The contribution of cloud and radiation anomalies to the 2007 Arctic sea ice loss

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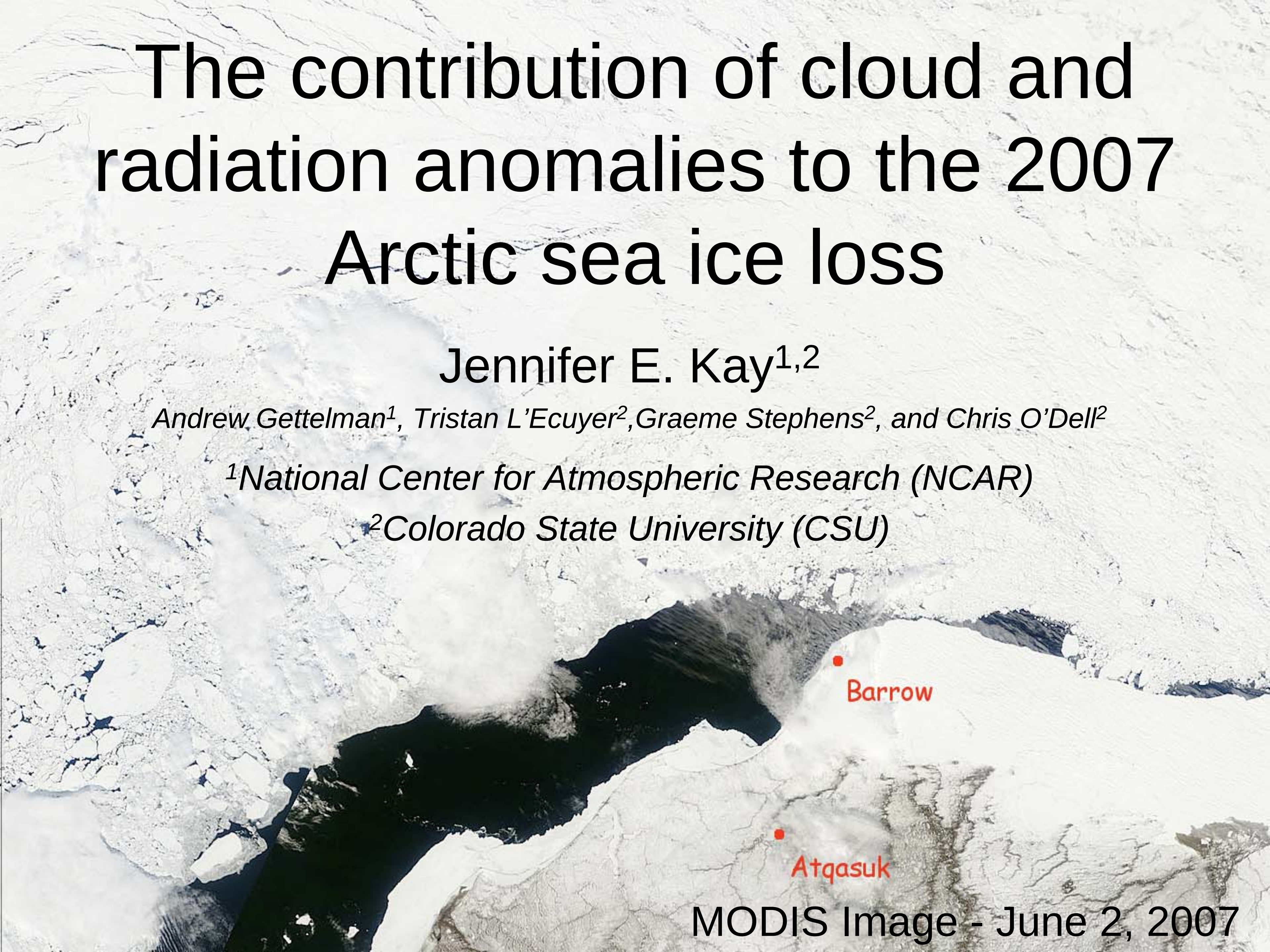
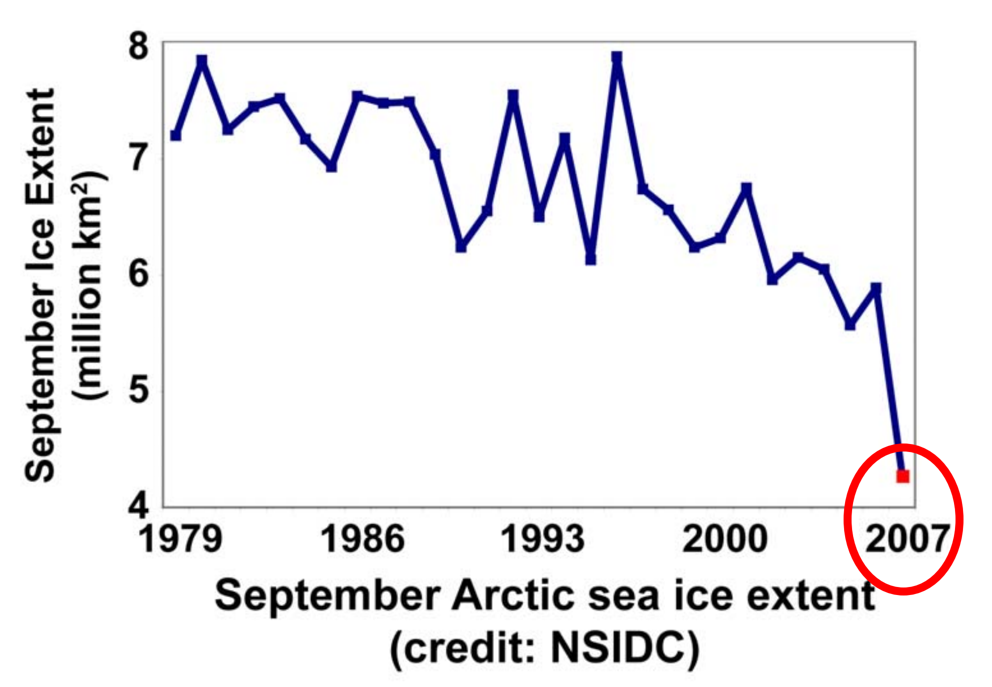
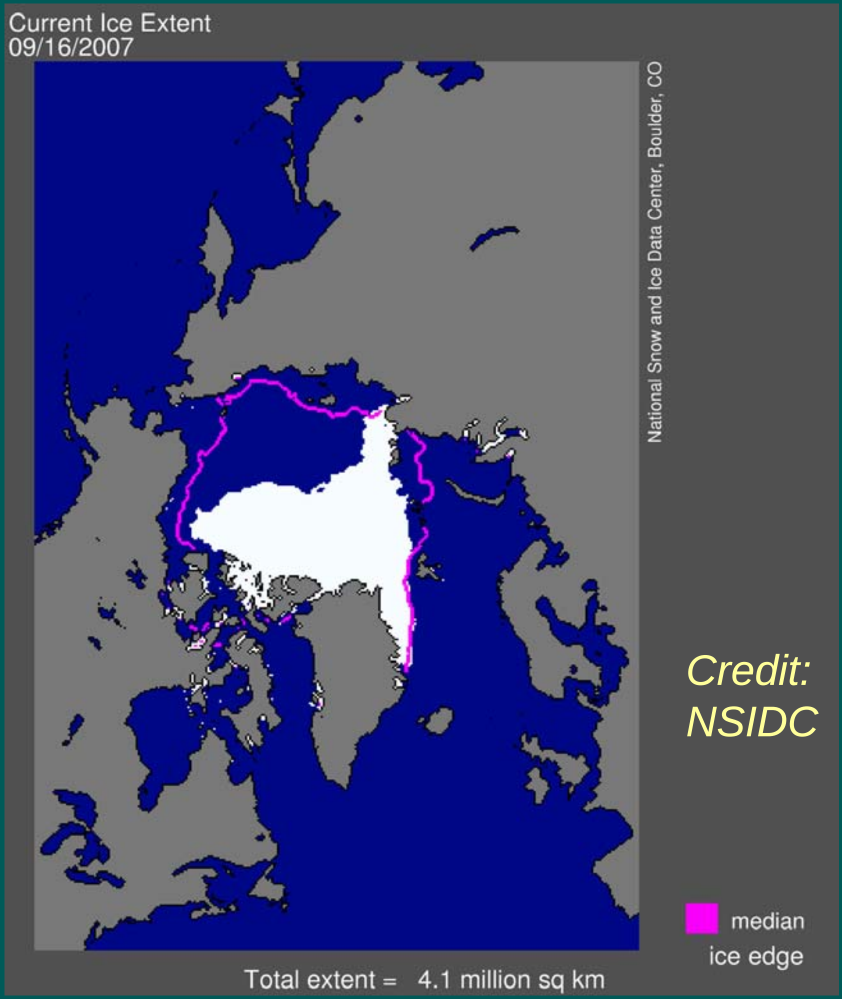


MODIS Image - June 2, 2007

2007 Record Minimum Arctic Sea Ice Extent

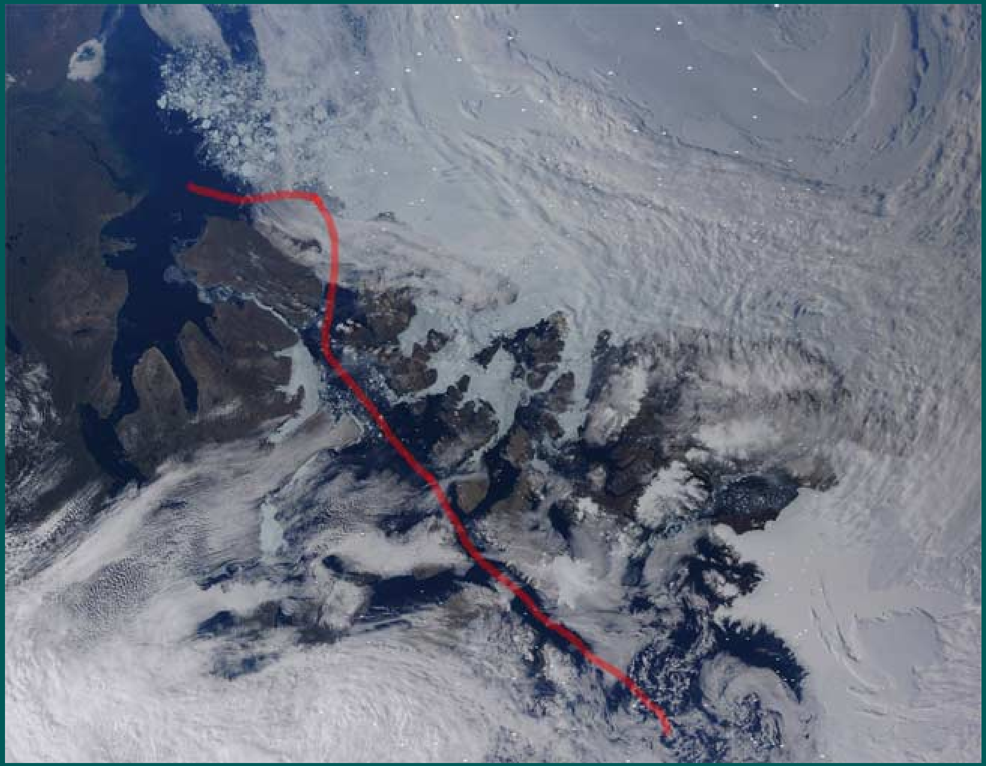




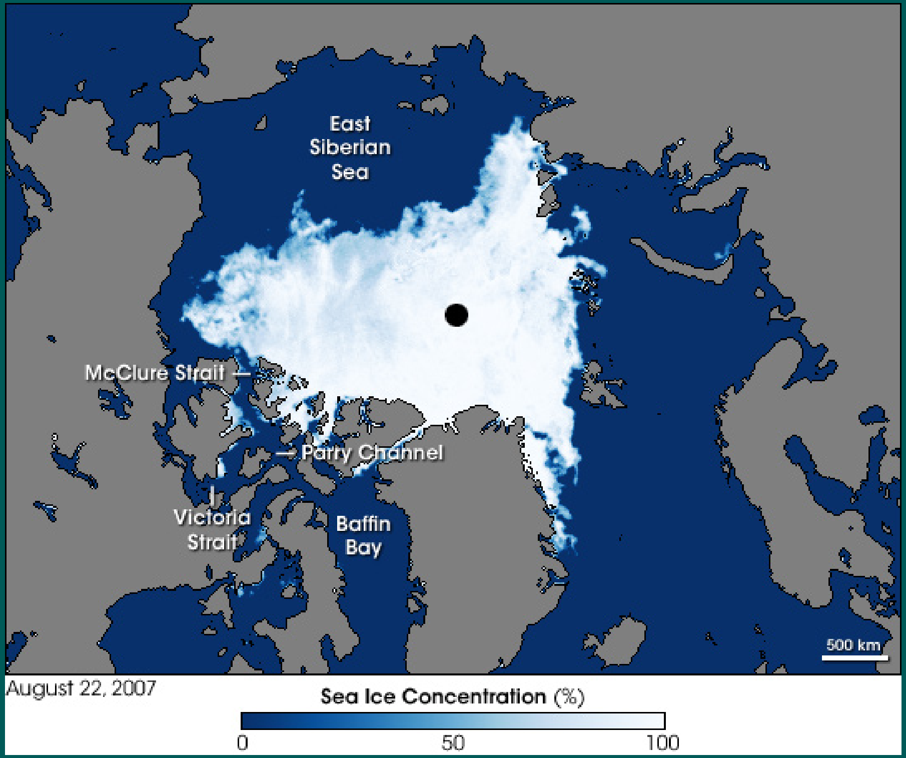
Credit: NSIDC

Additional open ocean in 2007 = Texas+Alaska!

The Northwest Passage was open!



Aug. 29, 2007,
Northwest Passage in red
Credit: NSIDC



AMSR-E late August sea ice coverage
Credit: NSIDC

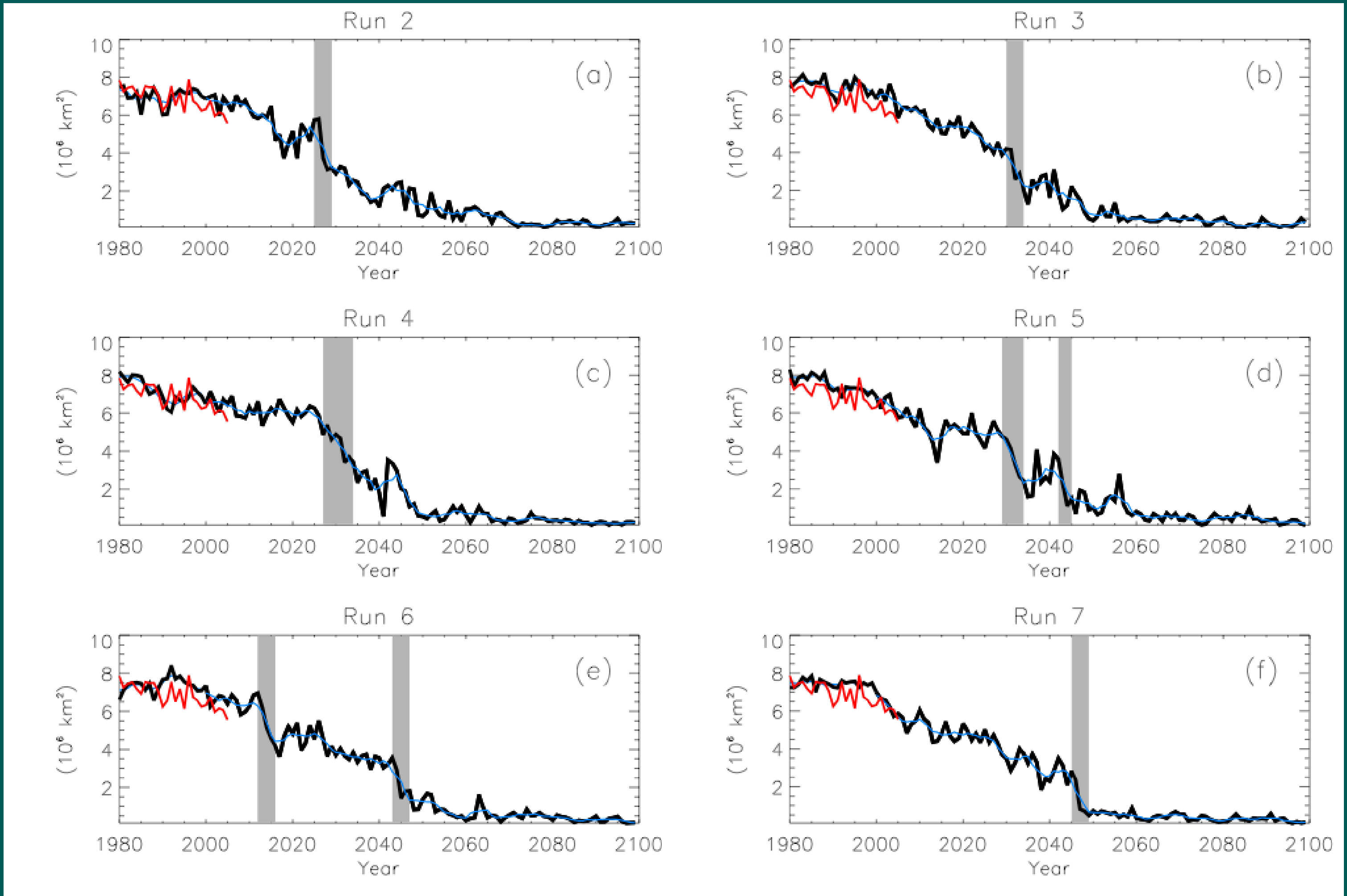
What controls Arctic sea ice extent?

SEA ICE THICKNESS!
Multi-year ice can be 6+ m thick,
while seasonal ice is only ~1-2 m thick.

Dynamic Factors (sea ice motion):
-Winds move and break up sea ice
-Winds can also enhance ice export out of the Arctic

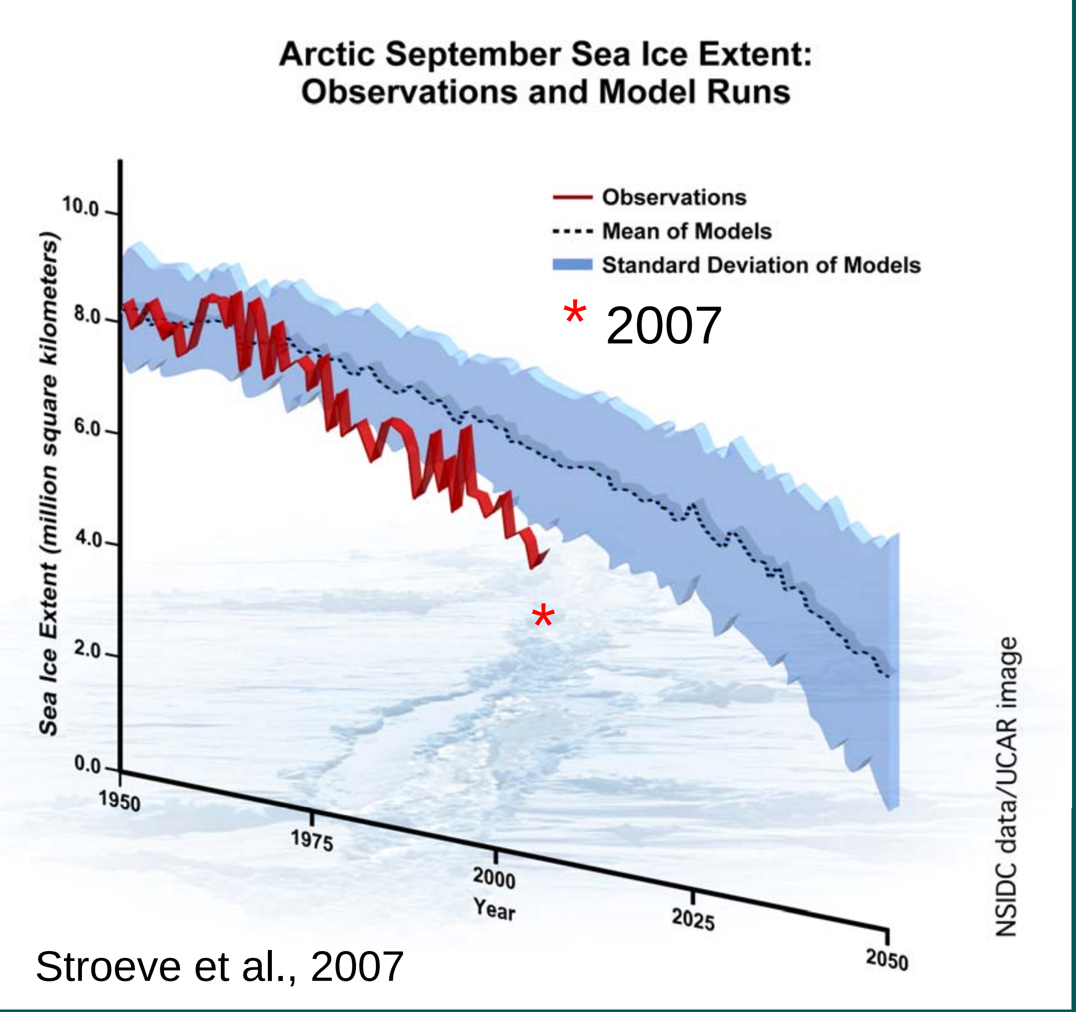
Thermodynamic Factors (heat):
-Heat from the ocean and the atmosphere
-Heat comes from lower latitudes (advection) and local heat sources (sun)

Abrupt sea ice extent reductions do occur in climate models



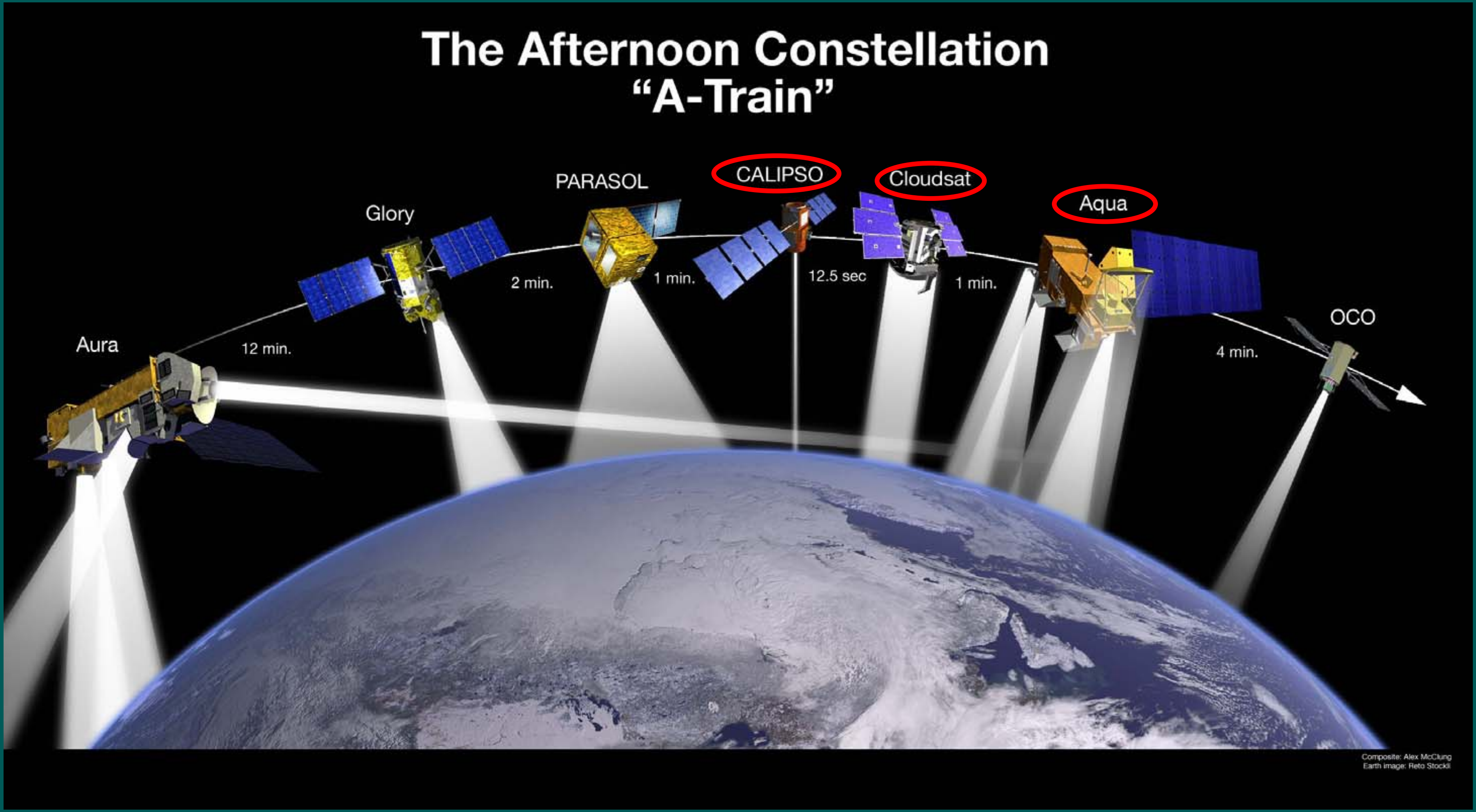
Holland et al., 2006

Arctic sea ice decline is faster than predicted by climate models…

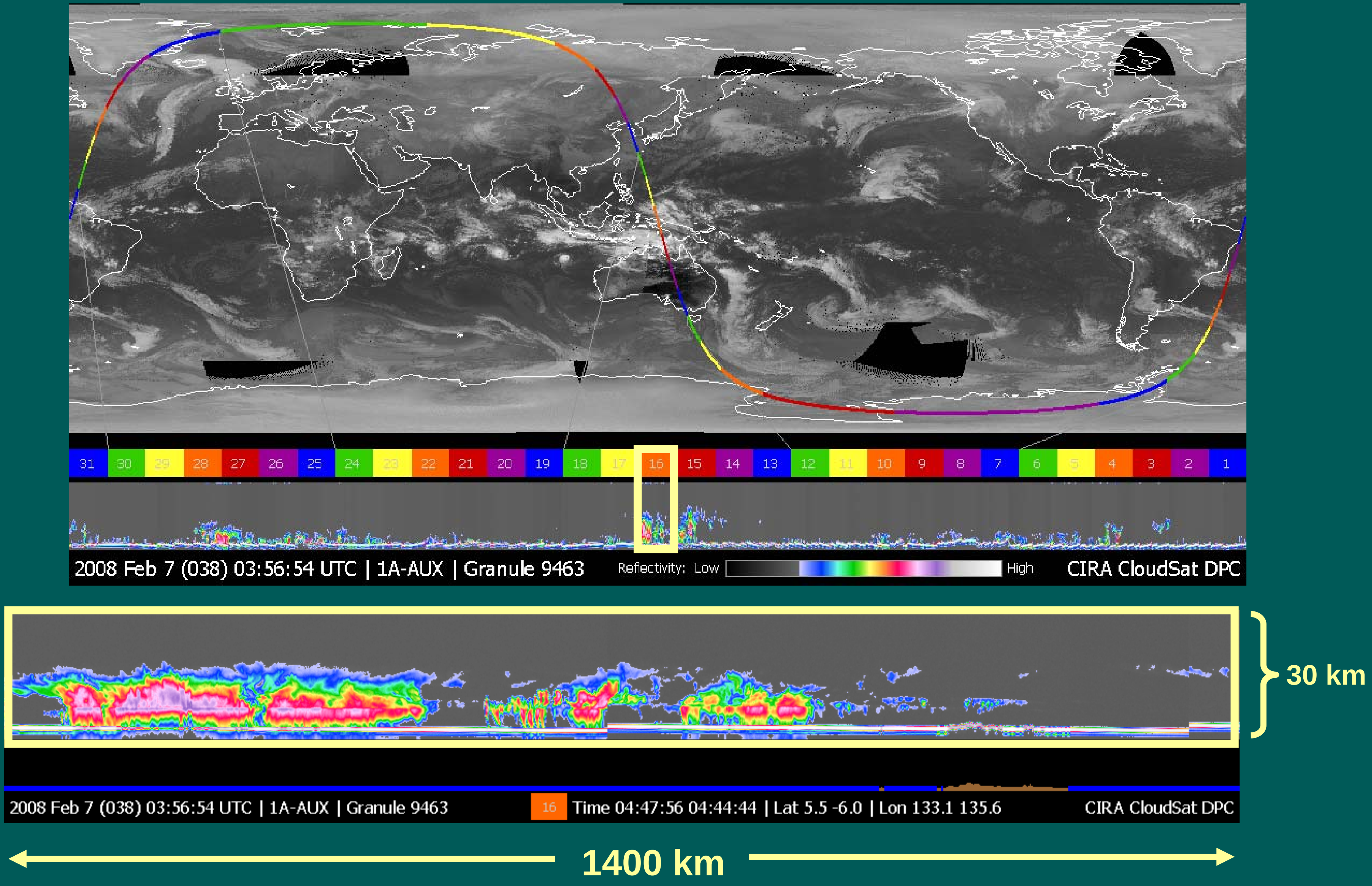



OUTLINE:
1. New A-train satellite data
2. Summer 2007 anomalies
3. Beyond Summer 2007

New cloud and radiation observations from the “A-train”



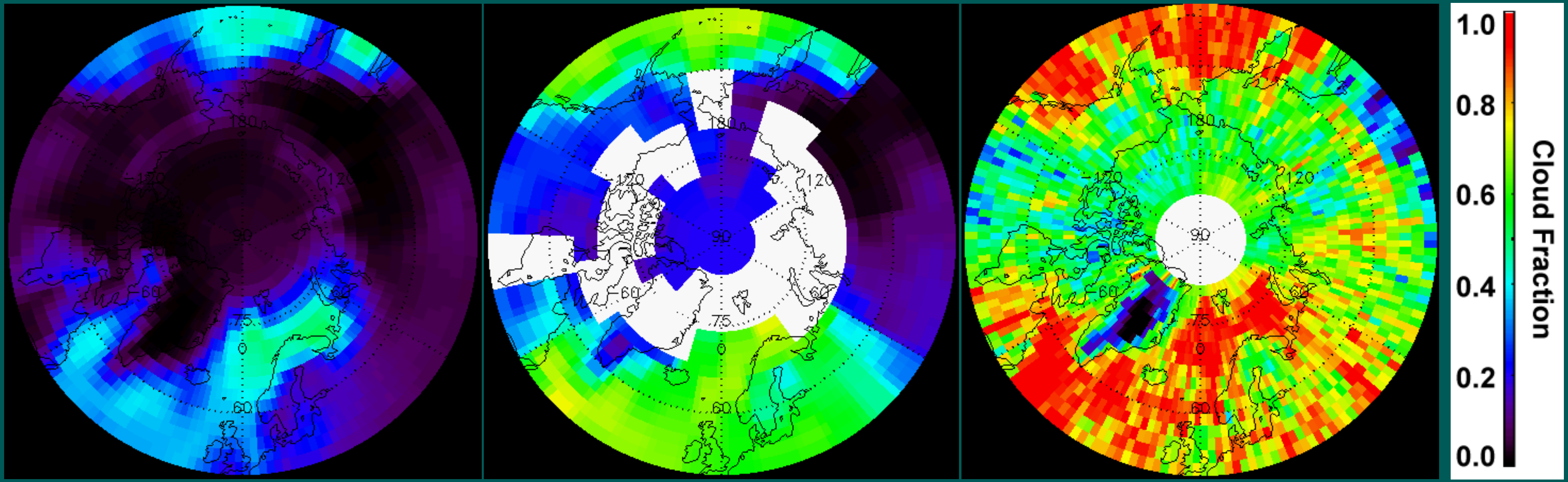
A-train Orbit: Global Data Sampling



Example radar 'quicklook' showing tropical convection - February 7, 2008

The A-train satellite data provide a unique view of Arctic clouds.

DJF Low Cloud Maps

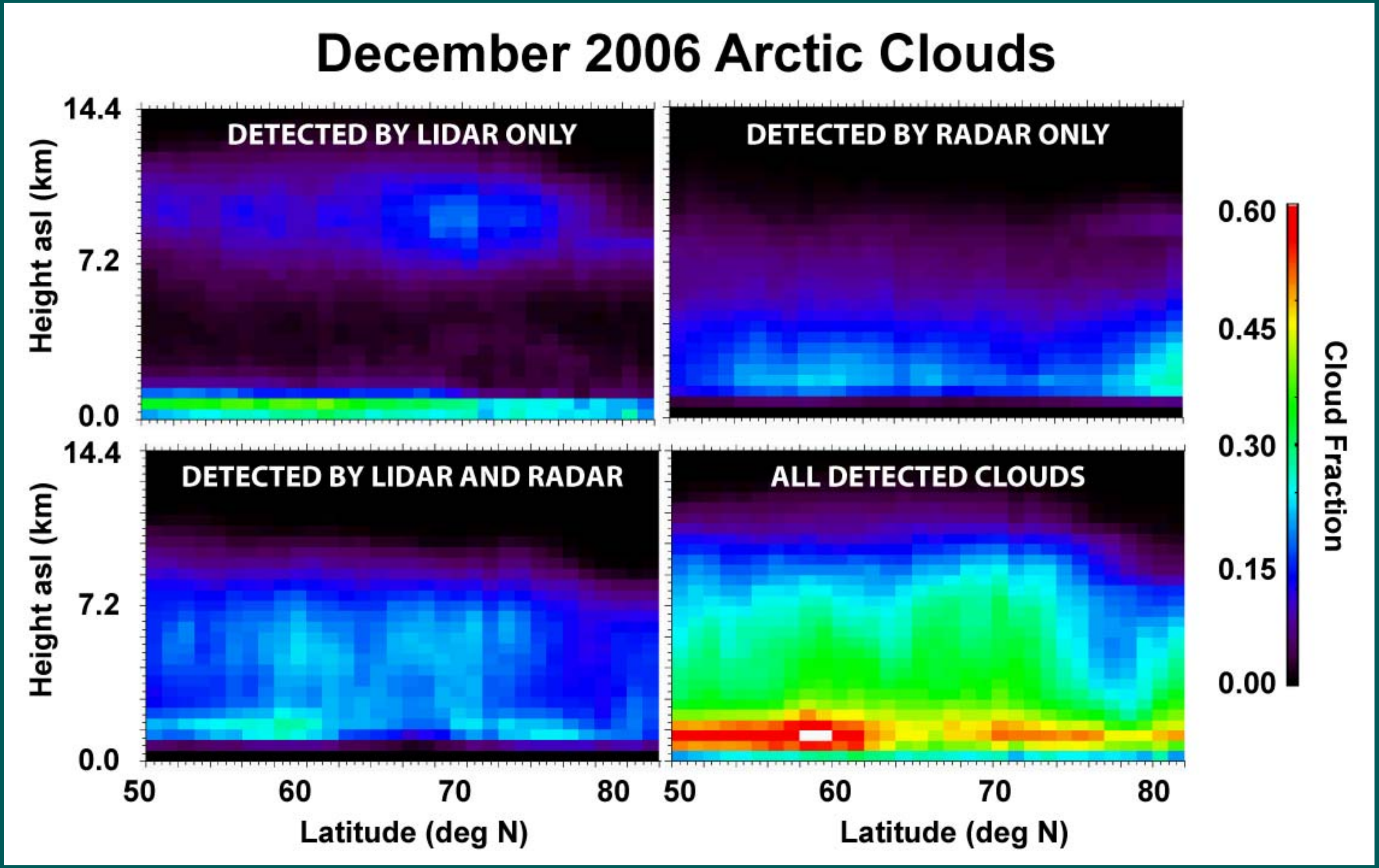


ISCCP D2
(infrared)

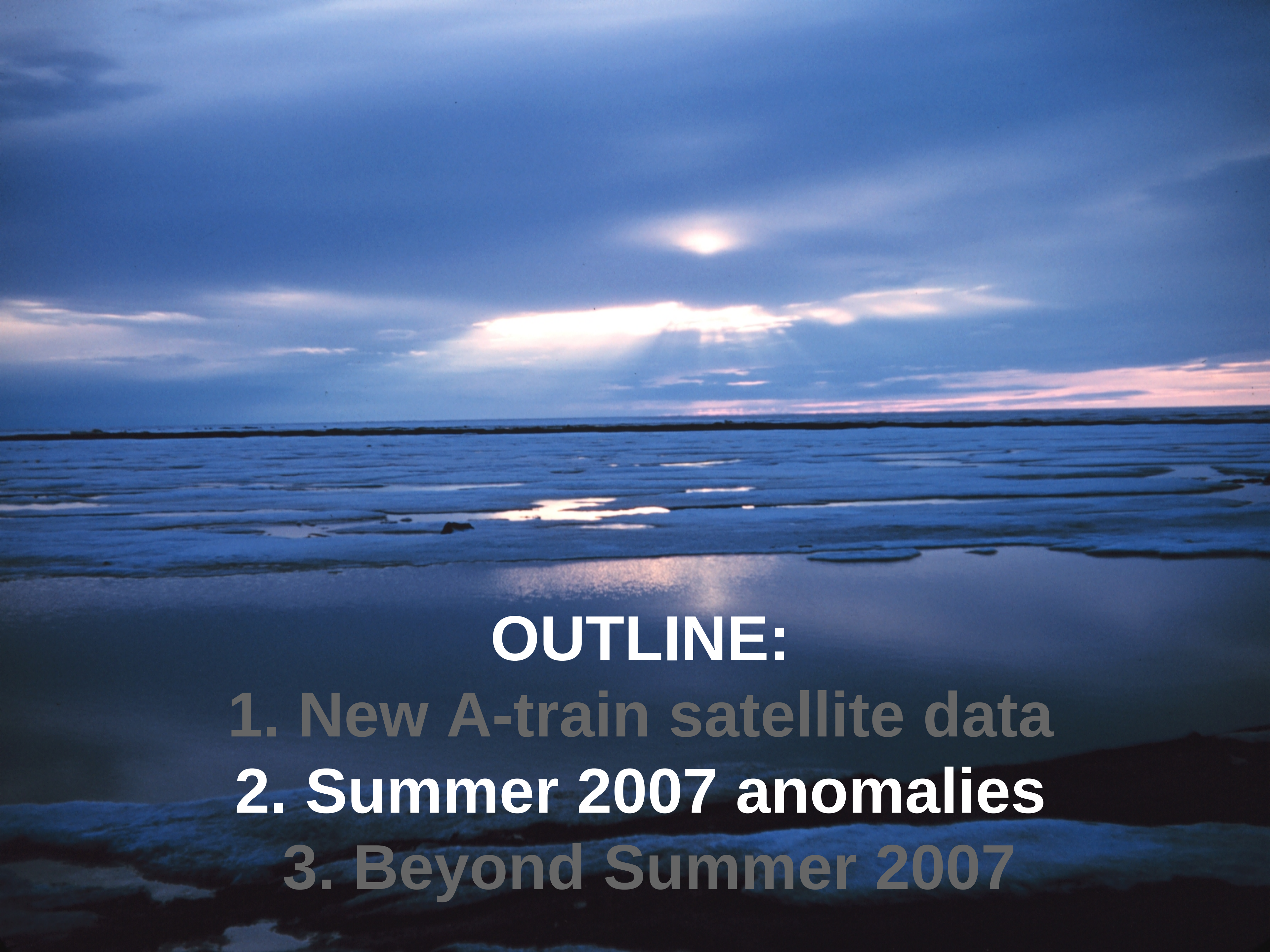
Warren
(surface obs.)

CloudSat+CALIOP
(radar+lidar)

CloudSat and CALIOP synergy



Together, spaceborne radar and lidar detect most Arctic clouds.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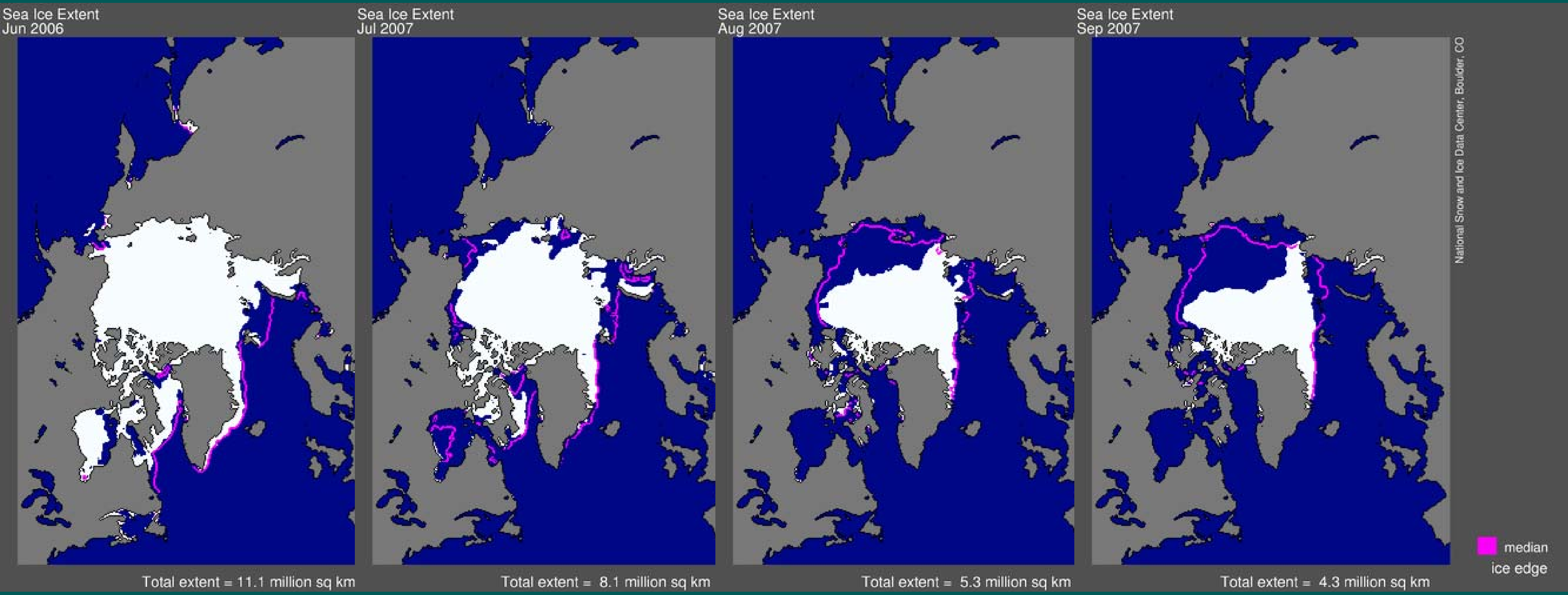
2007 Arctic sea ice extent



Credit: NSIDC

The sea ice extent at the 2007 minimum was 4.13 million km^2
down 43% from 1979 and
down 22% from the last record minimum in 2005.

March 2007 sea ice thickness

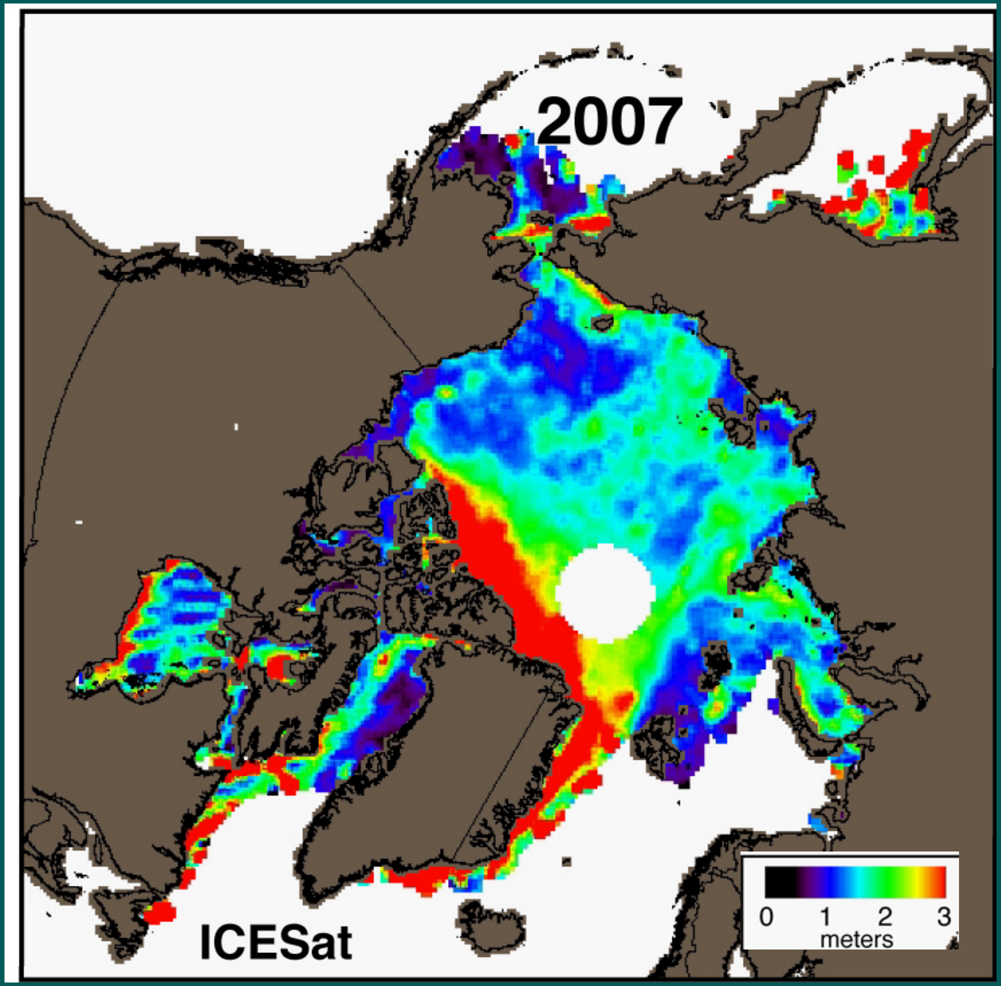
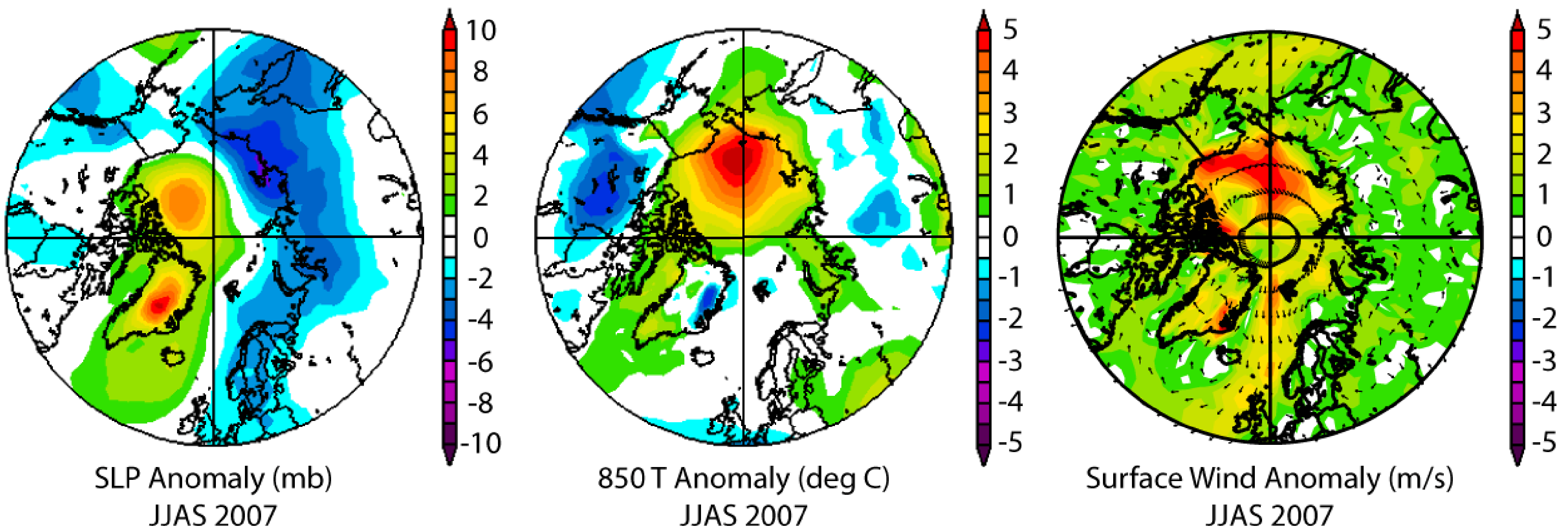


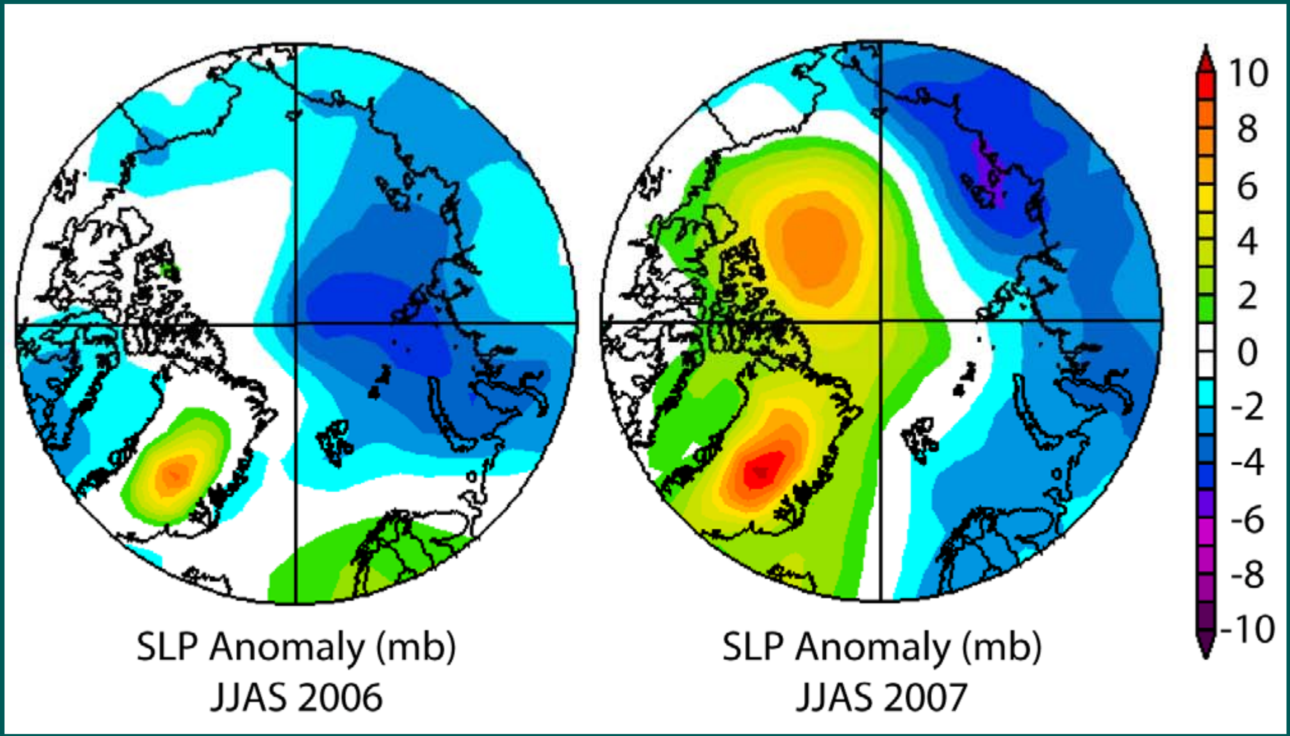
Figure from Stroeve et al. (2008)
courtesy M. Holland

2007 Arctic melt season atmospheric circulation pattern



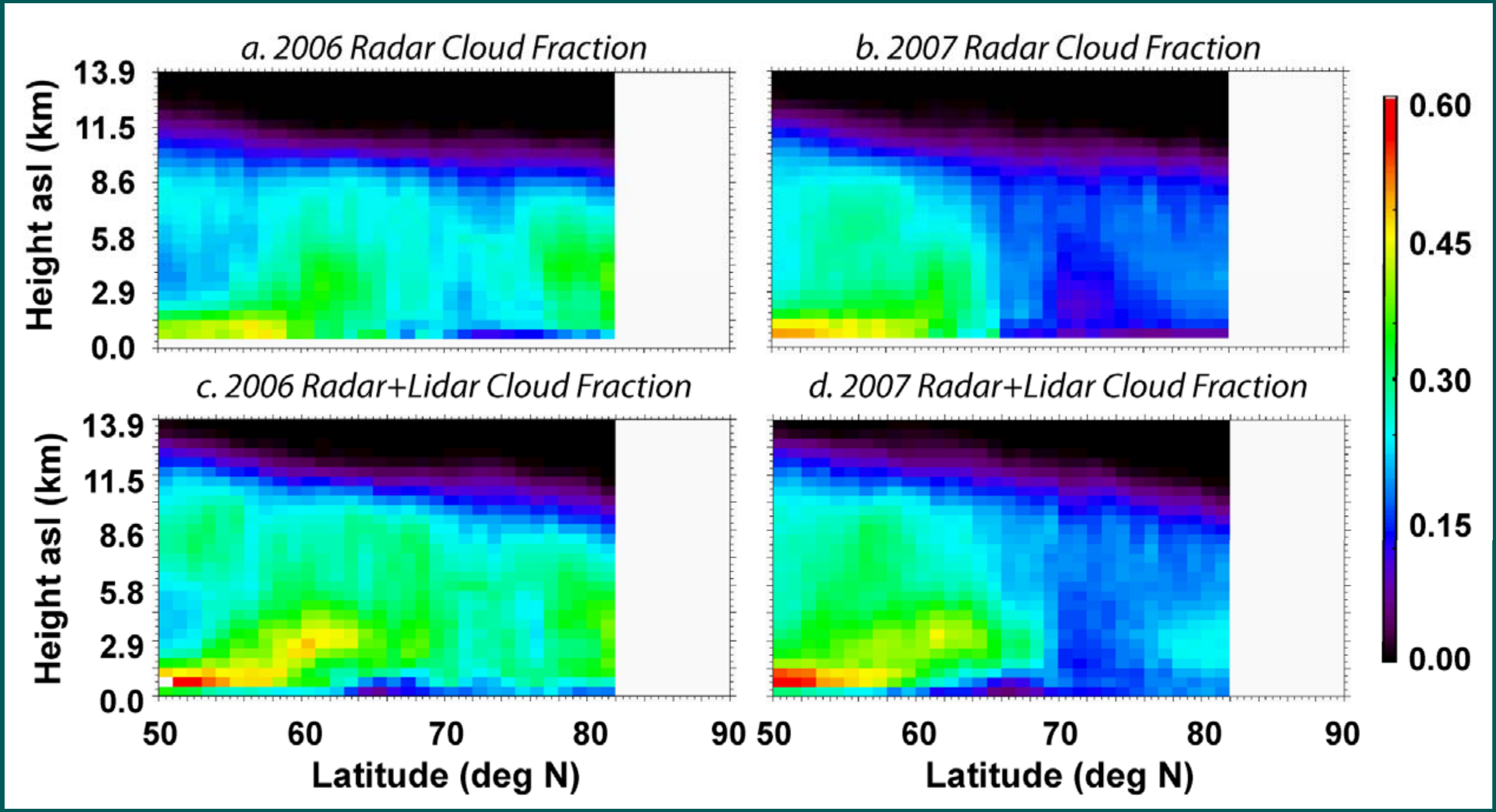
Positive sea level pressure (SLP), high temperatures (T), and strong southerly wind anomalies contributed to the dramatic sea ice loss.

Recent summer circulation patterns



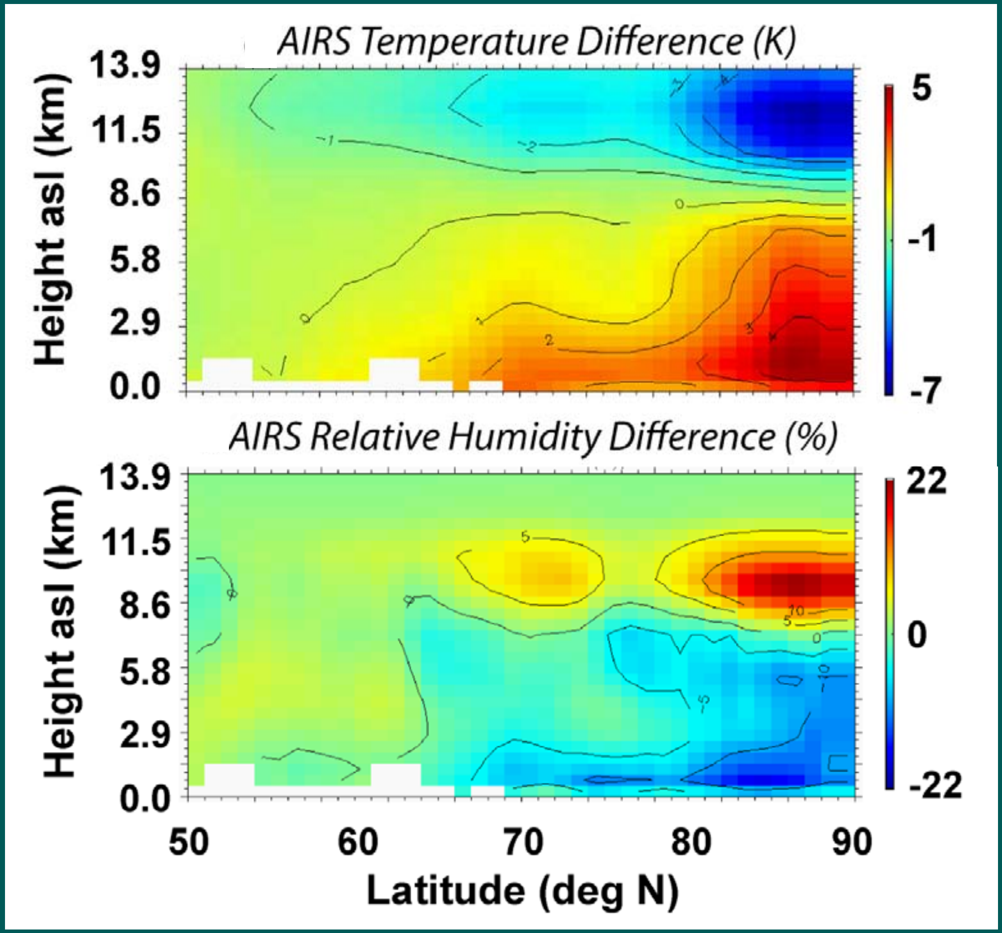
CloudSat radar and CALIOP lidar data are available in 2006 and 2007.

2007 Western Arctic cloud reductions



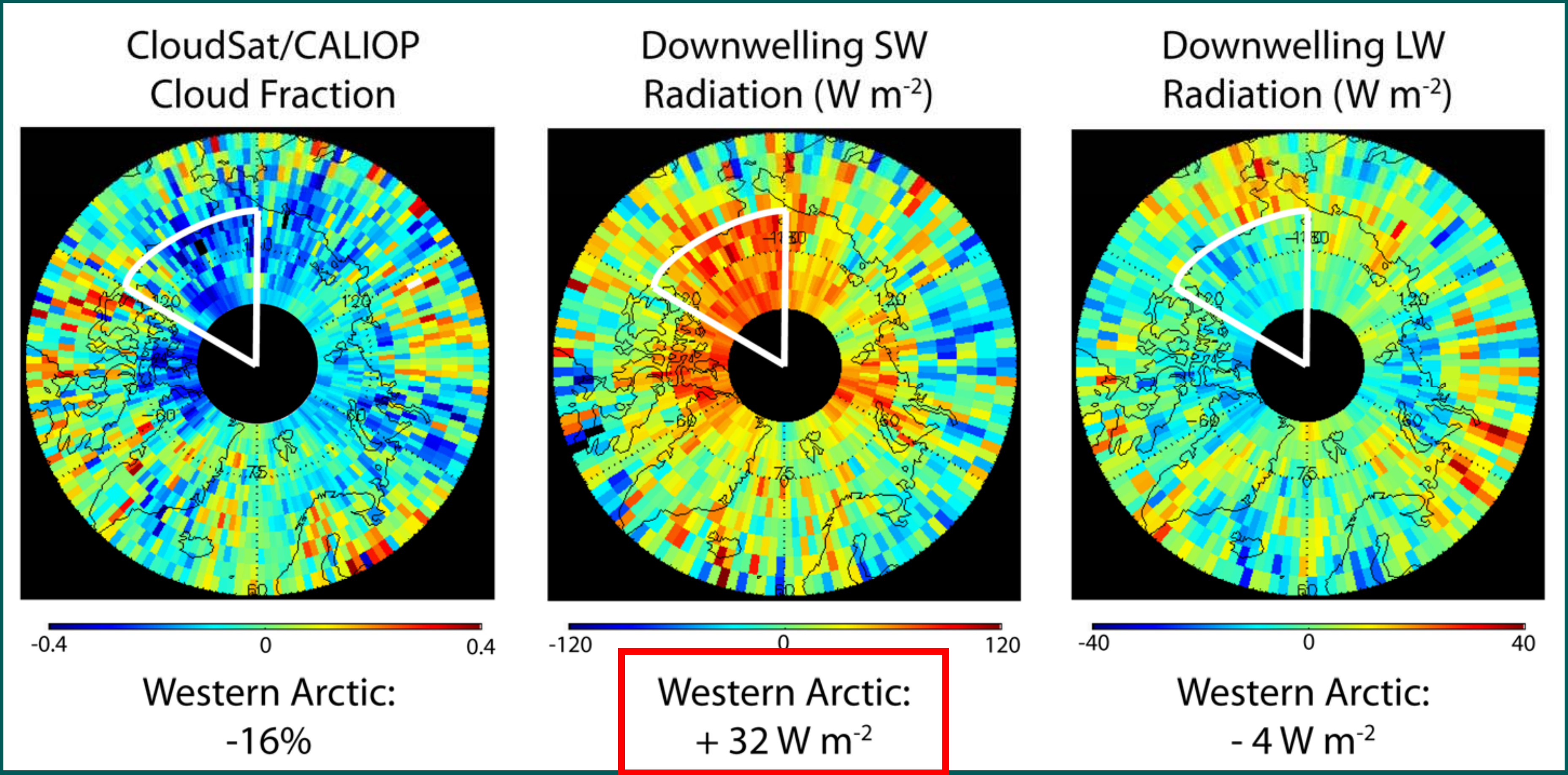
CloudSat/CALIOP data reveal reduced cloudiness from 2006 to 2007 associated with the differing circulation patterns.

2007 Western Arctic = warm and dry



AIRS data show a warmer and drier Western Arctic atmosphere in 2007 as compared to 2006.

Cloud and radiative flux differences (2007-2006)



Radiative fluxes from 2B-FLXHR produced by Tristan L'Ecuyer (CSU).

Over an ice-covered ocean, +0.3 m of surface melt.

Over an ice-covered ocean, the 2007-2006 flux differences could cause **0.3 m of additional surface melt**:

$$\Delta I = \frac{[\Delta RF_{sw} * (1 - a_{ice})) + \Delta RF_{lw}] * t}{L_{fusion} * \rho_{ice}}$$

where ΔI is the additional depth of surface ice melted (m), ΔRF_{sw} is the change in the shortwave downwelling irradiance (W m^{-2}), ΔRF_{lw} is the change in the longwave downwelling irradiance (W m^{-2}), a_{ice}=0.5 is the average albedo of the ice surface over the melt season (Curry et al., 2000), t=3 months, L_{fusion}=334000 J kg^{-1} is the latent heat of fusion, and ρ_{ice}=917 kg m^{-3} is the density of ice.

Over an ice-free ocean, +2.4 K surface ocean warming.

If all the additional heat absorbed by the ocean is used to melt ice in a marginal ice zone with 50% ice and 50% open ocean, **basal melting could be enhanced by 0.7 m.**

“Back-of-the envelope” calculations

Our “back-of-the envelope” calculations suggest large amounts of surface and basal melt could result from the observed 2007-2006 downwelling flux differences.

We do neglect important spatial and temporal variability (e.g., sea ice albedo=0.5, mixed layer depth=20 m, etc.).

Observed Surface Ocean Waming

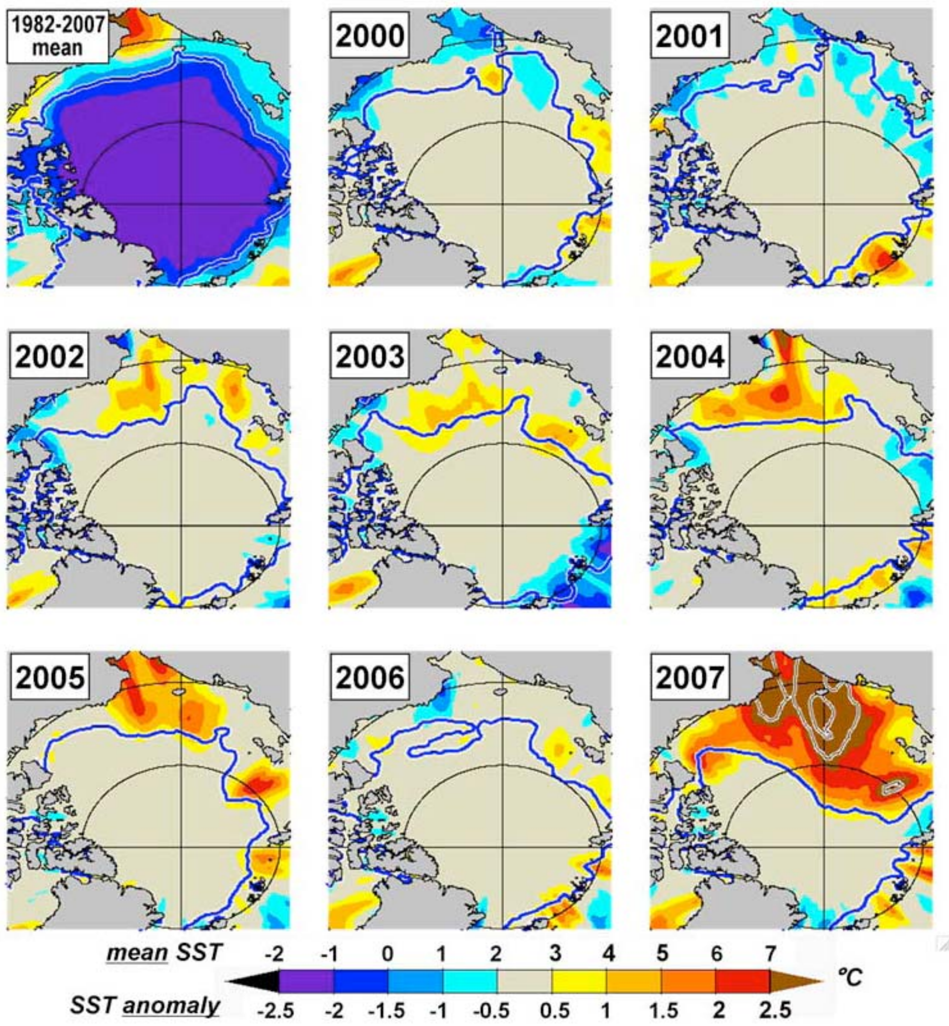
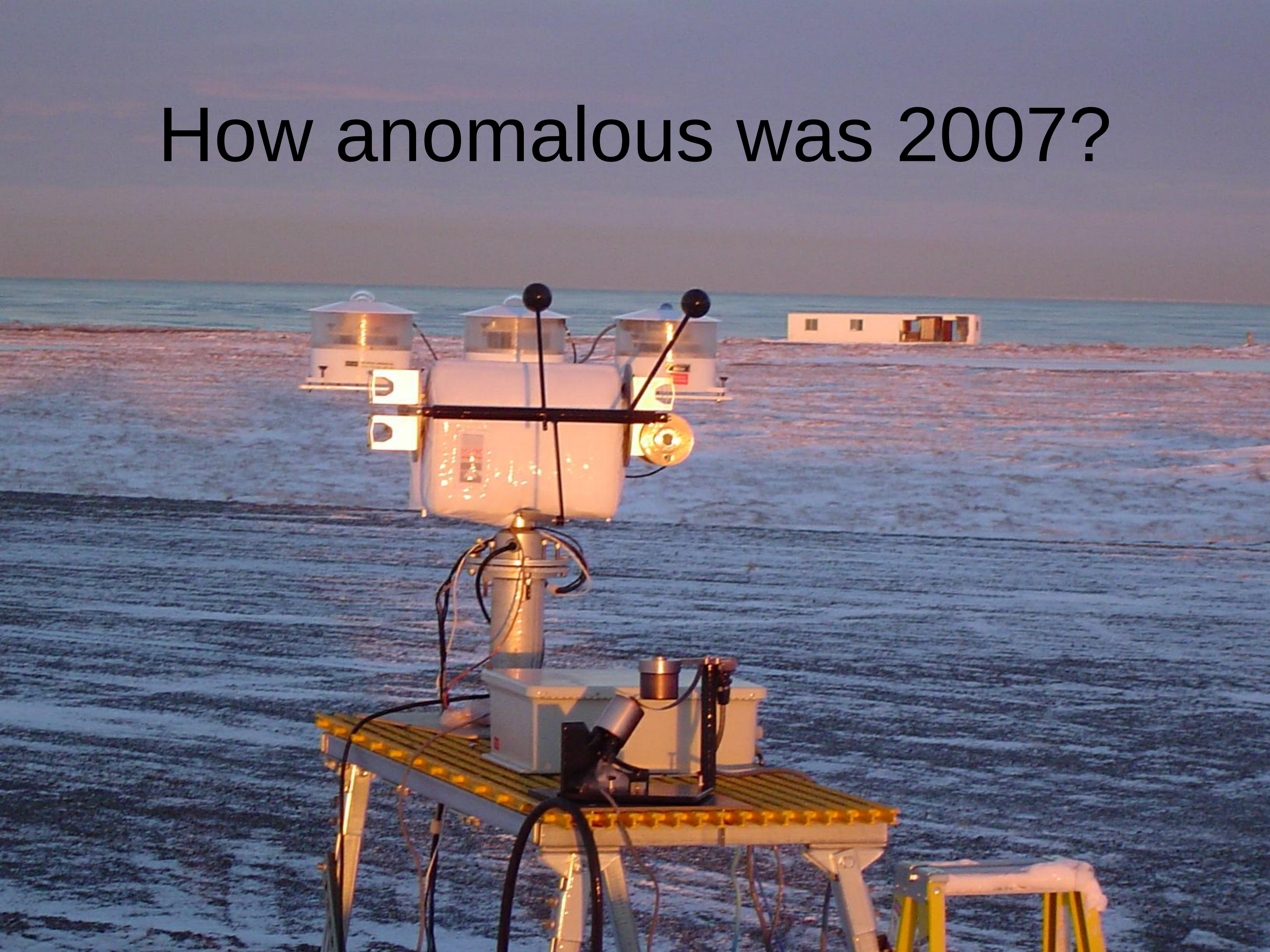


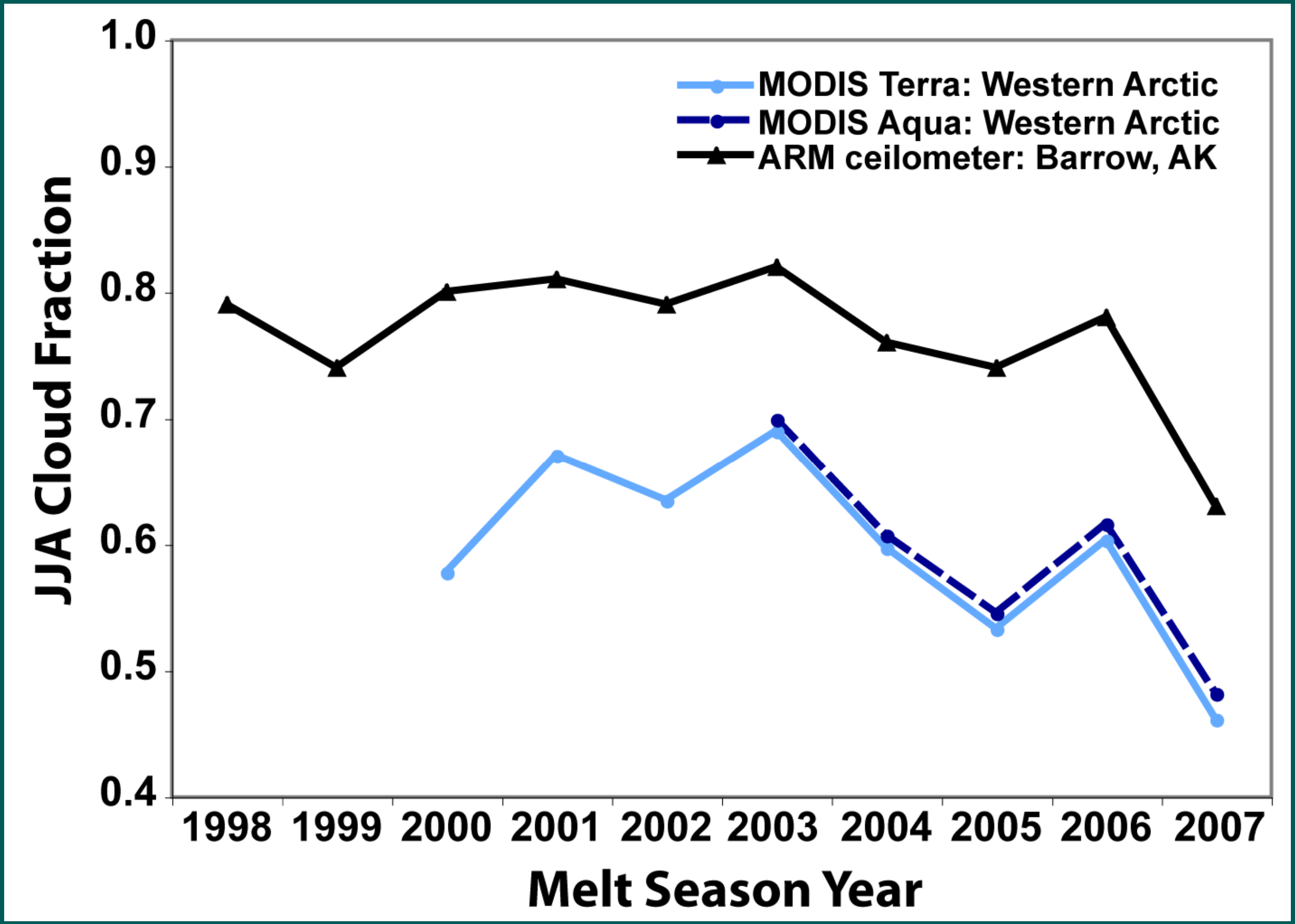
Figure 3. (top left) Mean satellite-derived summer SST [*Reynolds et al.*, 2002] and anomalies from this mean over 2000 2007, with no bias correction as in Figure 2. Latitudes 70°N and 80°N and longitudes 0°/180°E and 90°/270°E are shown. For 2007, extra contours for 3°C and 4°C are provided. Also shown is the September-mean ice edge (blue contour) from the Hadley Centre (1982 2006: http://badc.nerc.ac.uk/data/hadisst/) and from the National Centers for Environmental Prediction (2007: ftp://polar.ncep.noaa.gov/pub/cdas/).

Figure from Steele et al. (2008, GRL)

How anomalous was 2007?

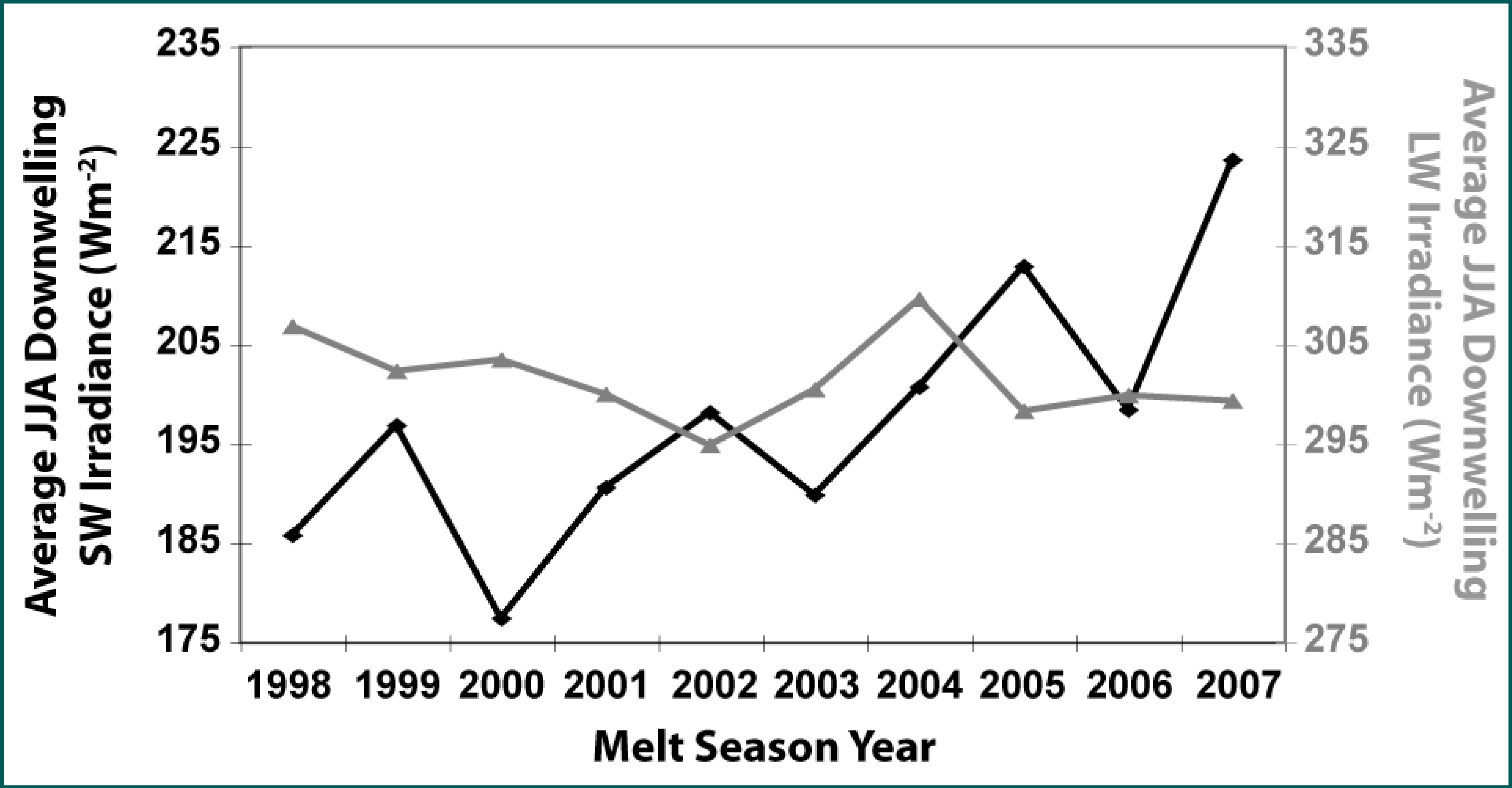


Recent Arctic cloud observations



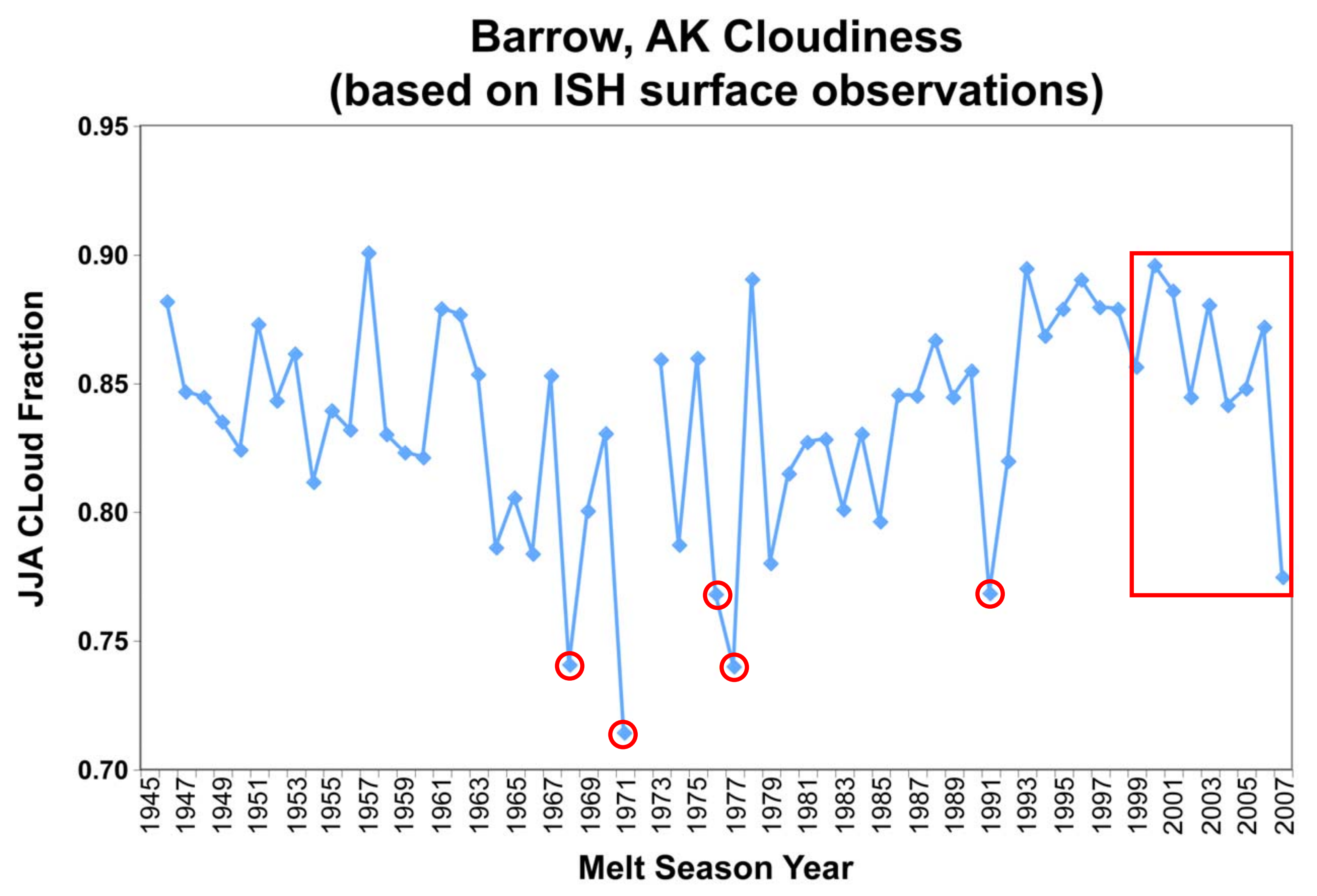
The 2007 cloud fraction is anomalous in the recent past.

Radiation observations from Barrow, AK



The 2007 downwelling shortwave radiation is anomalous in the recent past.

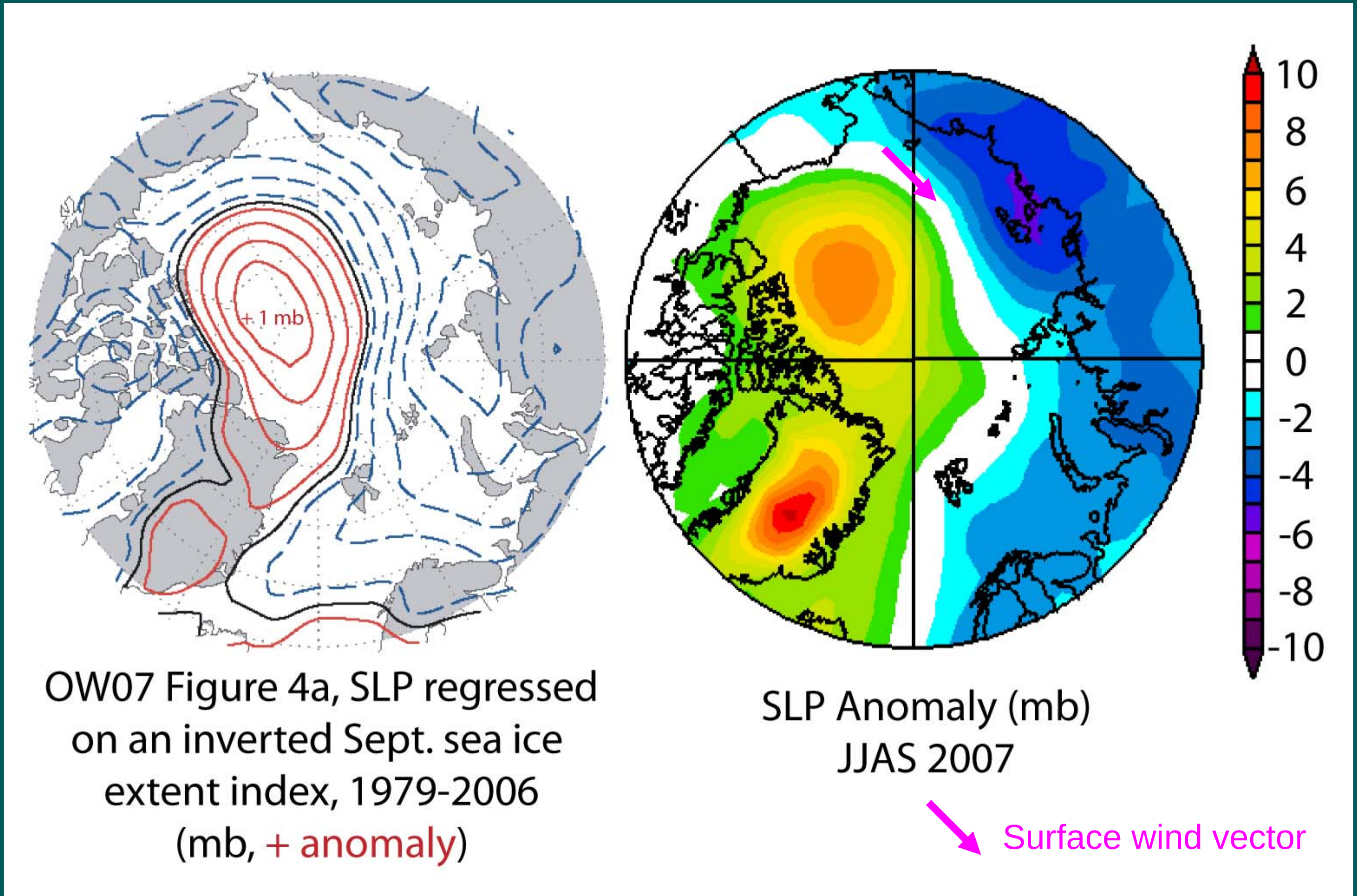
Were the 2007 clouds *really* anomalous?



In a warmer world with thinner ice, natural summertime circulation and cloud variability is an increasingly important control on sea ice extent.

Kay, L'Ecuyer, Gettelman, Stephens, and O'Dell
(in press *Geophysical Research Letters*)

Summertime circulation and ice loss



Ogi and Wallace 2007 (OW07) attribute sea ice loss to wind stress. Our work suggests additonal contributing factors.

Our results differ from previous work

Table 2. Sign of Correlation (>90% Confidence) Between Anomalies in Maximum Ice Retreat and Anomalies in Forcing Parameters From 1979 to 2004[a]

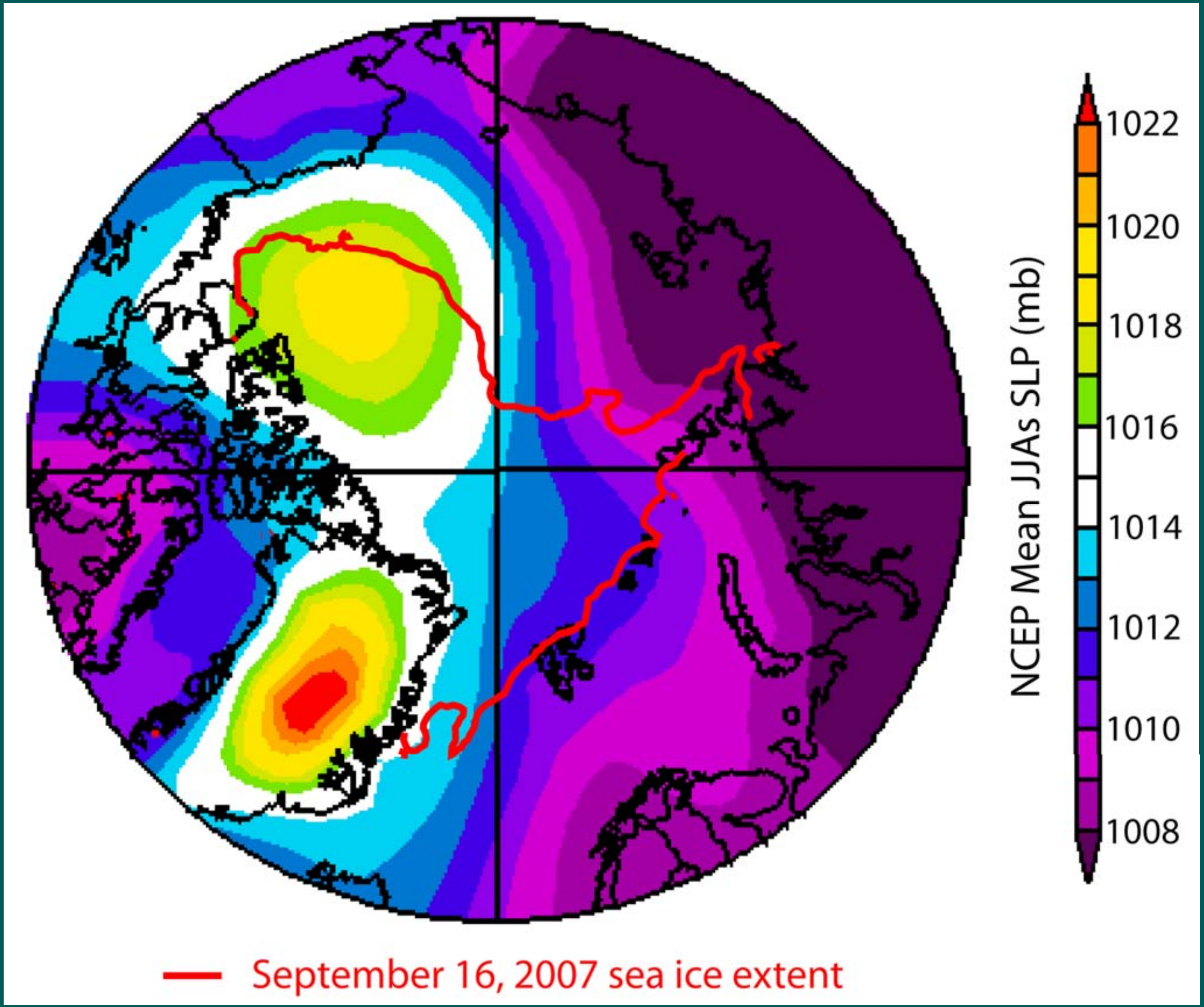
Region	u	v	DLF	DSF	ADV
Barents Sea	±	+	+	–	±
Kara Sea	–	+	+	–	+
Laptev Sea	n/s	+	+	–	±
E. Siberian Sea	+	+	+	–	+
Chukchi Sea	+	+	+	–	+
Beaufort Sea	±	n/s	+	–	+

[a]Varying sign at different lag values is indicated by ±. Non-significant correlations are indicated by n/s. DSF correlations are calculated for 1982 to 2000 only.

In contrast, we find that large increases in solar radiation are associated with significant sea ice loss during 2007 (and 2005).

Francis et al. (2005, GRL) found "the effect of solar flux anomalies is overwhelmed by the longwave influence on ice edge position."

“A perfect storm” for ice loss in 2007



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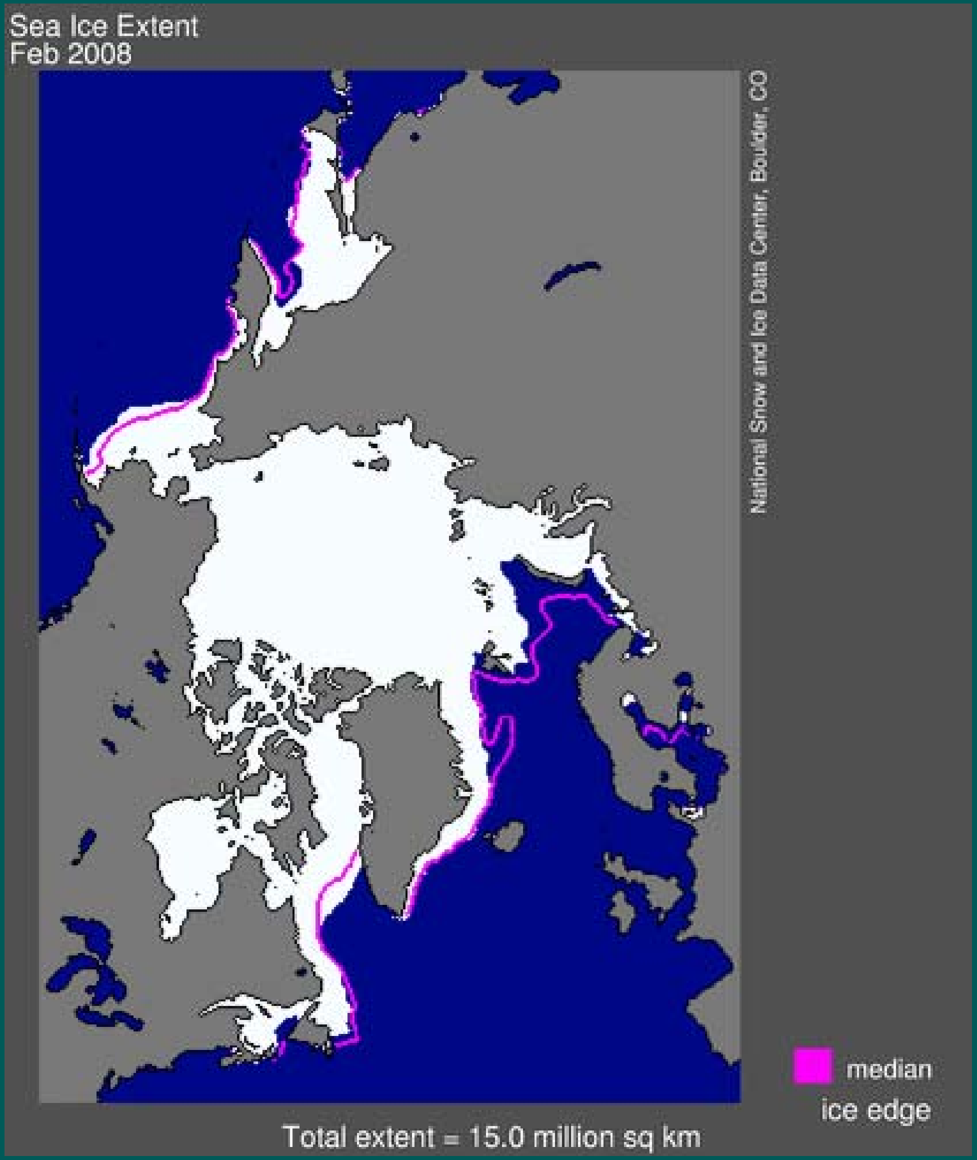
August 26, 2007 photo showing sea ice melt near 80° N, 159° W.
Credit: NCAR

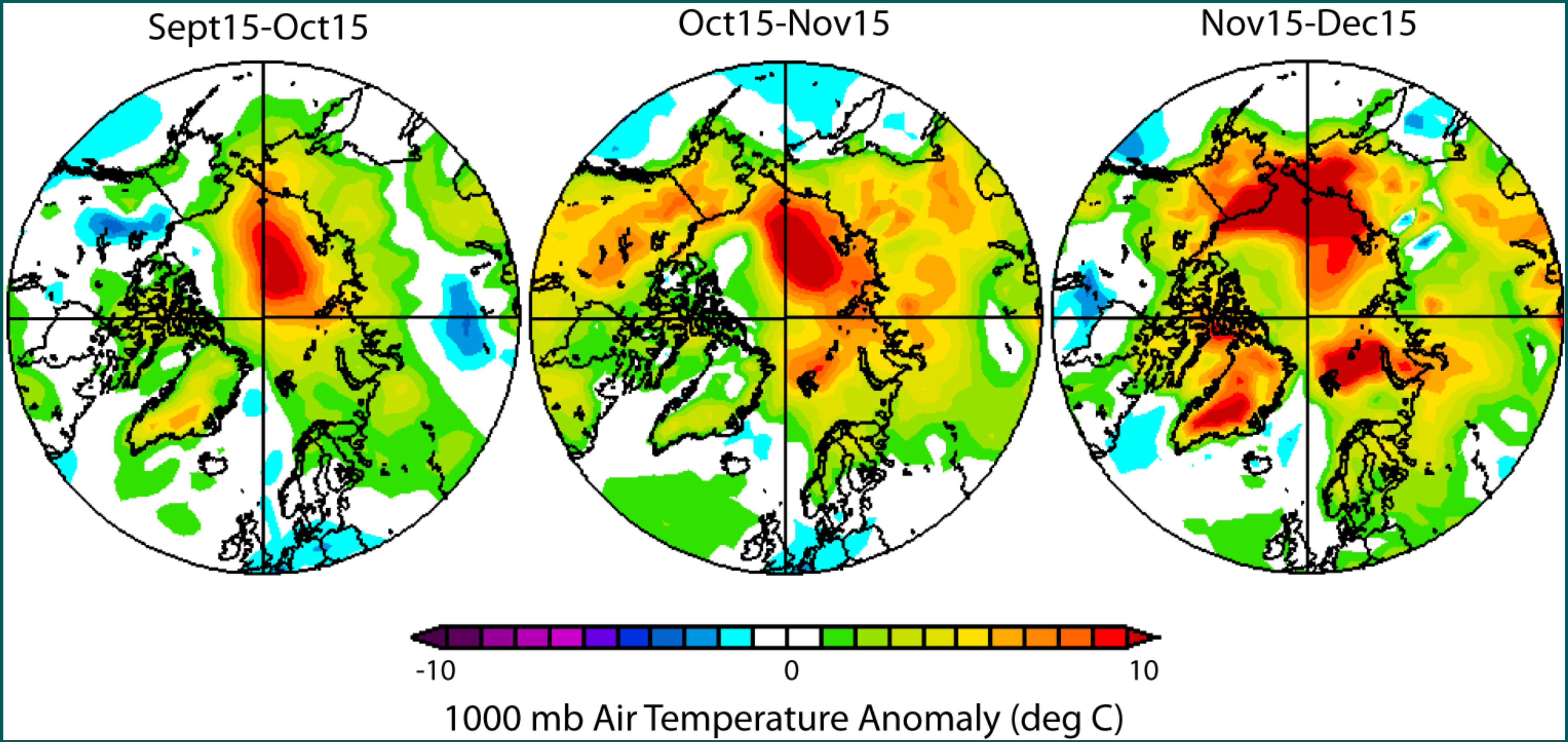
Will the ice recover? Have we reached a ”tipping point”?

Fall/Winter sea ice extent recovery



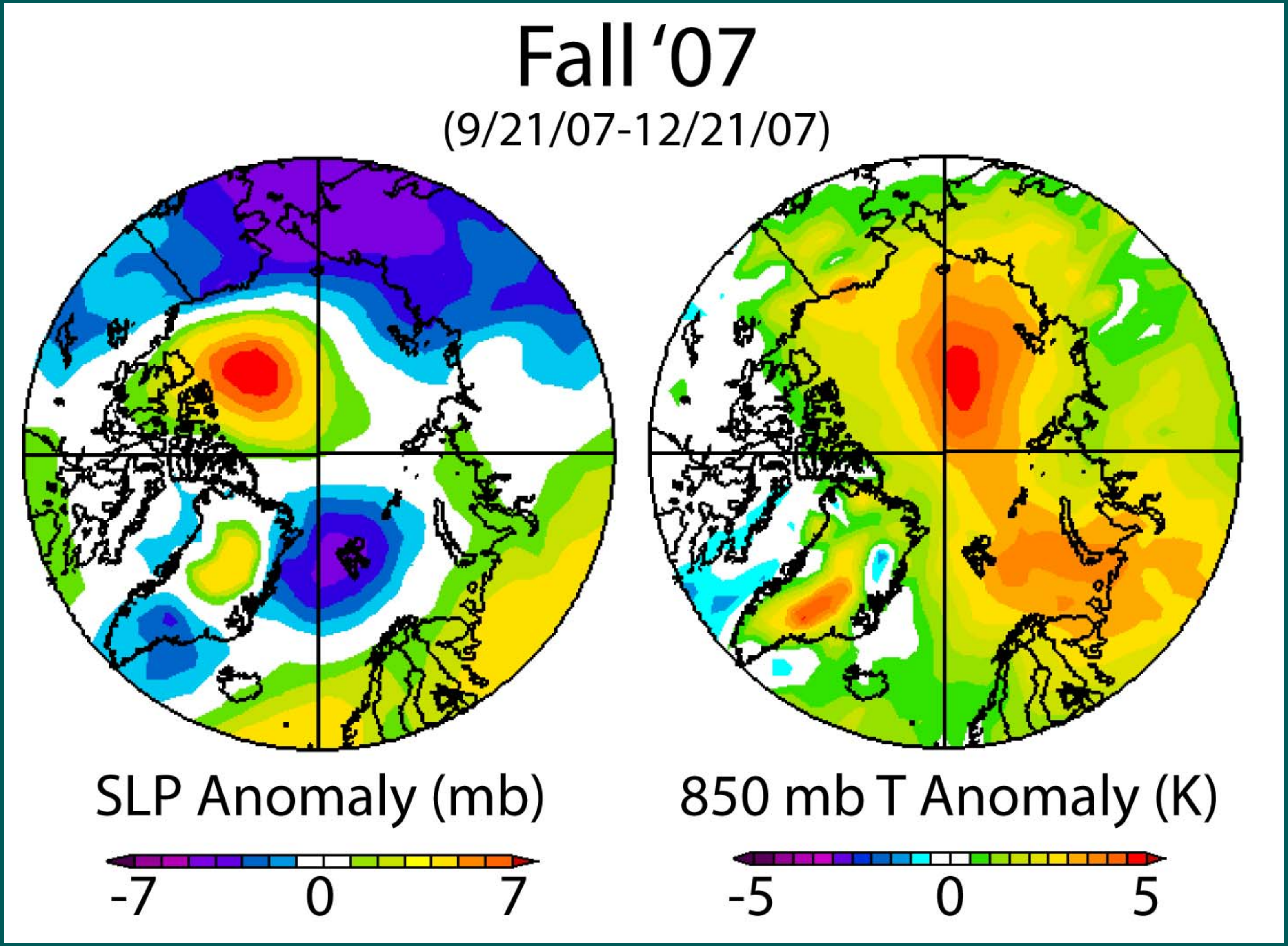
Credit: NSIDC

Memory of the 2007 sea ice loss?

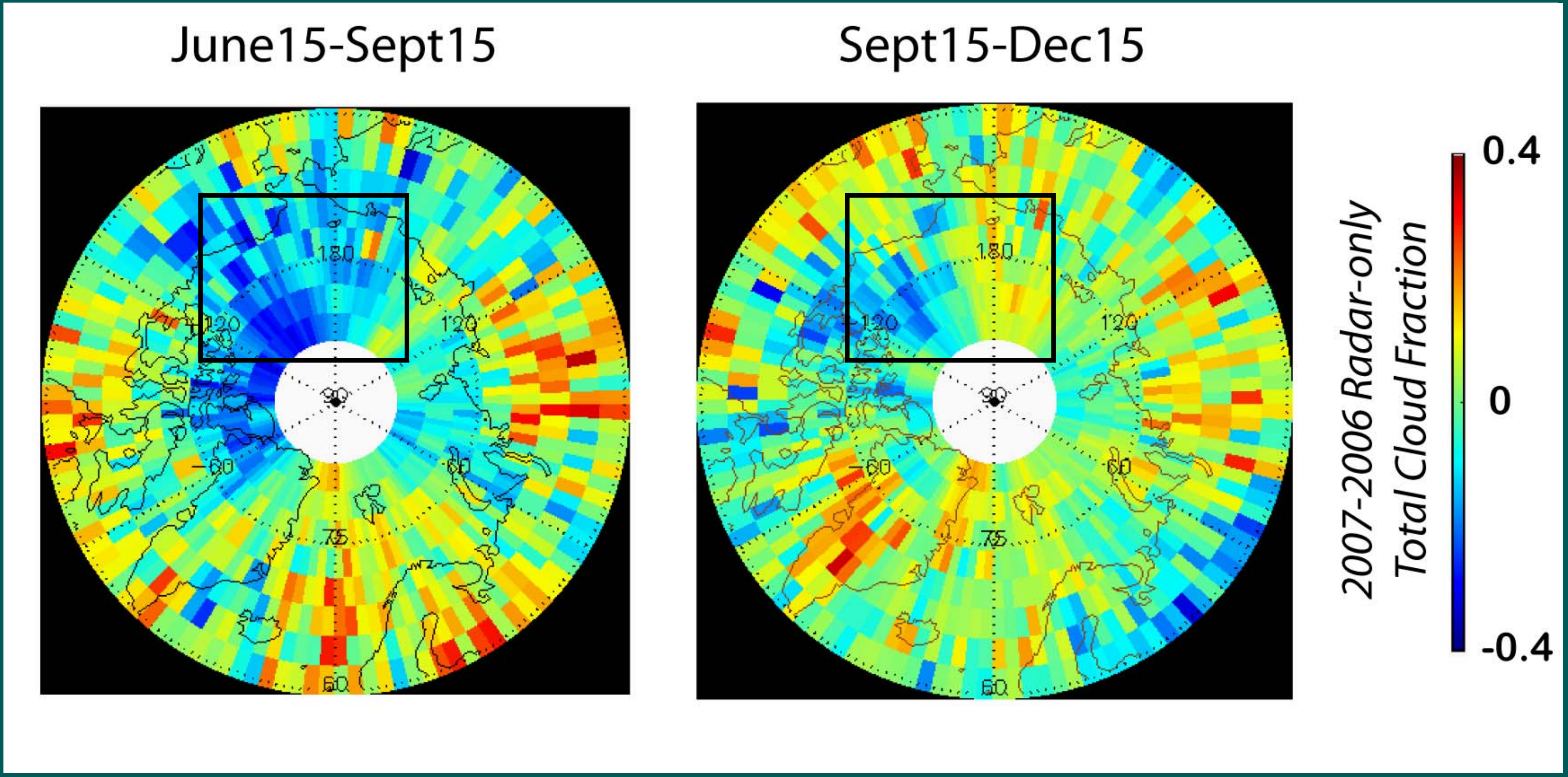


The extra heat absorbed by the ocean during Summer was released back to the atmosphere during Fall.

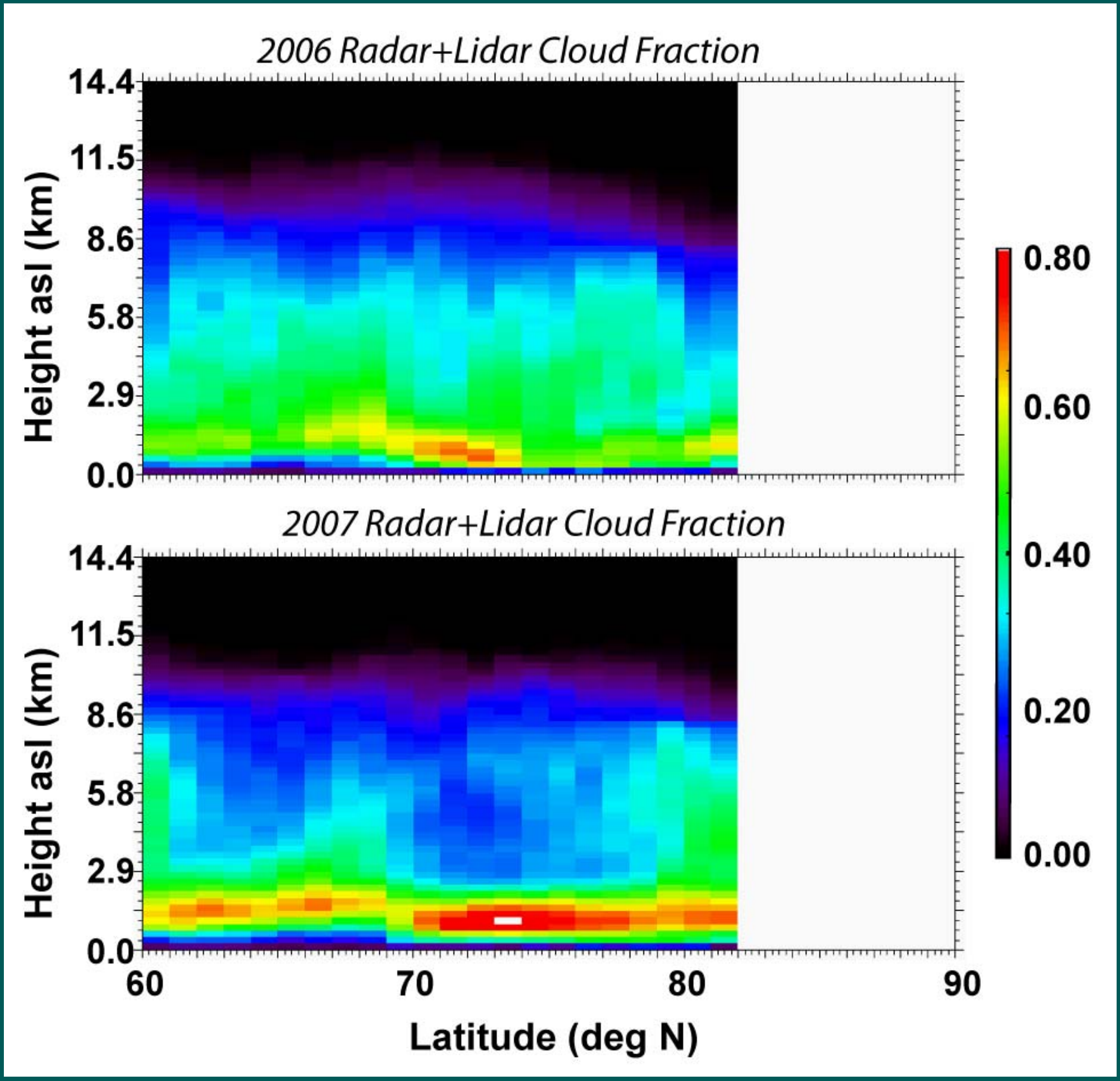
Atm. Conditions During Ice Growth



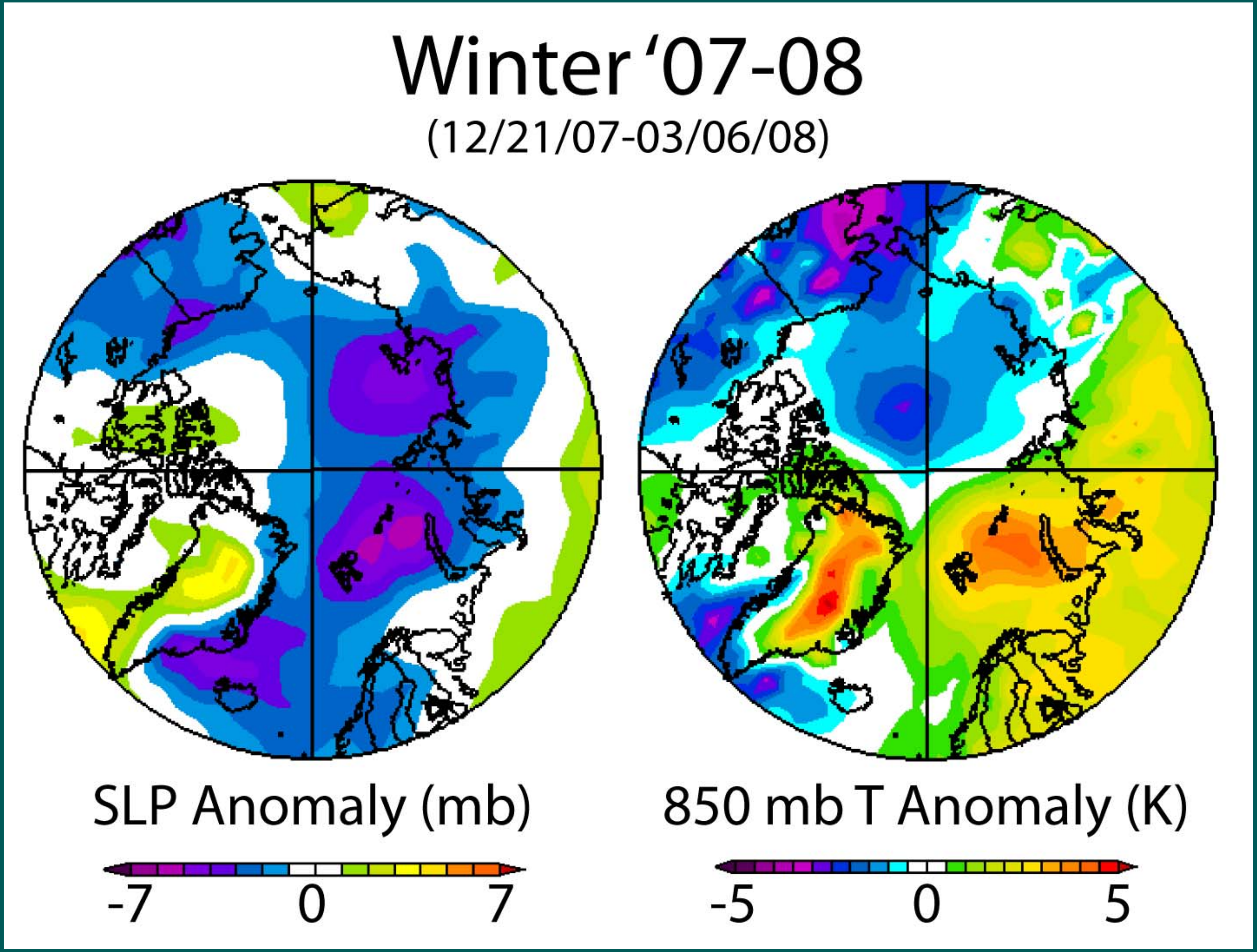
Summer vs. Fall
Cloud Differences (2007-2006)

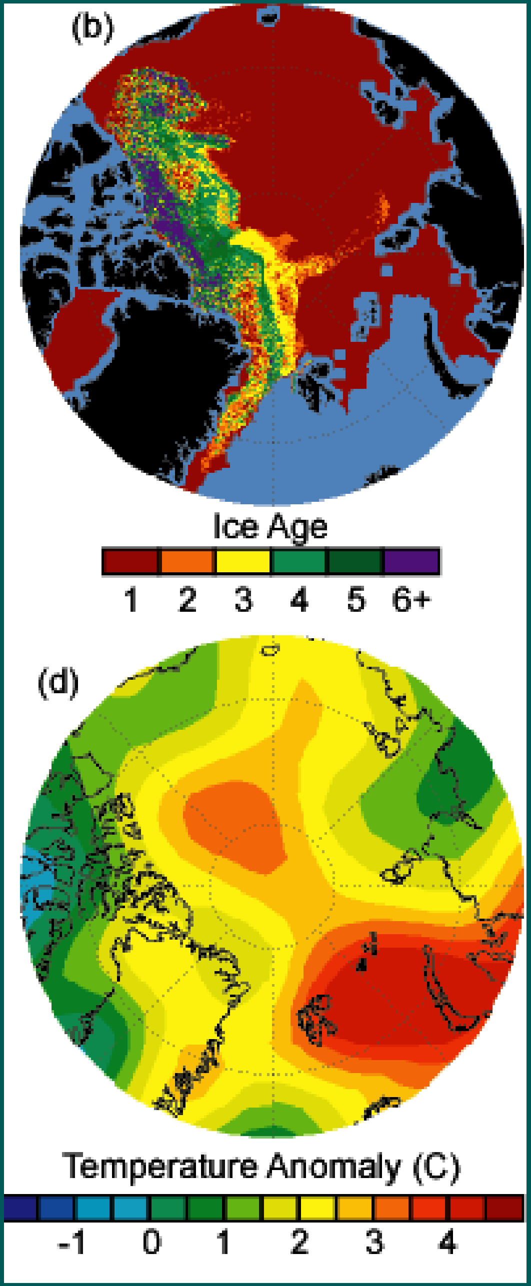


Early Fall Cloud Increases Near The Dateline



Atm. Conditions During Ice Growth





The sea ice did not recover during Fall/Winter!

Drobot, Stroeve, Maslanik, Emery, Fowler, and Kay (submitted to Science)

Summary

- A-train satellite and ARM NSA data provide unique information about the Arctic atmosphere.
- Reduced cloudiness and enhanced shortwave downwelling radiation contributed to the 2007 record-low Arctic sea ice extent.
- In a warmer world with thinner ice, the minimum sea ice extent is increasingly sensitive to year-to-year variability in weather and cloud patterns.
- The future is uncertain, but continued dramatic summertime Arctic sea ice extent loss is very likely.
- Our future work will continue to evaluate the efficacy of atmospheric forcing on sea ice extent and the potential for uncharted feedbacks using observations and models.

QUESTIONS?


UNITED STATES AIR FORCE
OLIKTOK
LONG RANGE RADAR SITE
FIRE EXIT ONLY
USE ID DOOR
WARNING

EXTRA SLIDES!!

Spaceborne radar and lidar 101

Active instruments such as radar or lidar *emit a pulse*.

The pulse is either reflected back to the instrument, continues downward, or is absorbed and lost.

The instruments *record the time delay and the magnitude of the reflected signal*.

CloudSat's 94 GHz (3 mm) radar measures cloud particles, raindrops, and snowflakes.
CALIPSO's 532/1064 nm lidar measures aerosols and thin clouds.

Ongoing Work

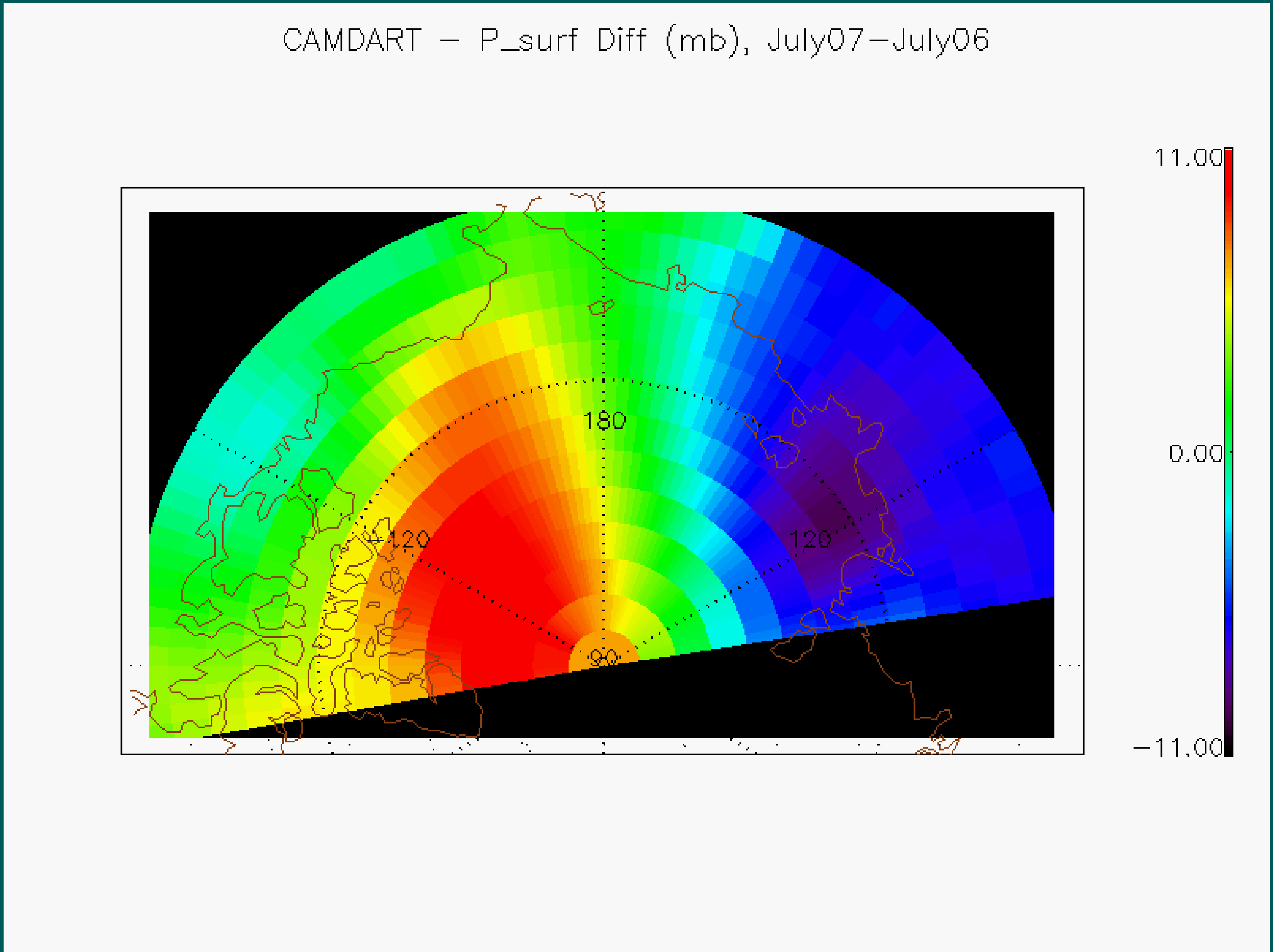
1) Evaluate the efficacy of cloud-radiation forcing on sea ice and explore cloud-ice-circulation feedbacks in a thin ice world.

2) Monitor Arctic clouds/radiation/circulation patterns and their relationship with sea ice using A-train and other satellite/ground-based observations.

3) Evaluate the representation of Arctic clouds and radiation variability in NCAR's climate model.

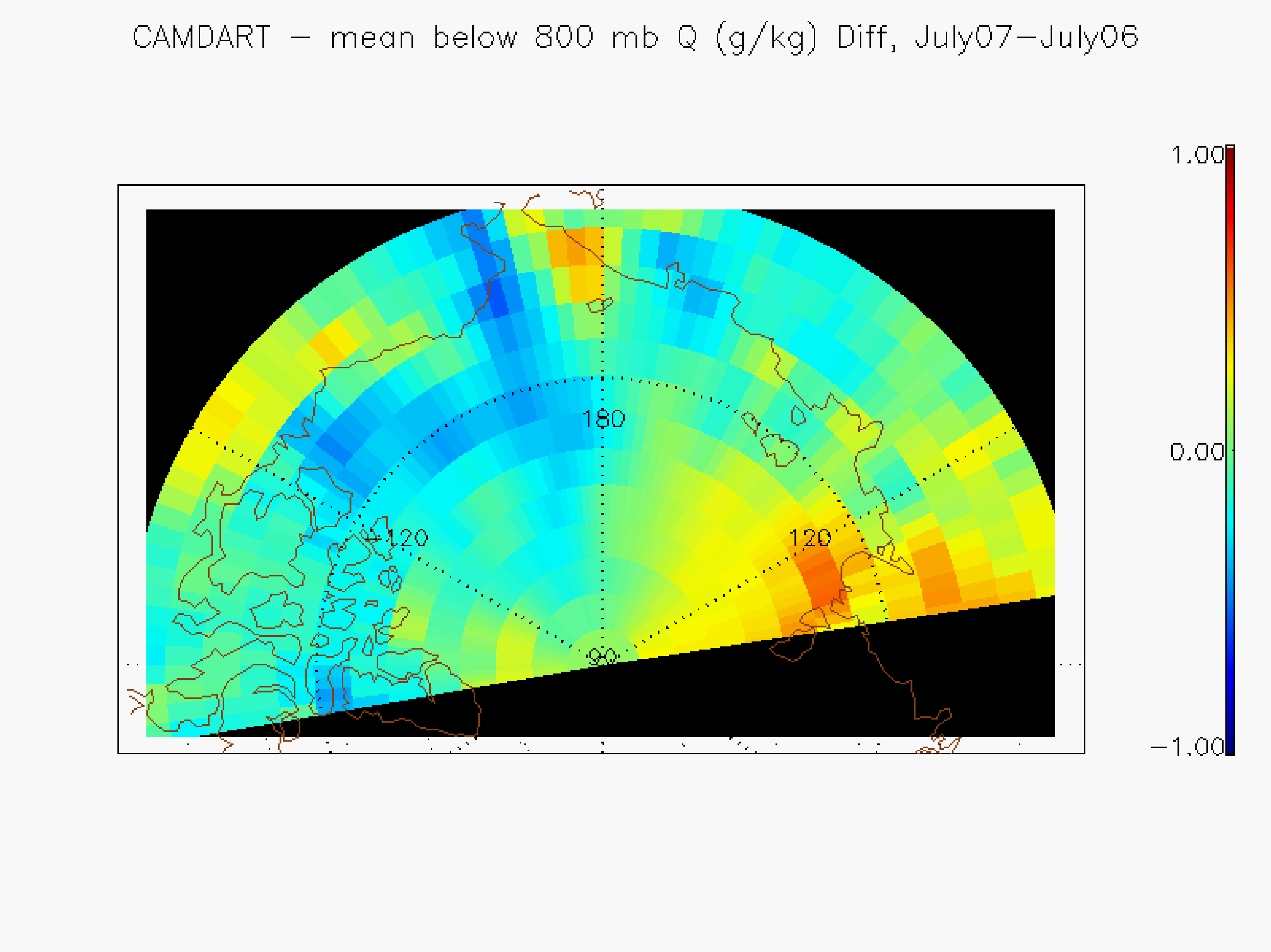
Climate model runs with data assimilation to compare atmospheric forcing on sea ice in 2007 and 2006.

climate model (CAM) with data assimilation



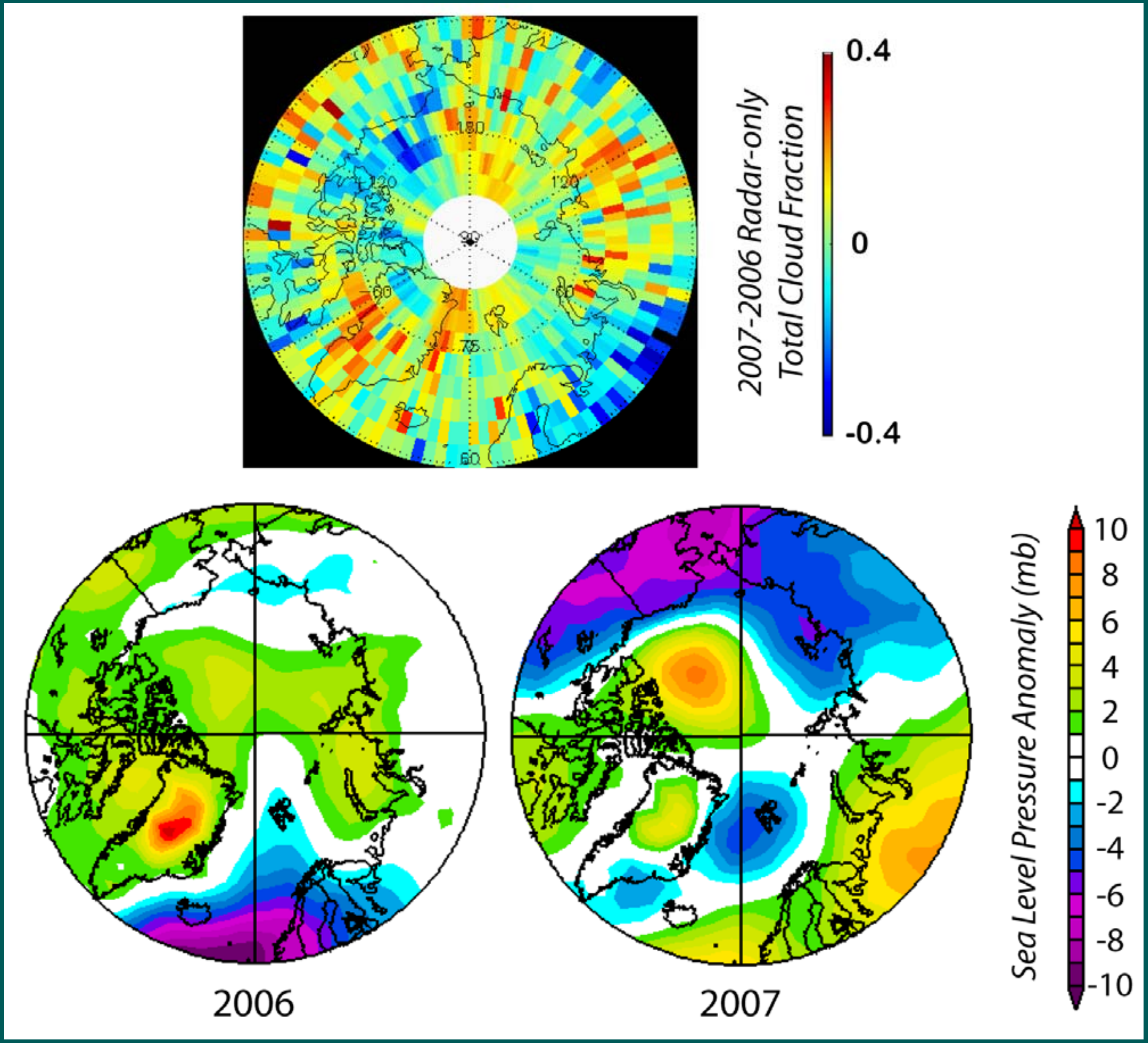
Kevin Reader (NCAR)

CAM w/data assimilation

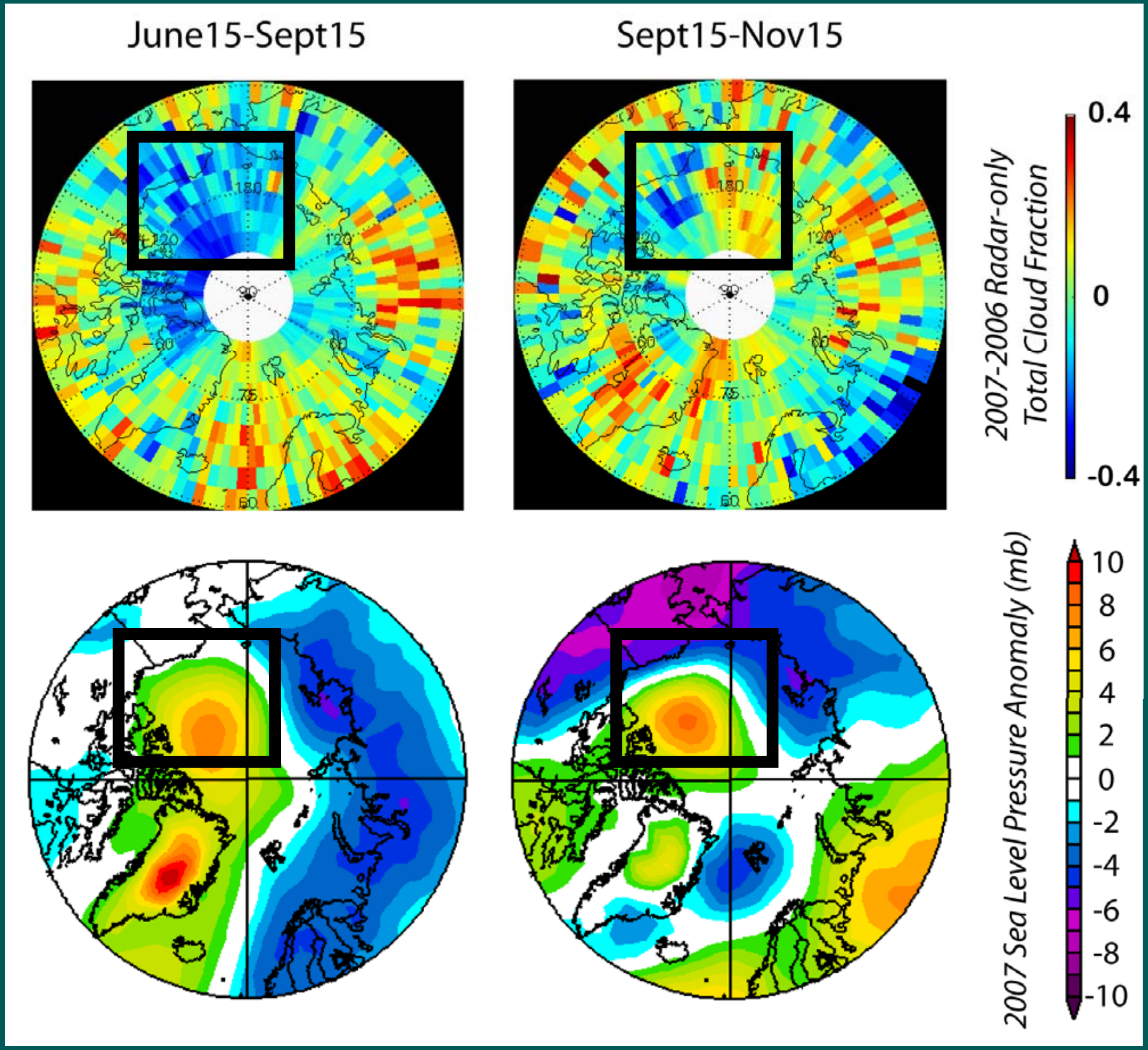


Kevin Reader (NCAR)

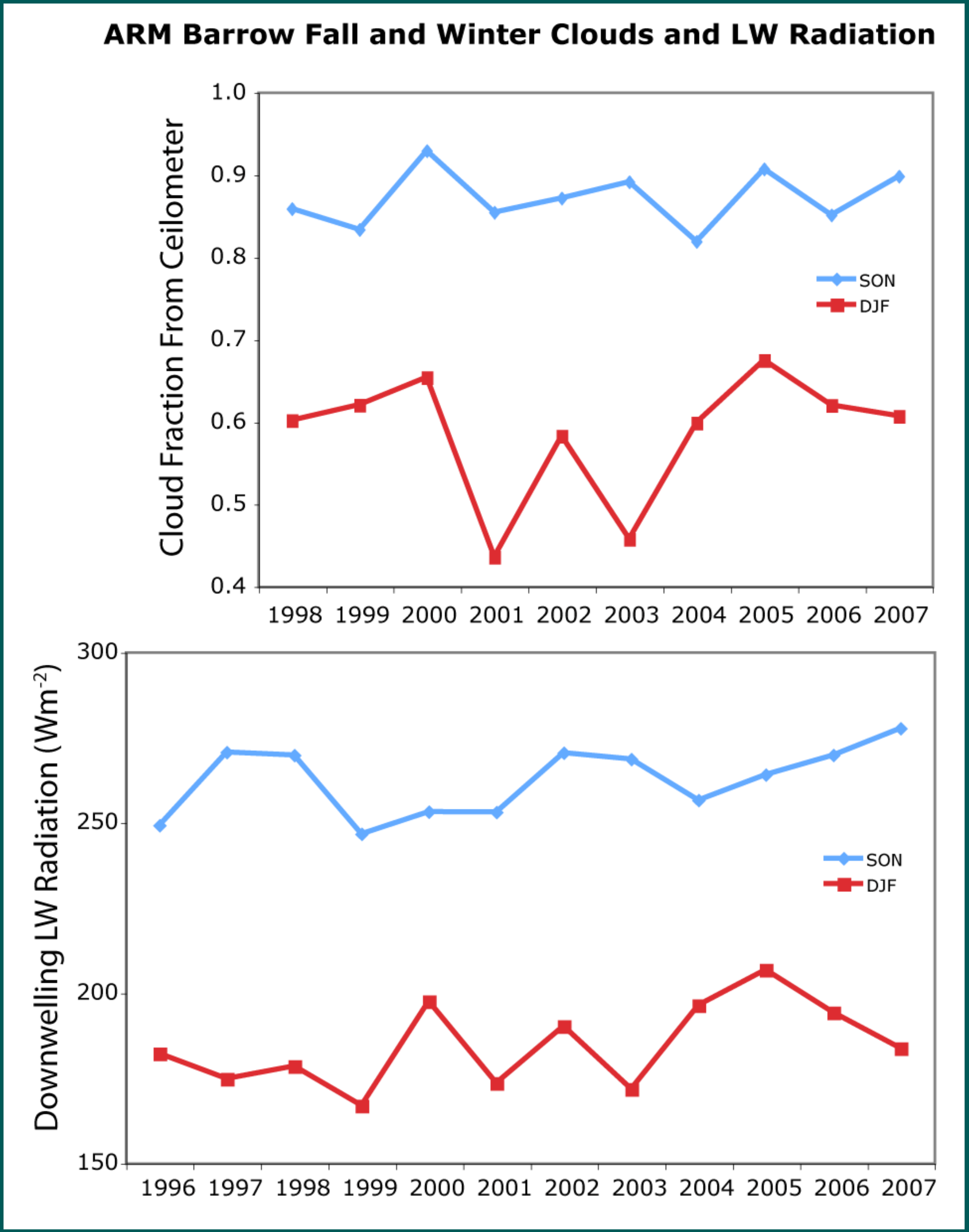
Early Fall Clouds and Circulation



Clouds/Circulation, Summer/Fall



Fall/Winter Clouds/LW Rad at ARM Barrow



2007 vs.2006, SON/DJF