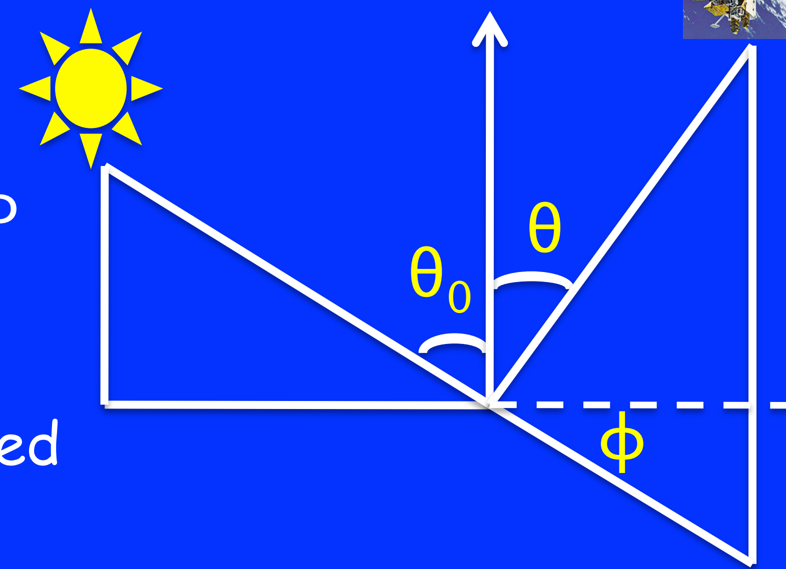
CERES Angular Distribution Model Working Group Report

Wenying Su
Wenying.Su-1@nasa.gov
NASA LaRC, Hampton VA

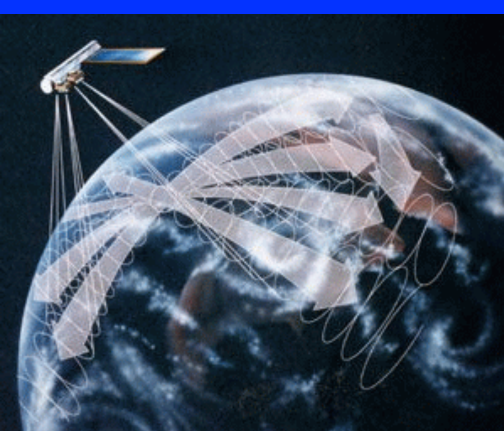
Joseph Corbett Lusheng Liang
Hailan Wang Zachary Eitzen
SSAI, Hampton VA

From radiance to flux: angular distribution models



- Sort observed radiances into angular bins over different scene types;
- Integrate radiance over all θ and ϕ to estimate the anisotropic factor for each scene type;
- Apply anisotropic factor to observed radiance to derive TOA flux;

$$R(\theta_0, \theta, \phi) = \frac{\pi \hat{I}(\theta_0, \theta, \phi)}{\int_0^{2\pi} \int_0^{\frac{\pi}{2}} \hat{I}(\theta_0, \theta, \phi) cos\theta sin\theta d\theta d\phi} = \frac{\pi \hat{I}(\theta_0, \theta, \phi)}{\hat{F}(\theta_0)}$$



$$F(\theta_0) = \frac{\pi I_o(\theta_0, \theta, \phi)}{R(\theta_0, \theta, \phi)}$$

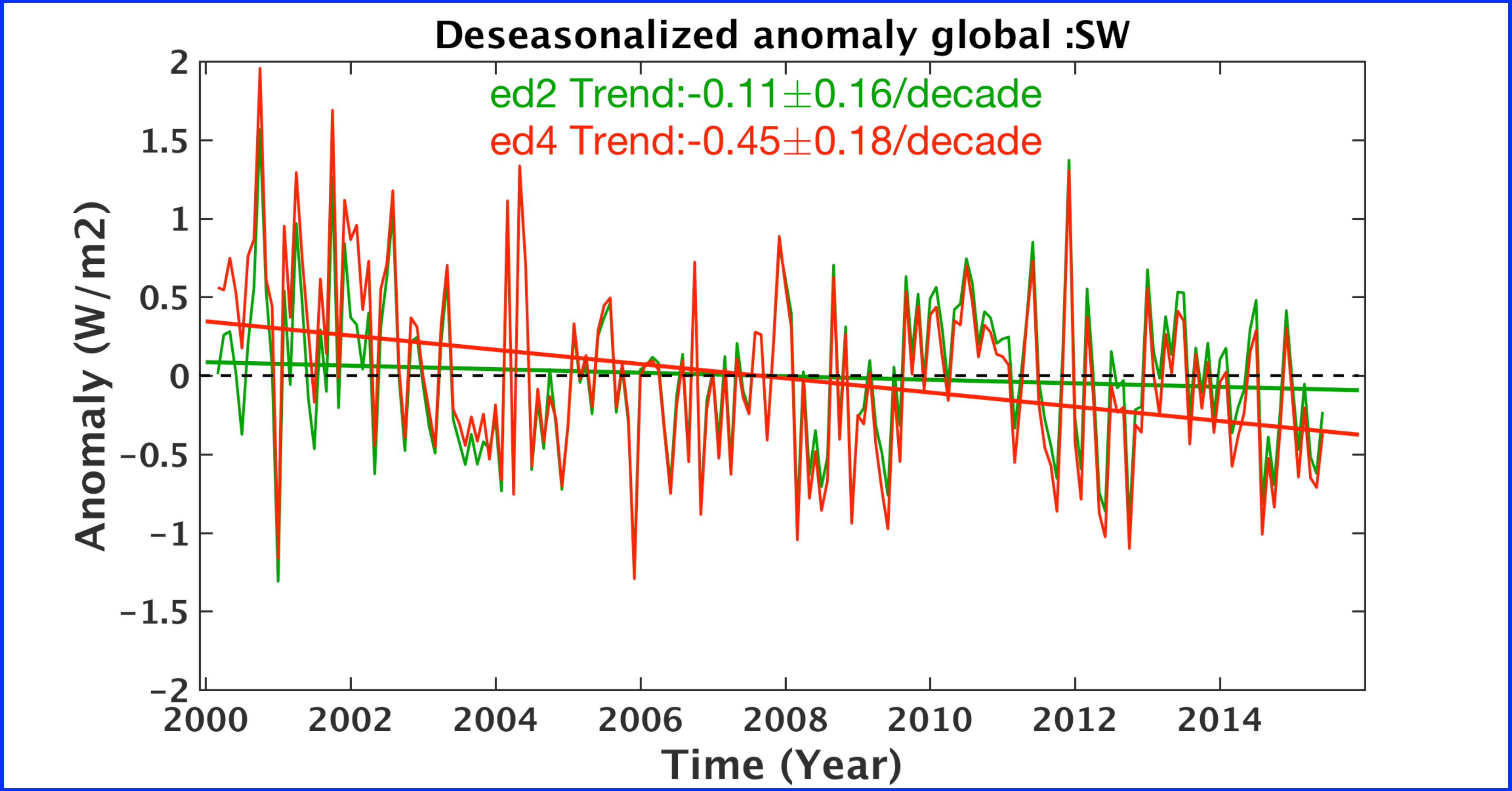
Improvements in the Ed4 Angular Distribution Models (ADMs)

- Developed the aerosol-dependent SW ADMs over clear ocean;
- Used Ross-Li kernels to develop SW ADMs over clear land;
- Accounted for the effects of sastrugi on clear-sky SW ADMs over Antarctica;
- Implemented a sea ice brightness classification scheme to discriminate different types of sea ice, and developed cloud optical depth dependent SW ADMs for overcast sea ice scenes;
- Included additional surface temperature bins for clear-sky LW ADMs;
- Replaced the polynomial fit between pseudo-radiance and radiance with the mean radiance over cloudy land/desert/ocean;
- Adopted the pseudo-radiance method for cloudy snow/ice scenes.

Future Plans

- Account for inhomogeneity of clouds (using standard deviation of cloud optical depth within the CERES footprint) when developing ADMs over cloudy scenes;
- Consider more phase separations for mixed phase clouds (mostly water, water-ice, mostly ice, etc.);
- Examine if it is necessary to develop ADMs for single-layer and multi-layer clouds separately;
- Account for sastrugi for clear and partly-cloudy ADMs over Greenland and Antarctic;
- Replace snow/ice data from NSIDC with snow/ice data of climate data quality;
- Investigate better ways to identify fresh snow and possibly including snow depth in developing fresh snow ADMs;
- Investigate if solar zenith angle and azimuth angle need to be considered for clear-sky daytime LW ADMs.

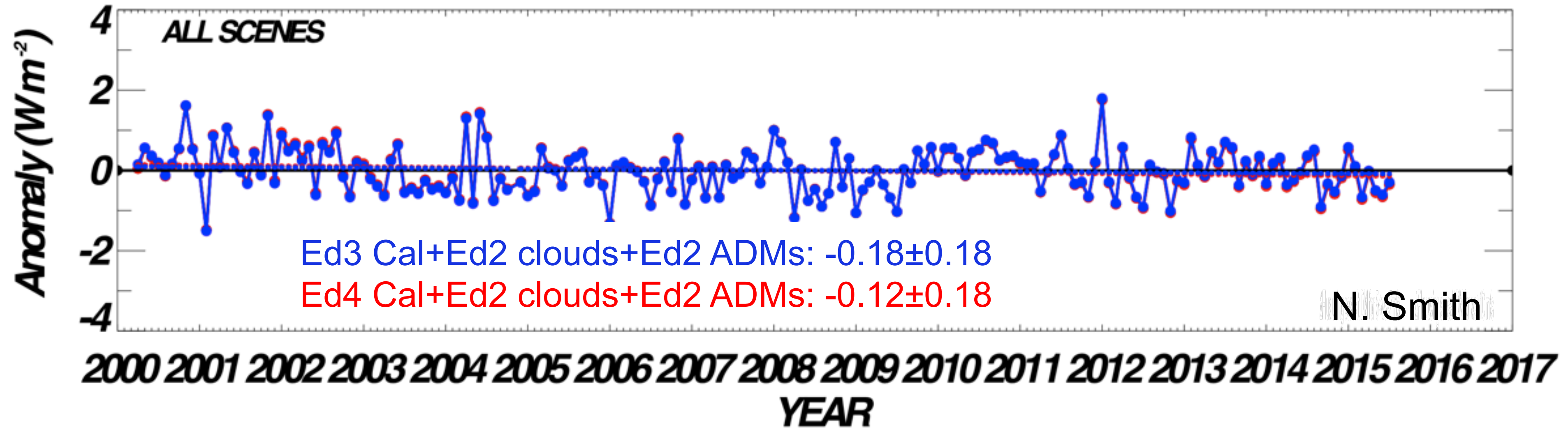
Global all-sky TOA SW flux from EBAF2.8 and EBAF4.0 (2000/03-2015/06)



- TOA all-sky SW flux from EBAF2.8 shows a small and non-significant decreasing trend of -0.11±0.16 Wm^{-2} per decade.
- TOA all-sky SW flux from EBAF4.0 shows a statistically significant decreasing trend of -0.45±0.18 Wm^{-2} per decade.

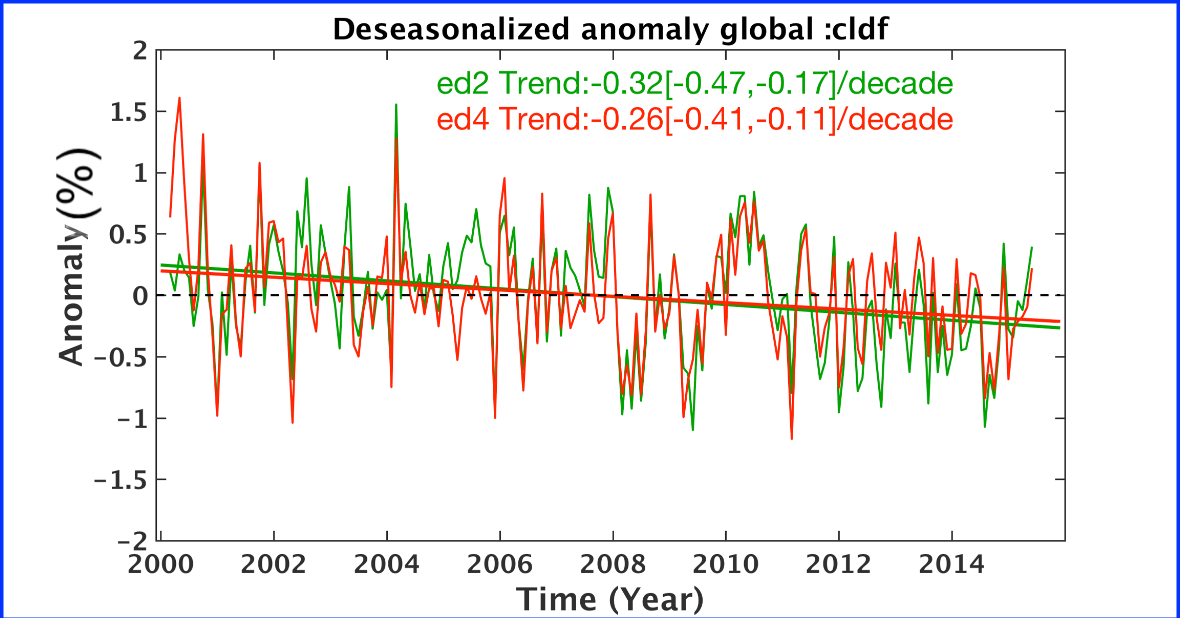
Why the SW flux trends in EBAF2.8 and EBAF4.0 are different?

- Calibration differences between Ed3 and Ed4
  - Comparisons of SW flux trends calculated using Ed3 Calibration + Ed2 Clouds + Ed2 ADMs with Ed4 Calibration + Ed2 Clouds + Ed2 ADMs show little difference → Ed3 versus Ed4 calibration difference is not the cause;

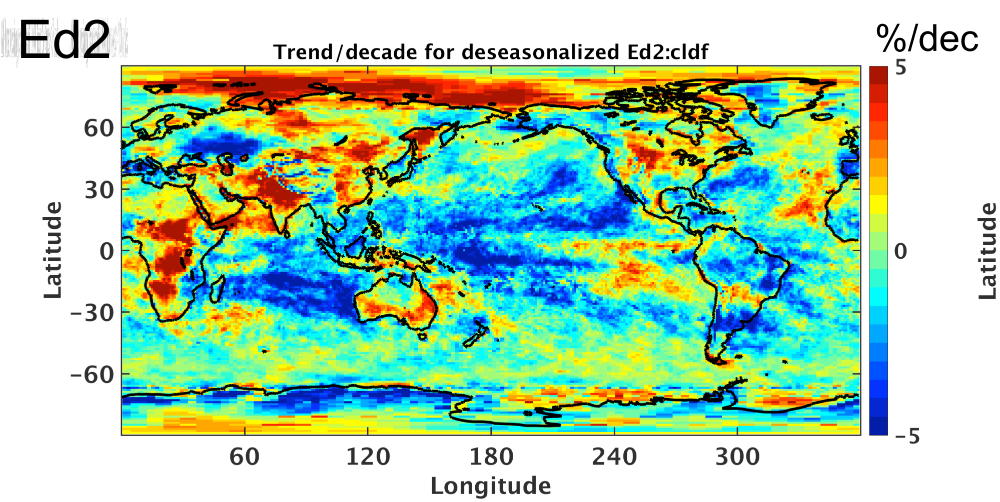


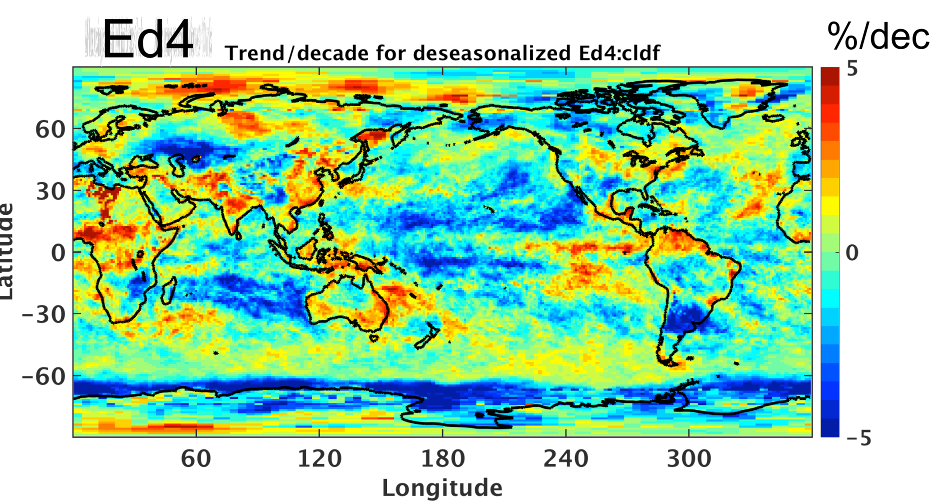
- Cloud retrieval and ADM differences between Ed3 and Ed4
- Diurnal correction difference between Ed2.8 and Ed4.0 is not addressed here

Daytime cloud fraction trend (%/decade): Terra 2000/03-2015/06

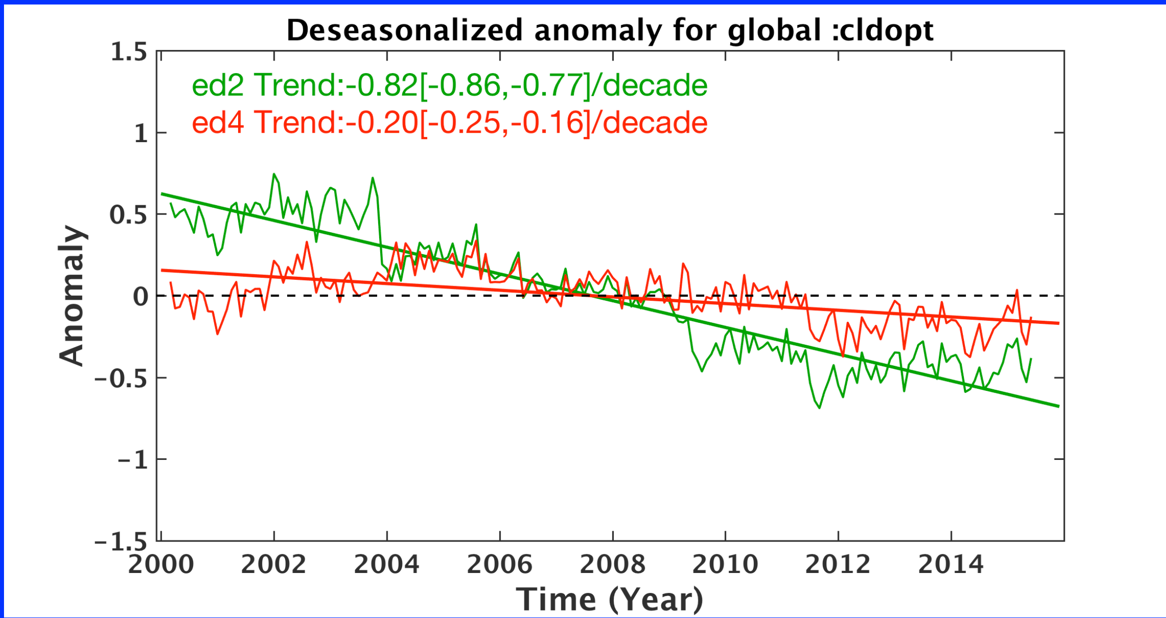


cldf	Ed2	Ed4
90-60N	1.31	-0.04
60-30N	0.10	-0.07
30-0N	-0.42	-0.07
0-30S	-0.83	-0.37
30-60S	-0.45	-0.04
60-90S	-0.50	-1.88

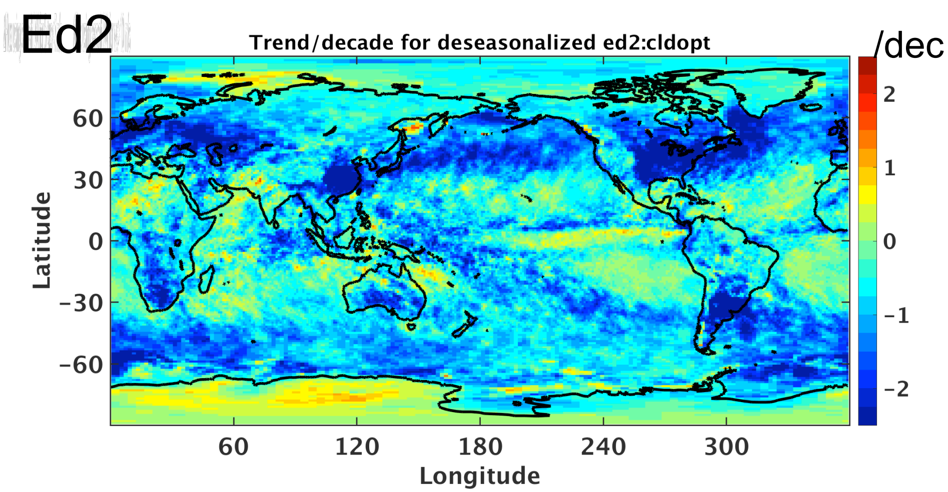


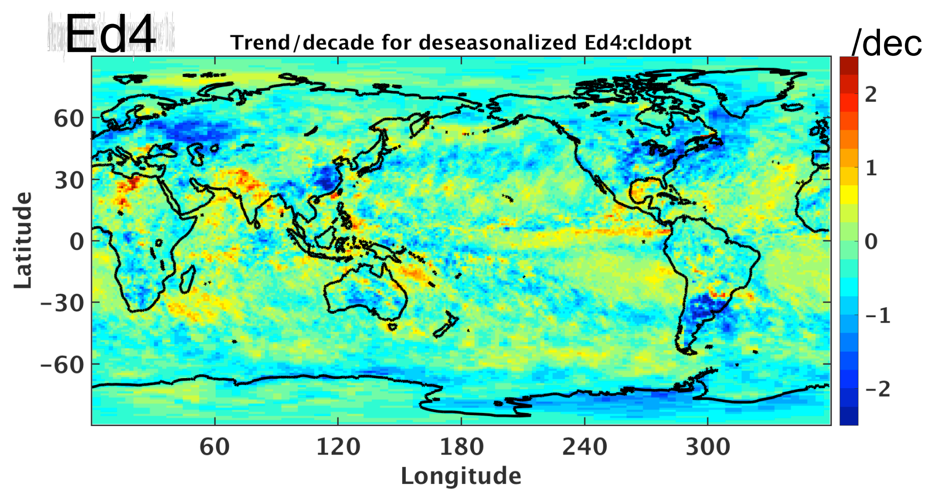


Daytime cloud optical depth trend (per decade): Terra 2000/03-2015/06



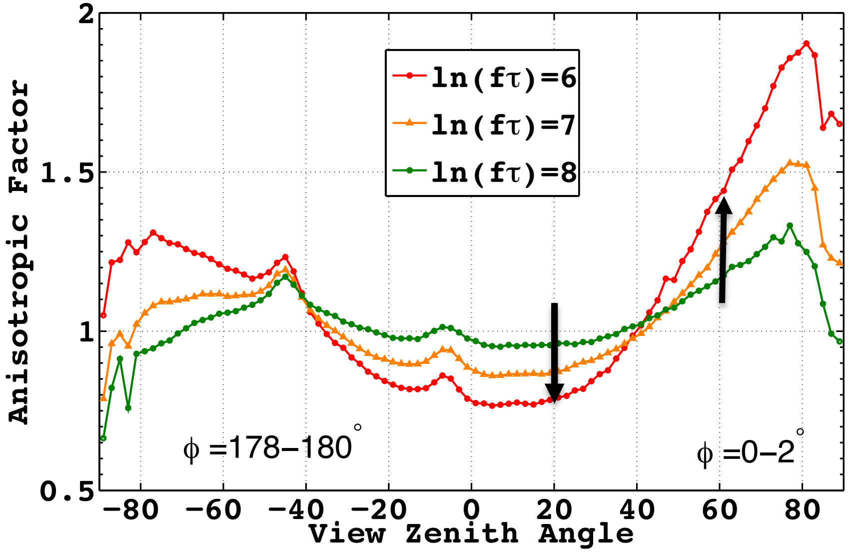
cldtau	Ed2	Ed4
90-60N	-0.58	-0.36
60-30N	-1.38	-0.42
30-0N	-0.60	-0.03
0-30S	-0.59	-0.08
30-60S	-1.05	-0.24
60-90S	-0.57	-0.49



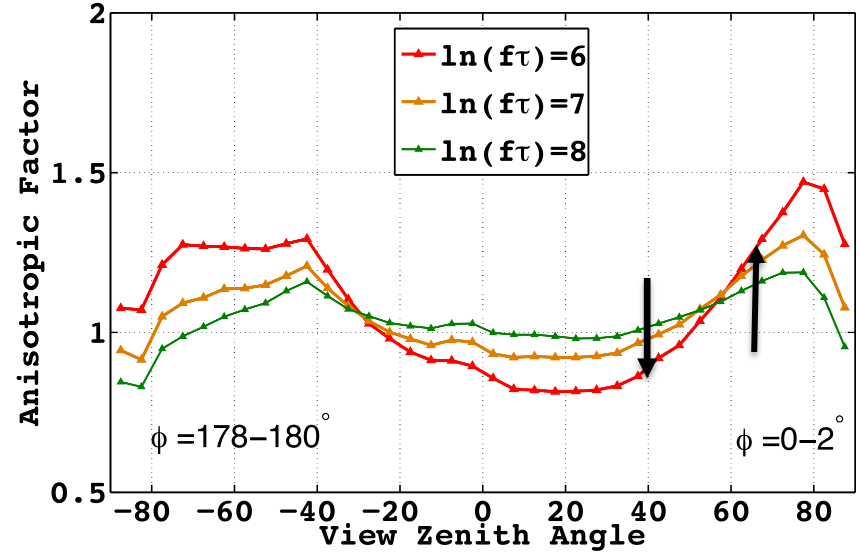


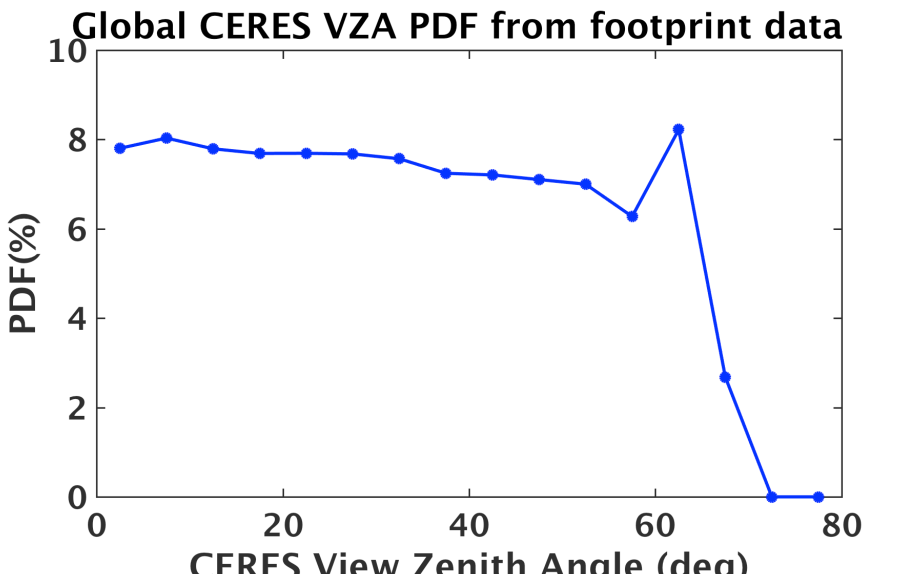
Anisotropic factors are sensitive to cloud optical depth

Liquid clouds over ocean at SZA=45



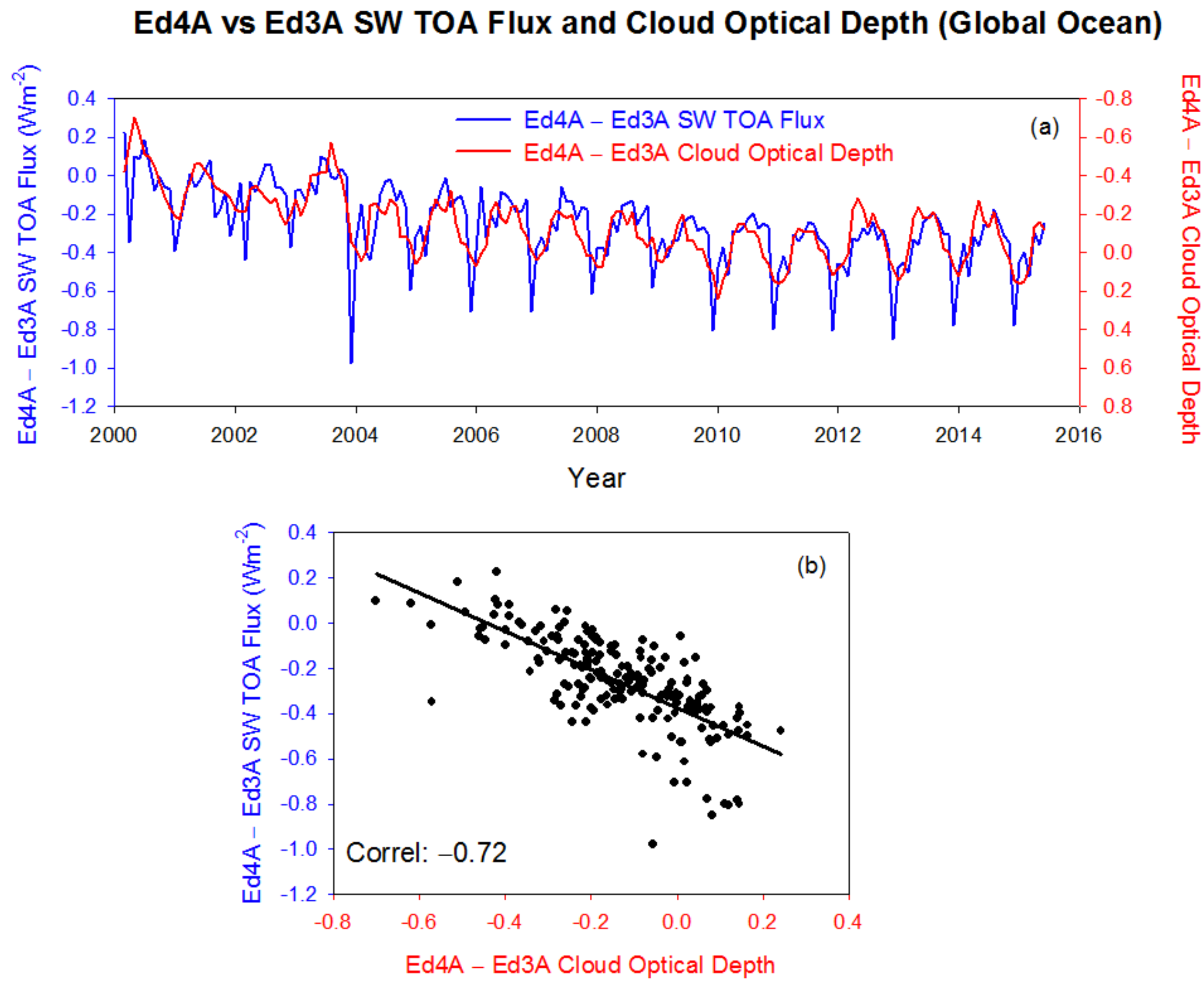
Liquid clouds over land at SZA=45





- SW anisotropy factors for thinner clouds are smaller than thicker clouds for VZA<40~50°, and larger for oblique views;
- There are more CERES footprints with VZA<40° than with VZA>40°;
- The net effect is that SW flux increases as cloud optical depth decreases.

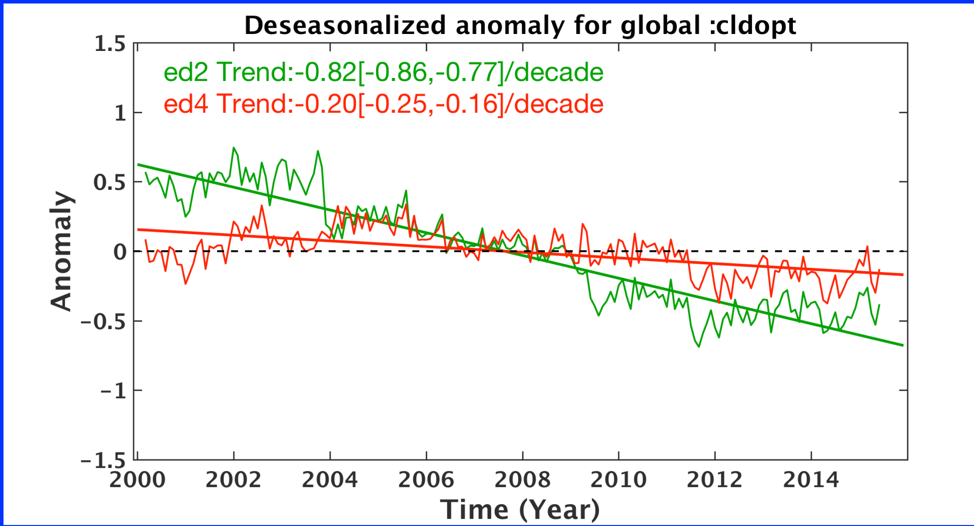
Flux differences between SSF1deg Ed4A and SSF1deg Ed3A are anti-correlated with the cloud optical depth differences

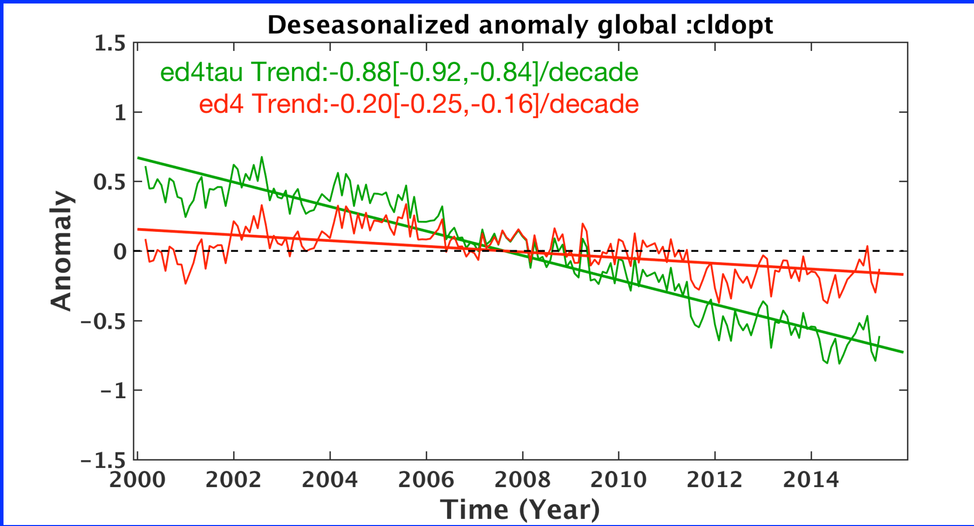


Loeb et al. (2017)

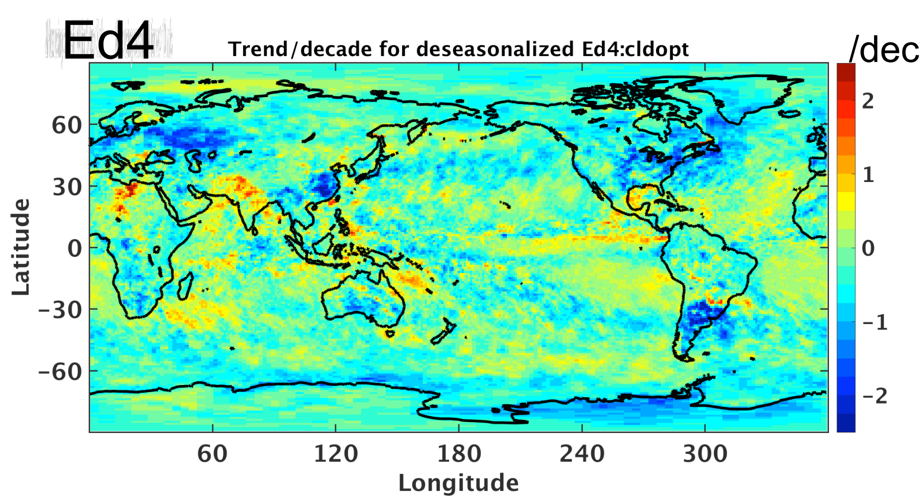
Are TOA all-sky SW flux trend sensitive to cloud property trend?

- Impose an Ed2-like cloud optical depth trend to Ed4 retrieval to test the hypothesis that negative trend in cloud optical depth changes the trend of all-sky SW flux;
- Decrease the Ed4 cloud optical depth by 0.005 per month for all cloudy footprints, set the cloud optical depth equal to 0.03 when negative cloud optical depth occurs.



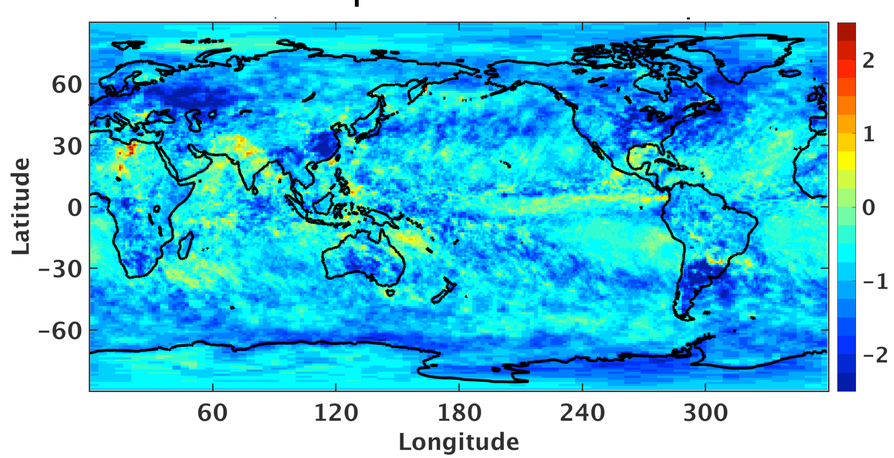


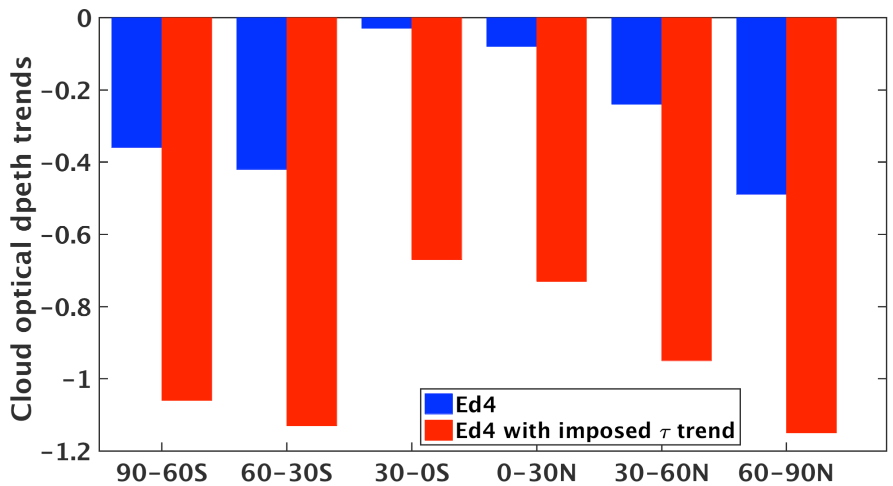
Regional cloud optical depth trend (per decade)



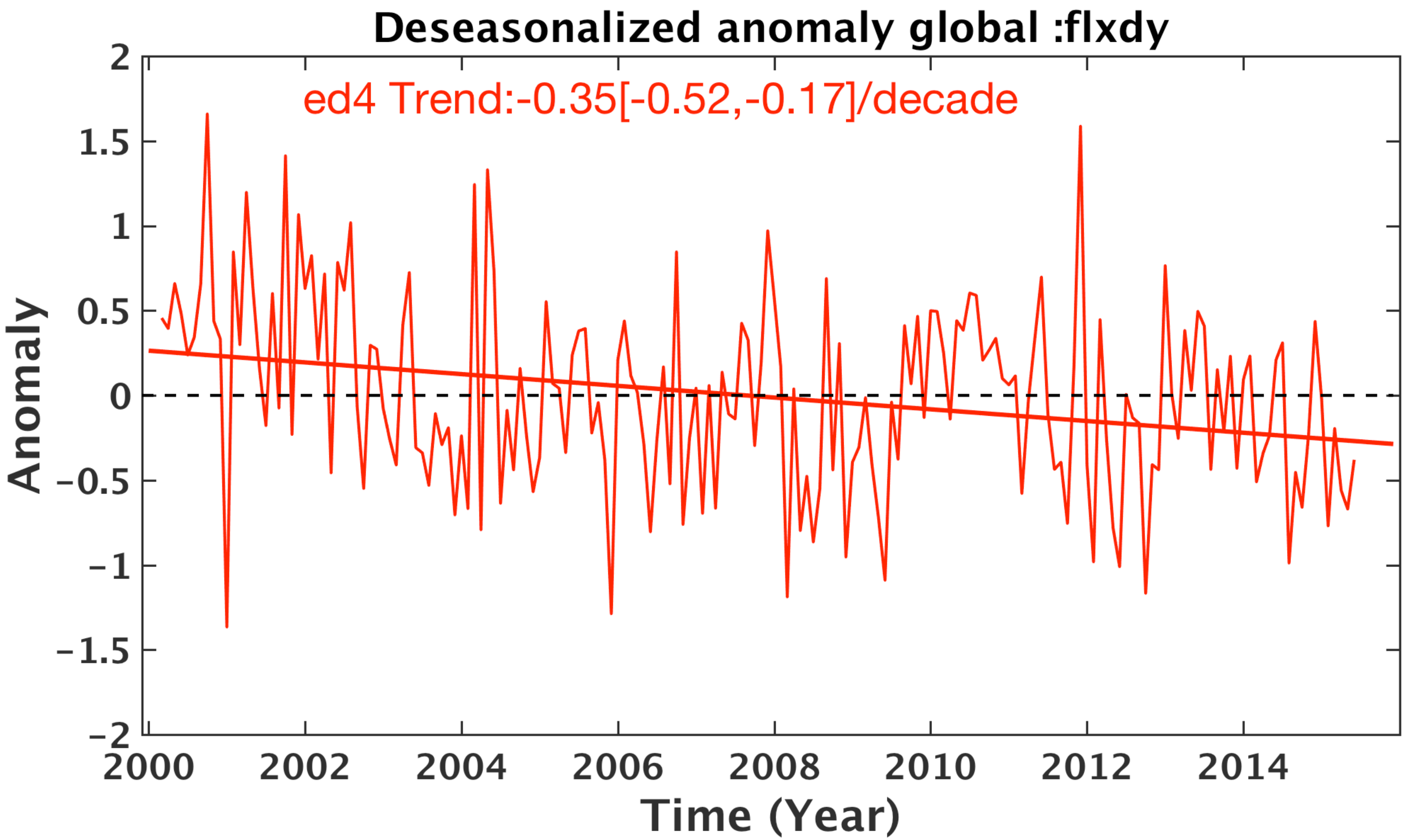
With imposed decreasing trend in cloud optical depth

Ed4 cloud τ with imposed trend



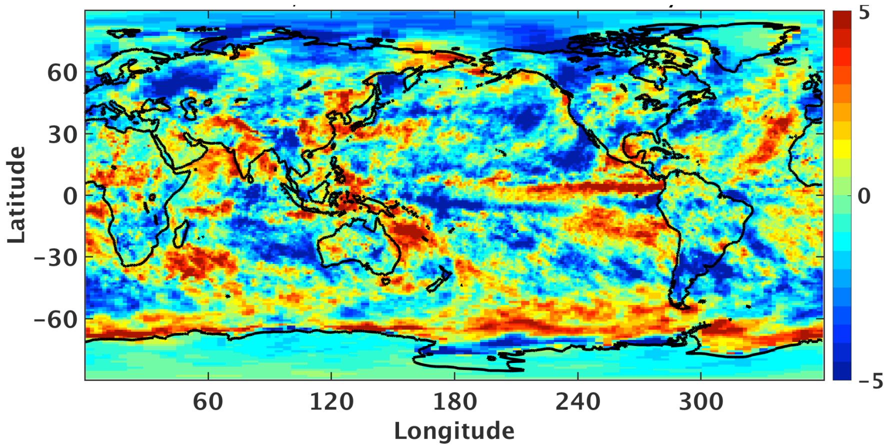


When we impose a decreasing trend for cloud optical depth, the diurnally averaged all-sky SW flux trend is reversed

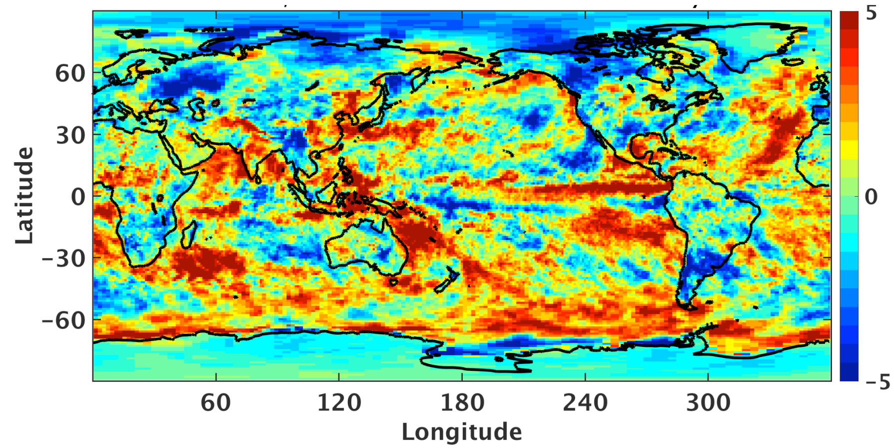


The imposed decreasing trend for cloud optical depth reversed the TOA all-sky SW flux trend

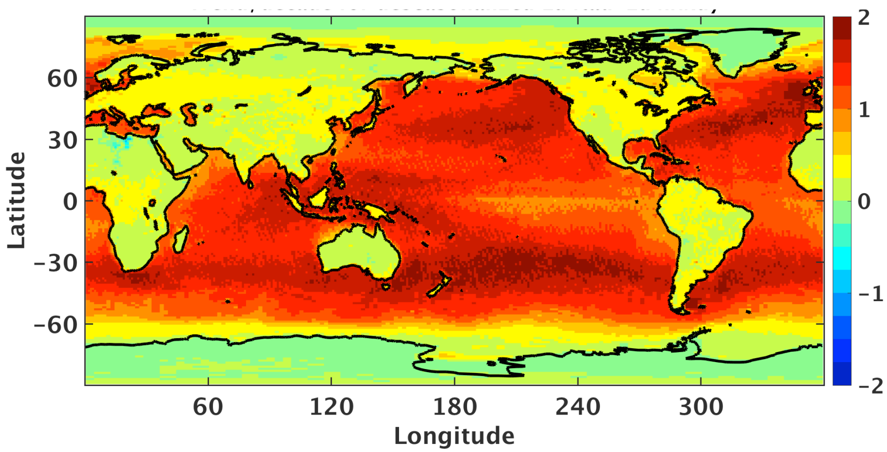
a) Ed4 TOA all-sky SW flux trend

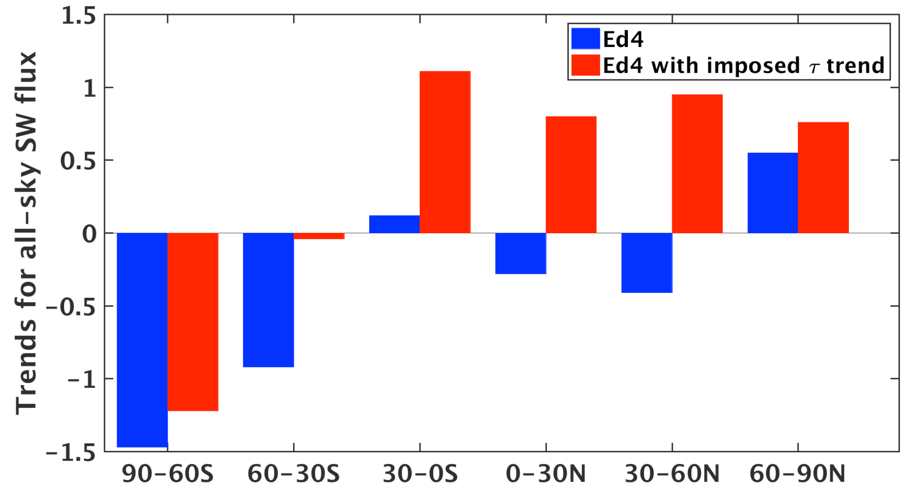


b)TOA all-sky SW flux trend with cloud $\boldsymbol{\tau}$ trend



TOA all-sky SW flux trend difference: b-a





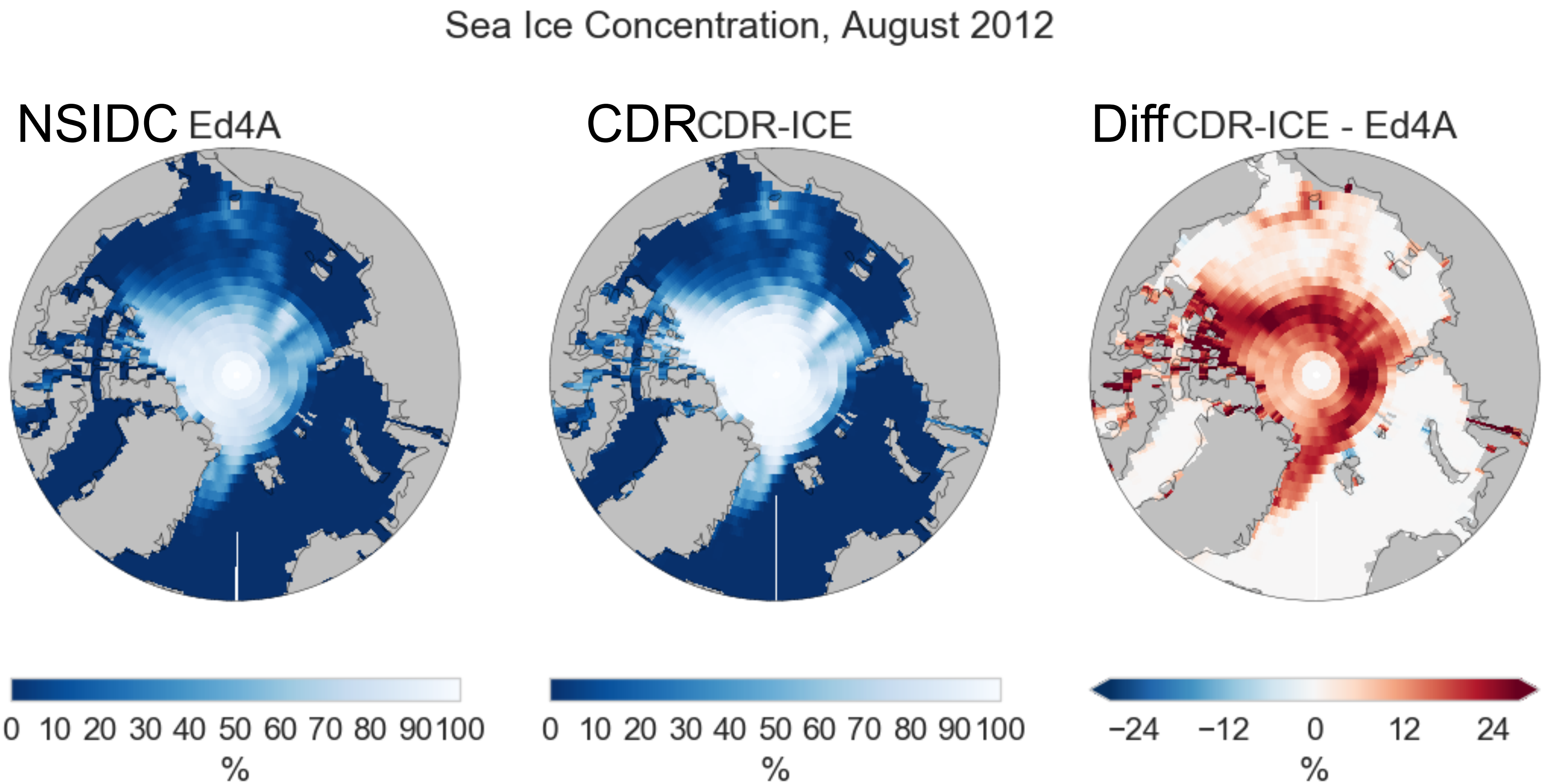
Sensitivity of TOA SW flux trend to cloud optical depth trend

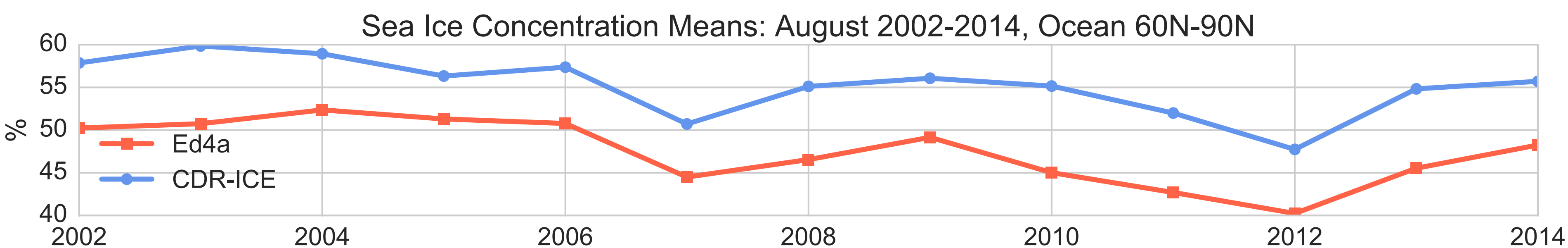
- For a cloud optical depth trend difference of -0.6 per decade, which corresponds to ~10% per decade relative to the mean cloud optical depth, resulted in a TOA SW flux trend difference of 1.0 Wm^{-2} per decade, which corresponds to ~1% per decade relative to the mean TOA SW flux.
- The calibration stability for imagers is about 1% (Jack Xiong, personal communication), except for some Terra bands which have experienced large changes in polarization sensitivities that made monitoring their stability difficult.
- The large cloud optical depth trend seen in Ed2 is a result of calibration anomalies. With constant monitoring and adjustment, these calibration anomalies can be much reduced, and the effect on TOA SW flux trend is expected to be less than 0.1-0.2% per decade.

Sea ice datasets

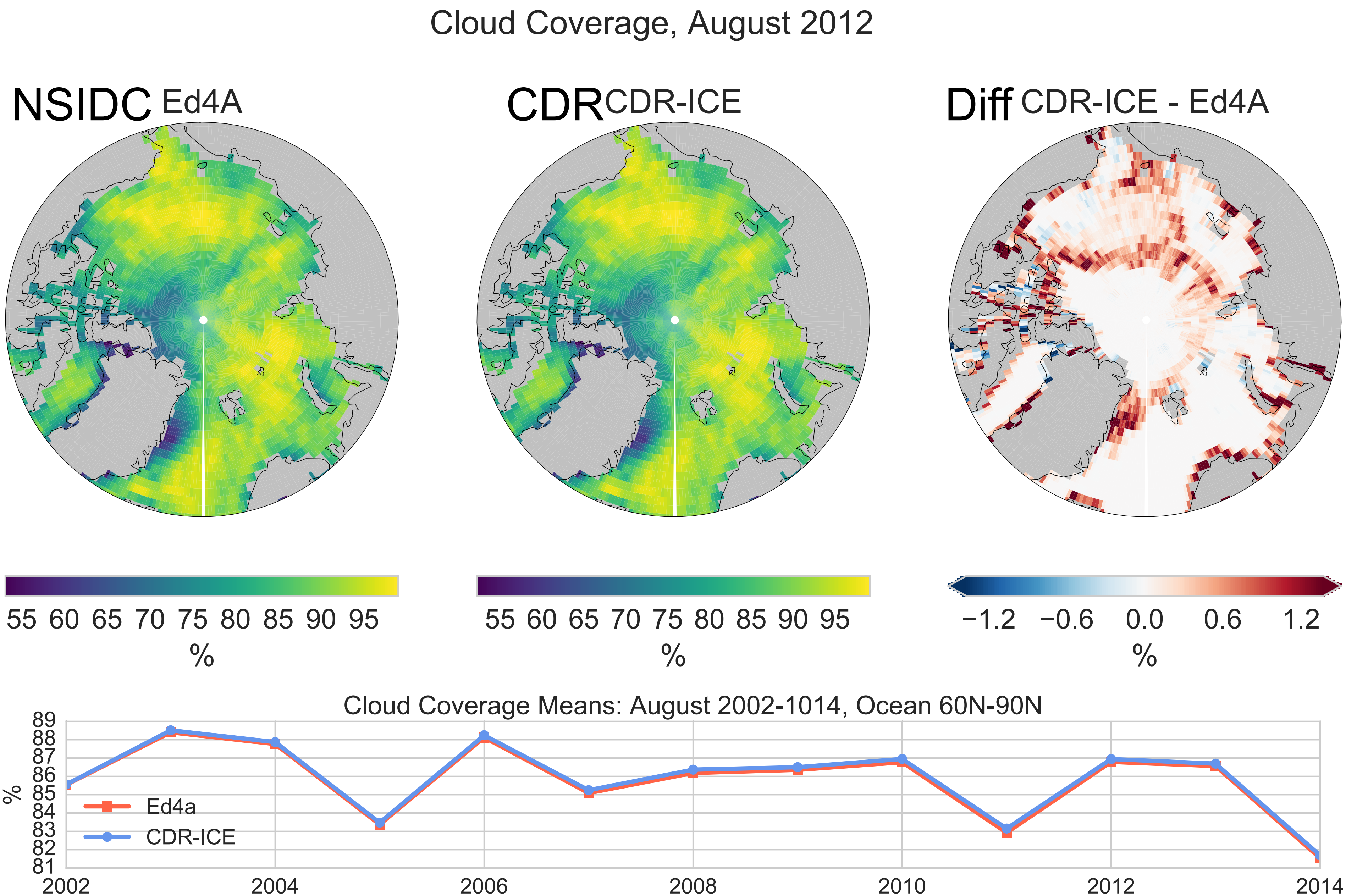
	NSIDC Near-Real time Snow and Ice Extent (NISE): used in Ed4	NSIDC/NOAA Climate Data Record of Passive Microwave Sea Ice Concentration (CDR)	Cloud Working Group Imager Clear sky snow/ice concentration
Instrument/ Radiances	SSMI, SSMIS on DMSP F13 and F17 19.4, 37.0 GHz Tb - NESDIS	SSMI, SSMIS on DMSP F13 and F17 19.4, 37.0 GHz Tb - RSS	MODIS/VIIRS 0.6µm, 2.1µm (or 1.6µm), 11µm and 12µm
Algorithm	GSFC NASA Team	Combination of GSFC NASA Team and GSFC Bootstrap	Combination of thresholds
Resolution	25 Km	25 Km	CERES footprint – clear sky portion only
Temporal Coverage	05/1994 – 10/2016	07/1987 - 12/2014	Coincident with CERES measurements
Quality Control	Low Forward processing only	High Consistent algorithm over time series	High Consistent over time, possibly subject to MODIS drifts

CDR product has higher sea ice concentration than NSIDC



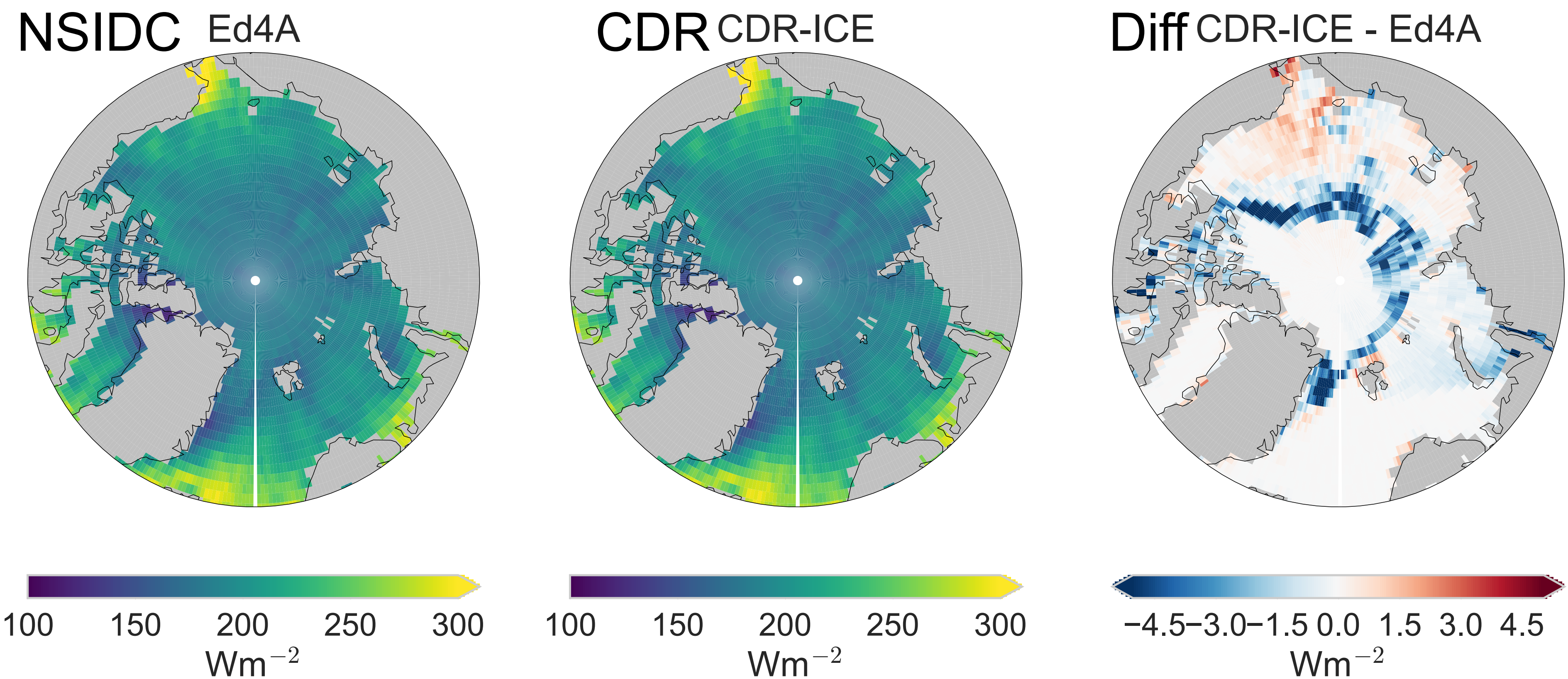


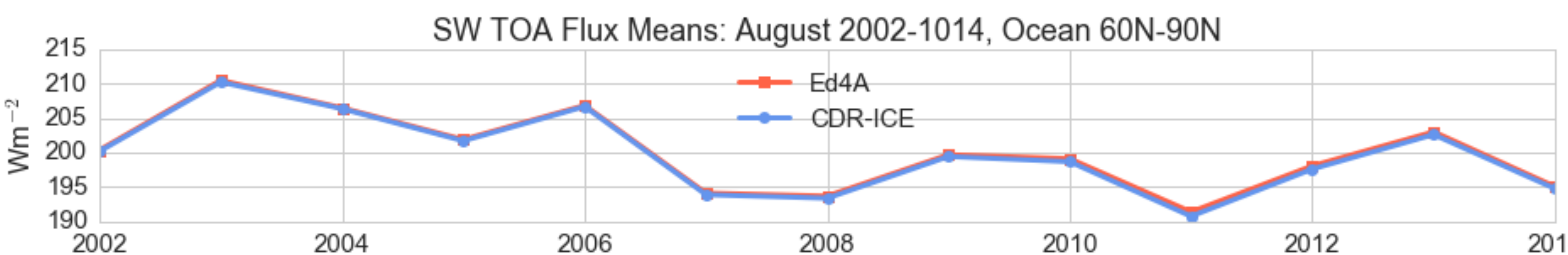
Different sea ice data sets have very little impact on cloud fraction



Effects on SW flux are also very small

SW TOA Flux, August 2012





But when we replace the CWG snow/ice concentration with the CDR snow/ice, flux over the Arctic ocean increased by 2-3 Wm^{-2}