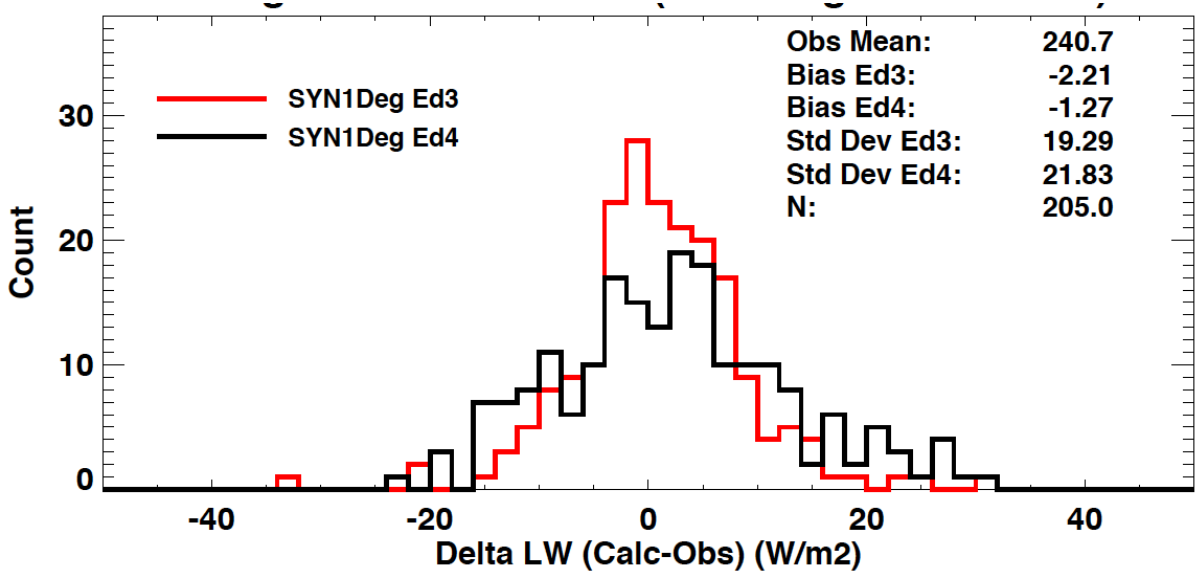


Uncertainty in downward longwave irradiance over polar regions

Antarctic (4 sites)



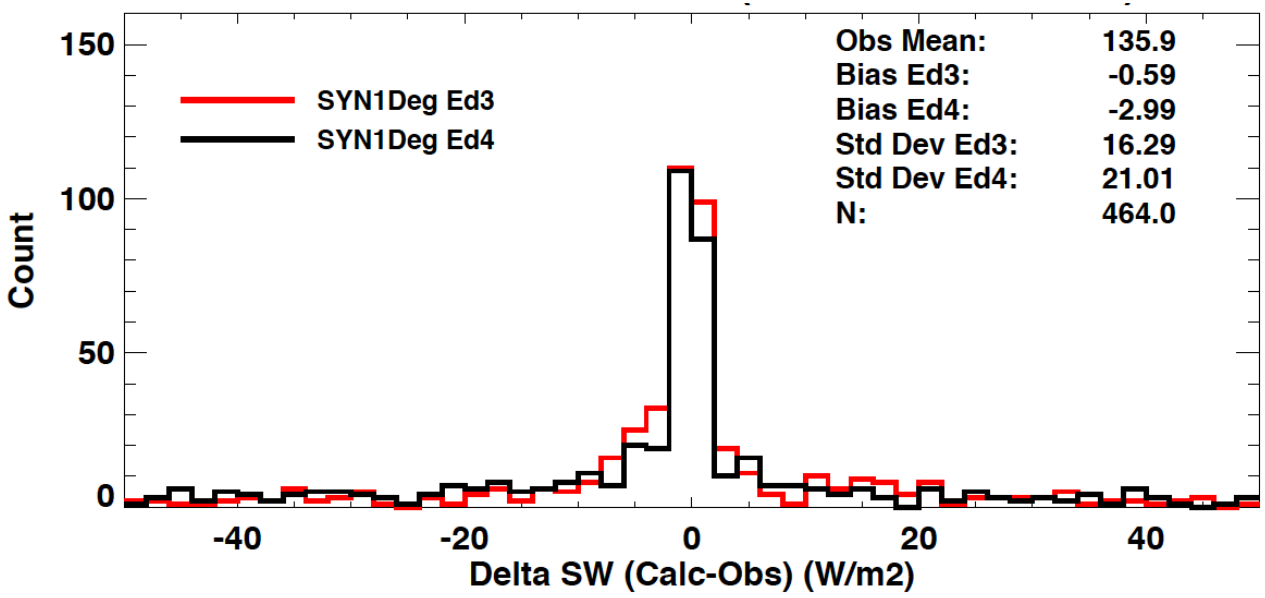
Arctic (6 sites)



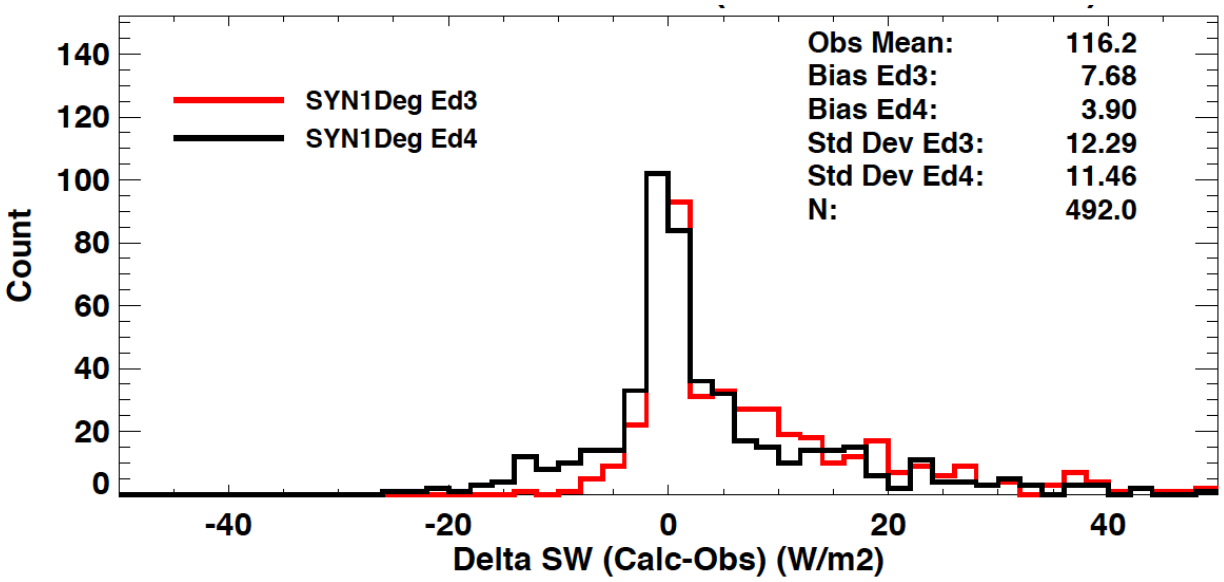
	Observation Mean (Wm^{-2})	RMS difference (Wm^{-2})
Antarctic Ed4	167	13.1
Ed3		13.6
Arctic Ed4	241	21.9
Ed3		19.4

Uncertainty in downward shortwave irradiance over polar regions

Antarctic

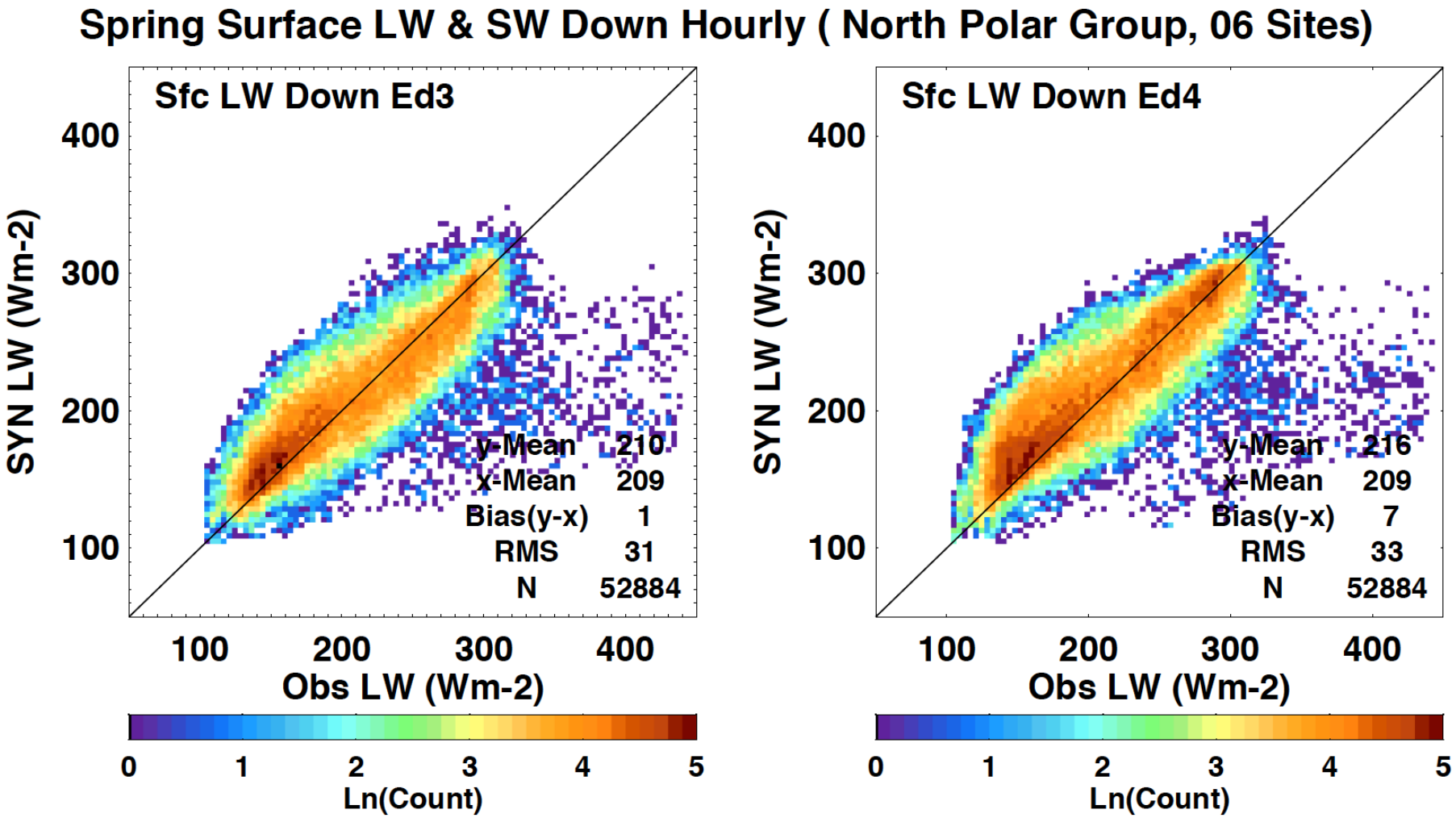


Arctic

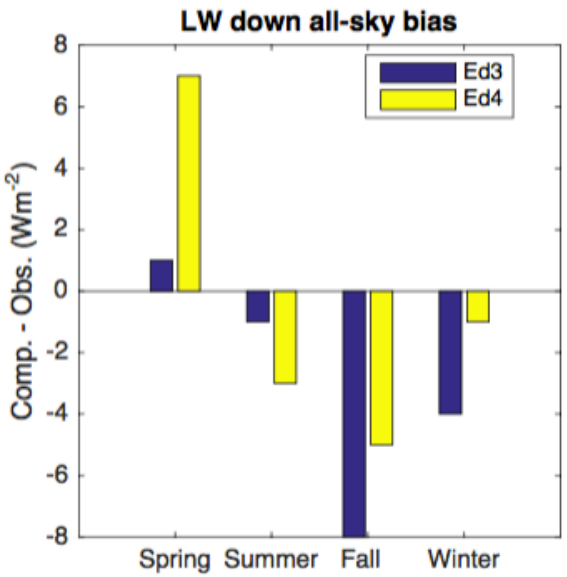


	Observation Mean (Wm^{-2})	RMS difference (Wm^{-2})
Antarctic Ed4	136	21.2
Ed3		16.3
Arctic Ed4	116	12.1
Ed3		14.5
Greenland Ed4	135	11.5
Ed3		12.6

Downward LW, Spring

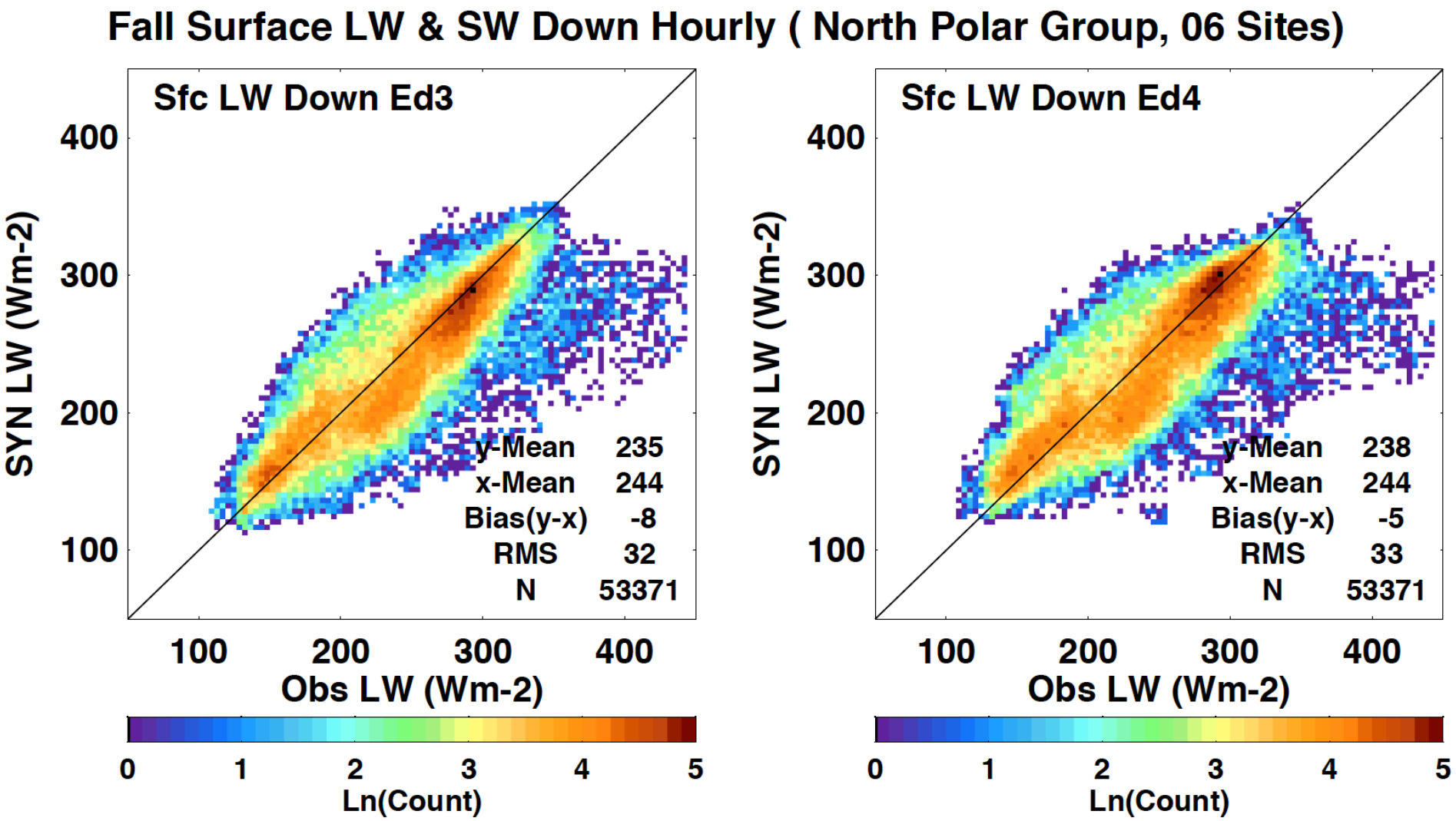


Clear-sky screening did not work. But a positive bias at lower end might indicate clear-sky LW down is positively biased



One possibility is that clouds are retrieved over cold surface, which give a positive bias

Downward LW, fall



Positive bias a the low end during fall is not pronounced as the bias in spring.

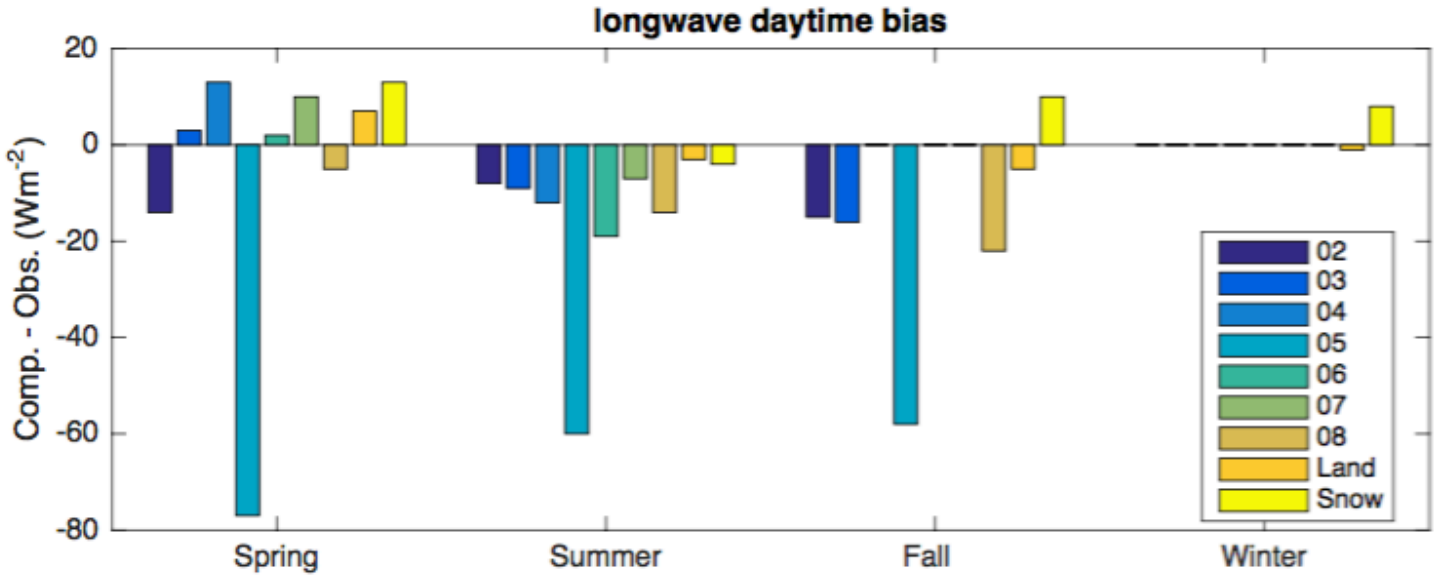
Over Arctic ocean

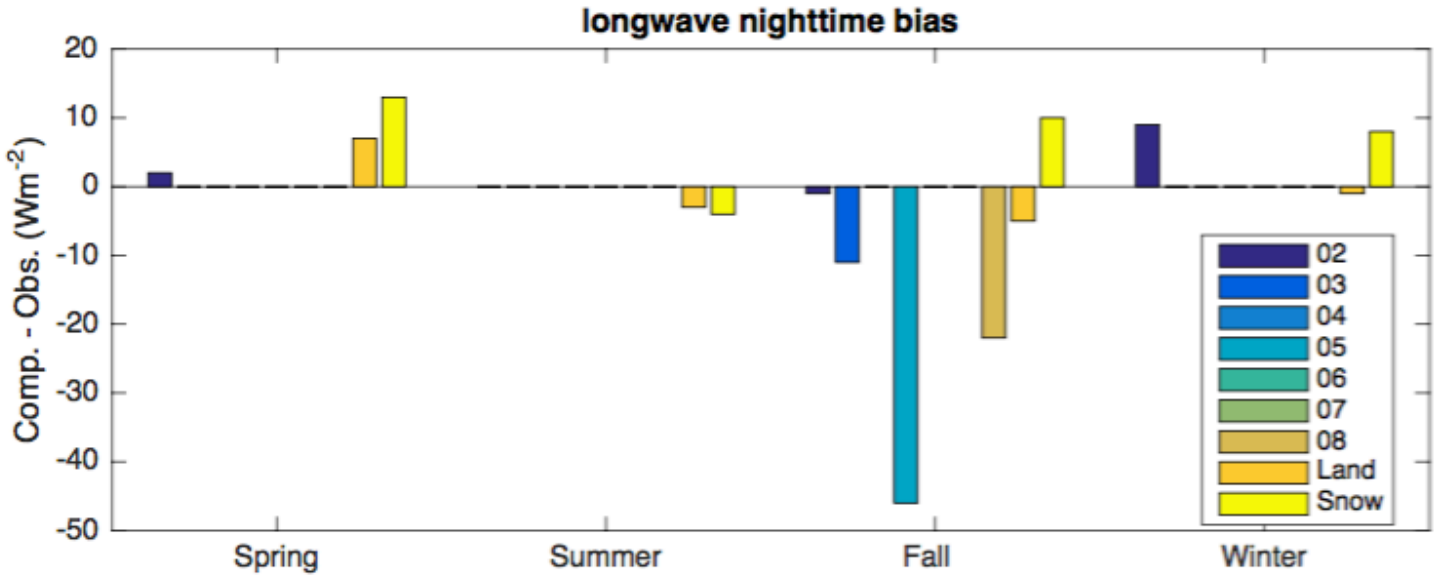
- Polar surface sites are located over land. Do bias and RMS differences over land sites represent bias and RMS difference over Arctic ocean?

Hourly downward LW comparison with Ice buoy data

Except 2005 and summer, absolute values of the bias at validation sites (land) are similar to biases at ice buoys.

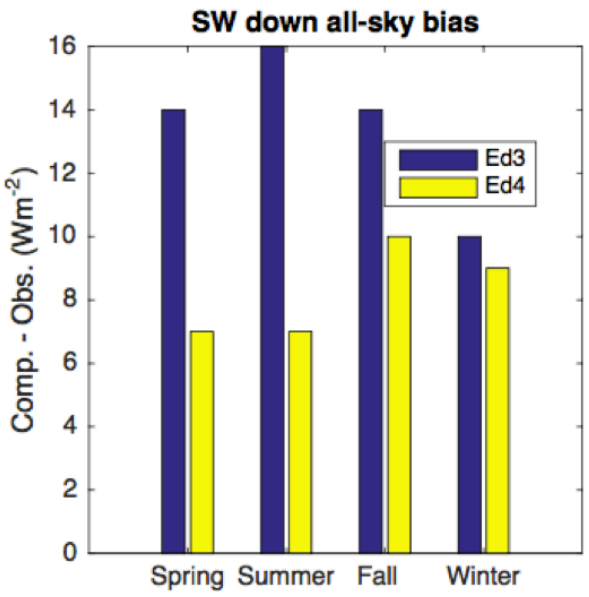
Larger biases over snow surface may be due to sampling size since no downward longwave measurements are available over Greenland

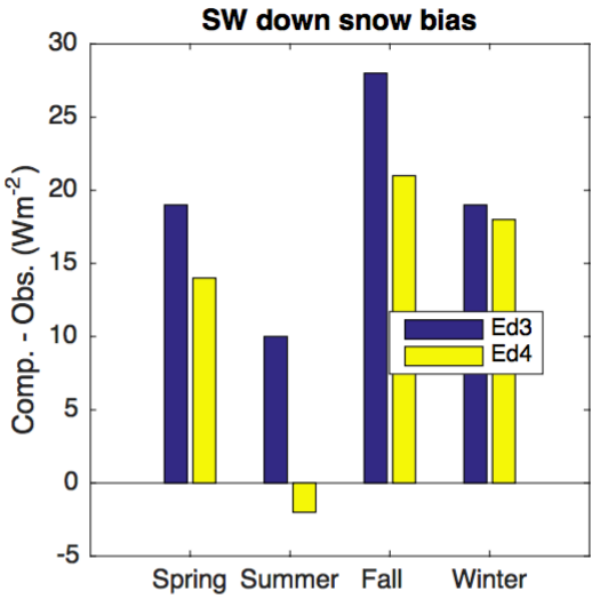


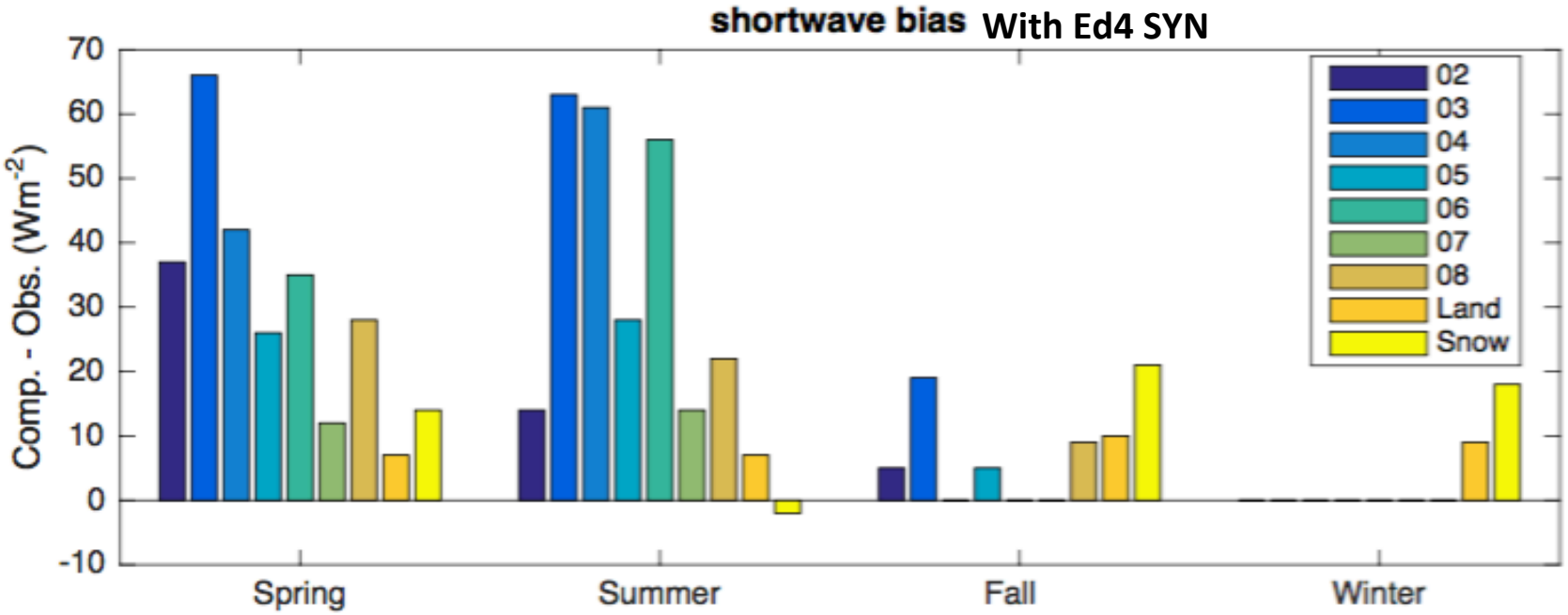


Hourly downward LW comparison with Ice buoy data

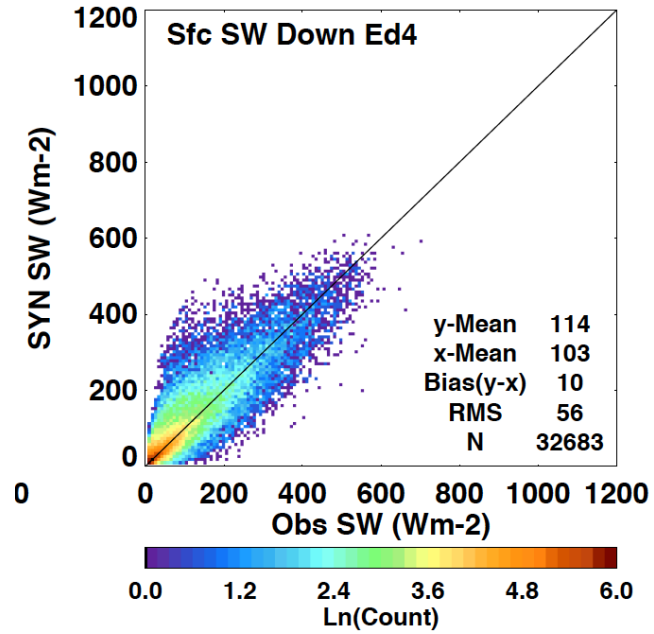
- The magnitude varies but almost all comparisons indicate that computed SW is positively biased.
- Ed4 bias is smaller than Ed3

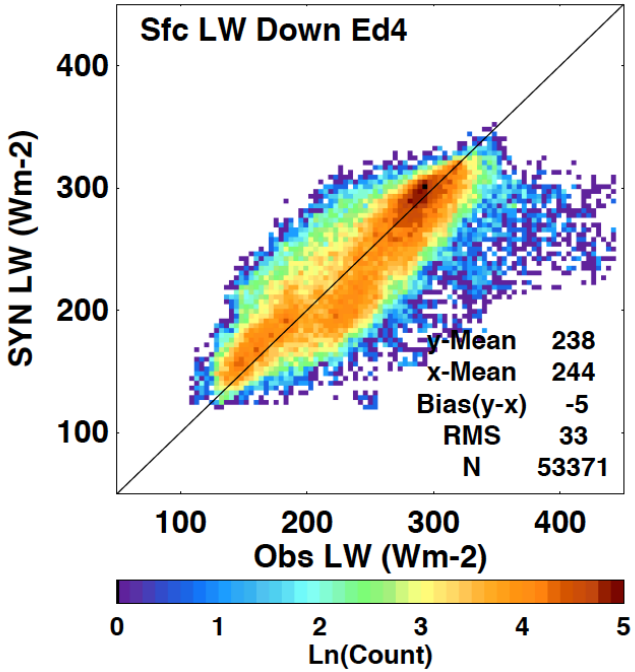






ARISE result (gridded hourly irradiance)



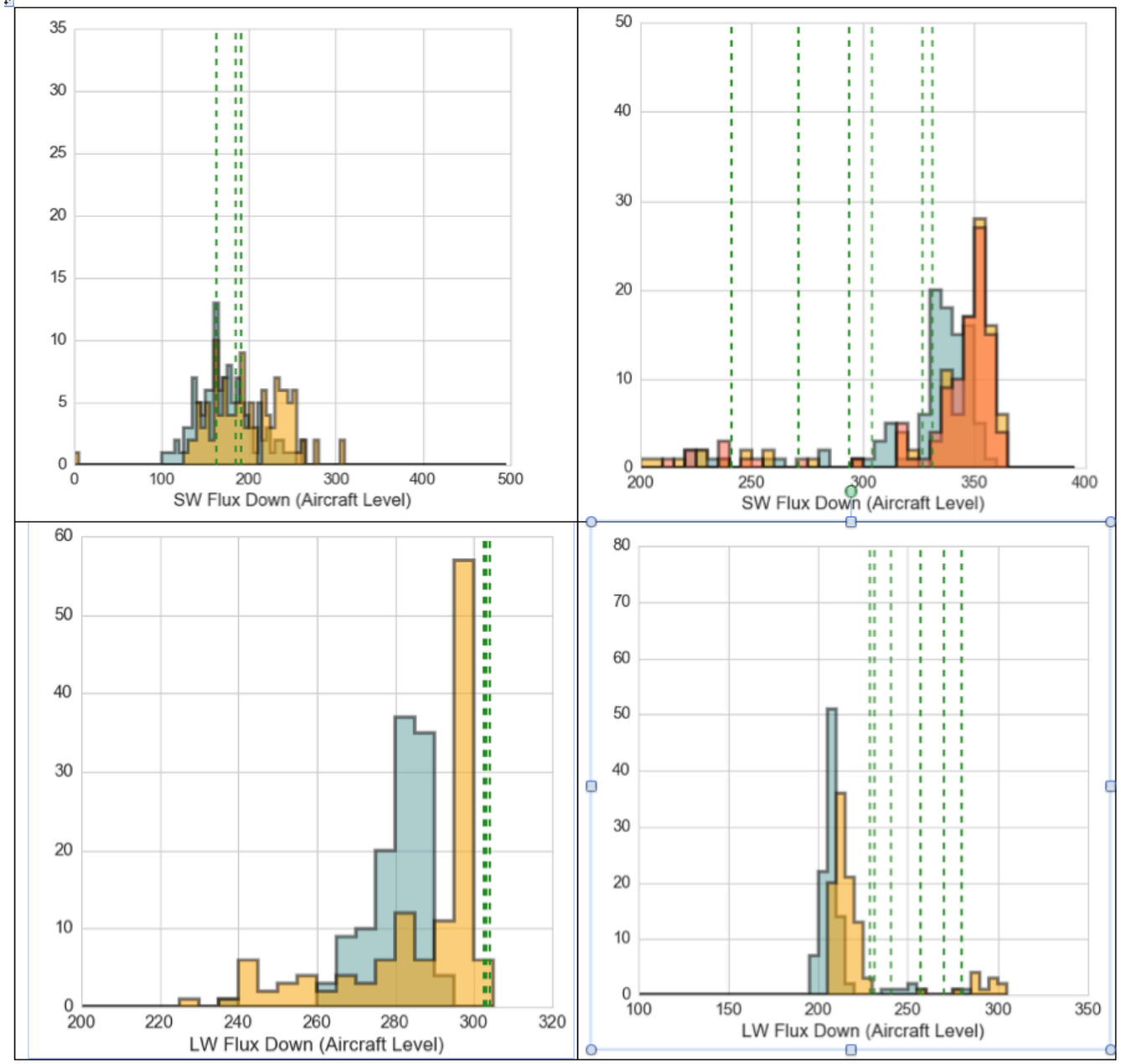


Shortwave

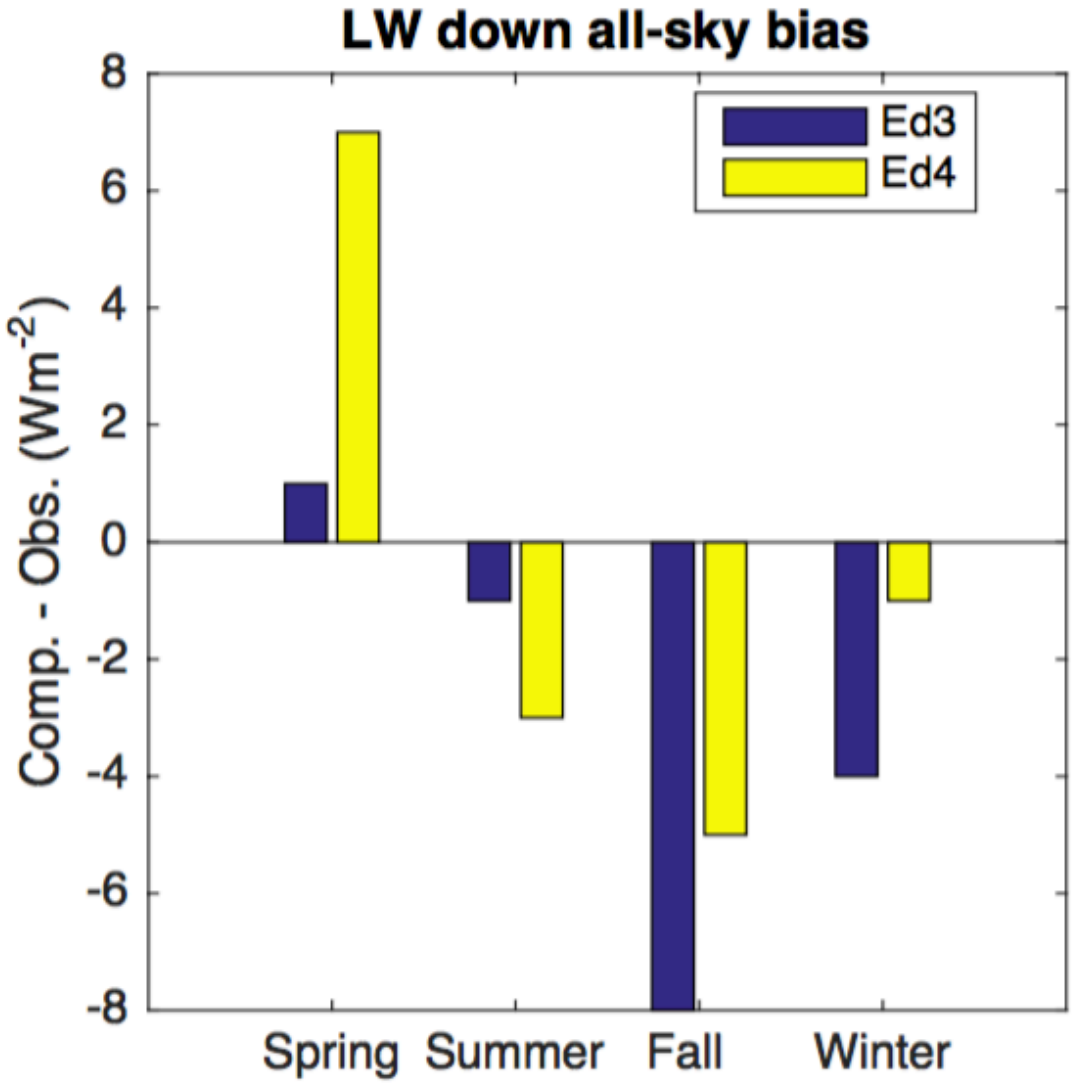
Longwave

9th

13th



Hourly surface downward irradiance over the Arctic regions



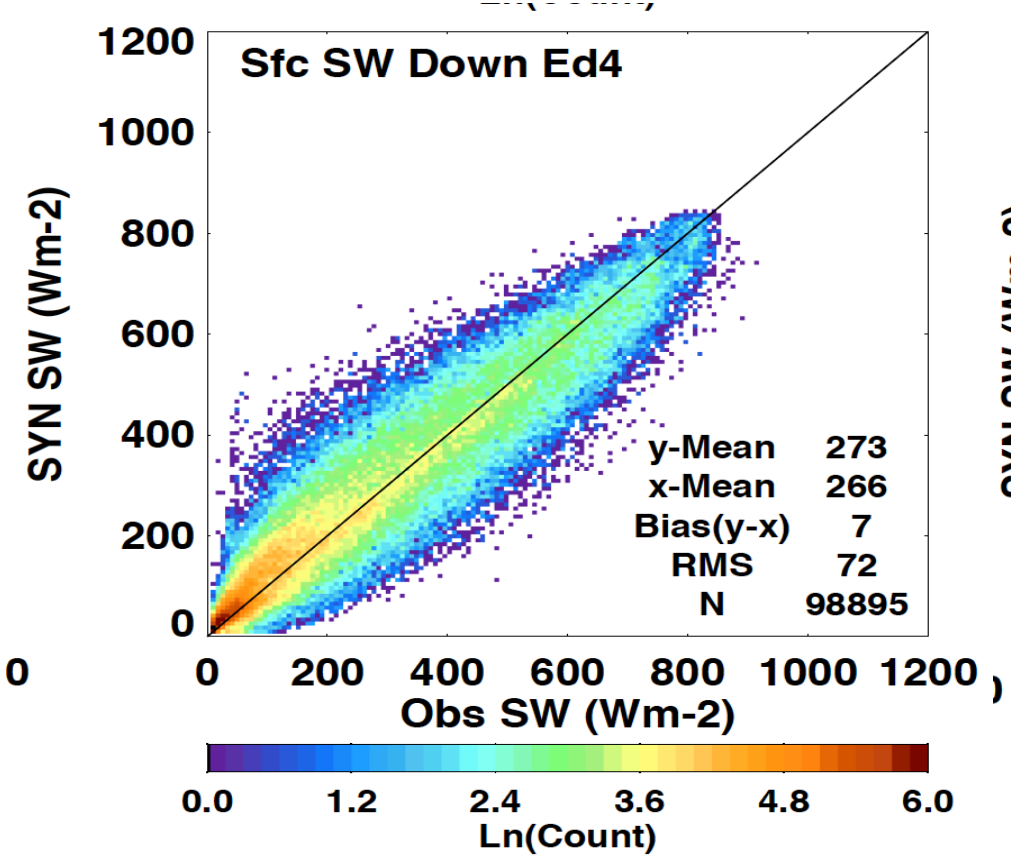
LW down might be negatively biased outside Greenland

Ed4 > Ed3 by 3 to 6 Wm-2 except for summer for

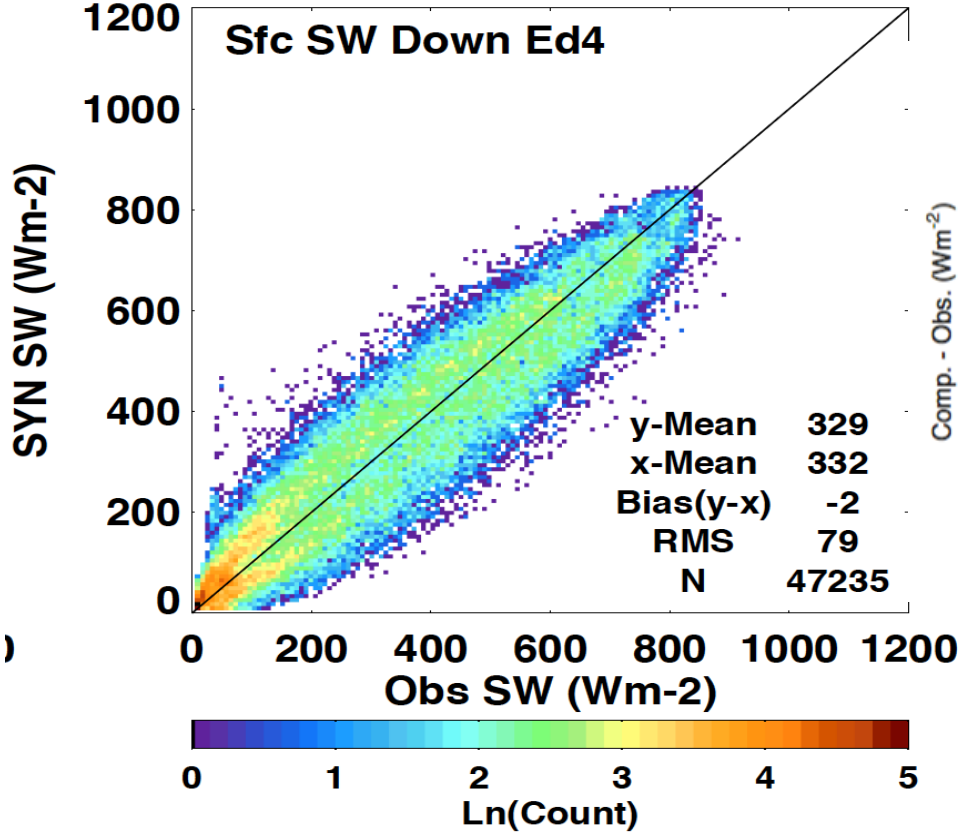
- more low-level clouds in Ed4
- warmer surface boundary layer

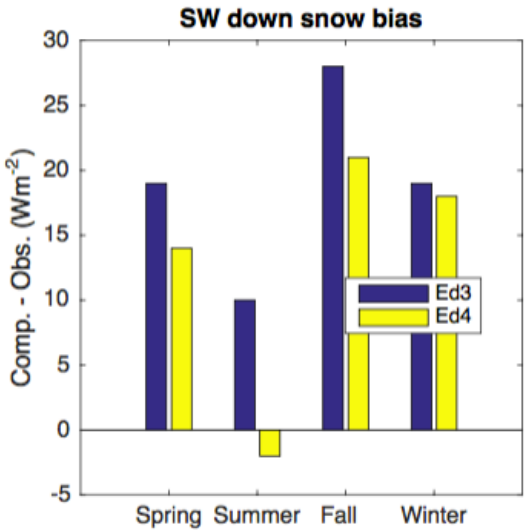
Effect of the correction of cloud optical depth over snow/ice to surface downward shortwave

All surface summer



Snow surface summer





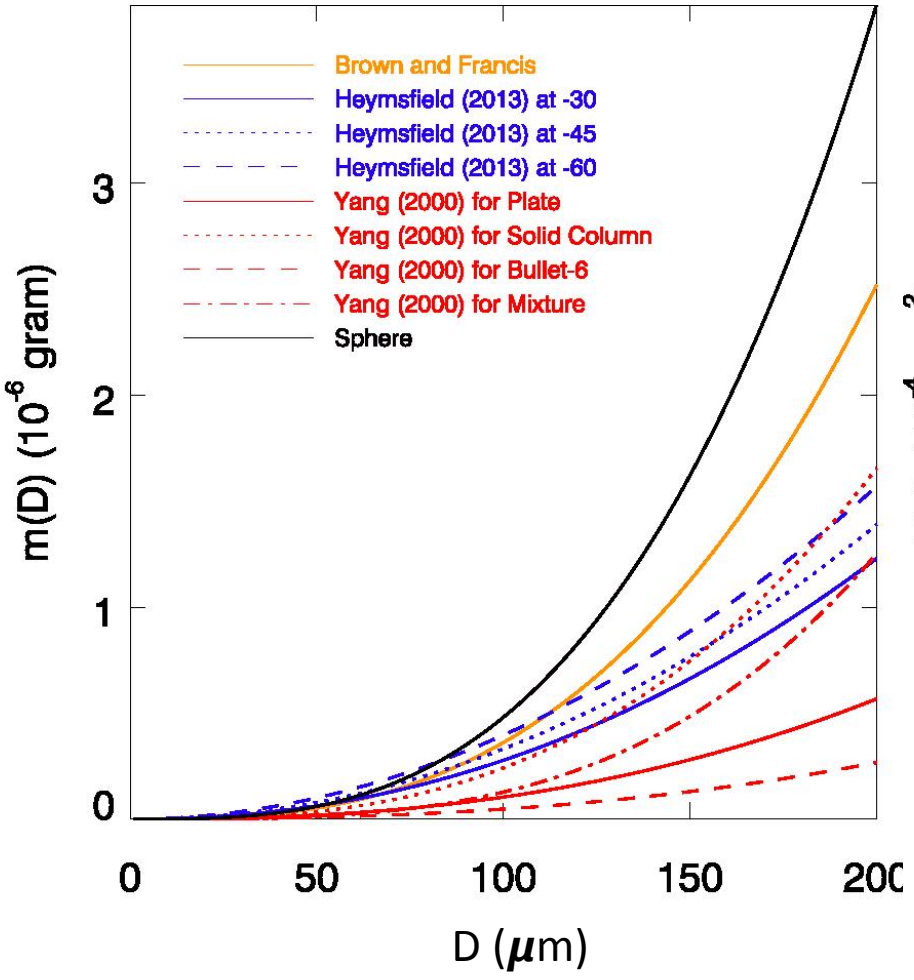
Viewing zenith angle dependent problems in cloud optical thickness retrieval ???
Solar zenith angle effect???

Assumptions for Effective Radius Conversion in Radar-Lidar Retrievals

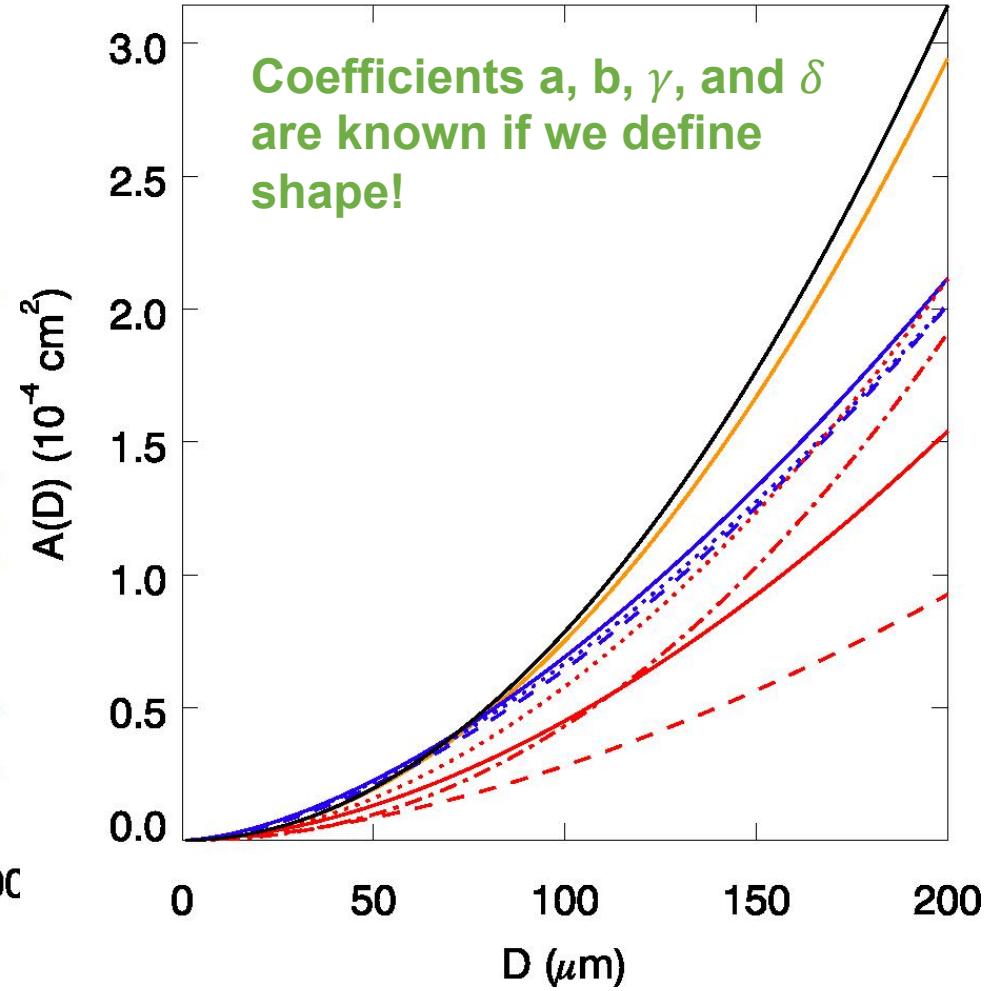
1. We know extinction coefficient (k_{ext}) and radar reflectivity factor (Z) from Lidar and Radar measurements. These are considered as true values (or constants).
2. Particle distribution follows gamma or lognormal (LN) distribution.
3. To describe shape of ice particles, we consider power laws that link between mass and maximum diameter (m-D) and area and maximum diameter (A-D).

Mass-Diameter (m-D) and Area-Diameter (A-D) Relationships Determined by Particle Shapes

$m(D) = aD^b$



$A(D)=\gamma D^{\delta}$



Optical Parameters with Gamma Distribution

Gamma PSD $N(D) = N_0 D^{\mu} \exp(-\Lambda D)$

Particle Shapes $m(D) = aD^b$ $A(D)=\gamma D^{\delta}$

Radar reflectivity (from measurement)

$$\boxed{Z = \frac{36}{\pi^2 \rho^2} a^2 N_0 \frac{\Gamma(2b+\mu+1)}{\Lambda^{2b+\mu+1}}}$$

Extinction coefficient (from measurement)

$$\boxed{k_{ext} = 2N_0 \gamma \frac{\Gamma(\delta+\mu+1)}{\Lambda^{\delta+\mu+1}}}$$

$$r_{eff} = 3aN_0 \frac{\Gamma(b+\mu+1)}{\Lambda^{b+\mu+1}} \frac{1}{4\rho_i N_0 \gamma} \frac{\Lambda^{\delta+\mu+1}}{\Gamma(\delta+\mu+1)} = \frac{3a}{4\rho_i \gamma} \frac{\Gamma(b+\mu+1)}{\Gamma(\delta+\mu+1)} \Lambda^{\delta-b}$$

$$r_{eff} = \frac{3a}{4\rho\gamma} \frac{\Gamma(b+\mu+1)}{\Gamma(\delta+\mu+1)} \left\{ \boxed{\frac{Z}{k_{ext}}} \frac{\pi^2 {\rho_i}^2}{18} \frac{\gamma}{a^2} \frac{\Gamma(\delta+\mu+1)}{\Gamma(2b+\mu+1)} \right\}^{(b-\delta)/(2b-\delta)}$$

r_{eff} is a function of a, b, γ, and δ for the given Z/k_{ext}.

Optical Parameters with Lognormal Distribution

Lognormal PSD

$$N(D)=N_T\, 1/\sqrt{2\pi}\,\omega D \exp[-(\ln D-\ln D_g)^2/2\omega^2]$$

Particle Shapes

$m(D) = aD^b$ $A(D)=\gamma D^\delta$

Radar reflectivity
(from measurement)

$$Z=36/\pi^2\,\rho_i^2\, a^2 N_T D_g^{2b} \exp(2b^2\omega^2)$$

Extinction coefficient
(from measurement)

$$k_{ext}=2\gamma N_T D_g^{\delta} \exp(1/2\,\delta^2\omega^2)$$

$$r_{eff}=3/4\rho_i\, a/\gamma\, D_g^{b-\delta} \exp(1/2\,(b^2-\delta^2)\omega^2)$$

$$r_{eff}=3/4\rho_i\, a/\gamma\, \{Z/k_{ext}\, \pi^2\rho_i^2\gamma/18a^2\}^{b-\delta/2b-\delta} \exp(-b/2\,(b-\delta)\omega^2)$$

r_{eff} is a function of a, b, γ, and δ for the given Z/k_{ext}.

Example of Effective Radius Conversion (1/2)

$r_{eff,1}$: Effective radius is retrieved with particle assumptions of a_1, b_1, γ_1, and δ_1 and gamma PSD.

$r_{eff,2}$: Effective radius is retrieved with particle assumptions of a_2, b_2, γ_2, and δ_2 and lognormal PSD.

$$r_{eff,2} = 3/4\rho_i \; a_2/\gamma_2 \; \{\pi^2 \rho_i^2 \gamma_2/18 a_2^2\}^{b_2-\delta_2/2b_2-\delta_2} \exp(-b_2/2(b_2-\delta_2)\omega^2)\{Z/k_{ext}\}^{b_2-\delta_2/2b_2-\delta_2}$$

$$= 3/4\rho_i \; a_2/\gamma_2 \; \{a_1^2/\gamma_1 \; \gamma_2/a_2^2\}^{b_2-\delta_2/2} b_2-\delta_2 \; \exp(-b_2/2(b_2-\delta_2)\omega^2)$$

$$\times\{r_{eff,1} \; 4\rho_i \gamma_1/3a_1 \; \Gamma(\delta_1+\mu+1)/\Gamma(b_1+\mu+1)\}^{2b_1-\delta_1/b_1-\delta_1} \; b_2-\delta_2/2b$$

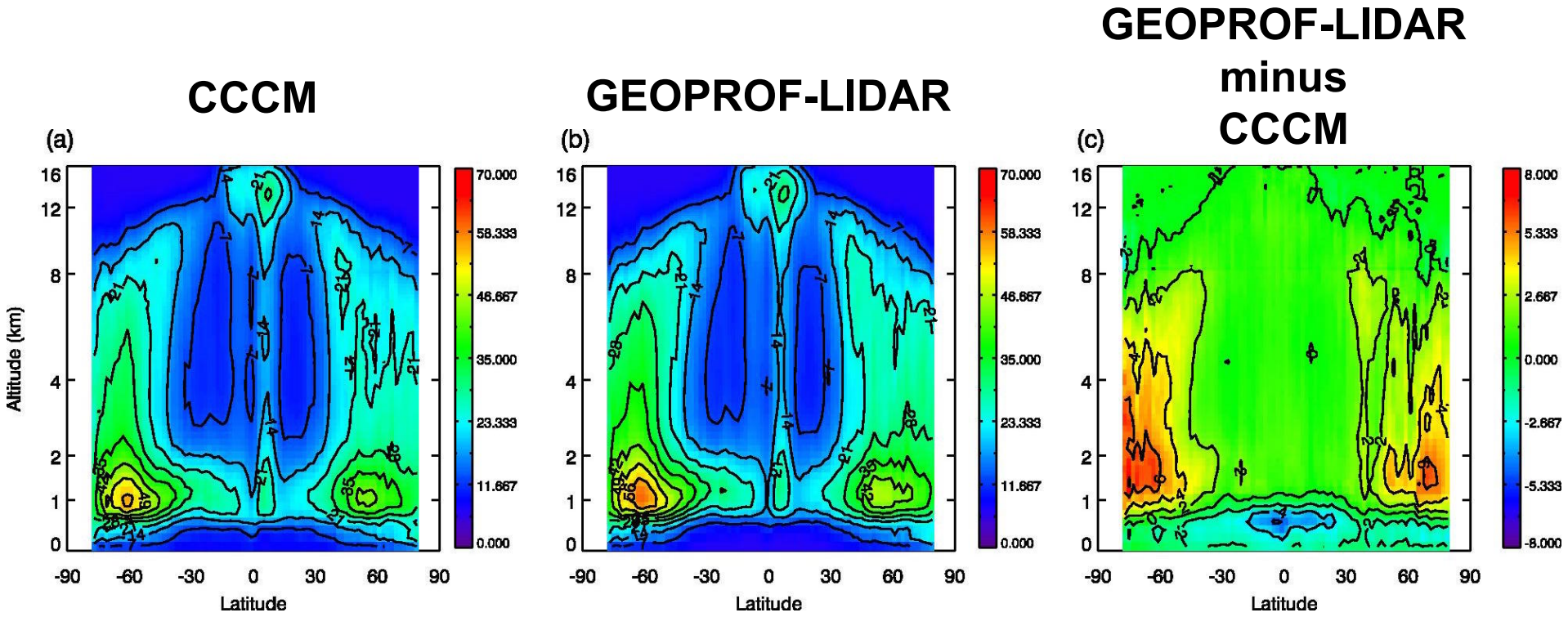
$$\mu = -0.84 - 0.0915\,T - 2.936\times10^{-3}\,T^2 - 3.653\times10^{-5}\,T^3 - 2.157\times10^{-8}\,T^4$$

Dispersion of gamma PSD (~ Temperature)

$$\omega = 0.694 + 0.0065\,T$$

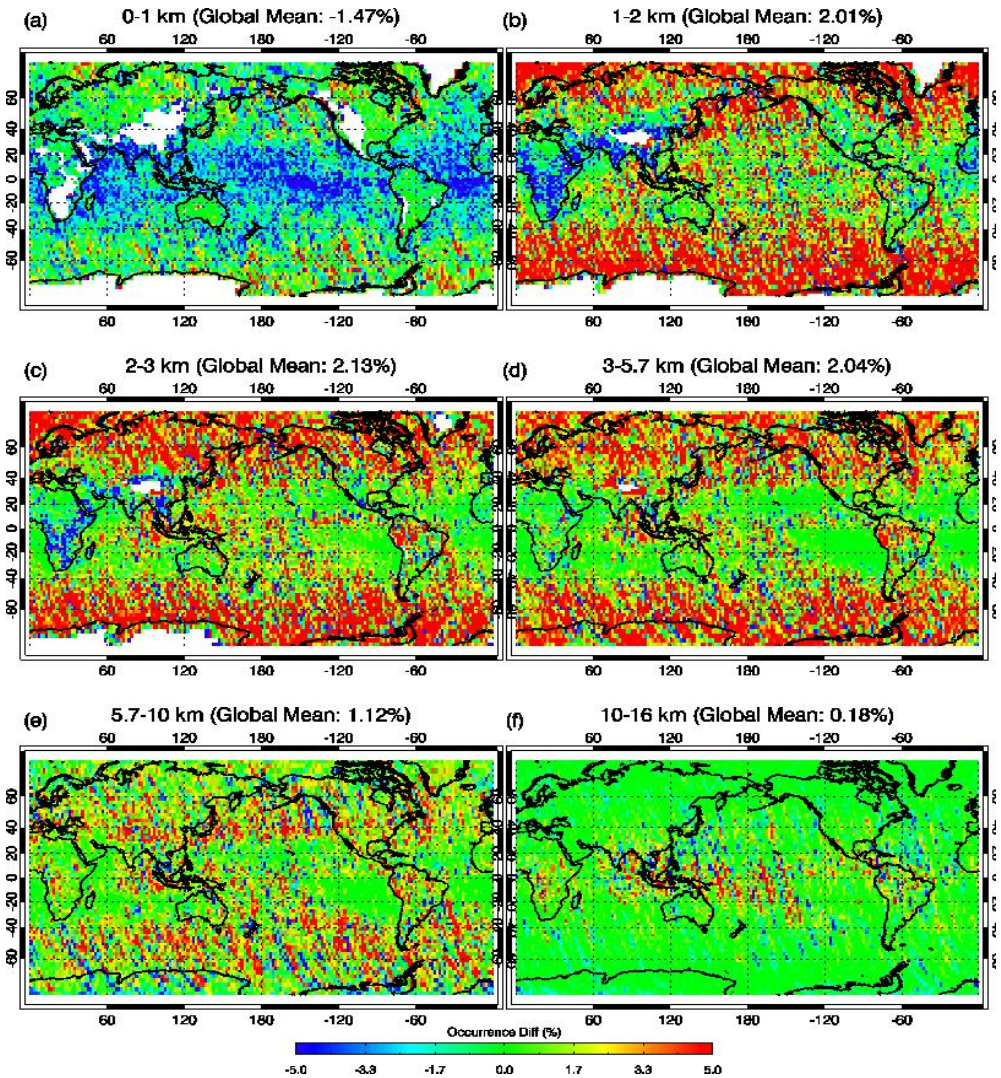
Width parameter of lognormal PSD (~ Temperature)

Cloud Occurrences (%) over Daytime Ocean Using Four-month Data (Feb/Apr/Jul/Oct 2010)

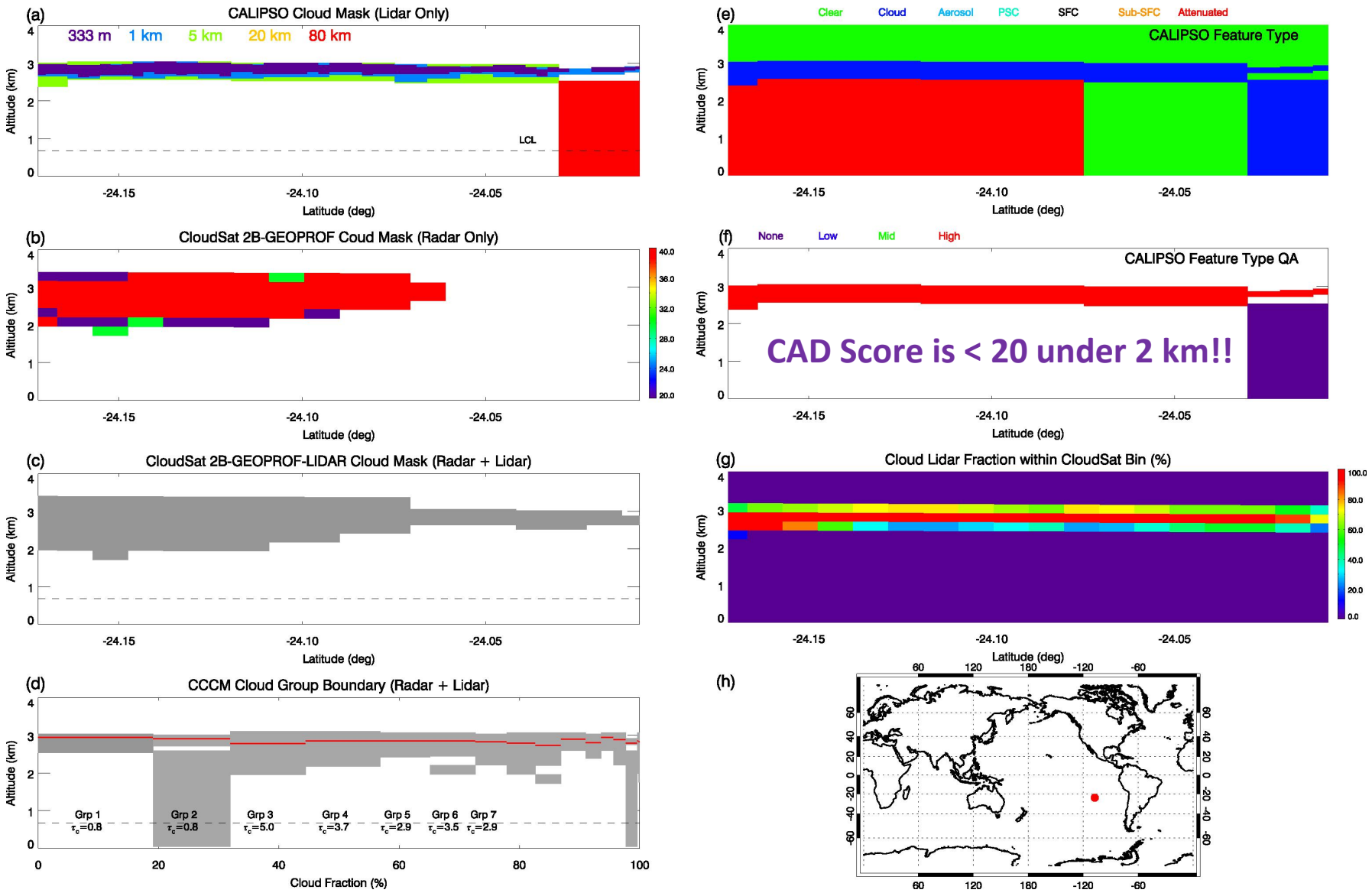


Cloud Occurrences (%) over Daytime Ocean Using Four-month Data (Feb/Apr/Jul/Oct 2010)

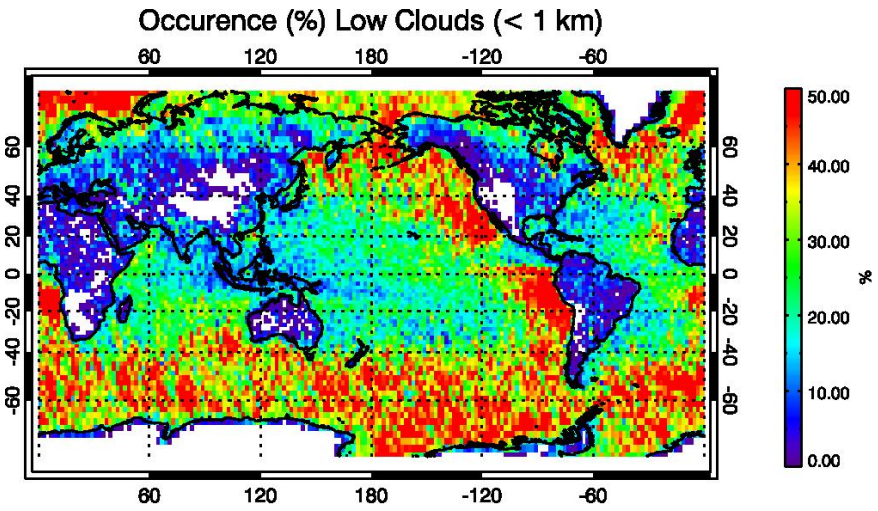
[GEOPROF-LIDAR] minus [CCCM]

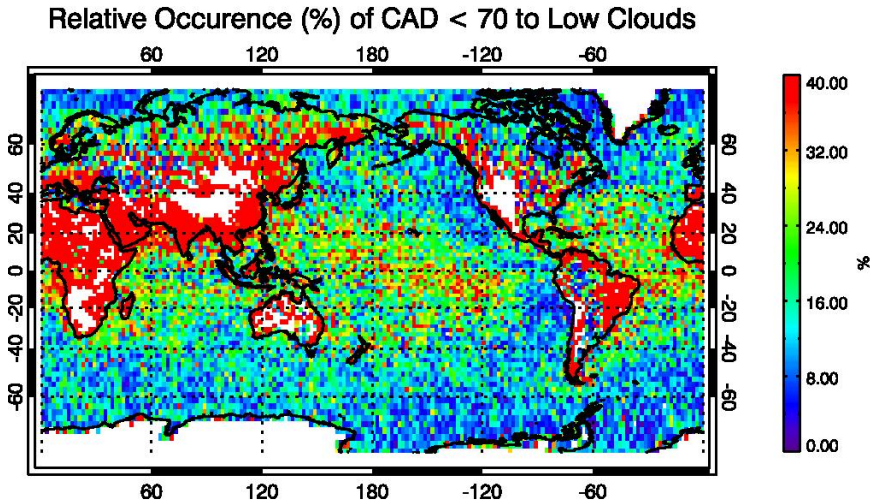


Case when CCCM has Low Clouds (< 2 km) but GEOPROF-LIDAR does not (related to low CAD score)

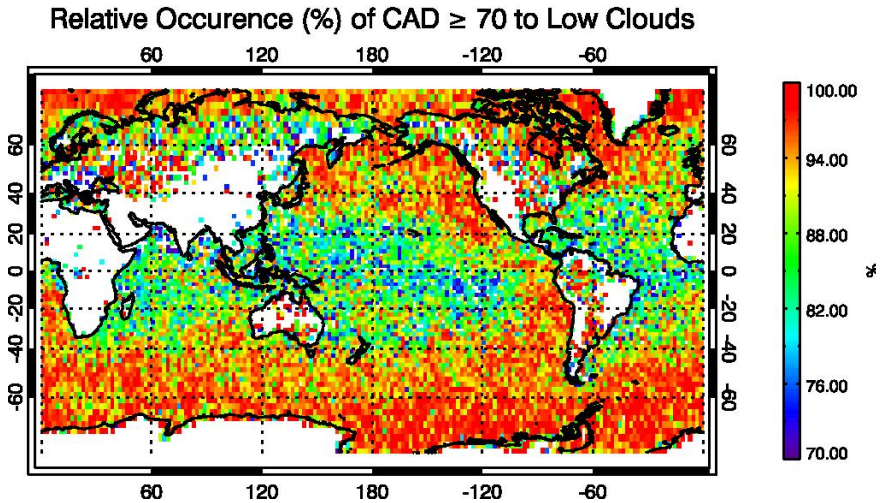


Occurrence of Low CAD Score below 1 km Altitude





Most of low CAD scores are distributed off-shore tropical ocean where absolute frequency of low-level clouds is pretty low.



Case When GEOPROF-LIDAR has Larger Cloud Occurrences than CCCM in High-Latitude Region