Surface Atmosphere Radiation Budget (SARB) working group update

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Earth Radiation Budget Workshop
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Boulder, Co

Work done after the spring 2018 CERES meeting

- Extended Ed4 EBAF-surface and SYN1deg through March 2018.
- Started MATCH aerosol processing with MODIS collection 6.1.
- Continue collaborating with GMAO in developing a new version of GEOS reanalysis for Ed5 CERES products.
- Estimated uncertainty in net surface and atmosphere irradiances.
- Evaluated Collection 6.1 MODIS aerosols.
- Estimated the effect of partly cloudy MODIS pixels to computed irradiances.
- Sea ice nadir view reflectance as a function of sea ice fraction.
- Continue revision C3M with new CALIPSO, CloudSat, CERES, and MODIS data.

Edition 4 EBAF-surface

- Uncertainty
  - Uncertainty in up and downward surface shortwave and longwave irradiances are estimated (Kato et al. 2018)
  - Error covariance matrix is needed to estimate net surface and atmosphere irradiance uncertainty
  - Uncertainty in irradiance differences between two time periods
- Plan for Ed 4.1
    - Revision is required due to MODIS calibration (6.7 and 8.6 μm channels) and aerosol issues

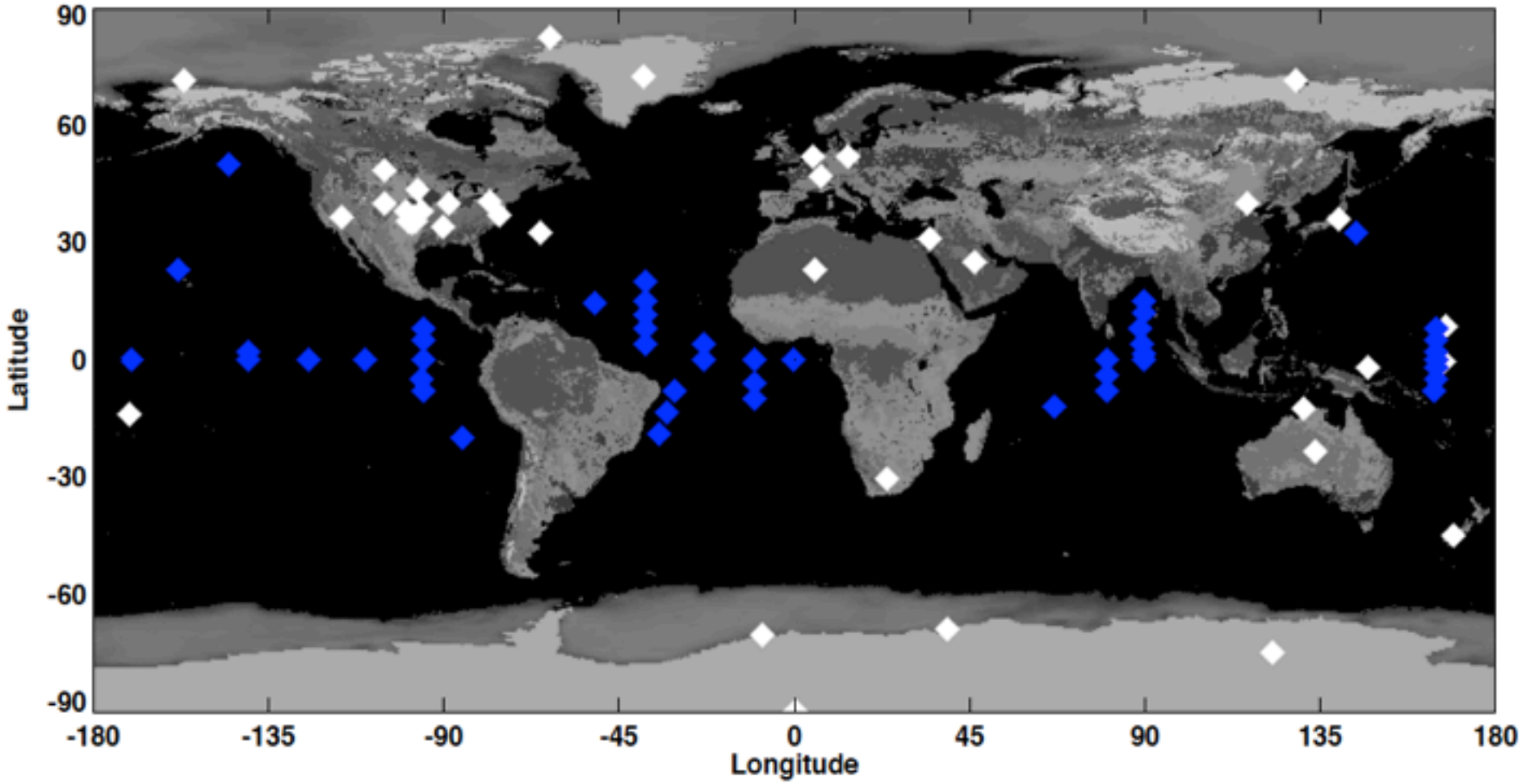
Satellite derived global annual mean energy fluxes

Flux[1]	Global mean (Wm^{-2})	Source
Surface net shortwave	164	Ed4 EBAF
Surface net longwave	-54	Ed4 EBAF
Latent heat fluxes = Precipitation	-78	GPCP version 2.3
Sensible heat	-23	SeaFlux, Princeton ET
Sum	9	
Ocean heating rate	Less than 1	0.68 Wm^{-2} + 0.03 Wm^{-2} (ice warming and melt + etc.)
Energy flux associated with mass (water) transfer	Less than 1	0.8 Wm^{-2} over ocean

[1]Fluxes are defined positive downward

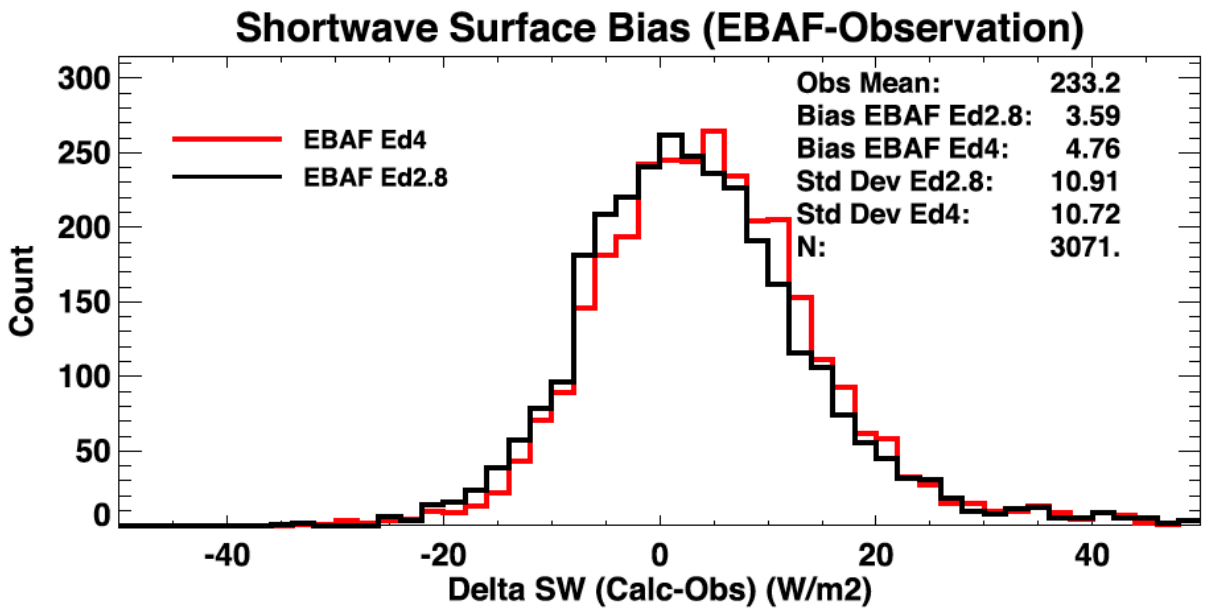
What is the uncertainty in net irradiance?

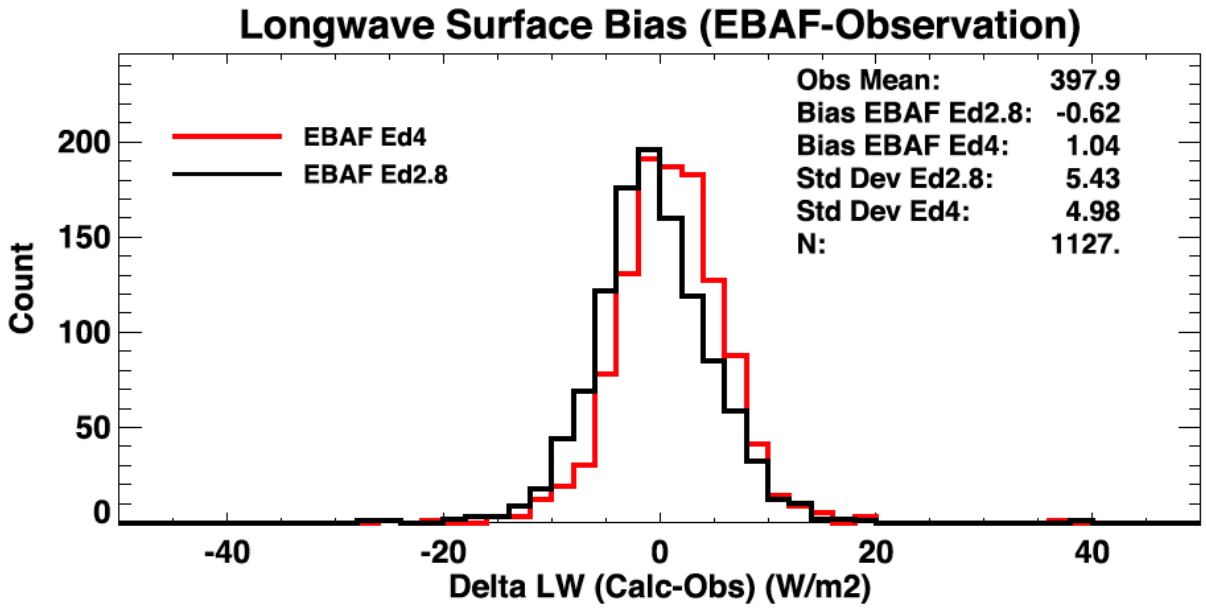
Surface validation sites



46 buoys (blue diamond) and 36 land surface sites (white diamond)

Validation of monthly mean downward surface irradiances over ocean





RMS difference is used for the uncertainty in monthly regional means

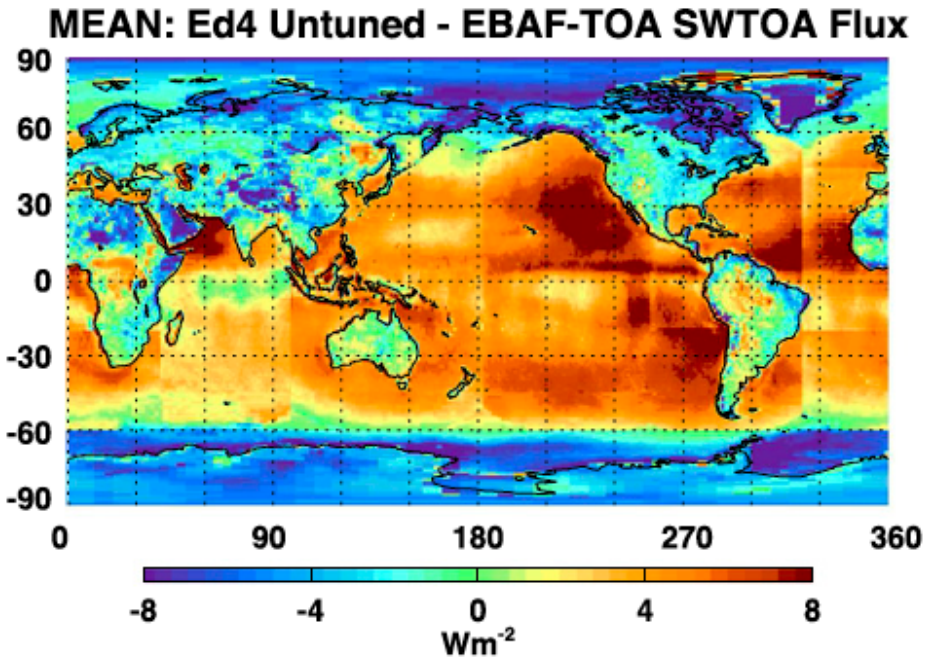
Downward irradiance uncertainty

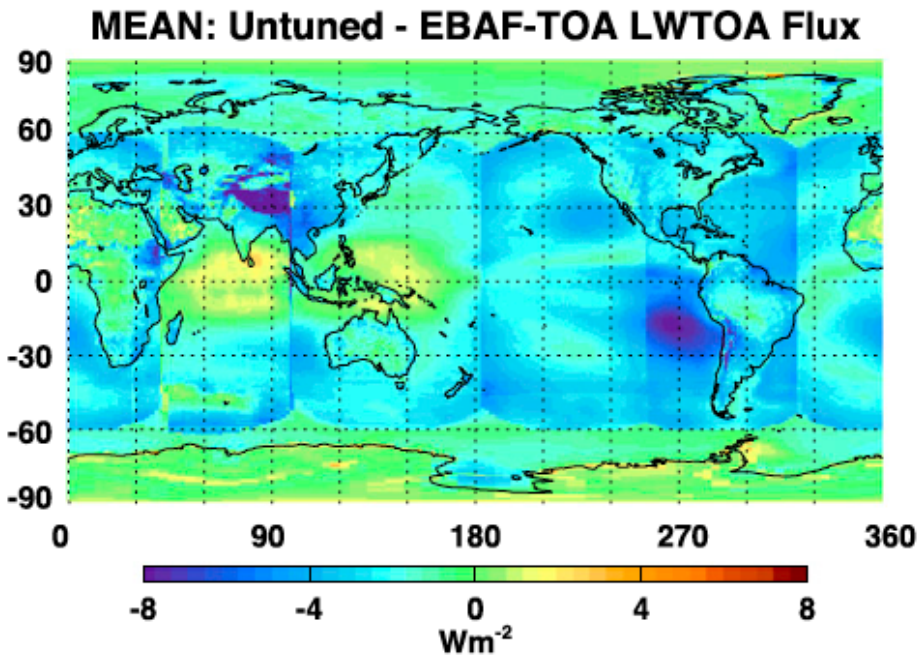
			Estimated uncertainty (Wm^{-2})			
		Mean irradiance	Monthly gridded	Monthly zonal	Monthly global	Annual global
Downward longwave	Ocean+Land	**345**	**7**	**6**	**5**	**5**
	Ocean	**364**	**5**	**5**	**5**	**5**
	Land	**333**	**10**	**9**	**5**	**5**
	Arctic	**183**	**12**	**-**	**-**	**-**
	Antarctic	**183**	**12**	**-**	**-**	**-**
Downward shortwave	Ocean+Land	**187**	**13**	**7**	**6**	**4**
	Ocean	**191**	**11**	**7**	**6**	**4**
	Land	**195**	**12**	**7**	**5**	**4**
	Arctic	**119**	**14**	**-**	**-**	**-**
	Antarctic	**119**	**21**	**-**	**-**	**-**

Upward irradiance uncertainty is estimated from bias errors in cloud fraction, surface skin temperature

Need to estimate the uncertainty in net irradiance

Error covariance estimated from surface irradiance adjustments in the EBAF-surface process





We adjust cloud, surface and atmospheric properties to match TOA irradiances.
We then use Jacobians to adjust surface irradiances.
Global annual mean adjustments are used to estimate error covariance

Uncertainty in surface net irradiance

	Downward (Wm^{-2})	Upward (Wm^{-2})	Correlation coefficient	Net uncertainty (Wm^{-2})
Shortwave	4	3	-0.29	5.7
Longwave	5	3	-0.36	6.7
SW+LW	5.7	6.7	0.26	9.8

$$x = u \pm v$$

$$uncertainty(\mathrm{x}) = V(u) + V(v) \pm 2Cov(u,v) = V(u) + V(v) \pm 2r(u,v)S(u)S(v)$$

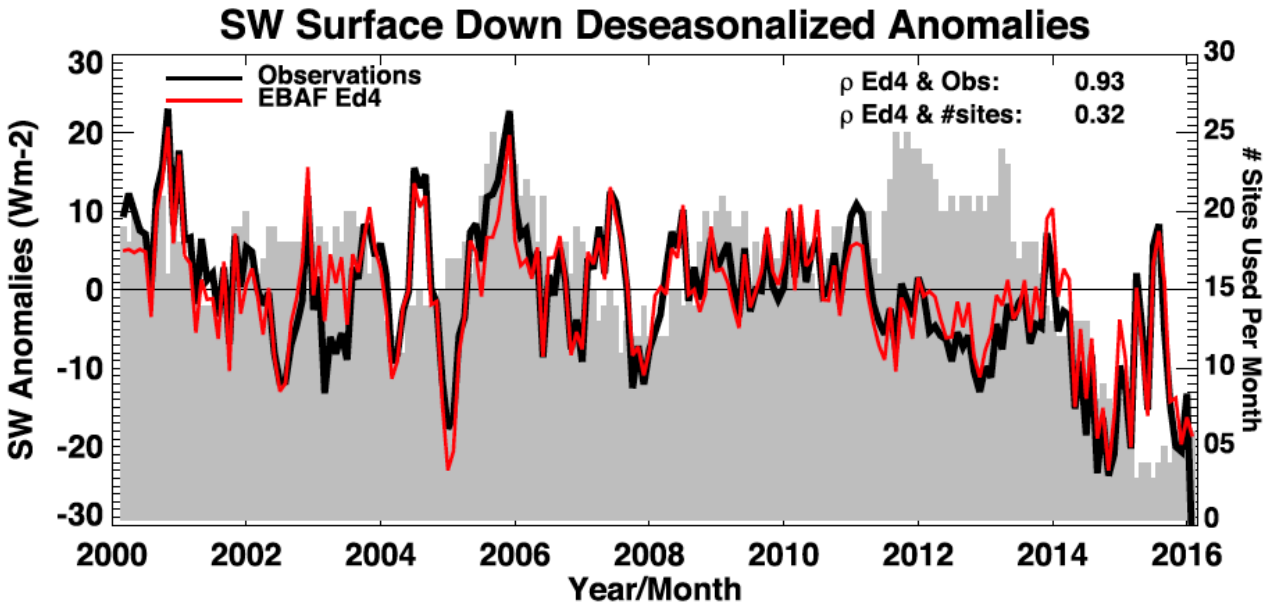
V: Variance
Cov: Covariance
S: Standard deviation
r: Correlation coefficient (estimated from surface irradiance adjustments)

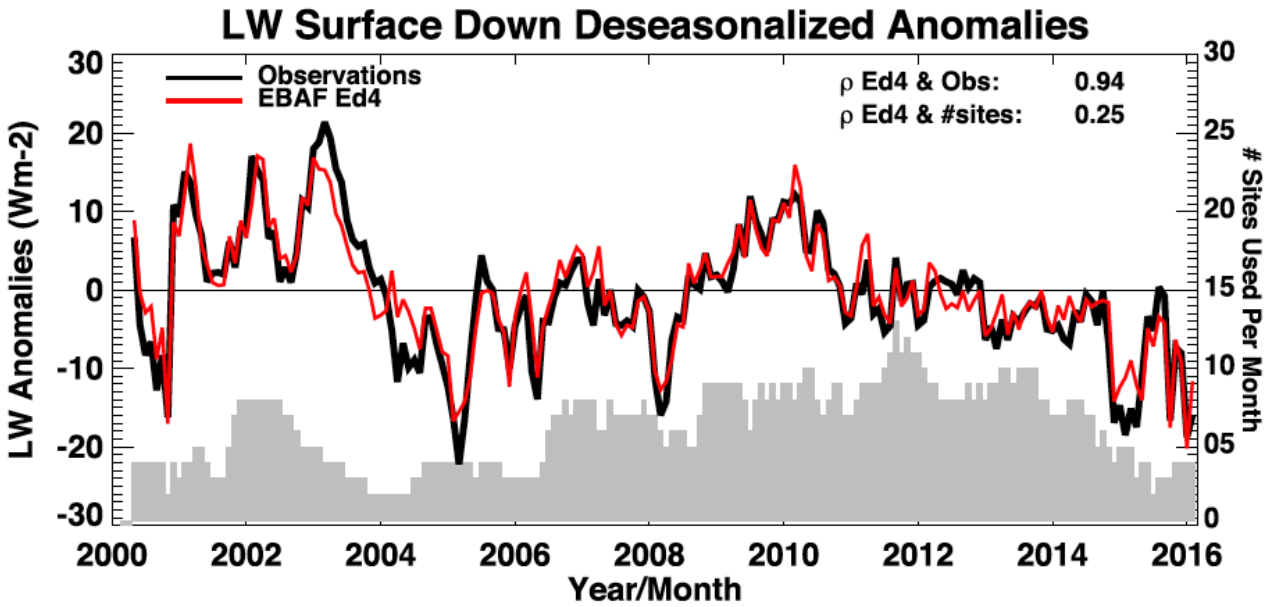
When the uncertainty is estimated by including error correlation, the uncertainty is larger than the uncertainty computed with independent error assumption (7.7 Wm^{-2})

Uncertainty in global mean precipitation is 9% (Adler et al. 2012), which is about 7 Wm-2.

- Relatively large uncertainty exists in net surface irradiance.
- How much does the uncertainty in mean irradiances affect the uncertainty in estimating irradiance change?
- Uncertainty in irradiance anomalies and uncertainty in detecting surface irradiance change.

Anomaly time series comparison





What is the uncertainty in estimating downward irradiance change?

Uncertainty in detecting surface irradiance change from the difference of surface irradiances averaged over two time periods

The error in the downward shortwave or longwave irradiance difference from two time periods is

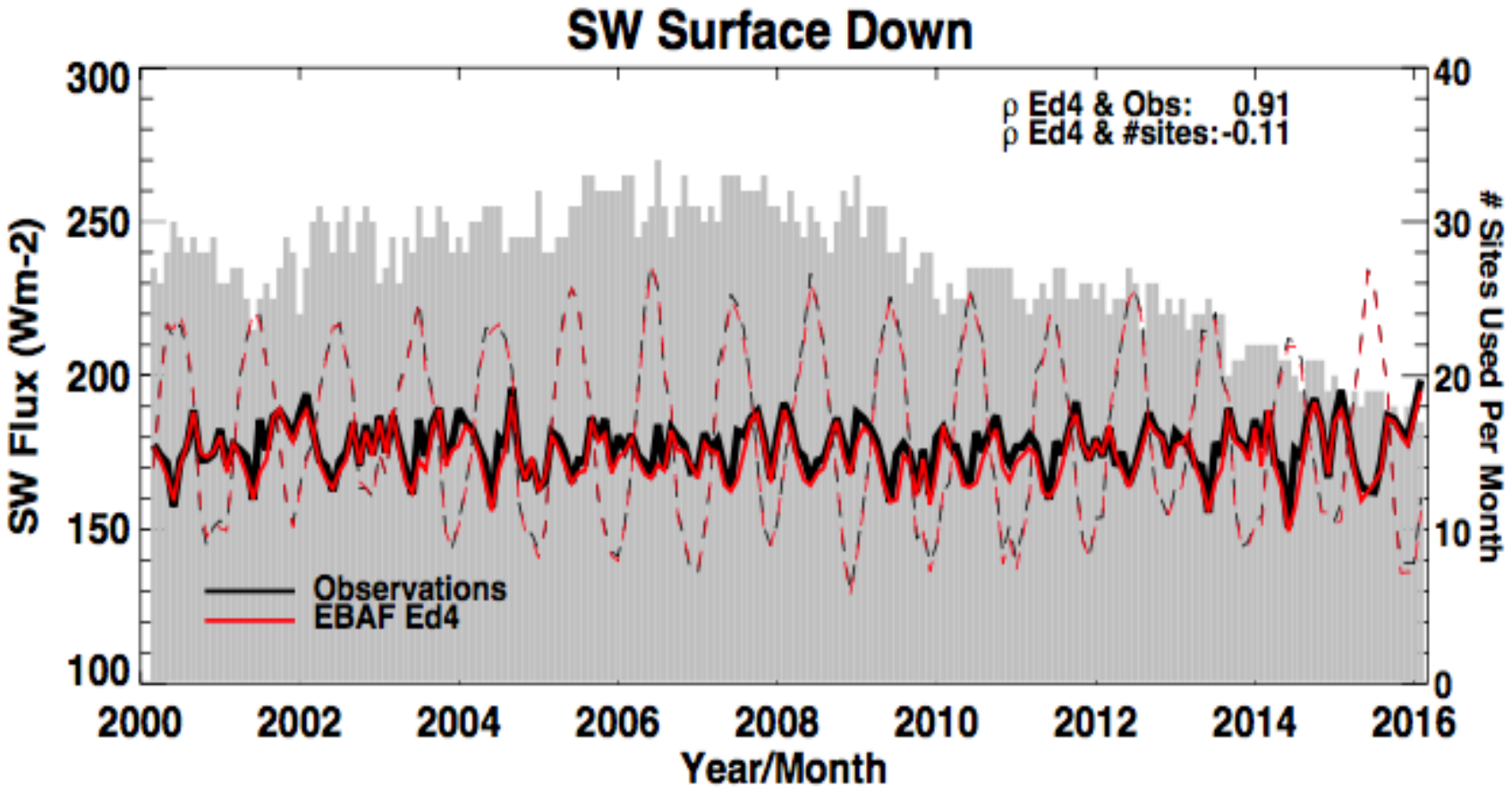
$$\Delta F=(1/N_2 \sum N_2 F_{comp} - 1/N_1 \sum N_1 F_{comp})-(1/N_2 \sum N_2 F_{obs} - 1/N_1 \sum N_1 F_{obs})$$

Rewriting this

$$\Delta F=(1/N_2 \sum N_2 F_{comp} - F_{obs})-(1/N_1 \sum N_1 F_{comp} - F_{obs})$$

Compute standard deviation of ΔF

Time series of computed (red) and observed (black) downward shortwave irradiance averaged over 36 sites over lands



$$\Delta F = (1/N_2 \sum N_2 \uparrow F_{comp} - 1/N_1 \sum N_1 \uparrow F_{comp}) - (1/N_2 \sum N_2 \uparrow F_{obs} - 1/N_1 \sum N_1 \uparrow F_{obs})$$

192 months are available

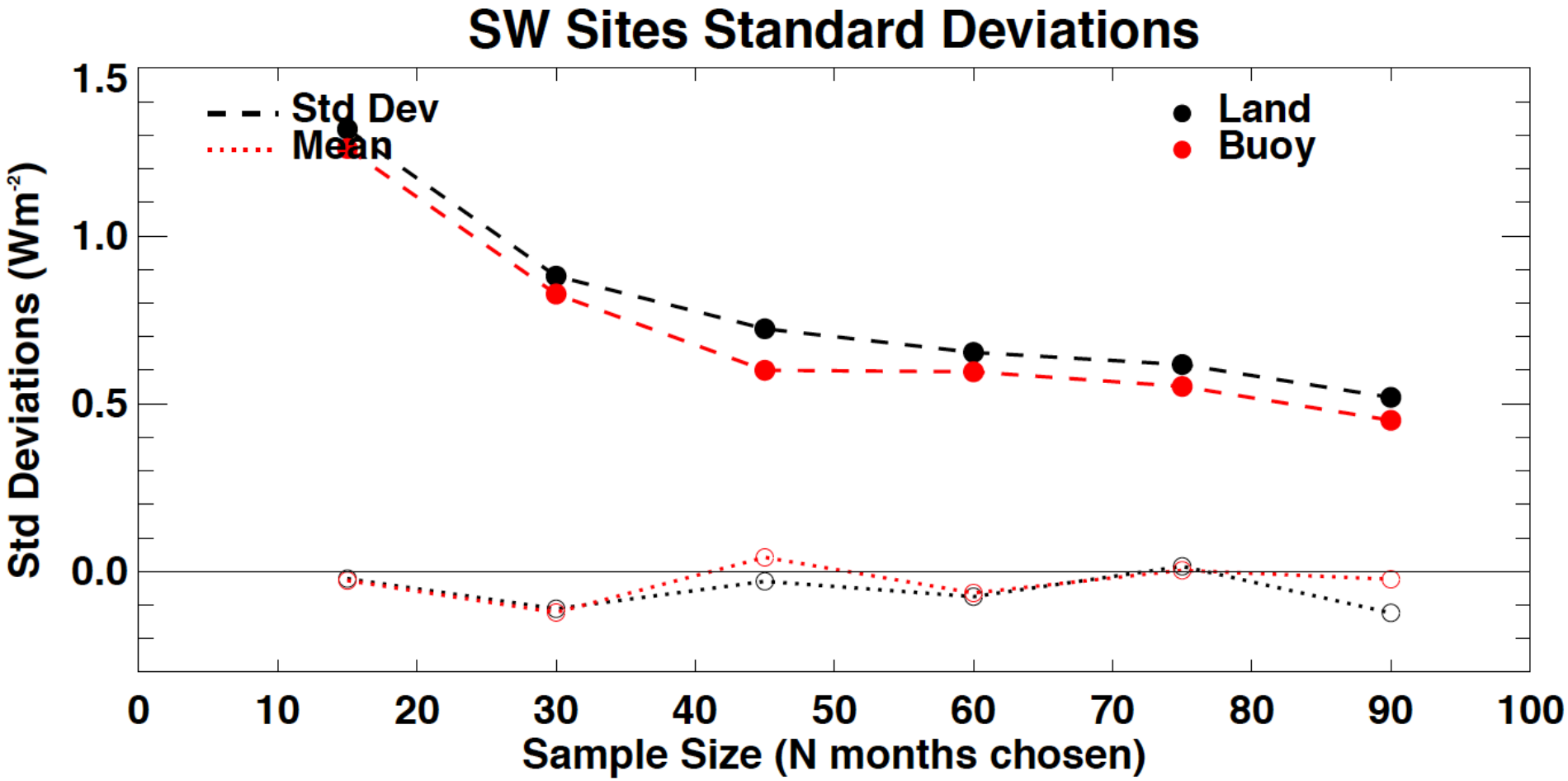
Randomly select N1 observed and computed irradiances

Randomly select N2 observed and computed irradiances from remaining 192 – N1 months.

Compute ΔF

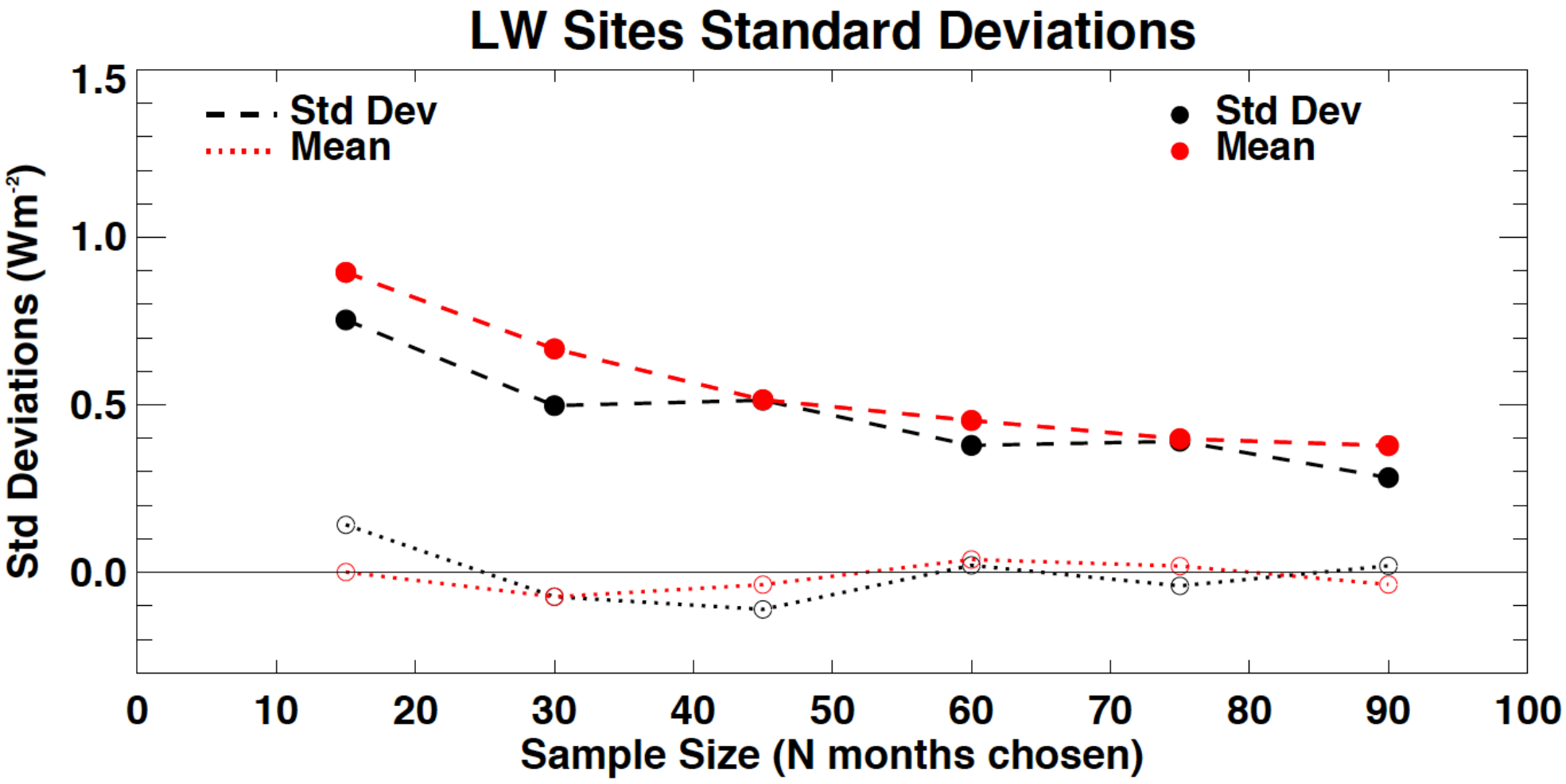
Repeat 100 times and compute standard deviation of ΔF

Downward shortwave irradiance change



$$\Delta F = (1/N_2 \sum N_2 \uparrow F_{comp} - 1/N_1 \sum N_1 \uparrow F_{comp}) - (1/N_2 \sum N_2 \uparrow F_{obs} - 1/N_1 \sum N_1 \uparrow F_{obs})$$

Downward longwave irradiance change

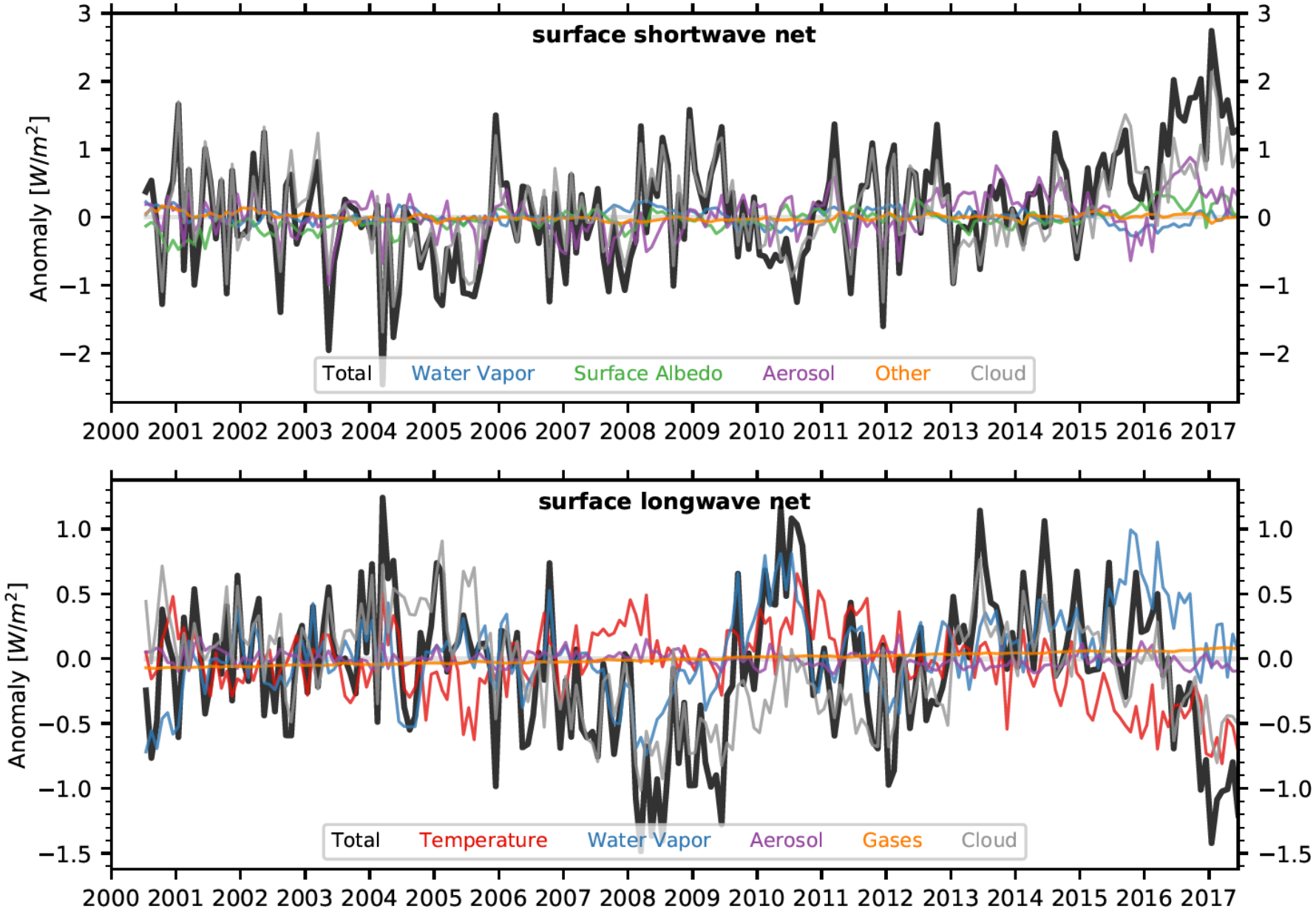


$$\Delta F = (1/N_2 \sum N_2 \uparrow F_{comp} - 1/N_1 \sum N_1 \uparrow F_{comp}) - (1/N_2 \sum N_2 \uparrow F_{obs} - 1/N_1 \sum N_1 \uparrow F_{obs})$$

Summary: uncertainty

- Even when the uncertainty in the global annual mean downward shortwave and longwave irradiances is, respectively, 4 Wm^{-2} and 5 Wm^{-2}, the uncertainty in the difference of downward irradiances from two time periods is about one order of magnitude smaller.
- According to the IPCC report (WG1AR5, Hartmann et al. 2013), the carbon dioxide concentration is increasing with the rate about 2 ppm per year or 20 ppm per 10 years.
- Increasing the carbon dioxide concentration from 360 ppm to 600 ppm increases the surface downward longwave irradiance about 1 Wm^{-2}.
- This gives about 0.08 Wm^{-2} surface downward longwave irradiance change caused by an increase of the carbon dioxide concentration by 20 ppm(i.e. 0.08 Wm^{-2} increase per decade).
- It takes about 50 years for the signal (not including feedback) to become greater than the uncertainty in downward longwave.

Contribution to anomalies



Thorsen et al. (2018)

Issues affecting edition 4.0 EBAF-surface

- Large changes occur in polar night cloud fraction after March 2016 due to MOIDS instrument issues
- A bug in MODIS aerosol algorithm causes large difference in the aerosol optical thickness over land between collection 5 and collection 6.1.
- These problems do not affect observed TOA irradiances, but affect computed surface irradiances.
- Edition 4 EBAF-surface is available from march 2000 through March 2018.
- Edition 4.1 EBAF-surface will replace Ed4 for the entire record in spring 2019.

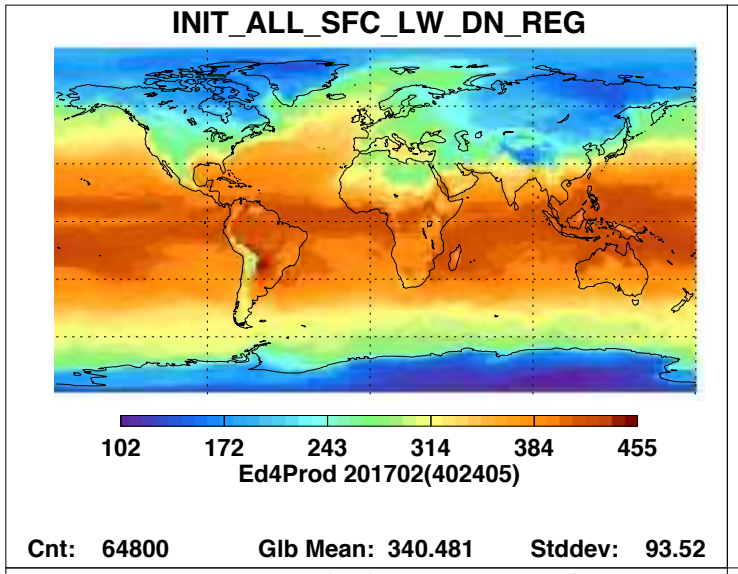
Polar nighttime cloud issue

Maximum surface downward longwave irradiance changes for February 2017

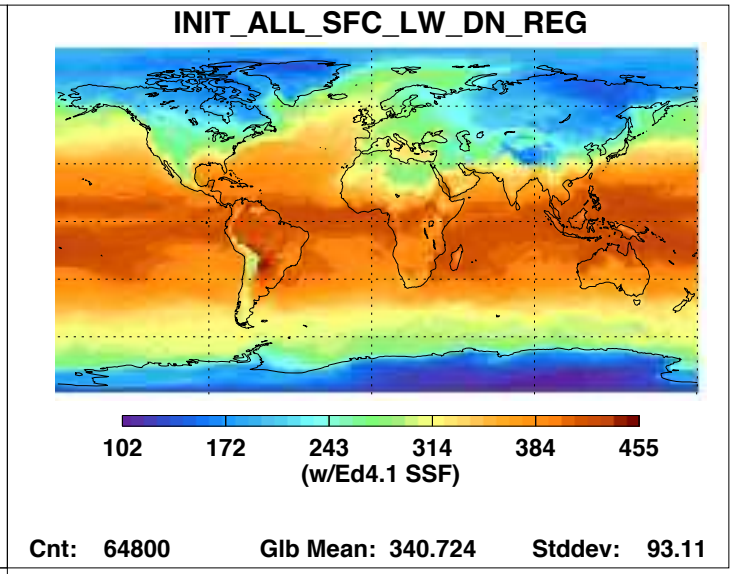
Actual changes between Ed4 and Ed4.1 EBAF-surface is smaller

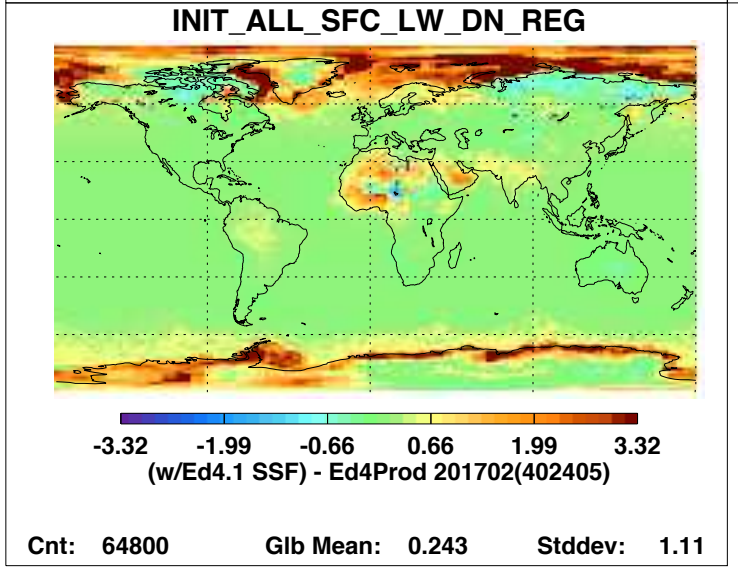
Trade off between best cloud properties at any given time vs. continuity with no significant artifacts

With collection 5



With collection 6.1



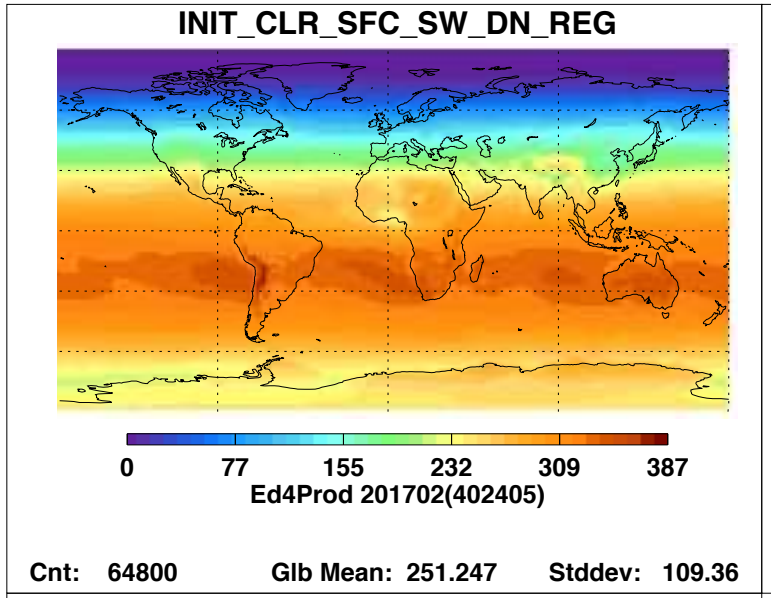


Aerosol issue

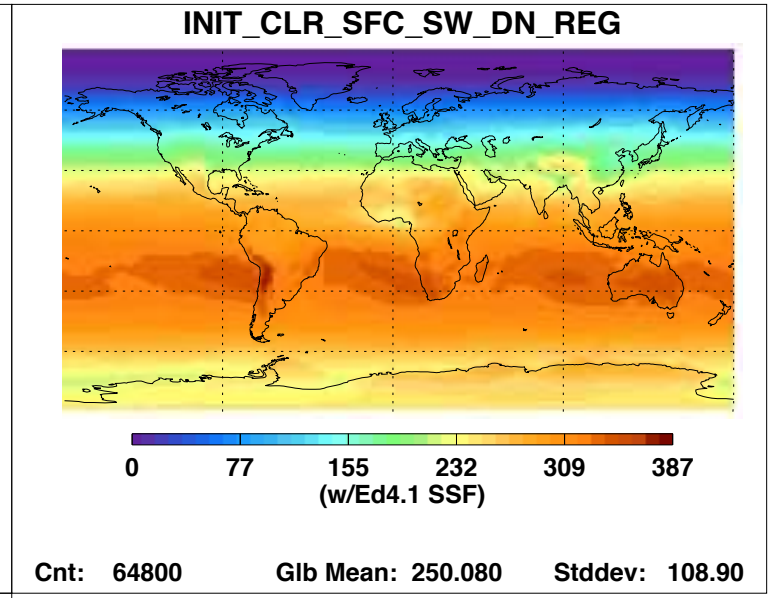
Collection 6.1 aerosol optical depth is approximately 10% larger than Collection 5 aerosol optical depth

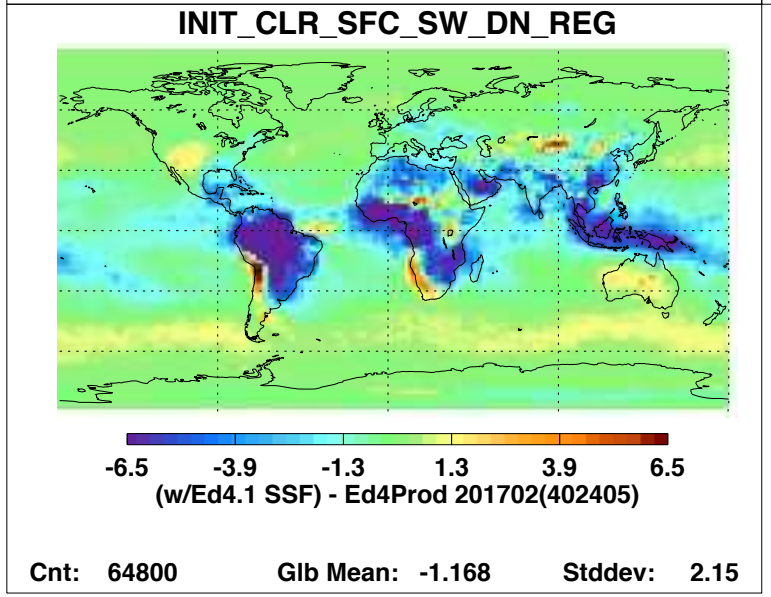
Clear-sky downward shortwave irradiance difference for February 2017

With collection 5



With collection 6.1





Edition 4.1 EBAF-surface

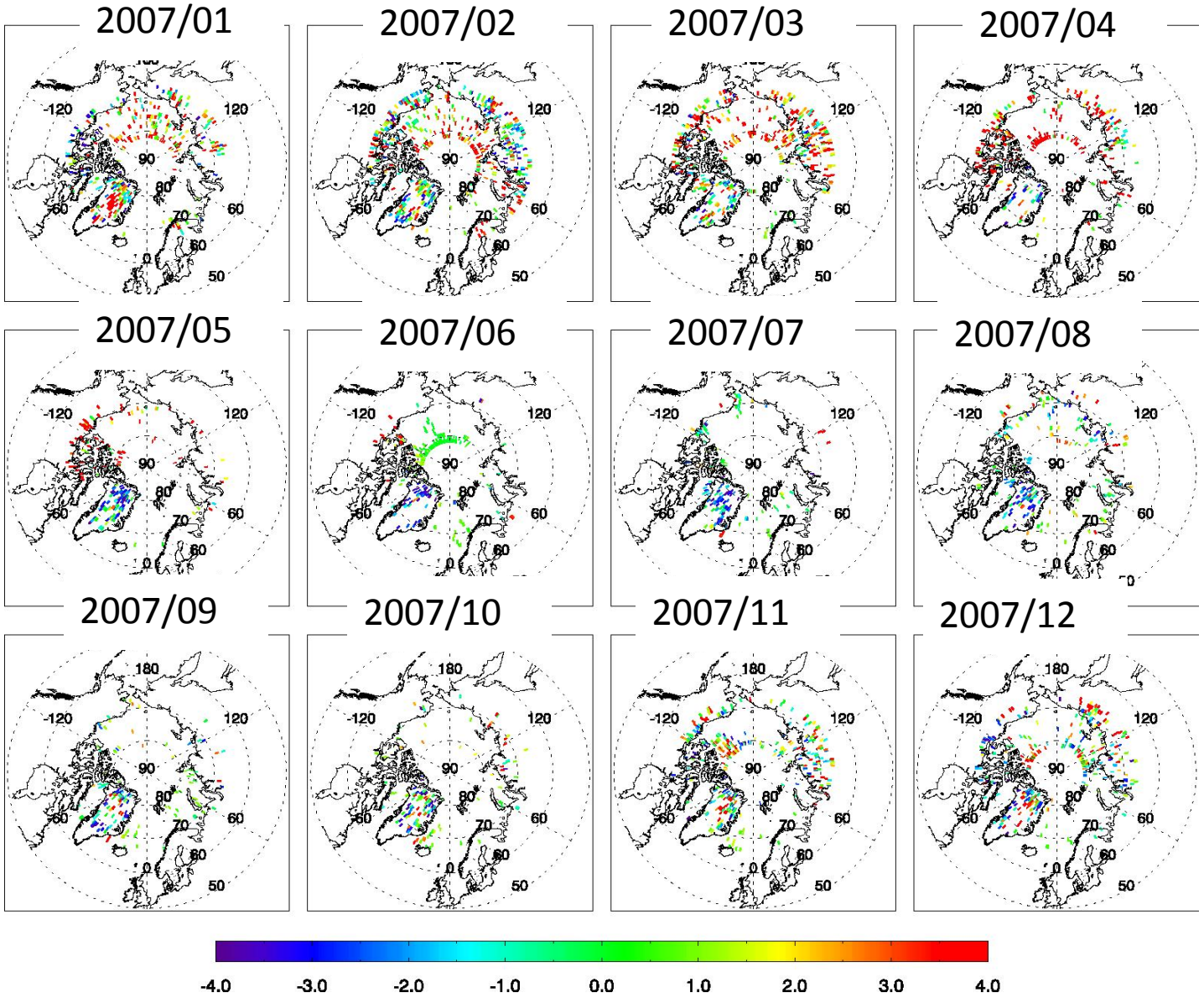
- Nighttime polar cloud fraction bias correction is applied from January 2008 through February 2016 to correct Terra cloud fraction. No correction is applied to Terra after March 2016 (when SSF is processed with MODIS Collection 6.1).
- New Himawari 8 clouds is processed with correct input including corrected collocation of IR and VIS from July 2015.
- MODIS collection 6.1 aerosol optical thickness (and new surface albedo history map) is used for the entire time period.

Results from CERES-GMAO collaboration

- Polar surface skin temperature
  - Compare MODIS derived skin temperature and GEOS skin temperature
  - MODIS skin temperatures are derived when CALIPSO and CloudSat do not detect clouds
  - Cases when GEOS reanalyses have clouds are excluded

Geographical Distribution of ΔT_s over the Arctic when Both CALIPSO-CloudSat (CC) and GMAO Indicate Clear

GOES-5.4.1 minus MODIS Ed4



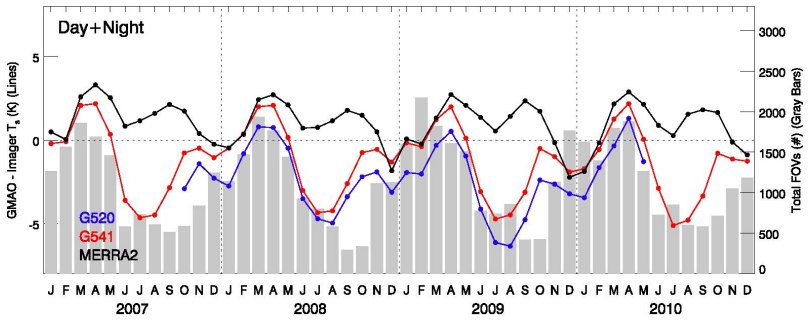
Skin Temperature Comparison Over The Arctic When CC cloud fraction = 0%

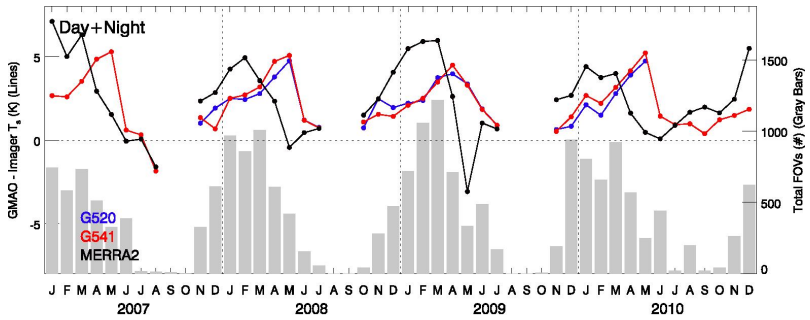
Greenland + snow over land

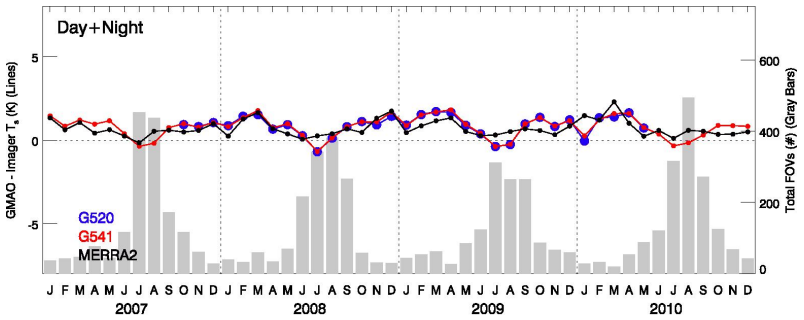
Sea Ice

Open water

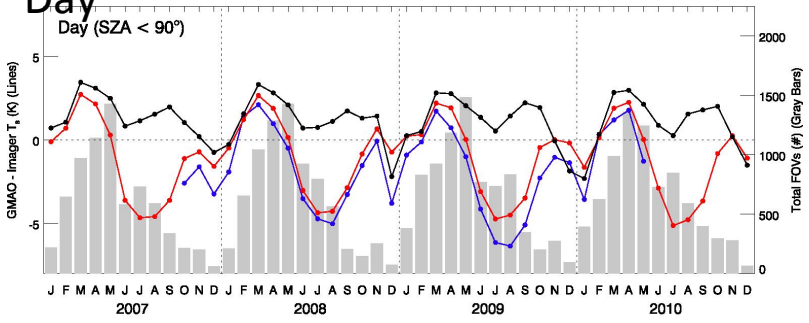
Day+Night

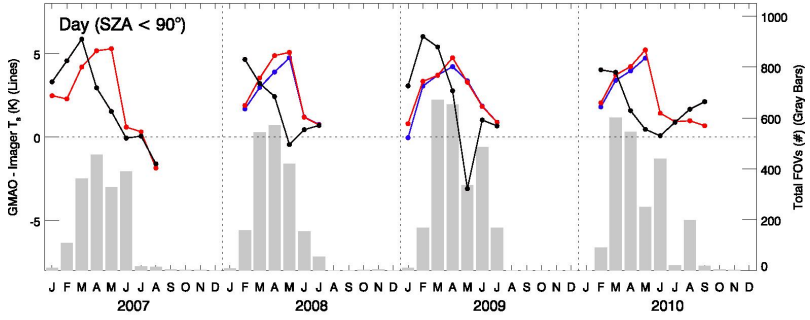


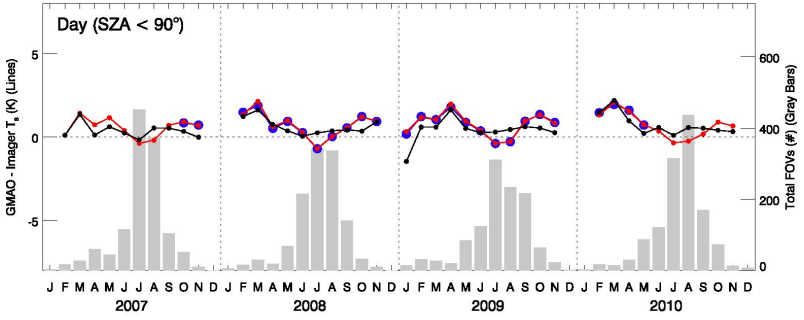




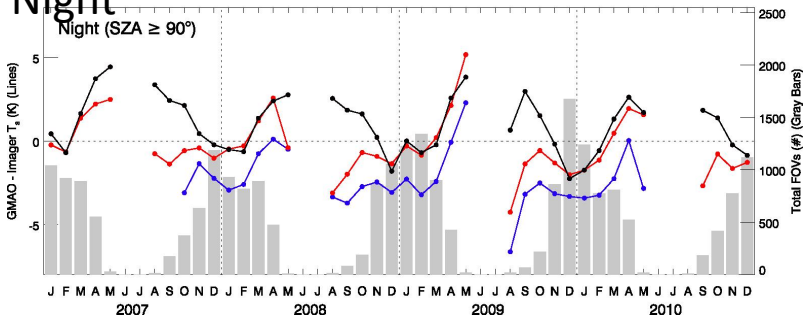
Day

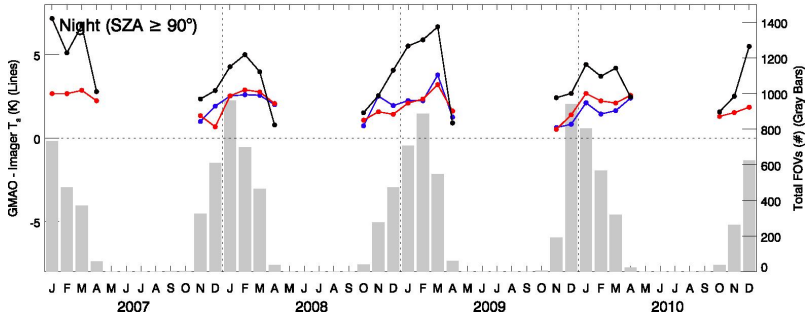


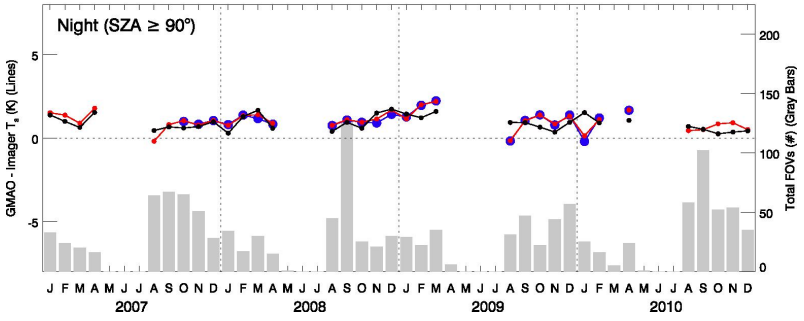




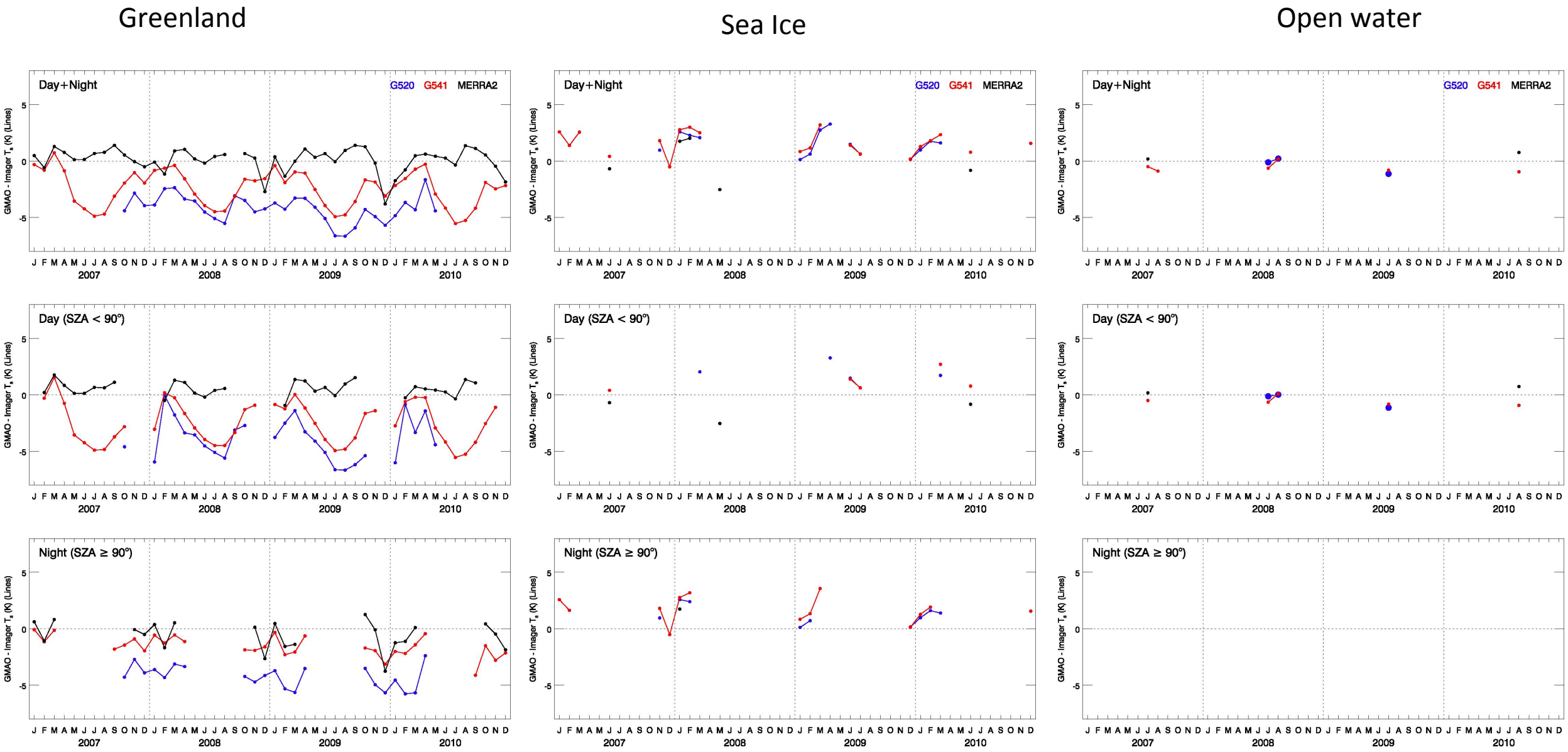
Night



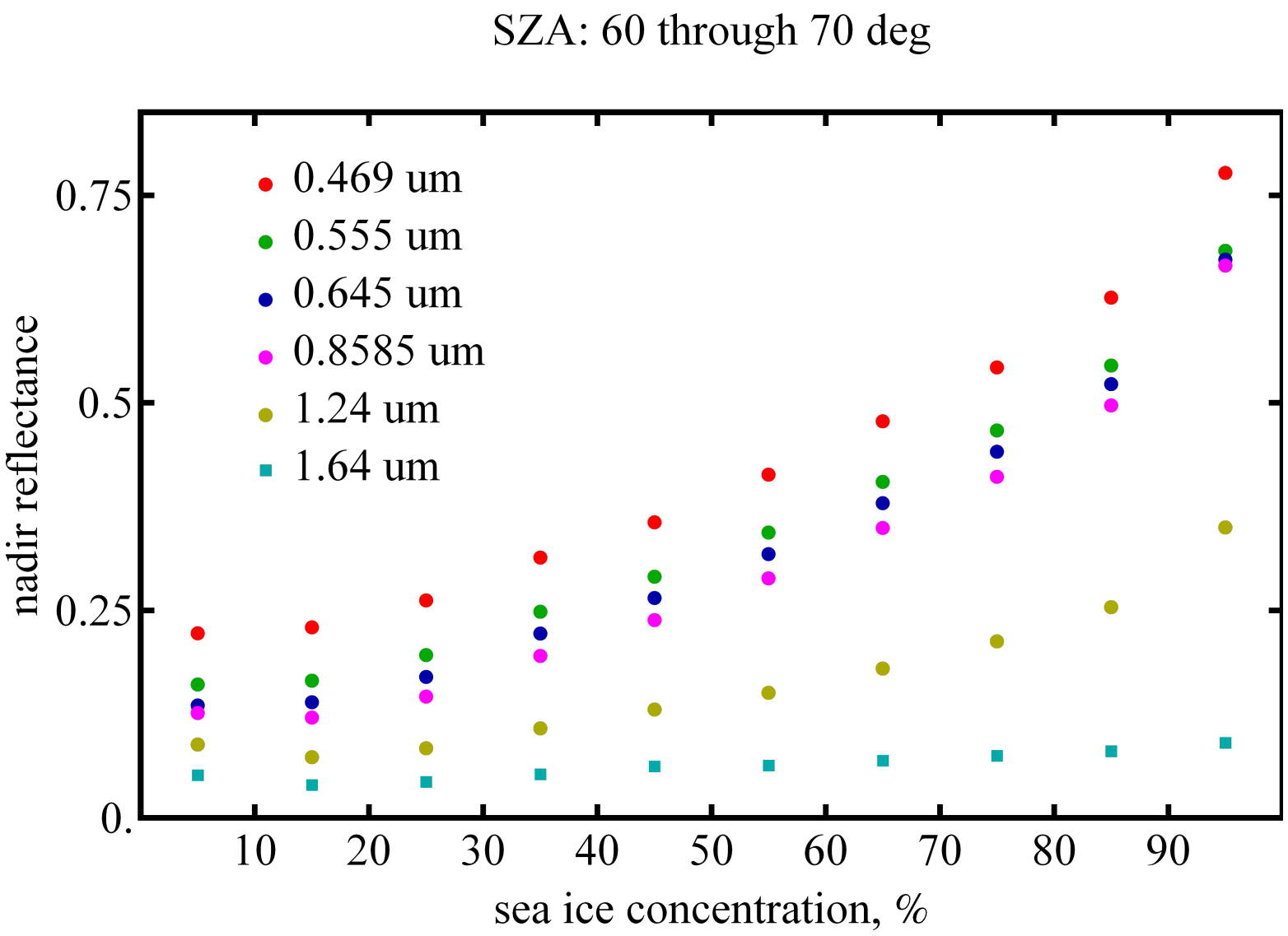




Skin Temperature Comparison Over The Arctic When CC cloud fraction = 0% and GMAO cloud fraction = 0%



Sea ice reflectance as a function of sea ice fraction



Summary

- Ed 4.0 EBAF-surface is released through March 2018.
- Ed 4.1 EBAF-surface will replace Ed4 in spring 2019.
  - Clear-sky irradiances and nighttime polar longwave irradiances are affected
- The uncertainty in the difference of downward irradiance averaged over two time periods is one order magnitude smaller than the uncertainty in the downward irradiance.
- An improvement of surface skin temperature in polar regions are expected in the next generation of GMAO-CERES reanalysis

List of publications

- Kato, S., F. G. Rose, S.-H., D. A. Rutan, A. Radkevich, T. E. Caldwell, S. Sun-Mack, W. F. Miller, and Y. Chen, 2018: Radiative heating rate computed with clouds derived from satellite based passive and active sensors and their effects on generation of available potential energy, submitted to *JGR-Atmosphere*.
- Ham, S.-H., S. Kato, and F. G. Rose, 2018: Impacts of Partly Cloudy Pixels on Shortwave Broadband Irradiance Computations, submitted to Journal of *Atmospheric and Oceanic Technology*.
- Thorsen, T. J., S. Kato, N. G. Loeb, and F. G. Rose, 2018: Observation-based decomposition of radiative perturbations and radiative kernels, submitted to *J Climate*.
- Radkevich, A., 2018: Modified geometric truncation of the scattering phase function, *Journal of Quantitative Spectroscopy & Radiative Transfer 217 (2018) 155–169.*
- Chen, X., X. Huang, X. Dong, B. Xi, E. Dolinar, N. G. Loeb, S. Kato, P. Stackhouse, M. G. Bosilovich, 2018: Using AIRS and ARM SGP clear-sky observations to evaluate meteorological reanalyses: a hyperspectral radiance closure approach, submitted to *JGR-Atmosphere*.
- Saito, M., P. Yang, N. G. Loeb, and S. Kato, 2018: A parameterization of surface snow albedo based on two-layer snow model in conjunction with a mixture of grain habits, to be submitted to Journal of the Atmospheric Sciences.

Surface and atmosphere net anomalies