Observing Recent Cloud and Radiation Budget Changes over Arctic Sea-Ice

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NASA Langley Research Center, Hampton, VA

Trend in Annual Mean CERES All-Sky TOA Flux by Latitude (2000-2012)

Reflected SW

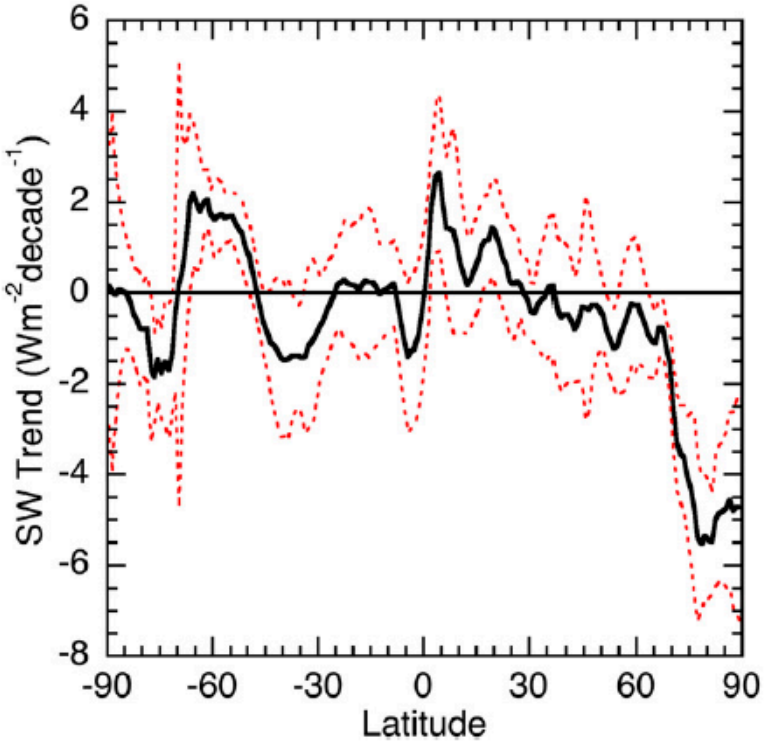


FIG. 1. Trend in reflected shortwave computed from annual-mean data and plotted as a function of latitude. The solid line shows the linear trend difference over the period 2000–12 for the zonal- and annual-mean reflected shortwave. The dashed lines show the 5% and 95% confidence levels.

Outgoing LW

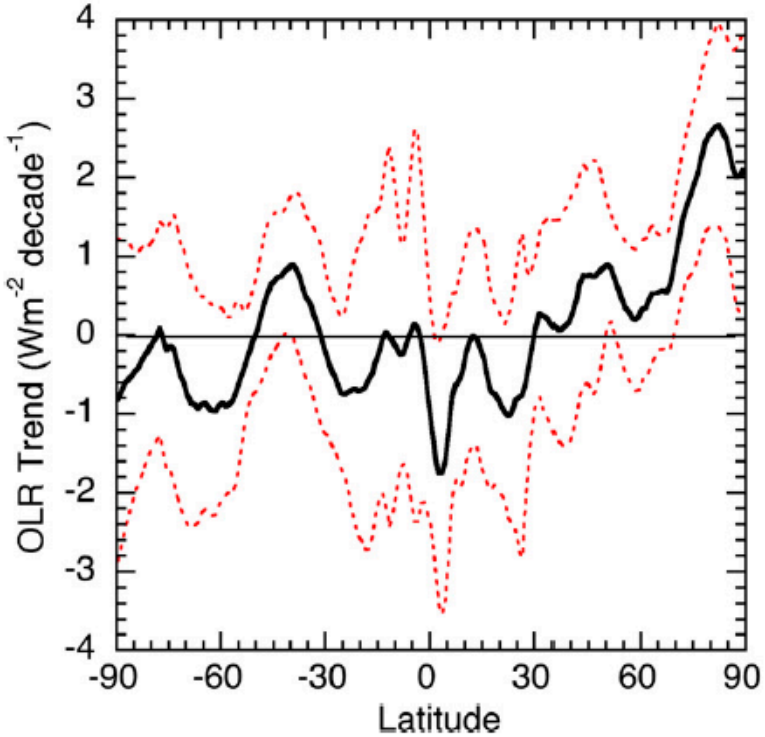


FIG. 11. As in Fig. 1, but for OLR.

Hartmann and Ceppi, JCLIM, 2014

CERES All-Sky SW TOA Flux Trend Tracks Decline in September Sea-Ice Extent

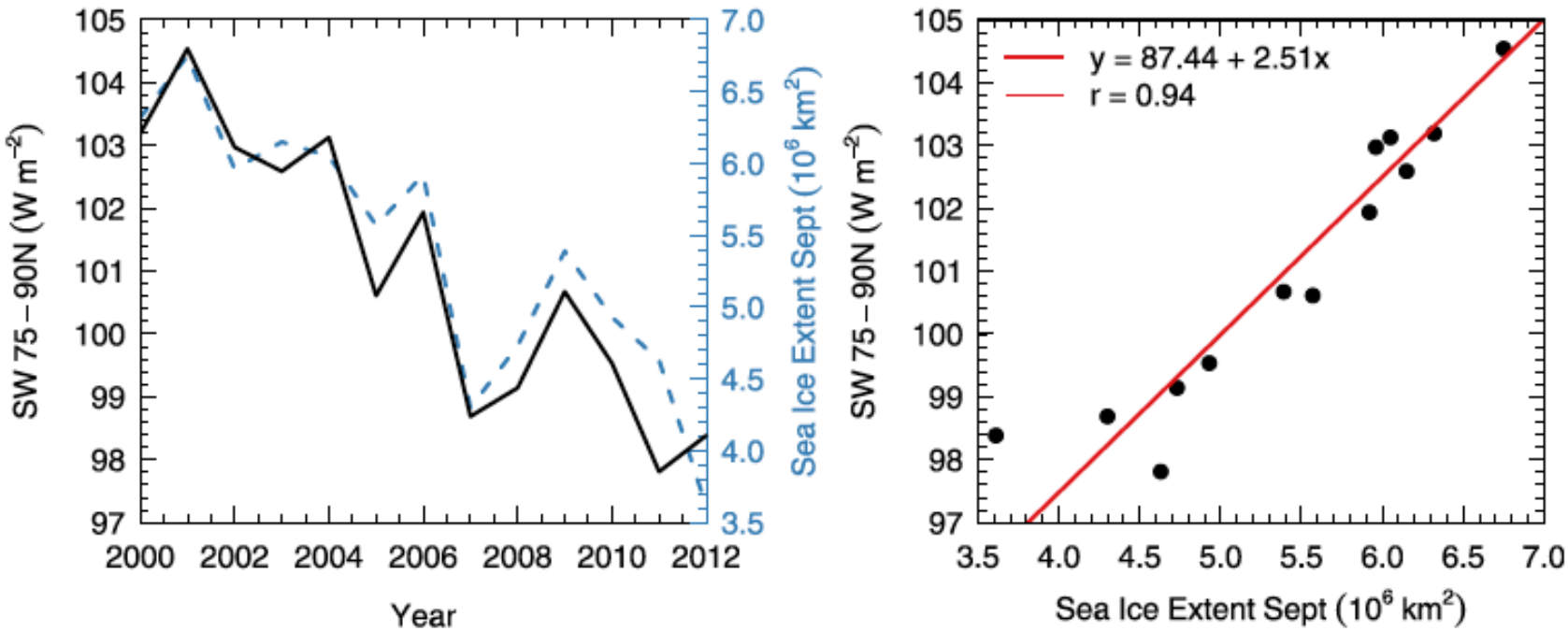


FIG. 4. (left) Annual-mean CERES reflected shortwave area averaged from 75° to 90°N for each (March–February average) vs the sea ice extent in September of the same year. (right) Scatterplot of annual-mean CERES shortwave reflected averaged over the area poleward of 75°N vs Arctic sea ice extent in September for 2000–12.

Hartmann and Ceppi, JCLIM, 2014

Regional Trends in Sea Ice Concentration & Clear-Sky TOA Albedo

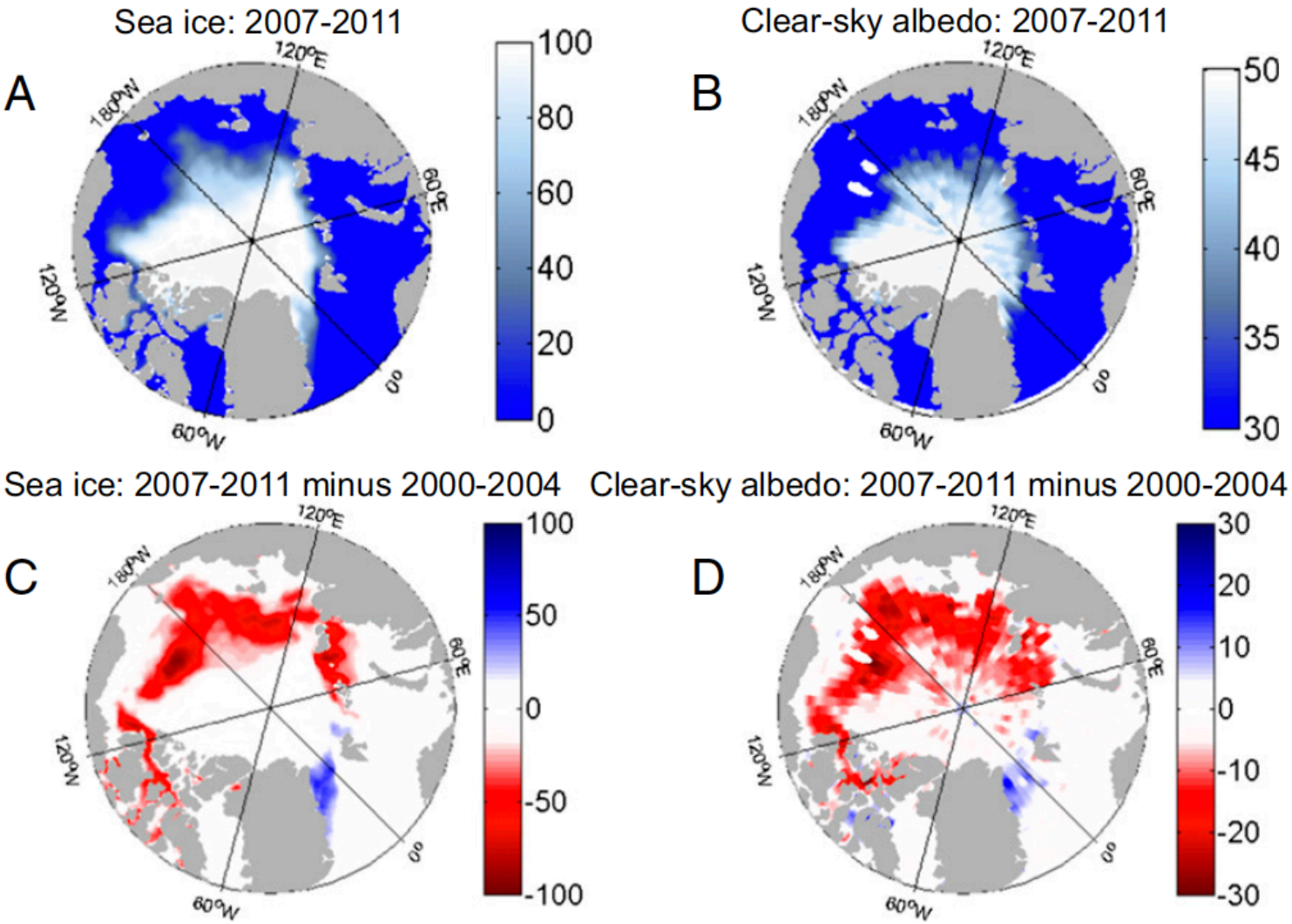
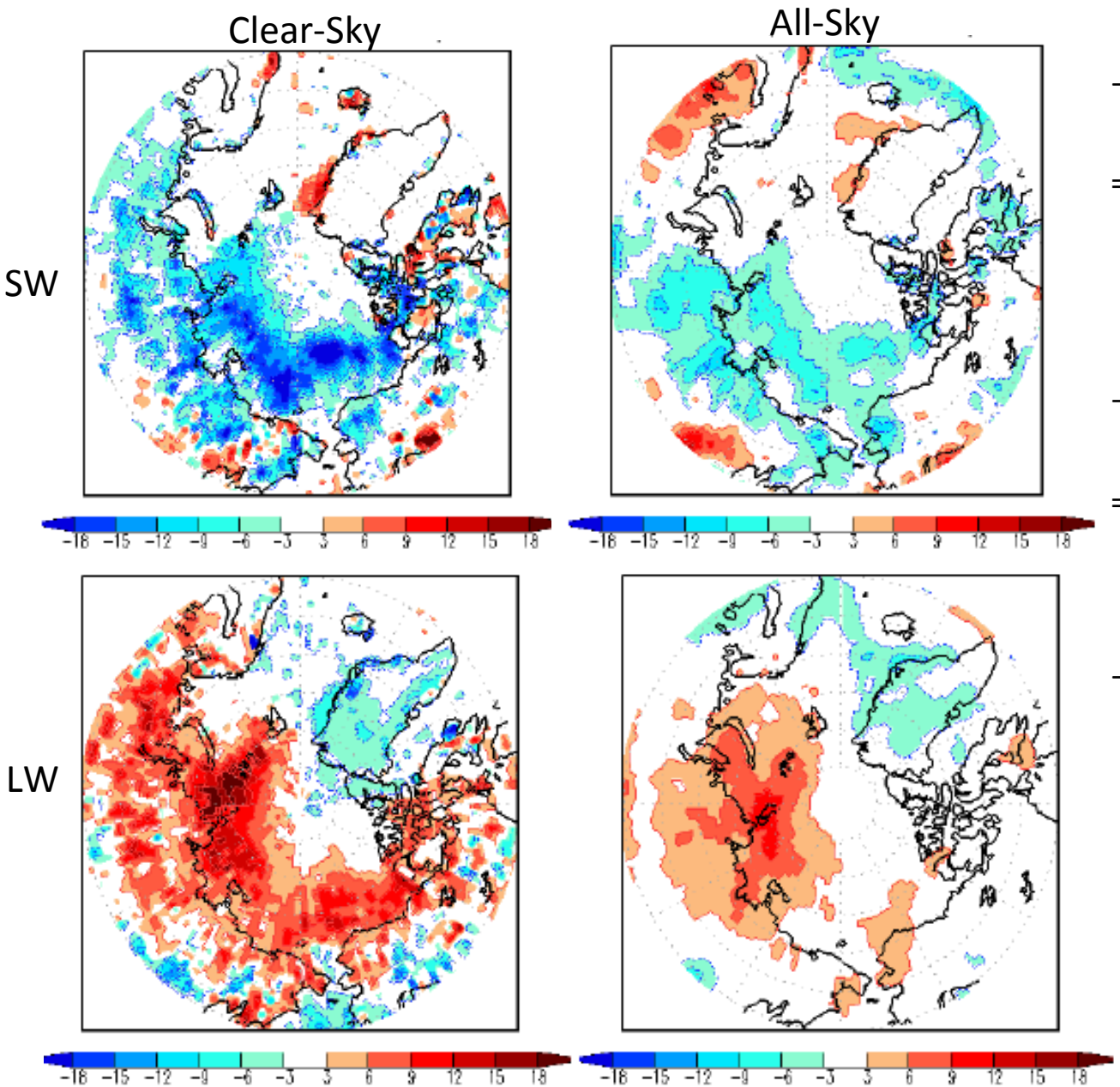


Fig. 1. (*A*) Sea ice concentration and (*B*) CERES clear-sky albedo averaged over each September during the last 5 y of the CERES record (2007–2011) and the change in (*C*) sea ice and (*D*) clear-sky albedo between the mean of the last five Septembers (2007–2011) and the mean of the first five Septembers (2000–2004) of the CERES record. Results for other months are included in Fig. S1.

Pistone et al, PNAS, 2014

TOA Flux Trends (2001 – 2012; CERES SYN1deg Edition 3)



- Weaker trends for all-sky than clear-sky TOA flux.

⇒ Clouds mask part of the influence of surface and lower atmosphere changes on TOA flux.

- Are clouds changing over the Arctic Ocean?

⇒ If so, do they enhance or counter radiative effects of sea-ice changes?

- How do you separate the radiative effects of cloud changes from those due to non-cloud changes (e.g., sea-ice extent, T & q)?

Radiative Perturbation Calculations

- Determine contributions of cloud and non-cloud changes on TOA flux through Fu-Liou radiative transfer model calculations.

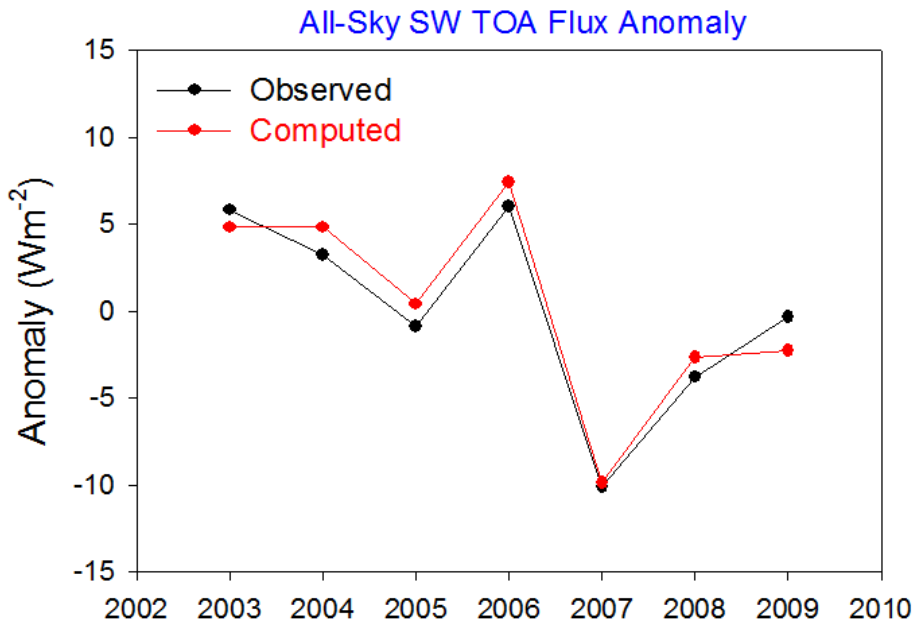
- Initialize Fu-Liou calculations using observed gridded monthly surface albedo, cloud fraction, cloud optical depth, cloud-top pressure, surface temperature, temperature/ humidity and aerosol optical depth.

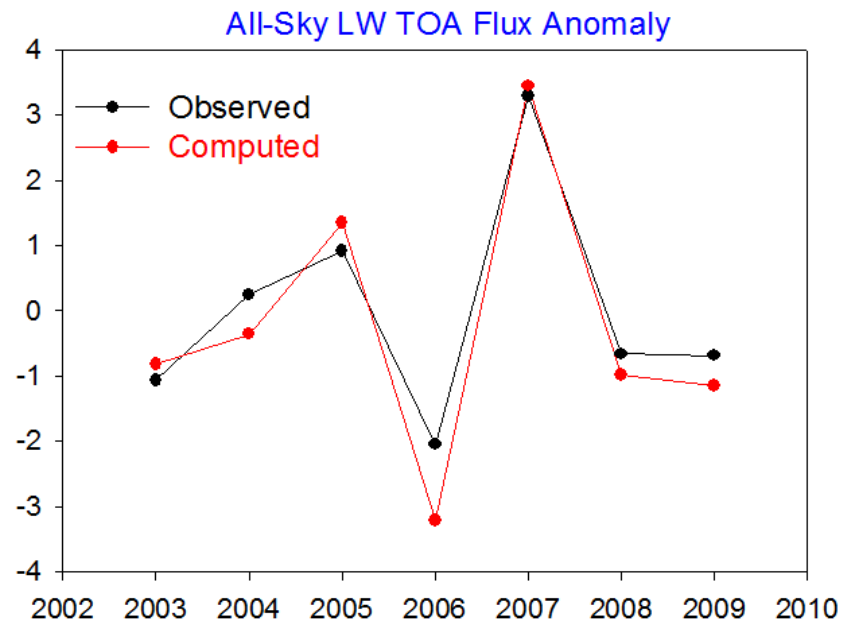
- Determine the radiative effect of a given parameter "x_1" as:

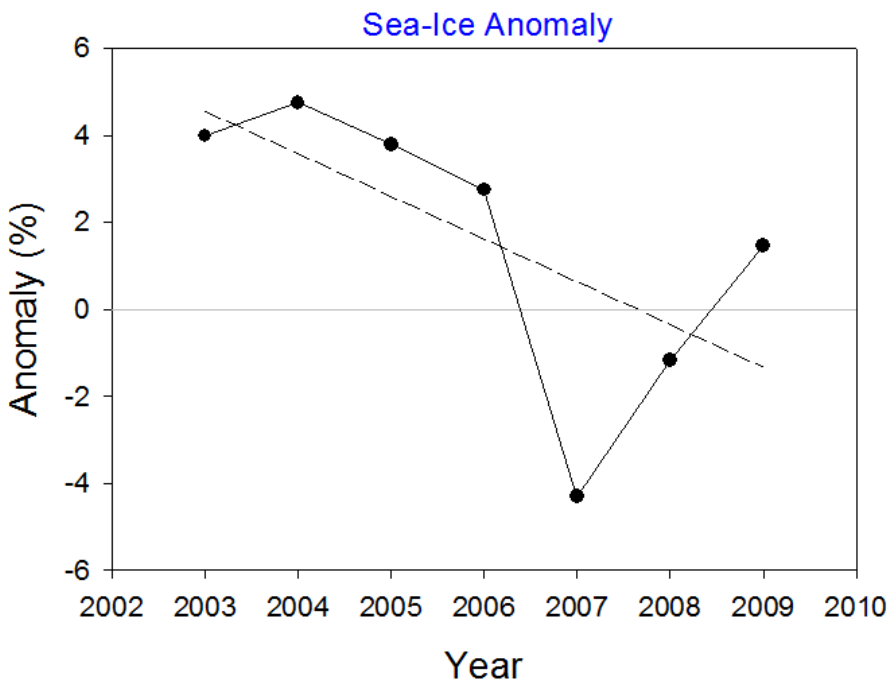
$$\Delta F(x_1) = F(x_1, \langle x_2 \rangle, \ldots, \langle x_N \rangle) - F(\langle x_1 \rangle, \langle x_2 \rangle, \ldots, \langle x_N \rangle)$$

where x_i is the monthly mean and $\langle x_i \rangle$ is the climatological monthly mean.

SW and LW TOA Flux & Sea-Ice Anomalies (JJA; Arctic Ocean Poleward of 70°N)







- Computed anomalies are from the sum of the individual parameter contributions $\Delta F(x_i)$.
- Observed is from SYN1deg Edition 3.

Separating Impact of Cloud and non-Cloud Changes on TOA Flux

$$CRE = F_{clr} - F_{all}$$

$$CRE_adj = CRE - [F_{clr} - F_{all}(<C>)]$$

where $F_{all}(<C>)$ is all-sky flux using climatological mean cloud properties.

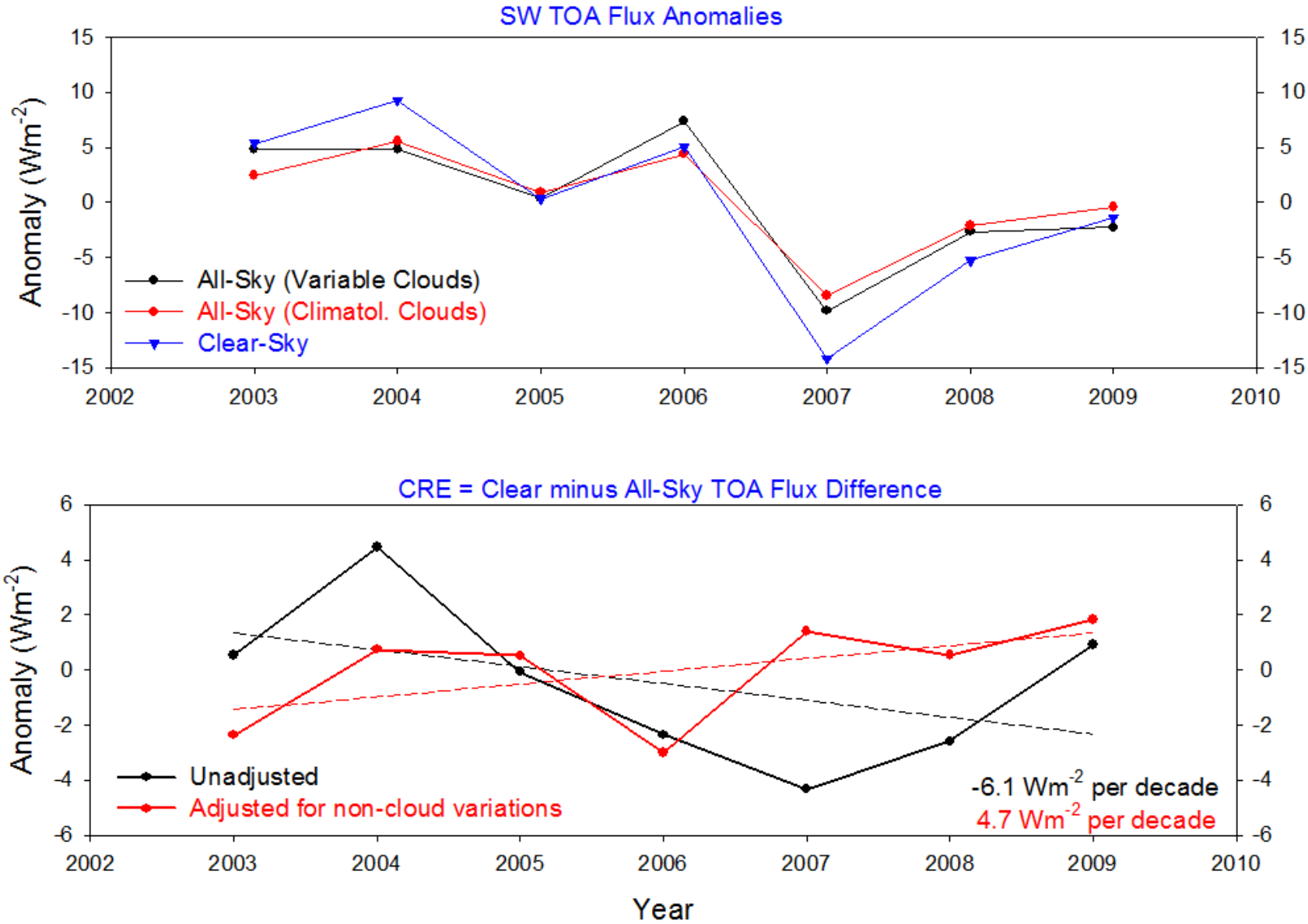
$[F_{clr} - F_{all}(<C>)]$ = radiative effect of non-cloud changes.

Therefore, adjusted CRE is:

$$CRE_adj = F_{all}(<C>) - F_{all}$$

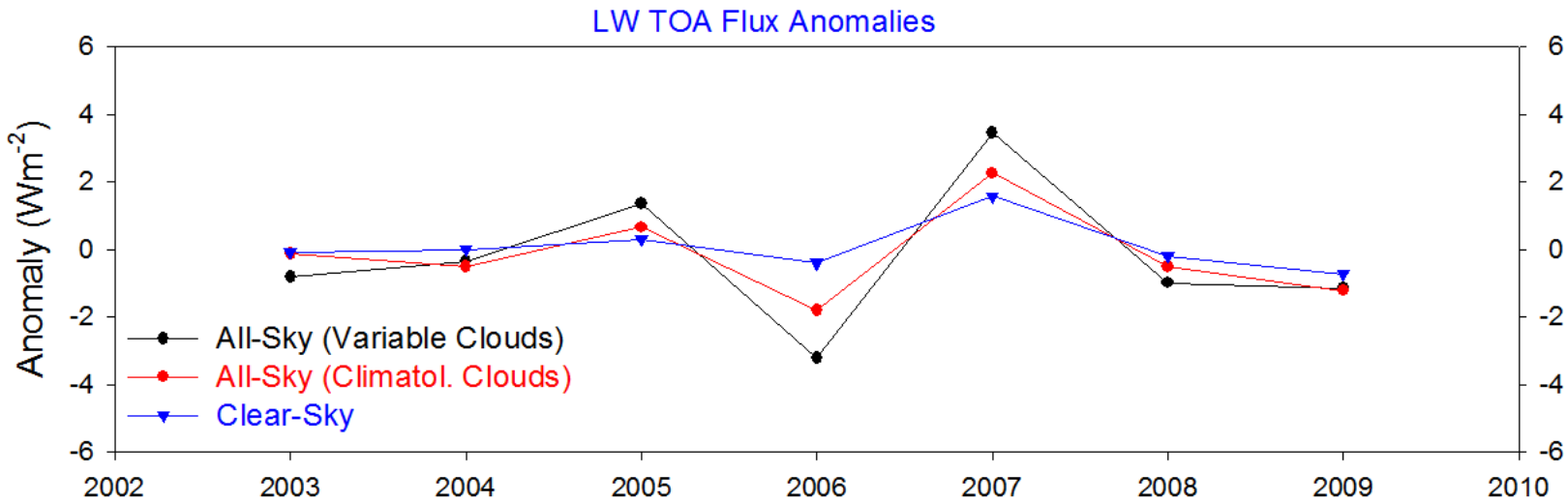
With this formulation, if clouds remain invariant (i.e., at their climatological mean), CRE_adj = 0.

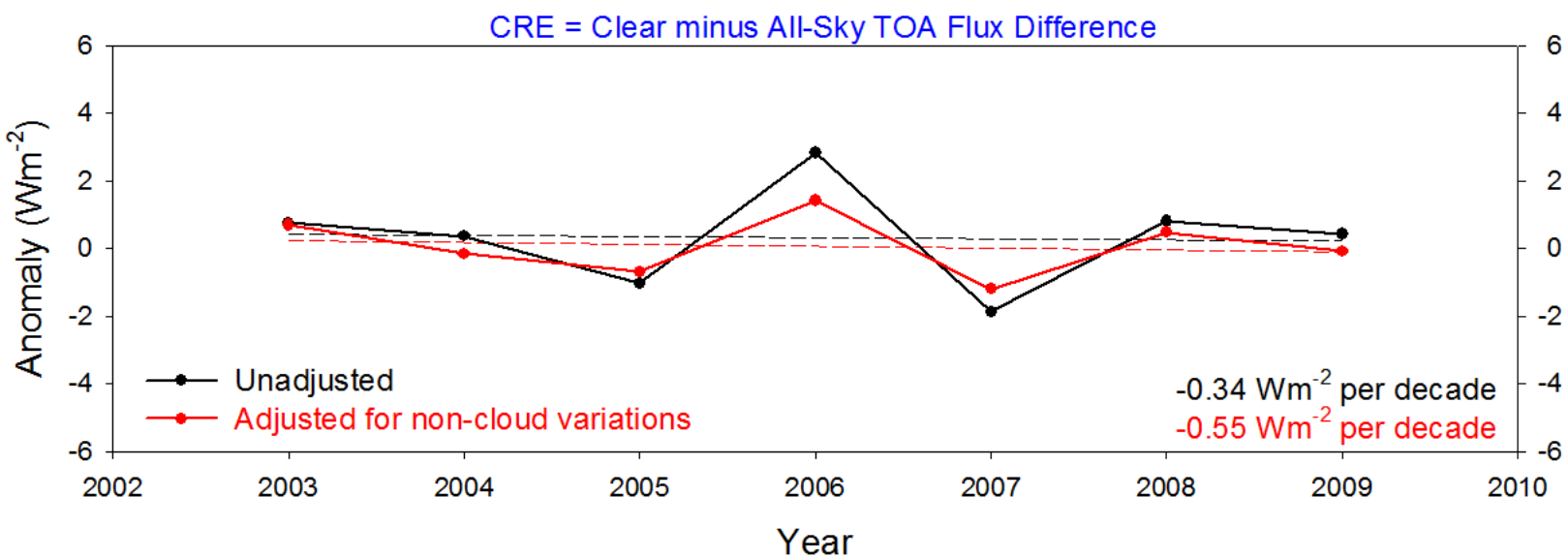
SW TOA Flux & SW CRE Anomalies (JJA; Arctic Ocean Poleward of 70°N)



=> Cloud changes increase absorbed SW radiation (caution: short record length!)

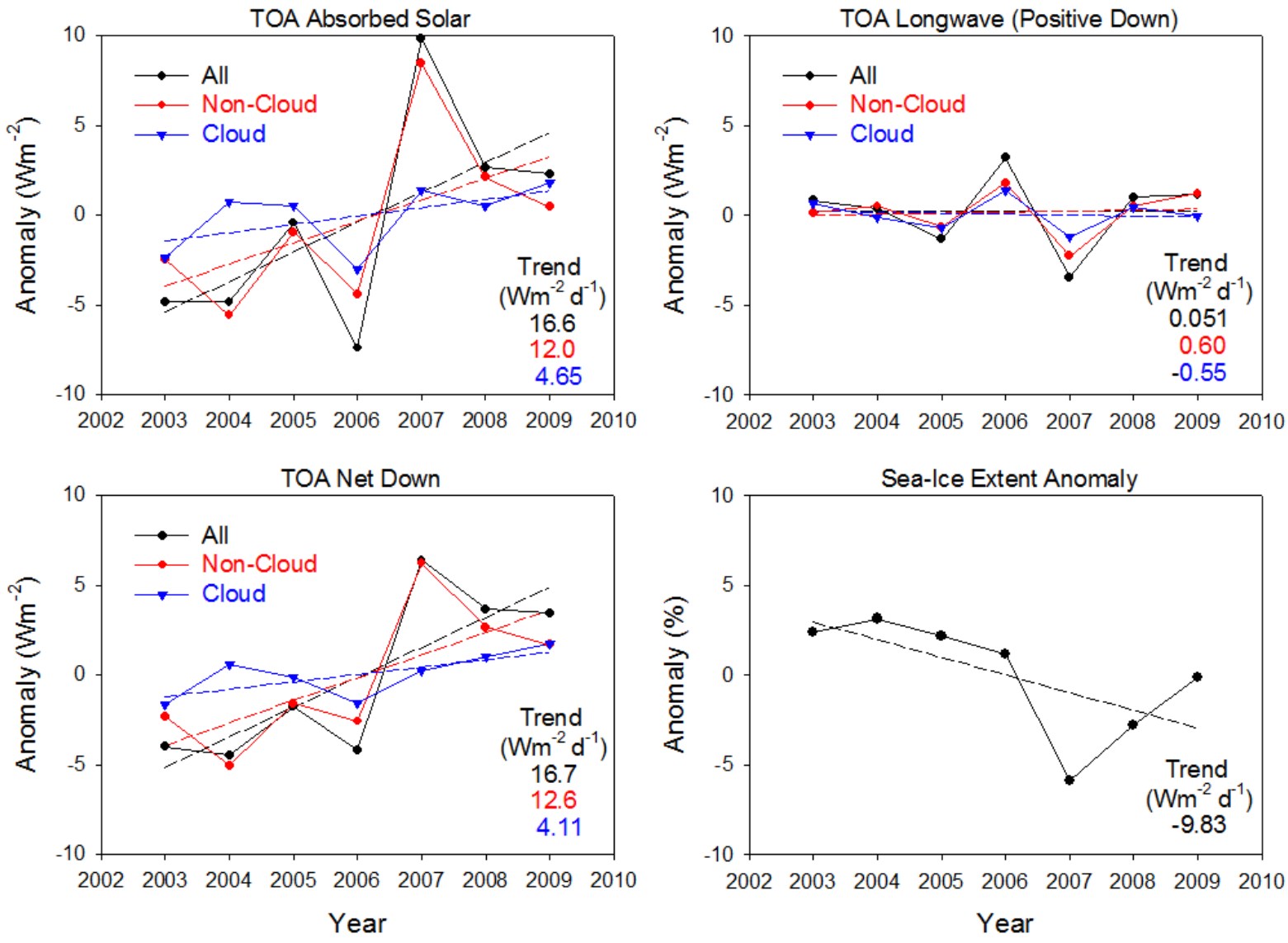
LW TOA Flux & LW CRE Anomalies (JJA; Arctic Ocean Poleward of 70°N)





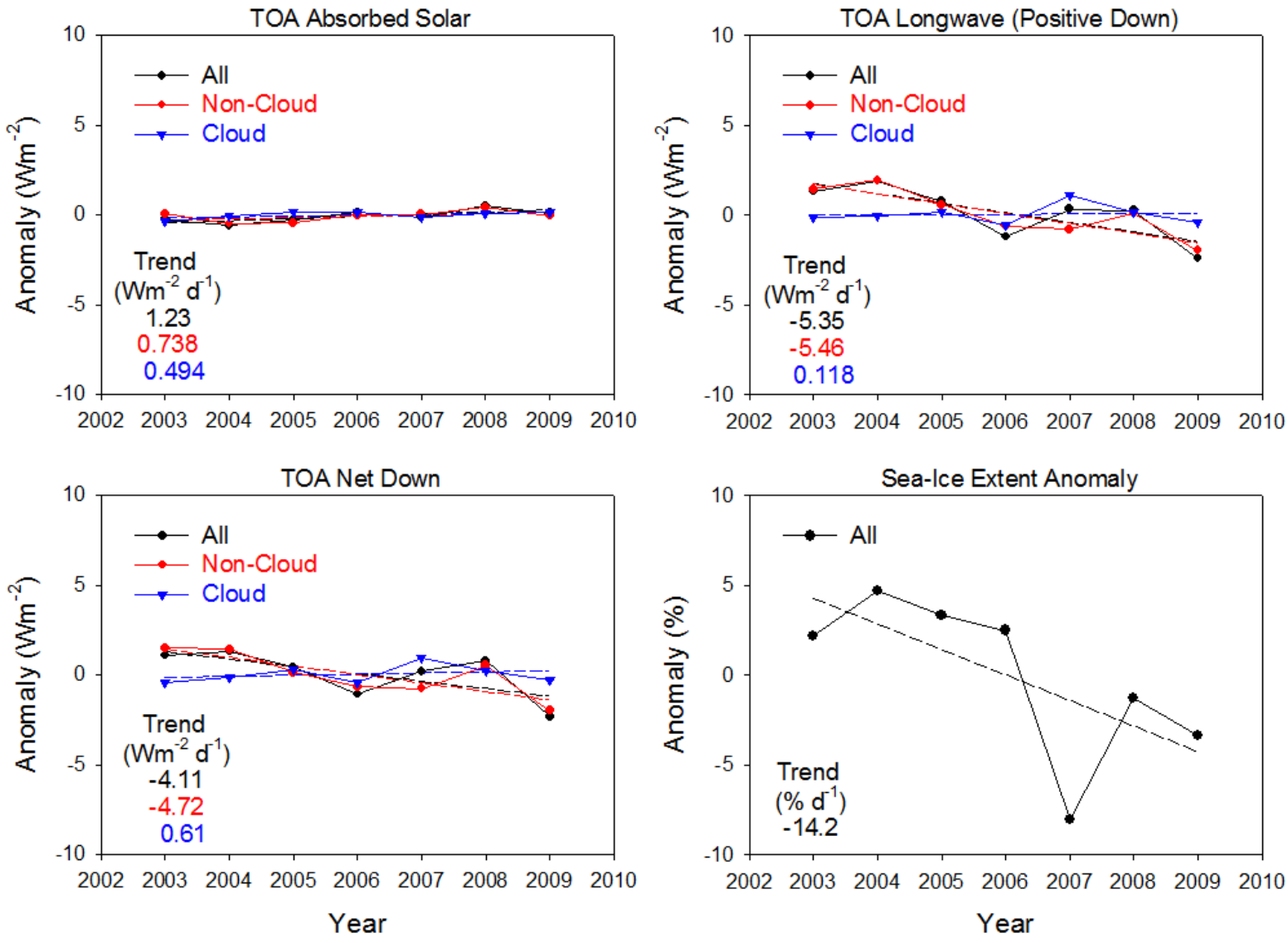
=> Cloud changes decrease absorbed LW radiation (caution: short record length!)

JJA Trend in TOA Flux (Down) & Sea-Ice Extent (70N-90N)

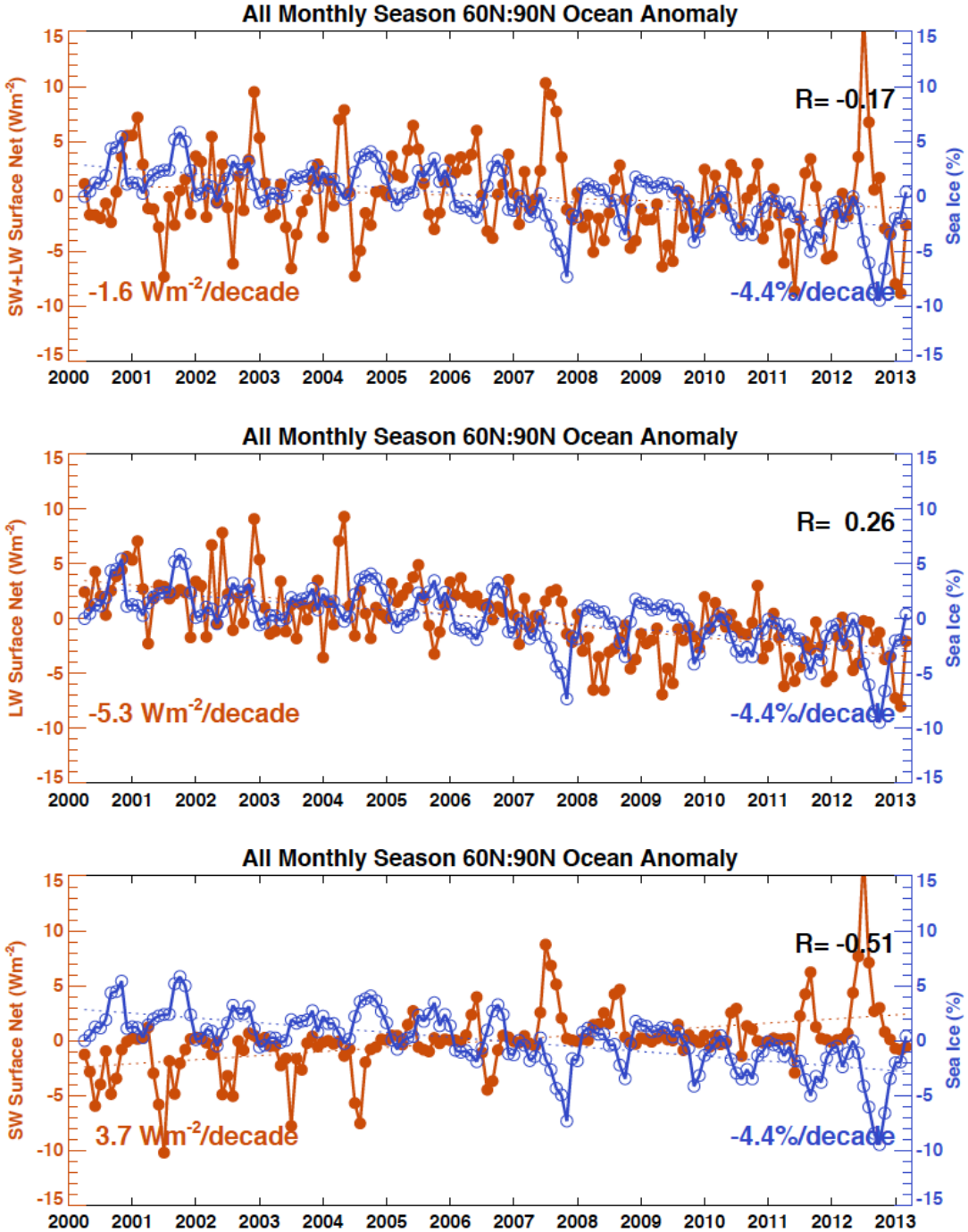


- Positive trend in TOA net downward flux is dominated by increased absorption of solar radiation.
- Roughly one-quarter of the increase in TOA net downward flux is associated with cloud changes.

SON Trend in TOA Flux (Down) & Sea-Ice Extent (70N-90N)

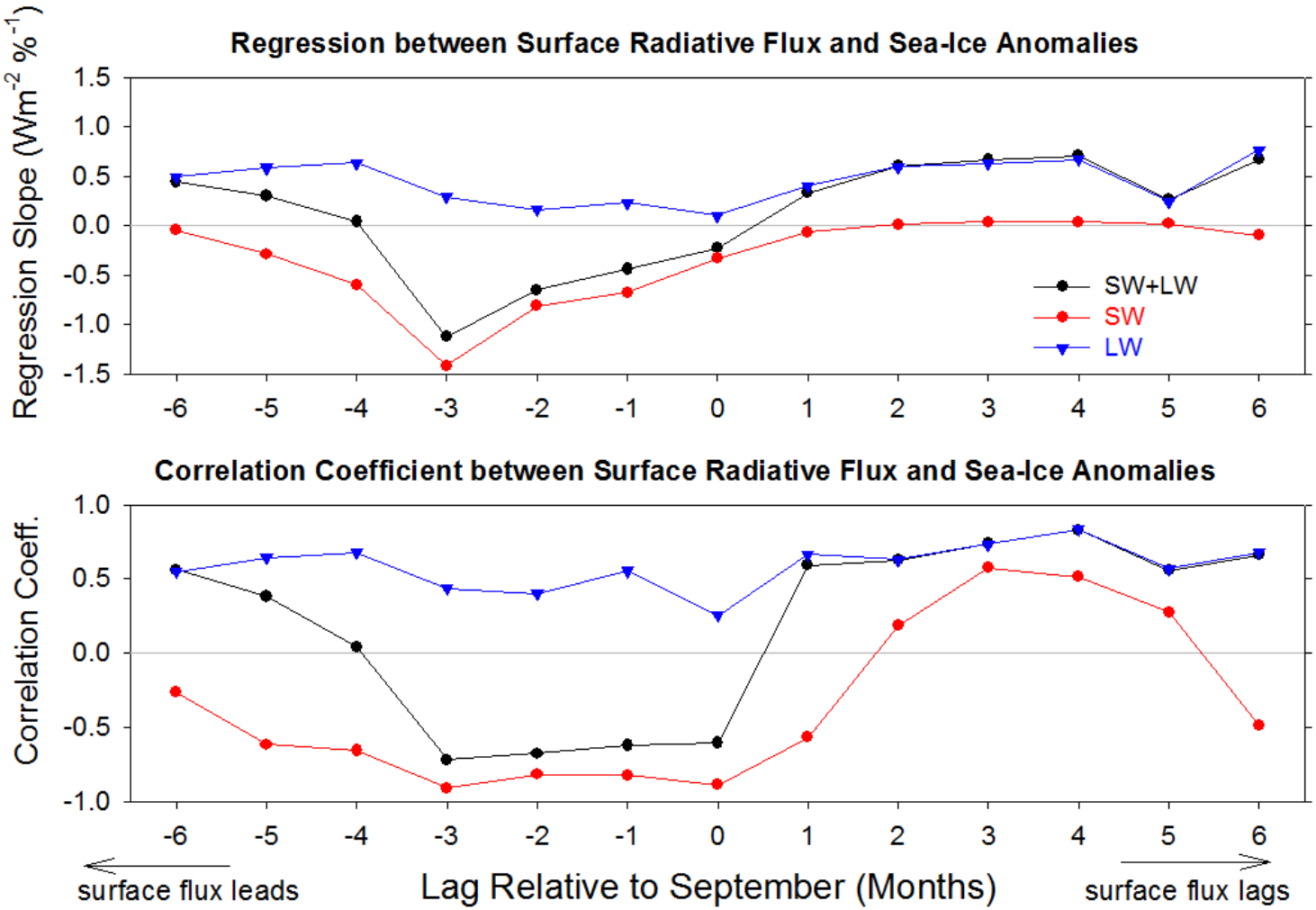


- Negative trend in TOA net downward flux is dominated by increased OLR.
- Cloud changes have small effect on TOA net downward flux in SON.


All Monthly Season 60N:90N Ocean Anomaly
SW+LW Surface Net (Wm-2)
Sea Ice (%)
R= -0.17
-1.6 Wm-2/decade
-4.4%/decade
All Monthly Season 60N:90N Ocean Anomaly
LW Surface Net (Wm-2)
Sea Ice (%)
R= 0.26
-5.3 Wm-2/decade
-4.4%/decade
All Monthly Season 60N:90N Ocean Anomaly
SW Surface Net (Wm-2)
Sea Ice (%)
R= -0.51
3.7 Wm-2/decade
-4.4%/decade
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013

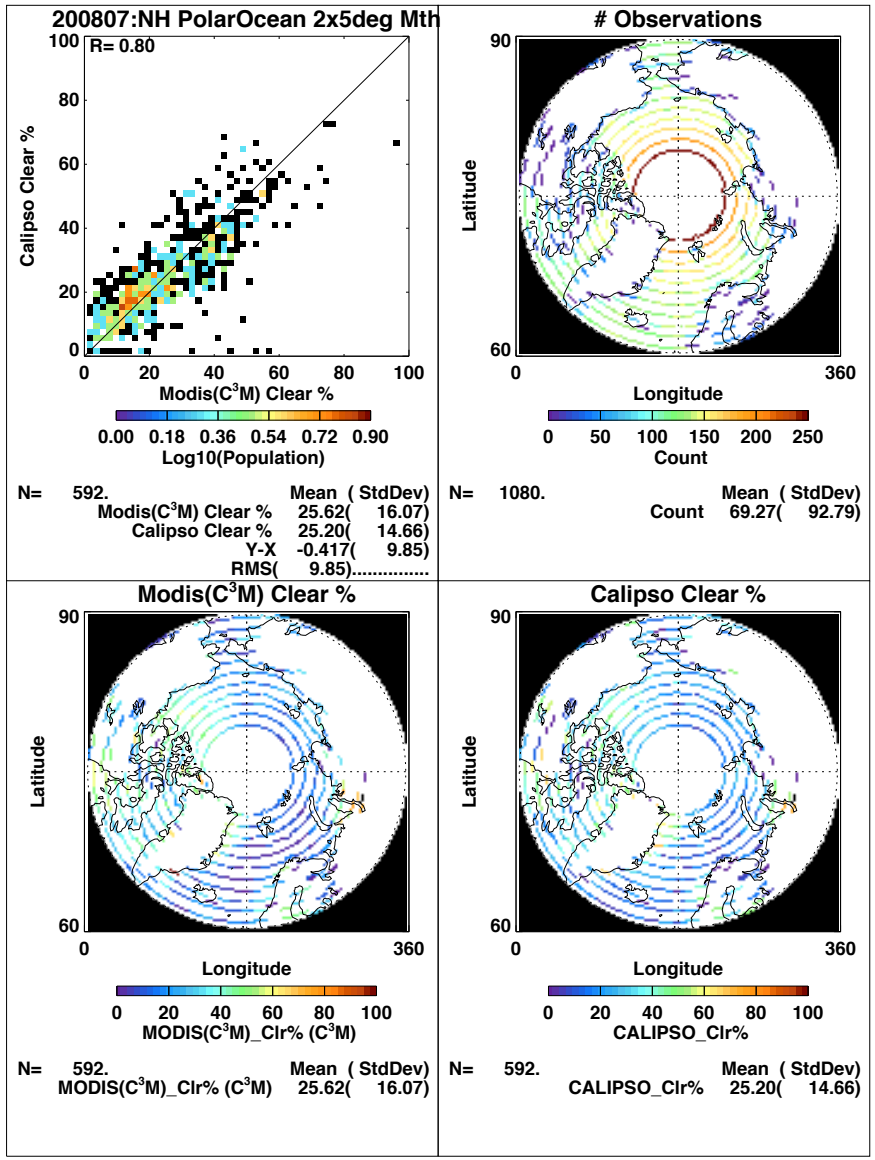
Lagged Relationship Between Surface Net Downward Flux & Sea-Ice Extent

(March 2000-February 2013; EBAF-SFC Ed2.8; 60N-90N; Ocean Only)

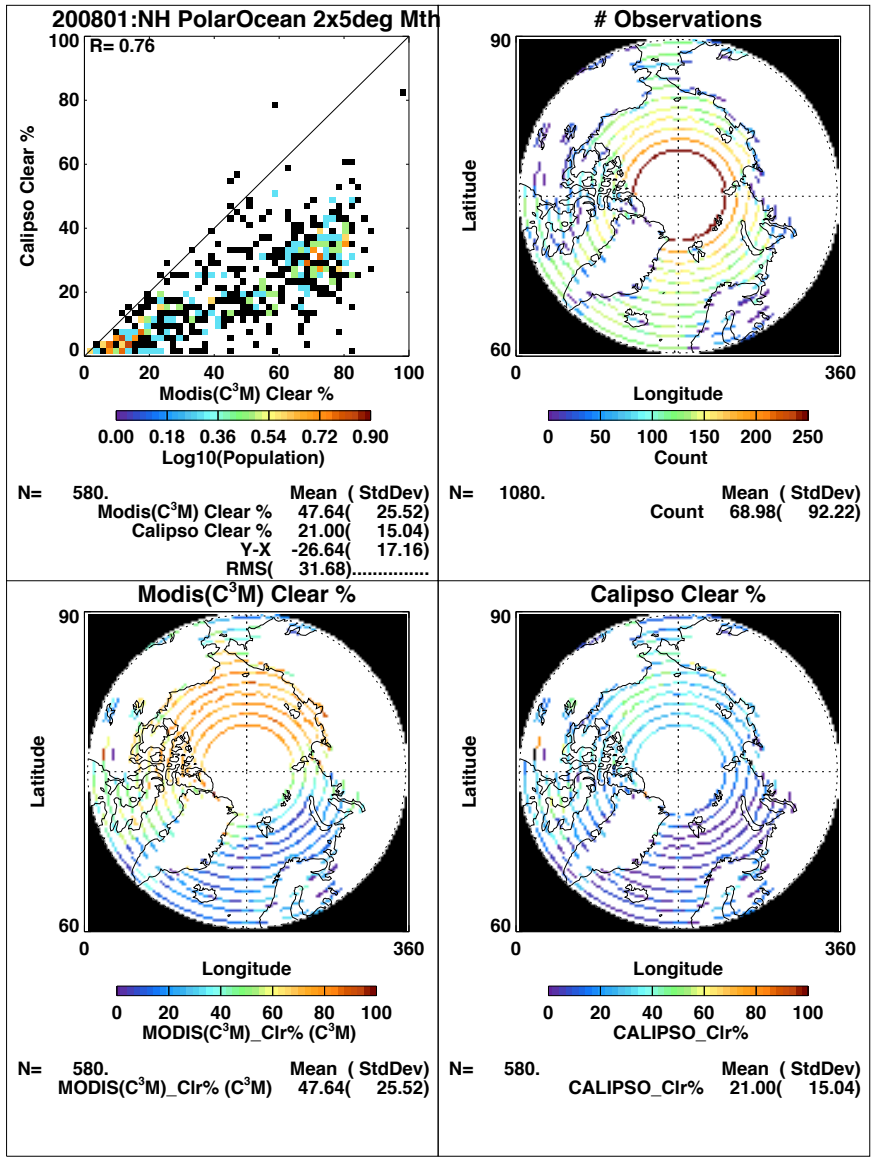


- September minimum in sea-ice extent is preceded by summertime maximum in downward SW radiation (especially June when insolation is greatest).
- Following September sea-ice extent minimum, there's an increase in SFC LW up, and therefore a decline in net downward LW radiation.

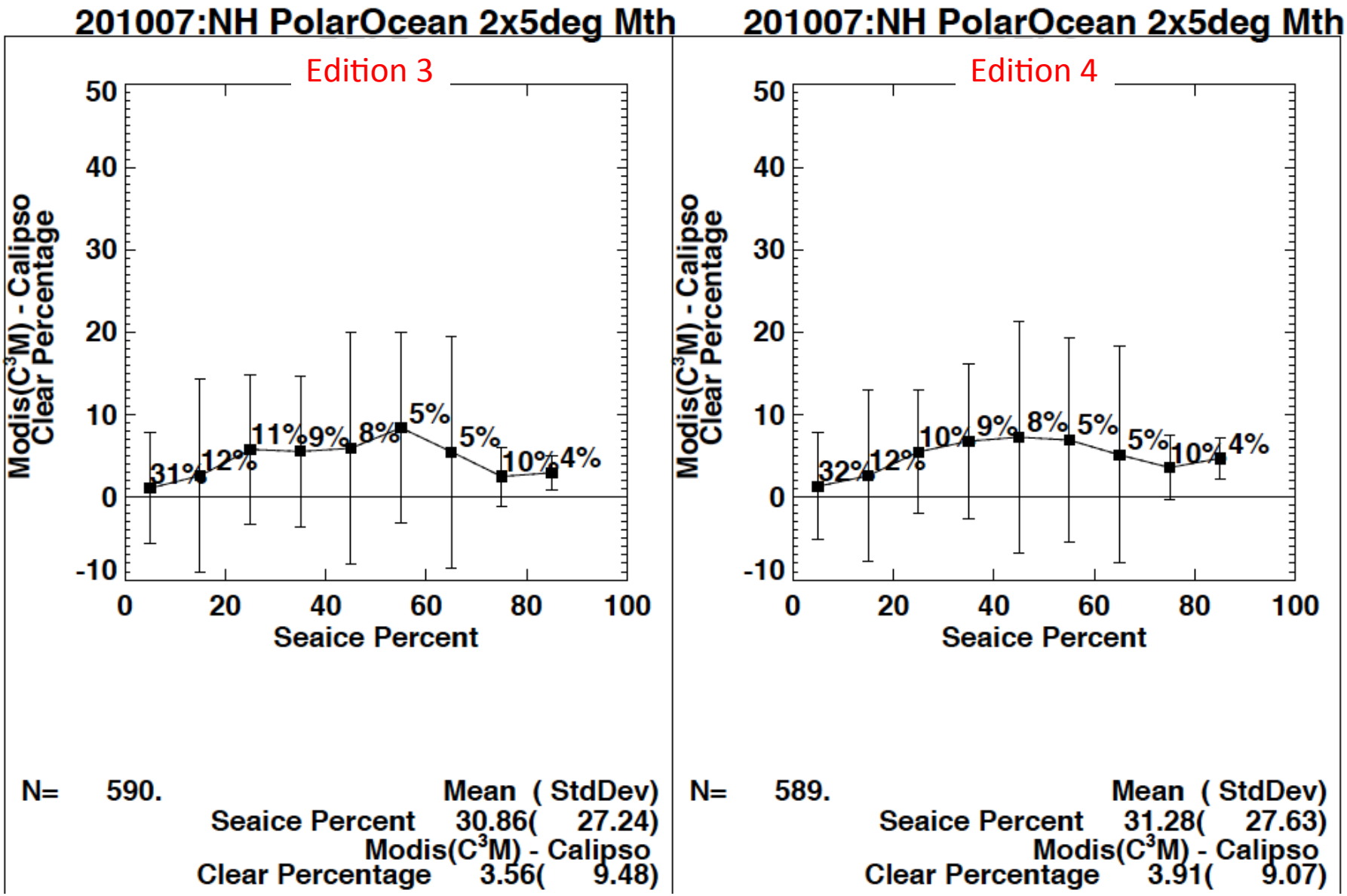
MODIS C3M – CALIPSO Clear Percentage (60°N-82°N; JULY 2010)



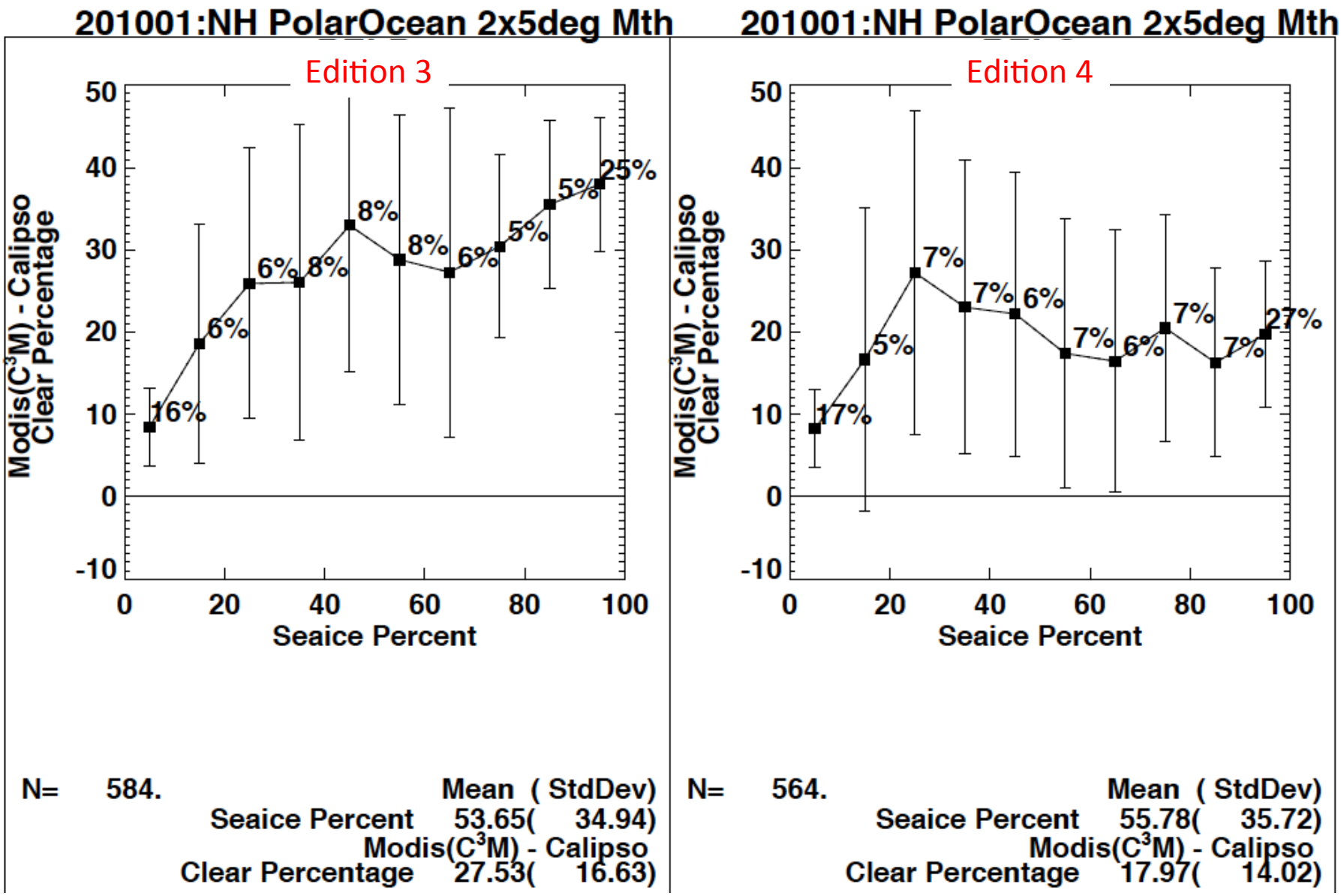
MODIS C3M – CALIPSO Clear Percentage (60°N-82°N; JANUARY 2010)



MODIS C3M – CALIPSO Clear Percentage By Sea-Ice Extent (60°N-82°N; JULY 2010)



MODIS C3M – CALIPSO Clear Percentage By Sea-Ice Extent (60°N-82°N; JANUARY 2010)



Summary

Trends in TOA radiation over Arctic Ocean (70N-90N):

- During JJA, there is a positive trend in TOA net downward flux:
  - Dominated by increased absorption of solar radiation.
  - Roughly one-quarter of the increase is associated with cloud changes.
- During SON, there is a negative trend in TOA net downward flux:
  - Dominated by increased OLR.
  - Cloud changes have small effect.

Lagged regressions between surface flux and sea-ice extent show:

- September minimum in sea-ice extent is preceded by summertime maximum in surface downward SW radiation.
  => warms the surface & contributes to melting of sea-ice.
- September minimum in sea-ice extent is followed by increase in surface upward LW radiation.
  => cools the surface & contributes to regeneration of sea-ice.