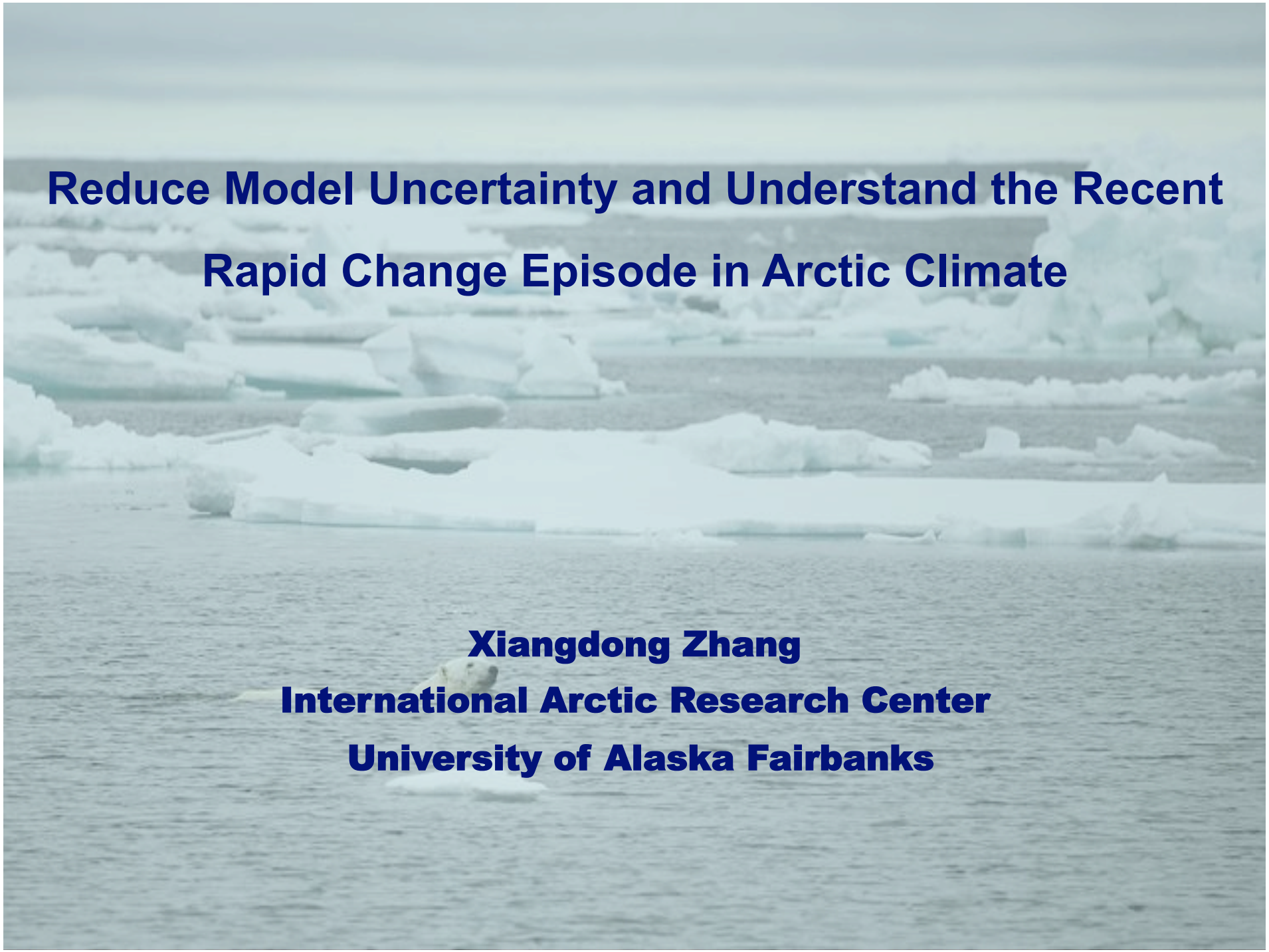


Reduce Model Uncertainty and Understand the Recent Rapid Change Episode in Arctic Climate

Xiangdong Zhang

International Arctic Research Center

University of Alaska Fairbanks

Outline

1. **Detect externally forced changes in the CMIP3 climate models:**
   - **Observational constraint to reduce uncertainty**
   - **Ensemble mean to minimize natural variability**
2. **Understand internally generated variability in the recent observations (subject to external forcing):**
   - **Identify mode to reduce complexity/dimensions**
   - **Look for persistent signal behind "noises"**

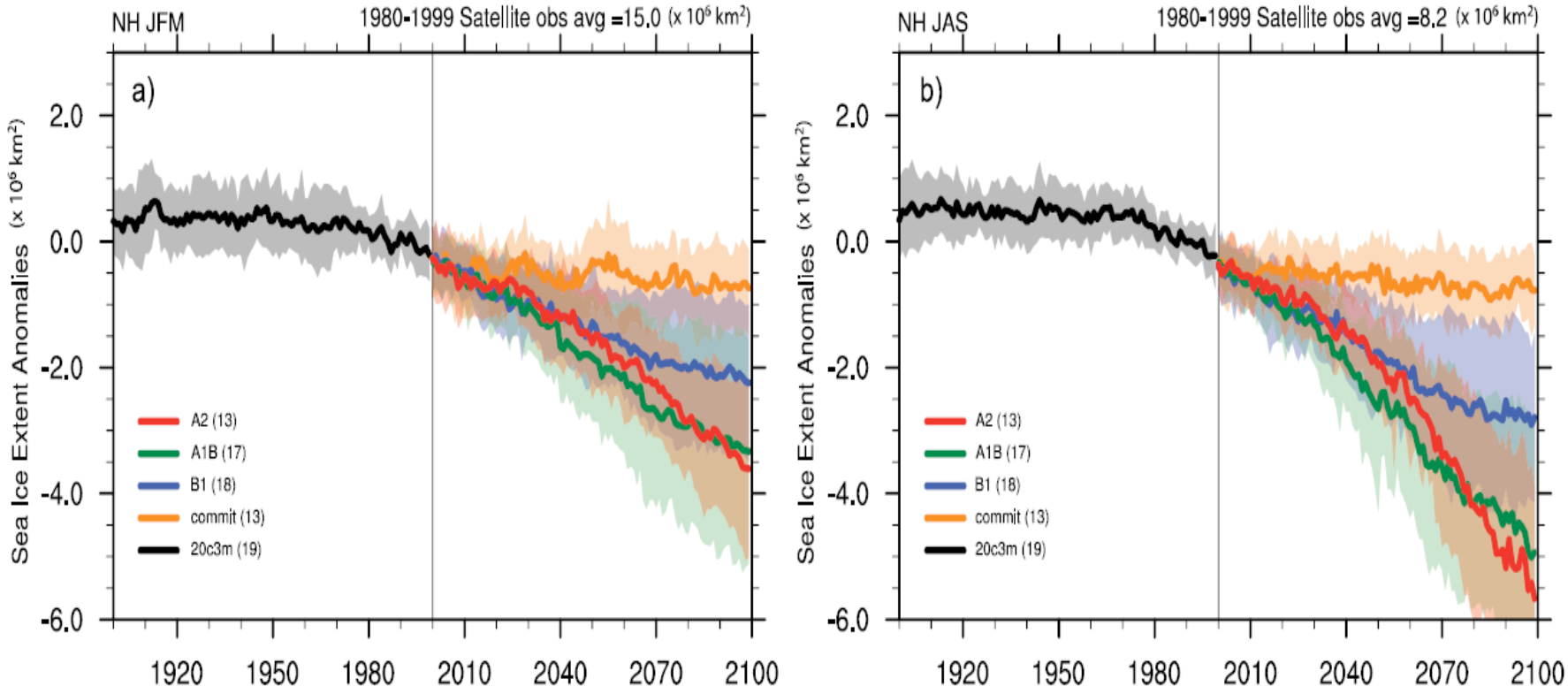
X. Zhang

10 (IPCC AR4)

Global Climate Projections

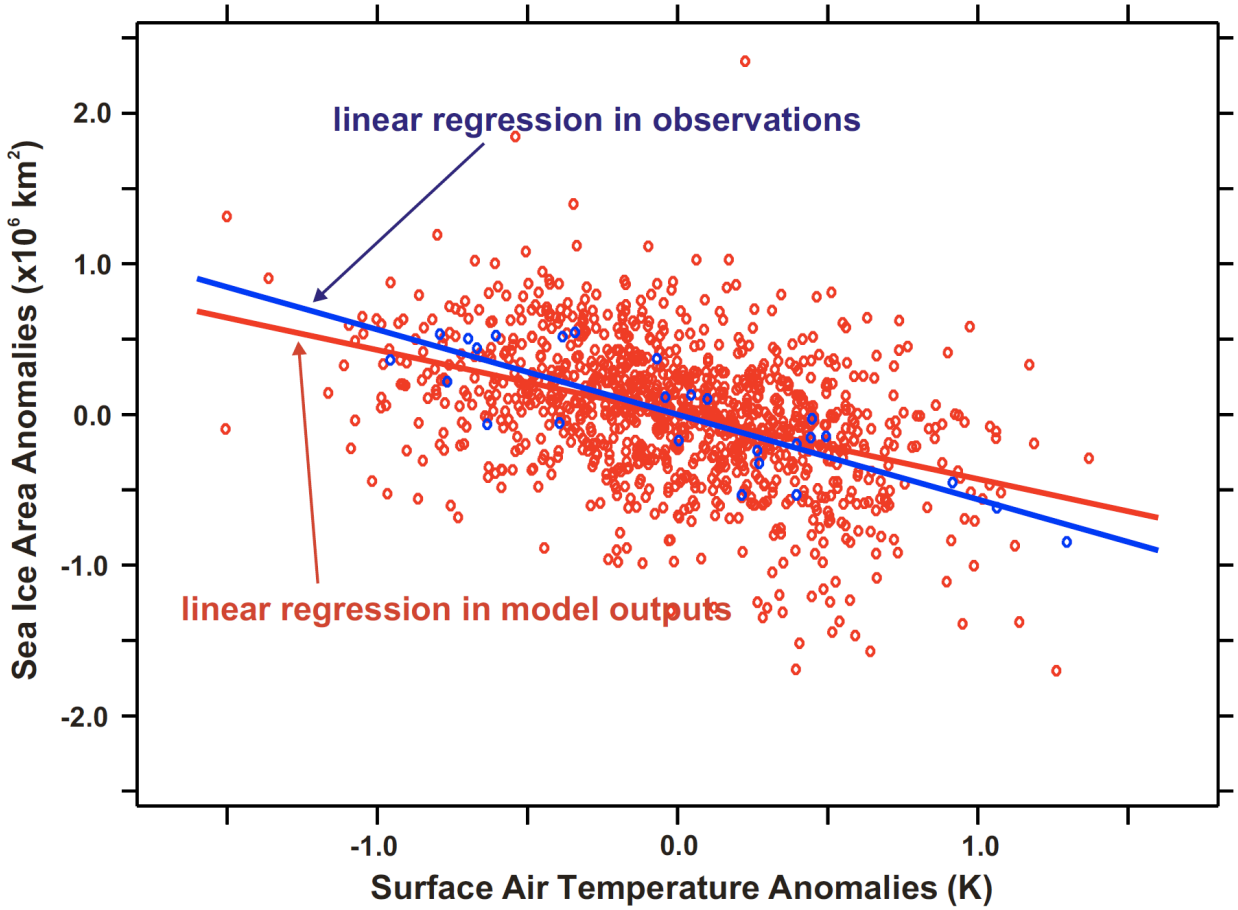
As shown by Zhang and Walsh (2006), the coupled models show a range of responses in NH sea ice areal extent ranging from very little change to a strong and accelerating reduction over the 21st century (Figure 10.13a,b).

Detect externally forced changes by multi-model and multi-model-ensemble-member mean



- **Transient climate sensitivity analysis $\Delta A_{ice} = -Y*\Delta Ts$**

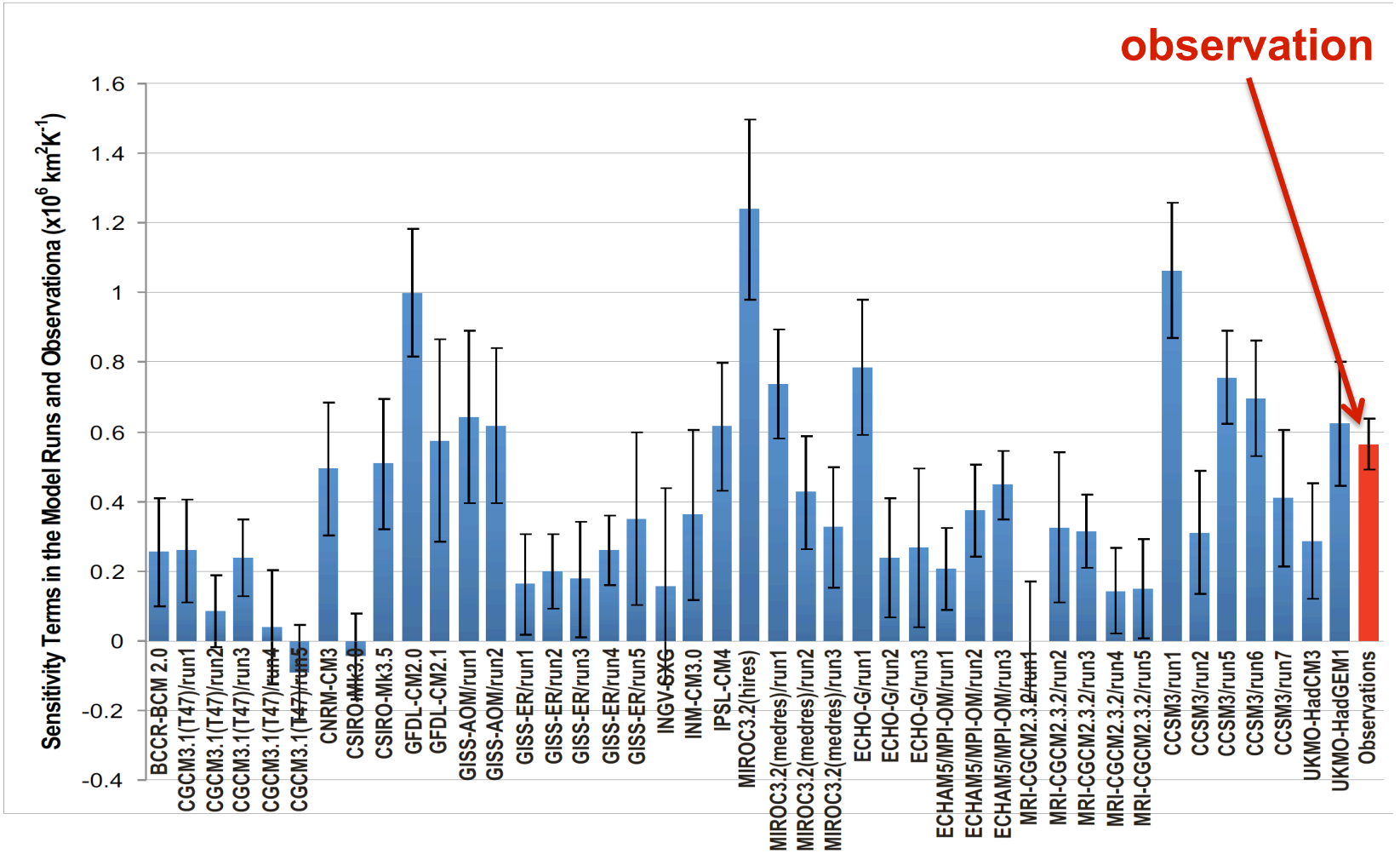
CMIP3 models as a group underestimated observed sensitivity



ΔTs: no matter whether it is caused by external forcing or internal variability.

X. Zhang, 2010

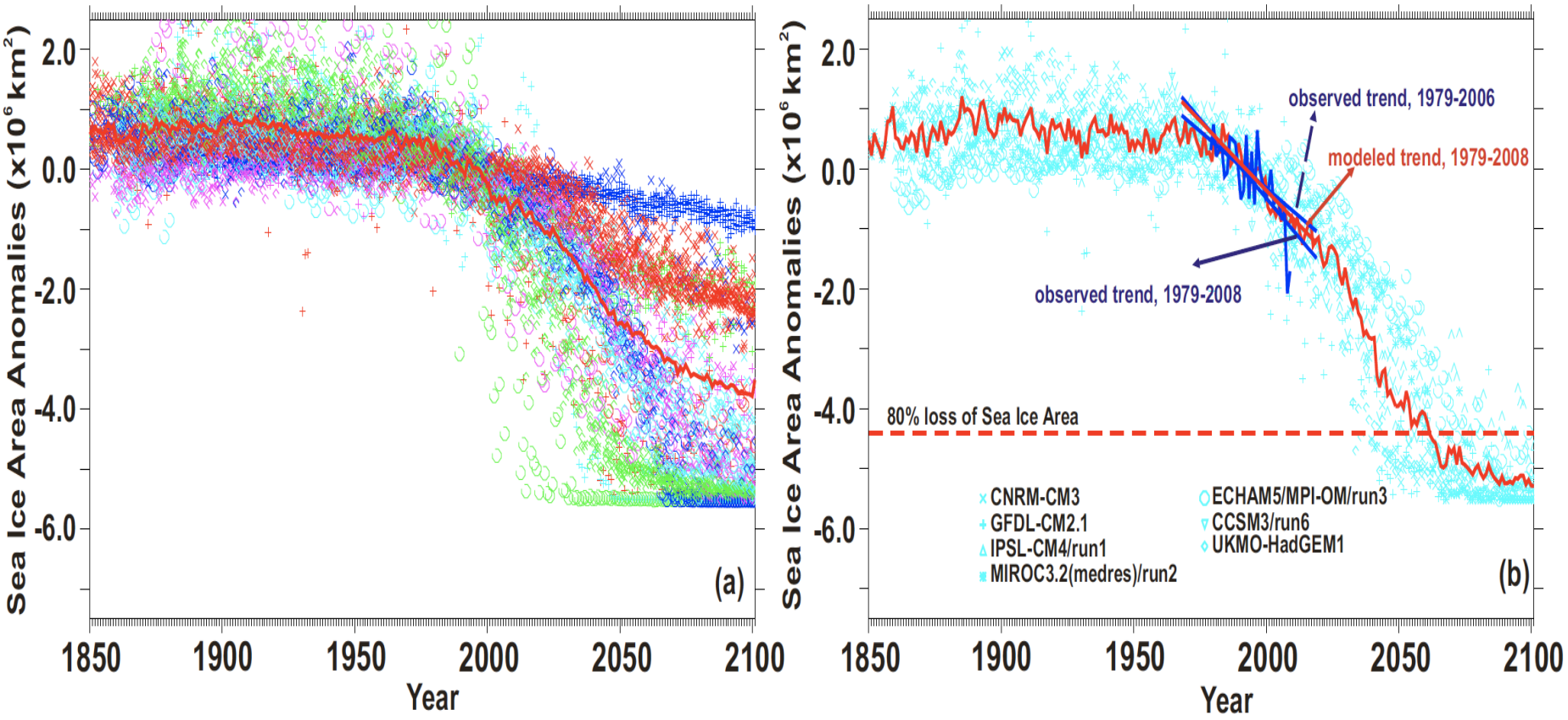
- **The sensitivity terms for each model are largely diversified**



X. Zhang, 2010

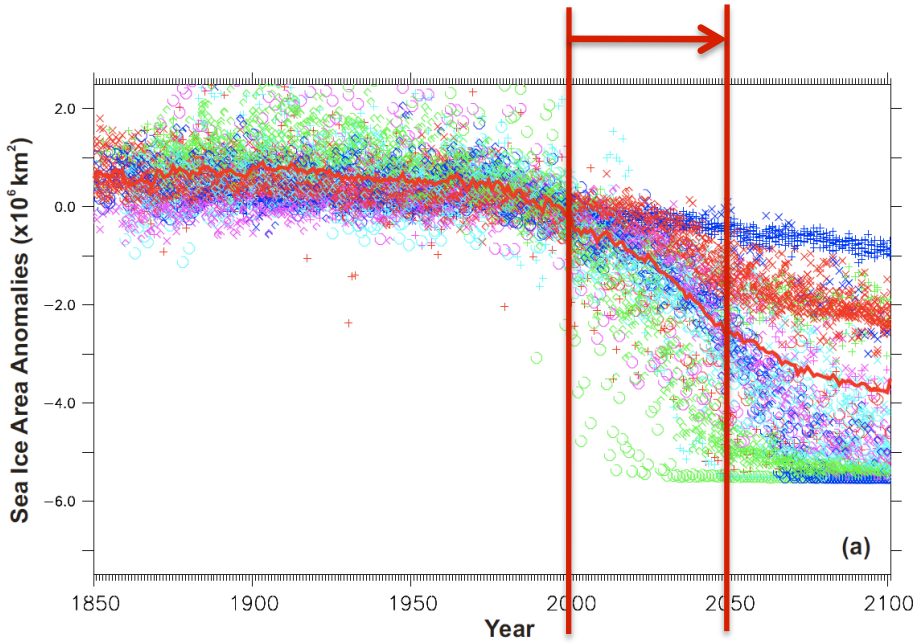
- **Reduce model uncertainties by two criteria:**

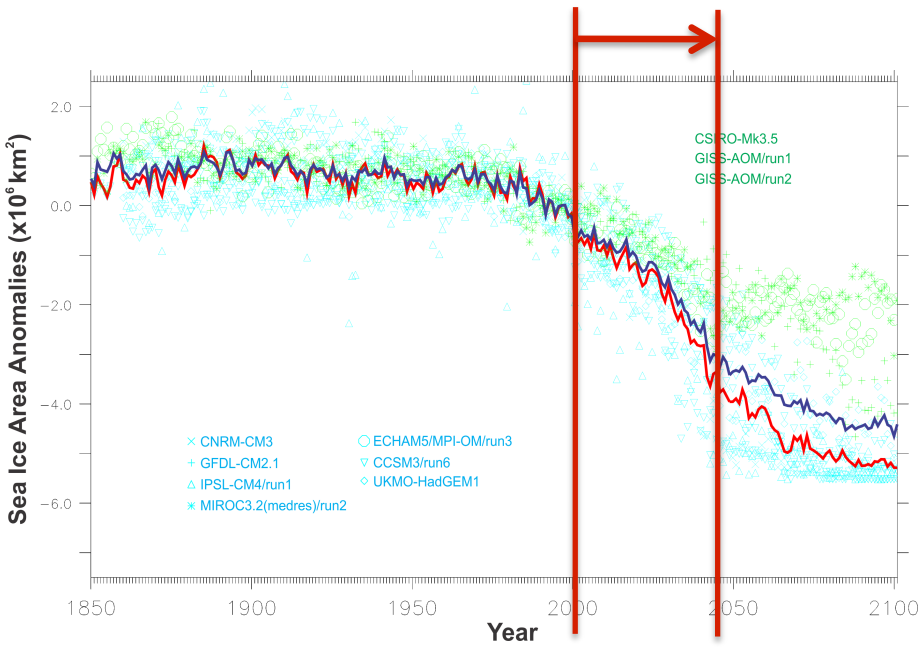
1. **99% confidence interval of observed sensitivity term;**
2. **Rapid change episode (sophisticated treatment of sea ice physics)**

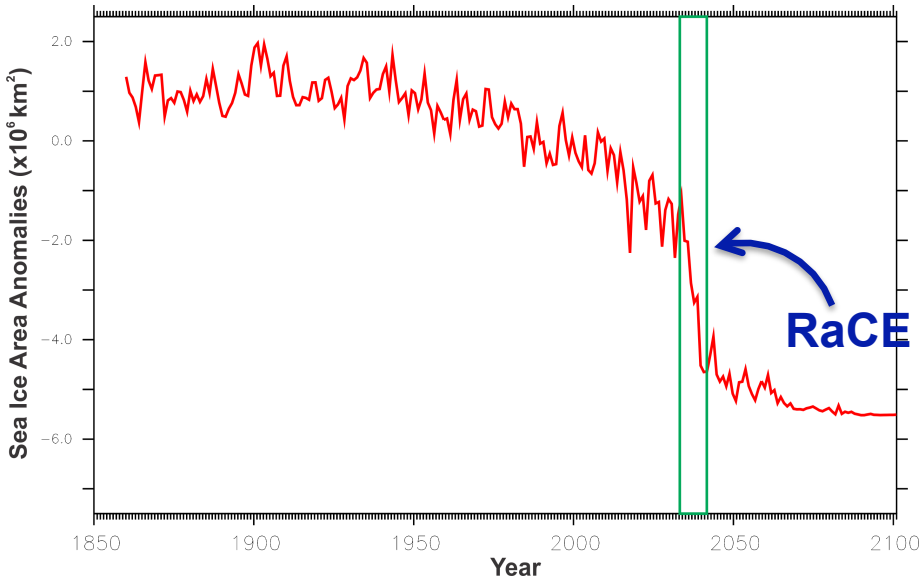


X. Zhang, 2010

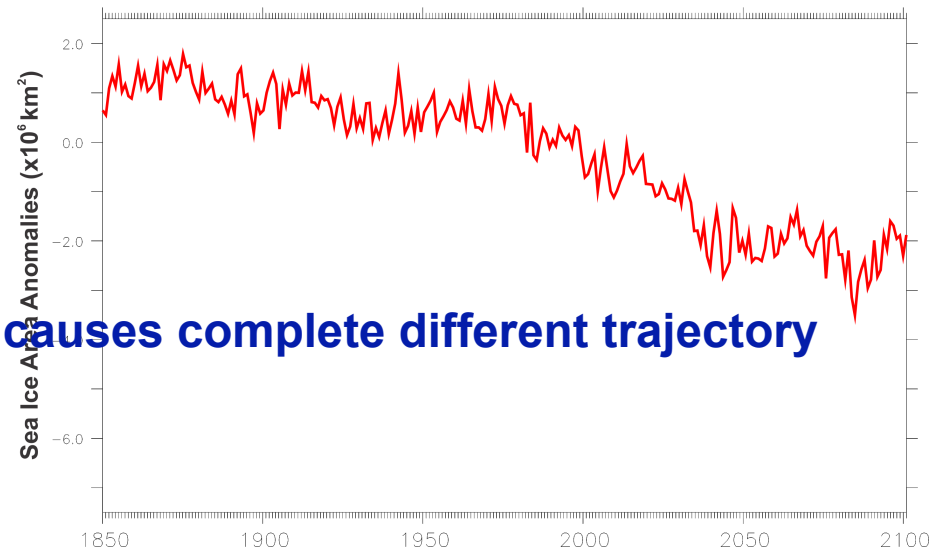
• Impact of the second criterion [rapid change episode (RaCE)]







RaCE causes complete different trajectory



X. Zhang, 2010

Summary:

- **Large uncertainties in the Arctic sea ice cover changes result from the large spread of sensitivities or feedback strengths in the models.**

- **The transient-sensitivity-constrained selection of the subset of the model ensembles substantially reduced uncertainties.**

- **The capture of rapid change episode also crucially impacts the projection of future sea ice change trajectories.**

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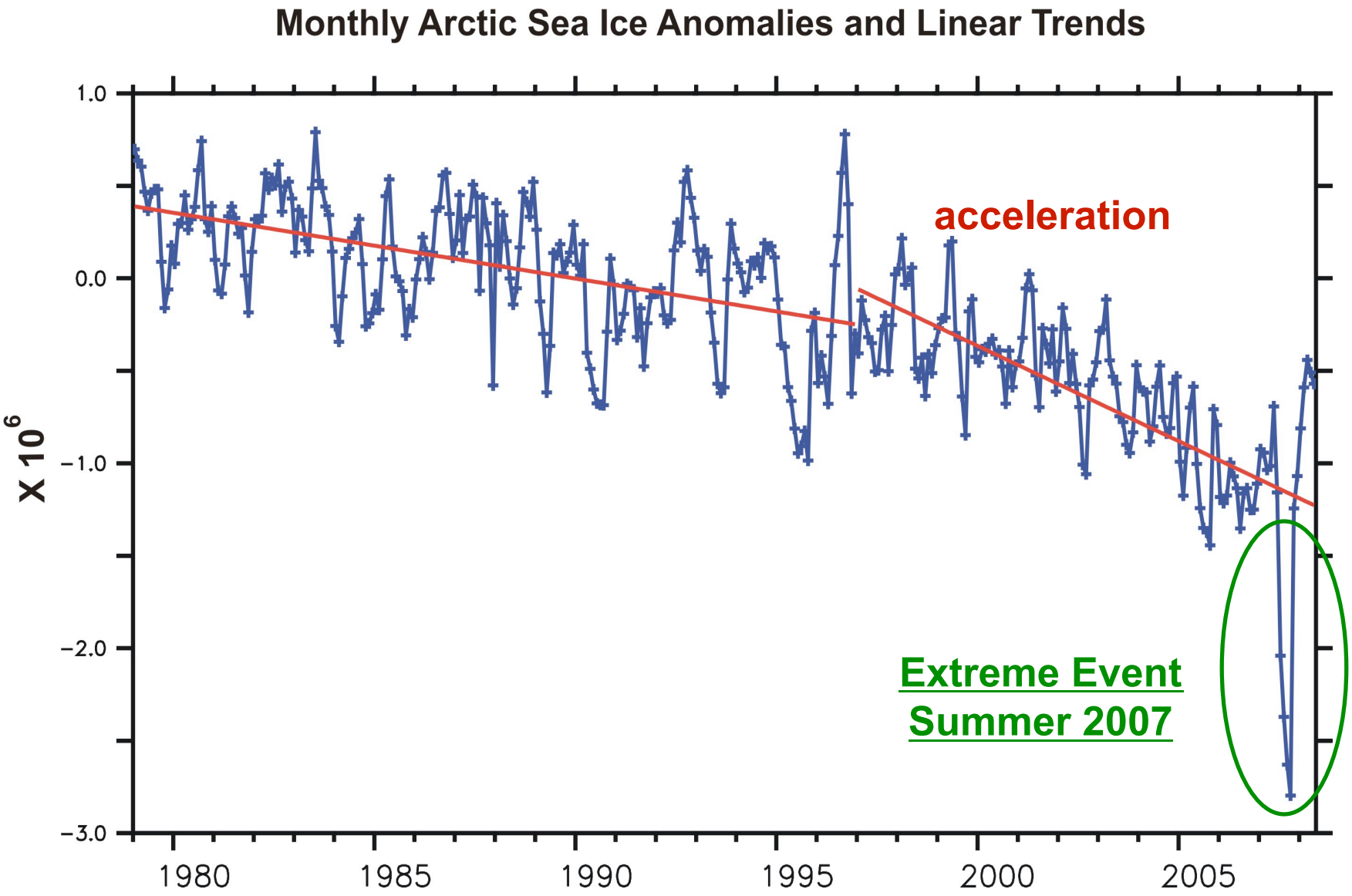
TELLUS

Sensitivity of arctic summer sea ice coverage to global warming forcing: towards reducing uncertainty in arctic climate change projections

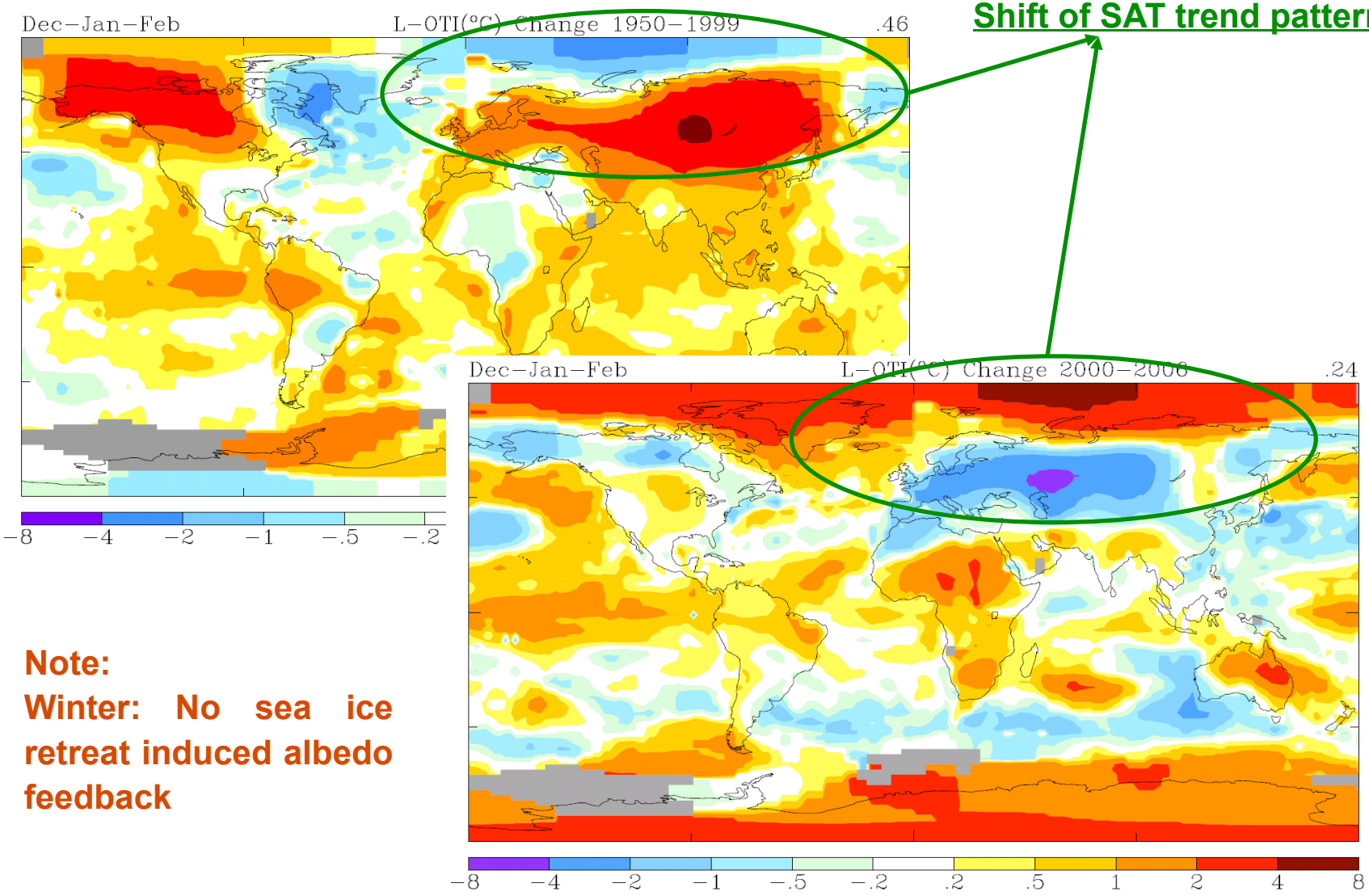
By XIANGDONG ZHANG*, *International Arctic Research Center, University of Alaska Fairbanks, Fairbanks, AK 99775, USA*

- **Reduction of sea ice coverage has been accelerated**



X. Zhang et al, 2010

- **Arctic surface warming has been dramatically amplified**

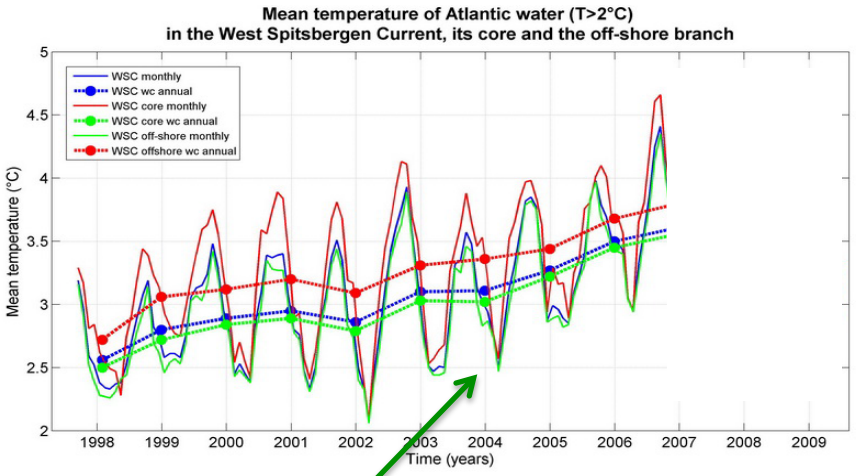


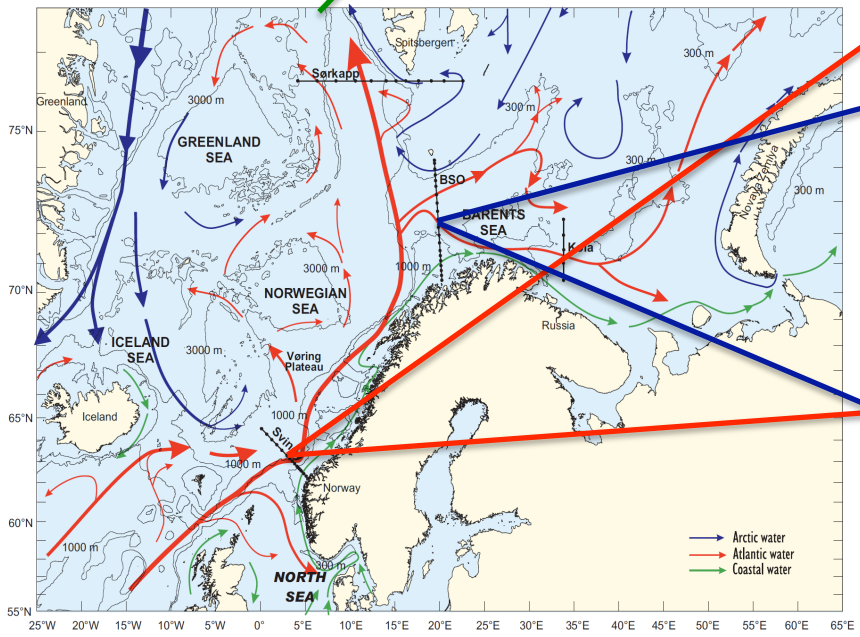
Shift of SAT trend pattern

Note:
Winter: No sea ice retreat induced albedo feedback

X. Zhang et al, 2010

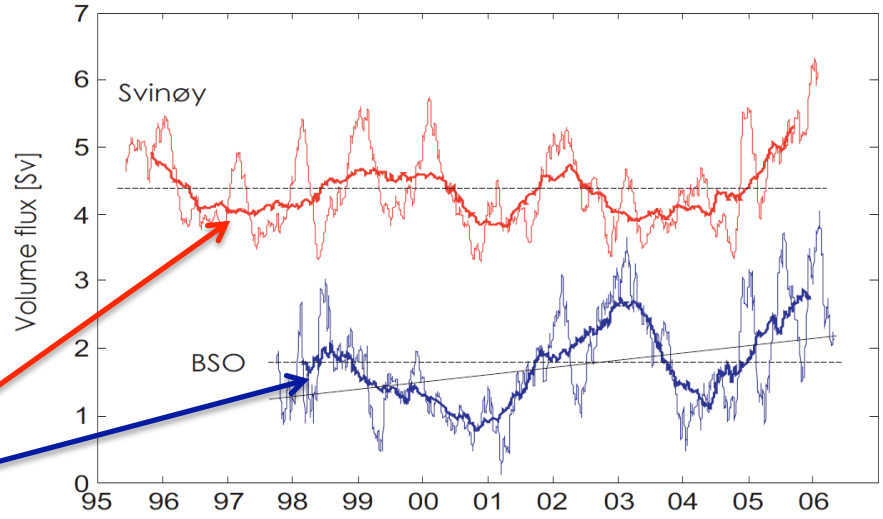
- **Atlantic warm water intrusion has been further enhanced**

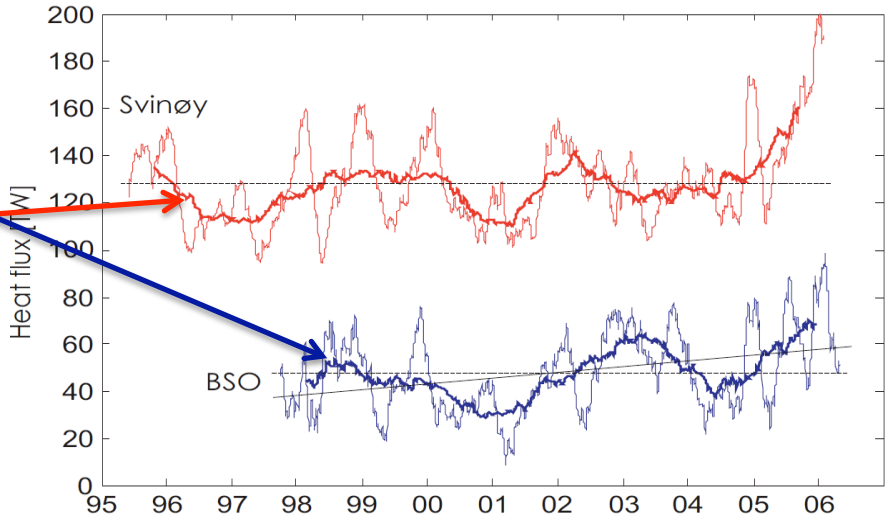




Skagseth et al.

Beszczynska-Möller et al.

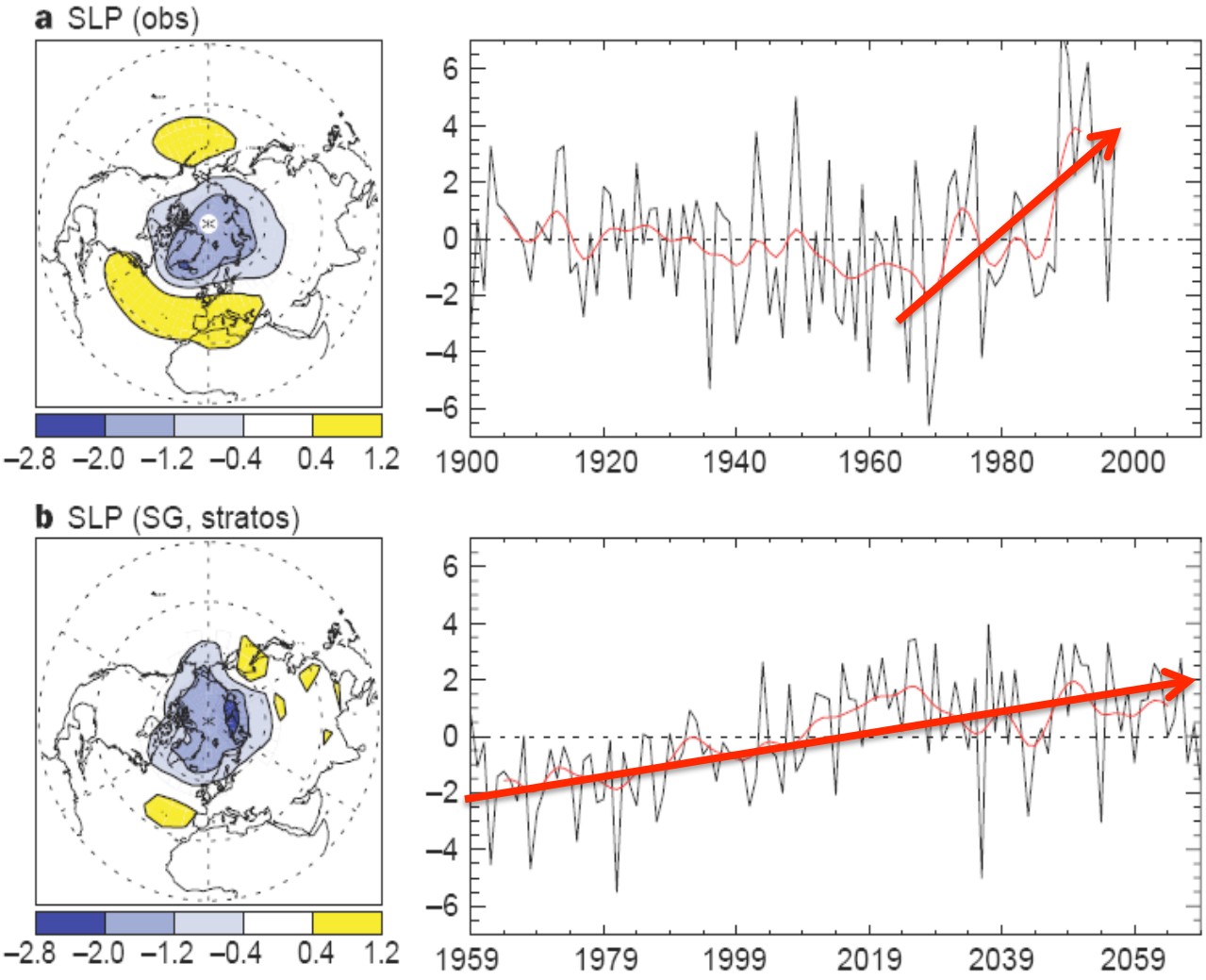




•Arctic/North Atlantic Oscillation has played a driving role

Many changes in Arctic climate have been attributed to the upward trend of AO.

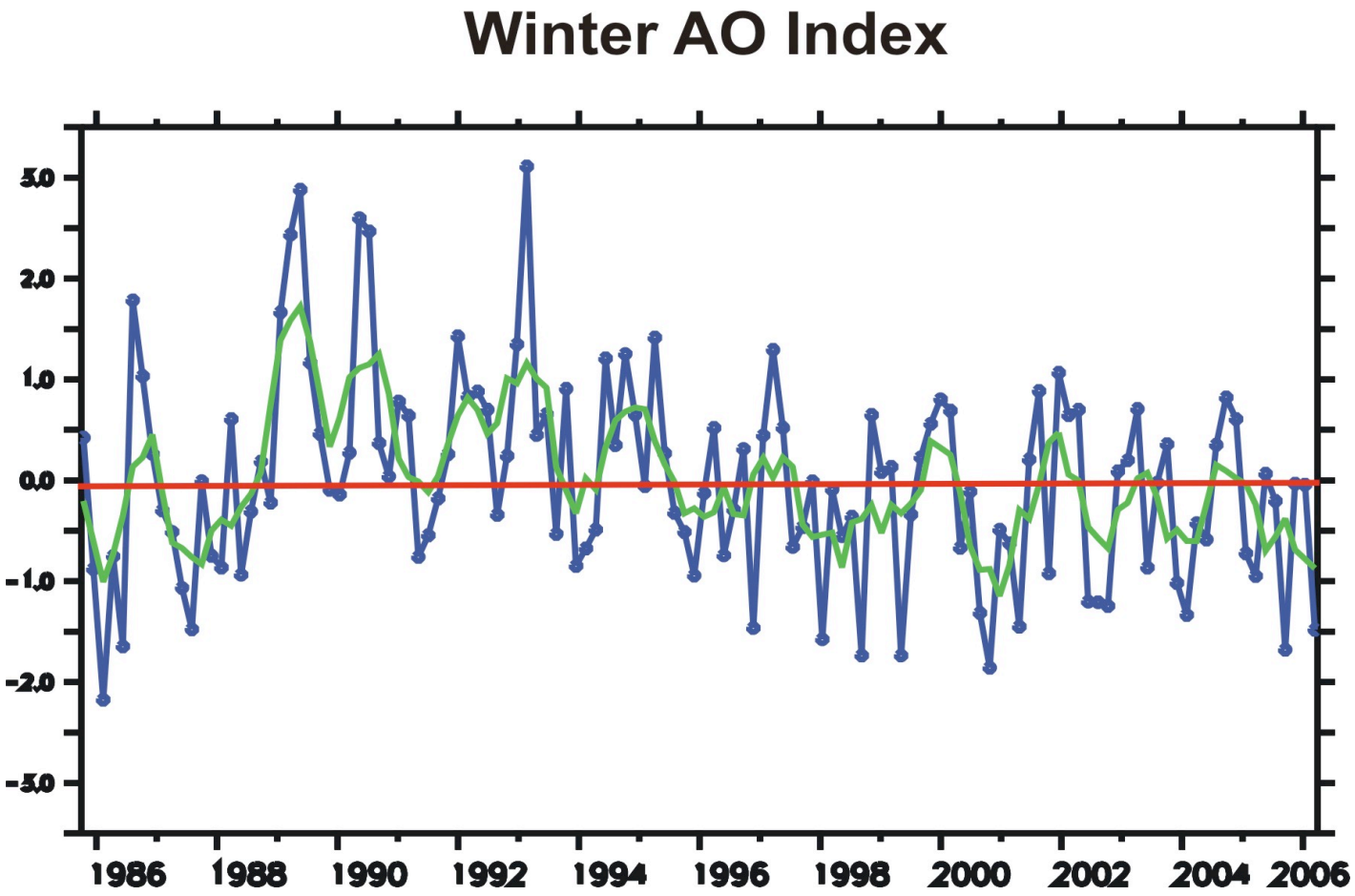
The upward trend of AO is expected to continue under global warming forcing in climate model simulations.



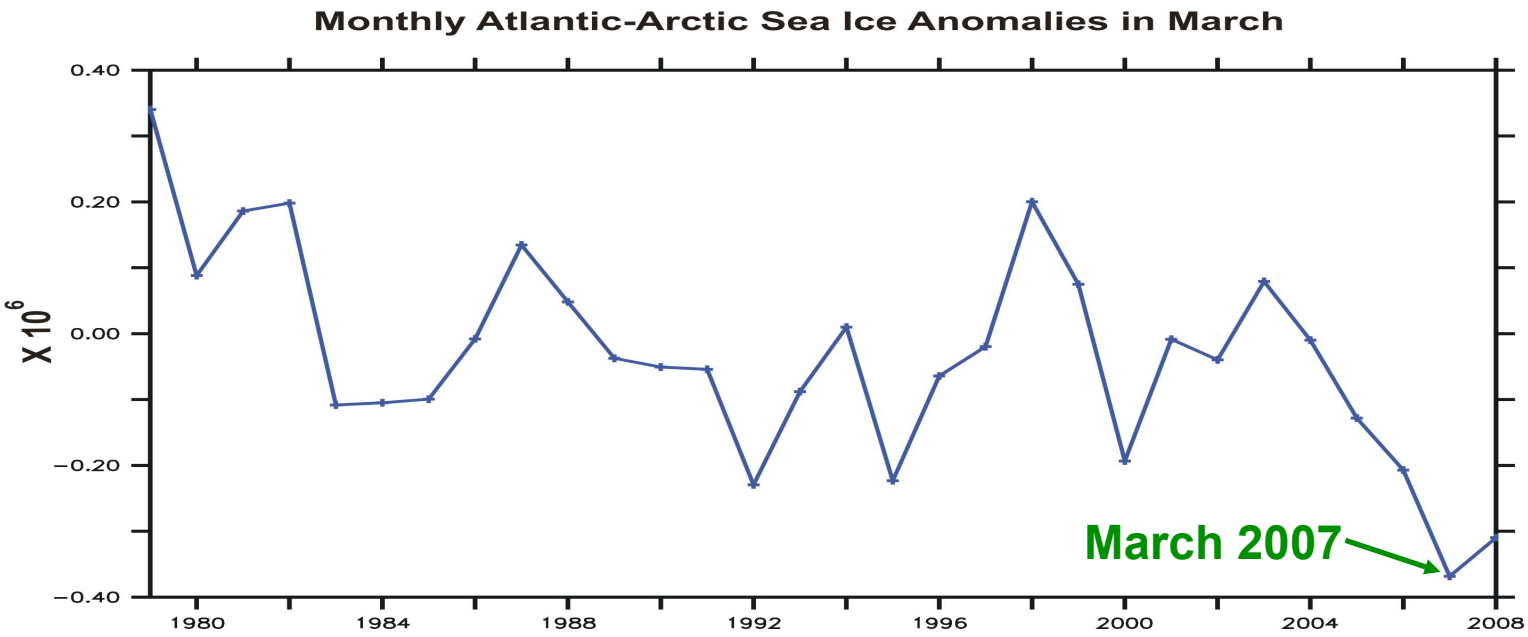
Thompson and Wallace GRL,1998; Shindell et al. Nature, 1999

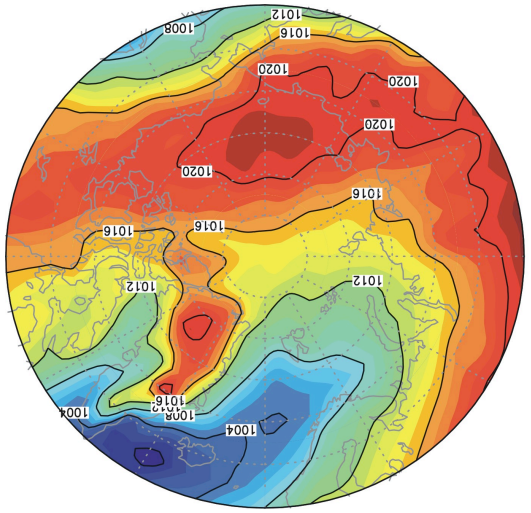
- **Surprising and unexpected changes of AO occurred**

➢ Arctic Oscillation has gone to neutral and slight negative since the mid-1990s

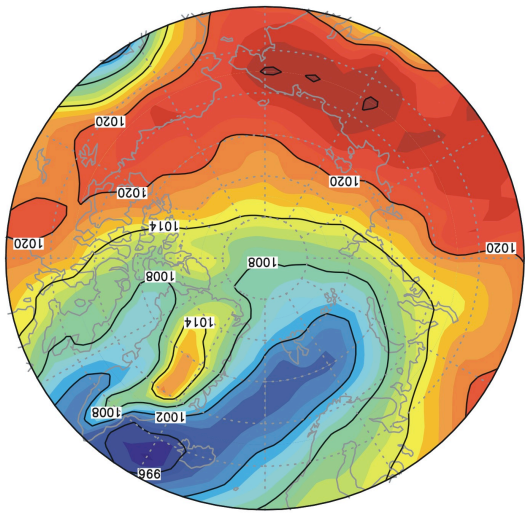


- **Question: What drove the acceleration?**





SLP Climatology



SLP in March 2007

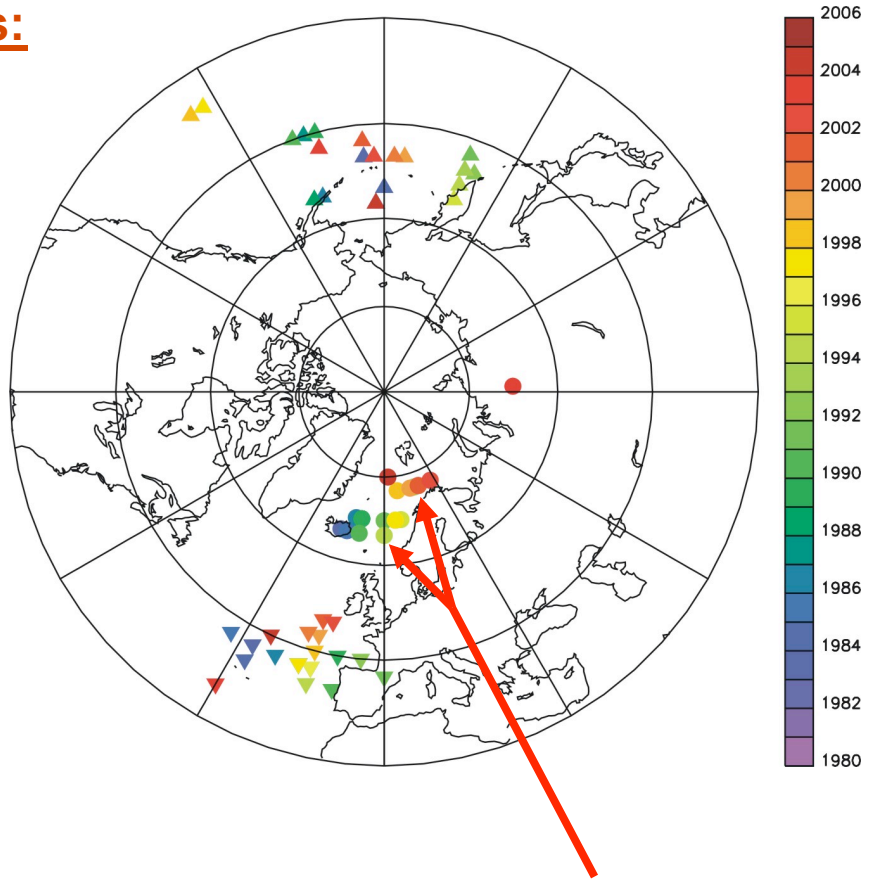
X. Zhang et al, 2010

• **Atmospheric circulation shift and Arctic Rapid change Pattern (ARP)**

Running EOF/PC (Rn-EOF/PC) analysis:

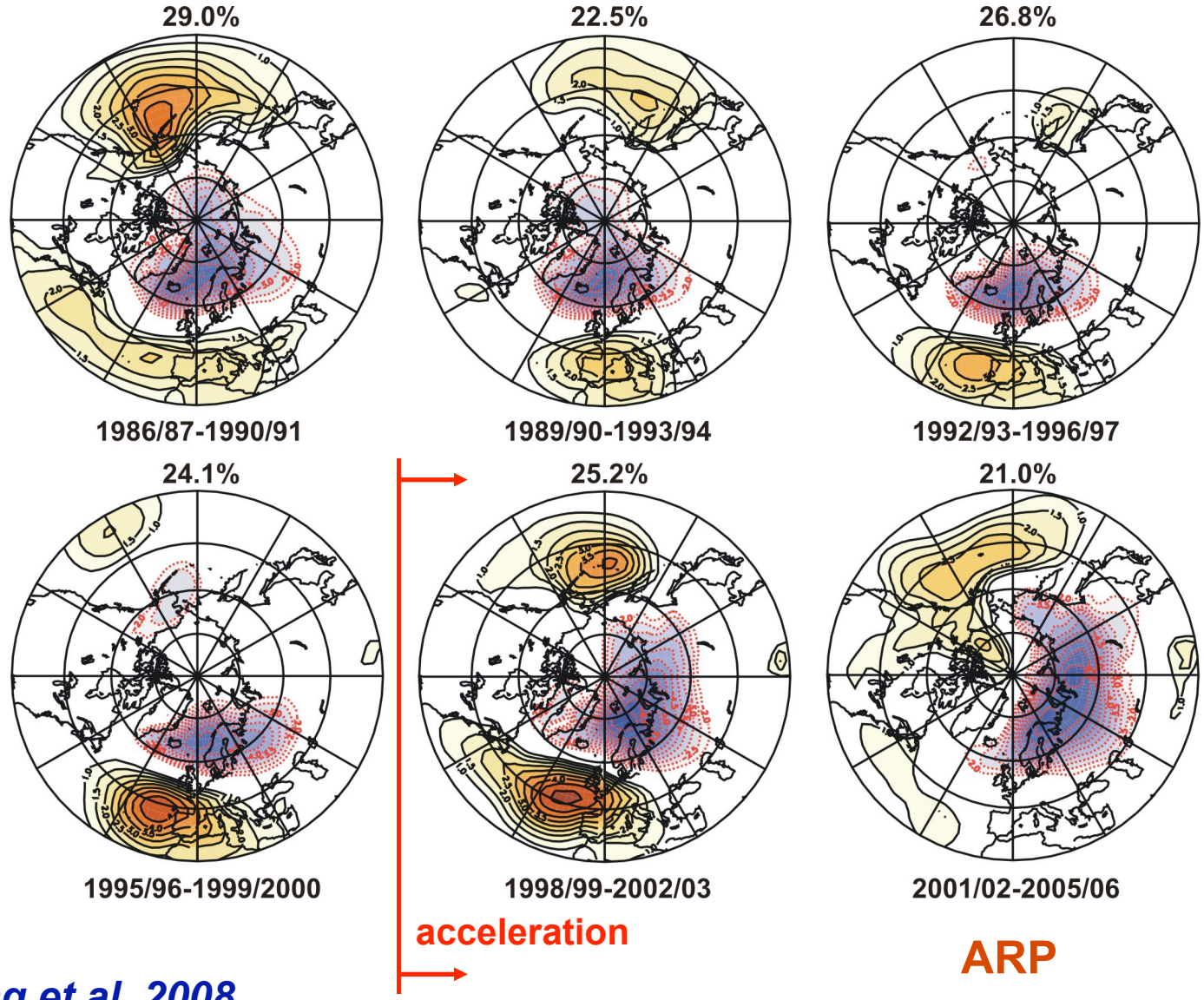
• **30-winter-month running window**

• **EOF/PC analysis seeks spatially- and temporally-coordinated pattern that explains maximum variance and identifies centers of action**



X. Zhang et al, 2008

- **Atmospheric circulation shift and Arctic Rapid change Pattern (ARP)**



X. Zhang et al, 2008

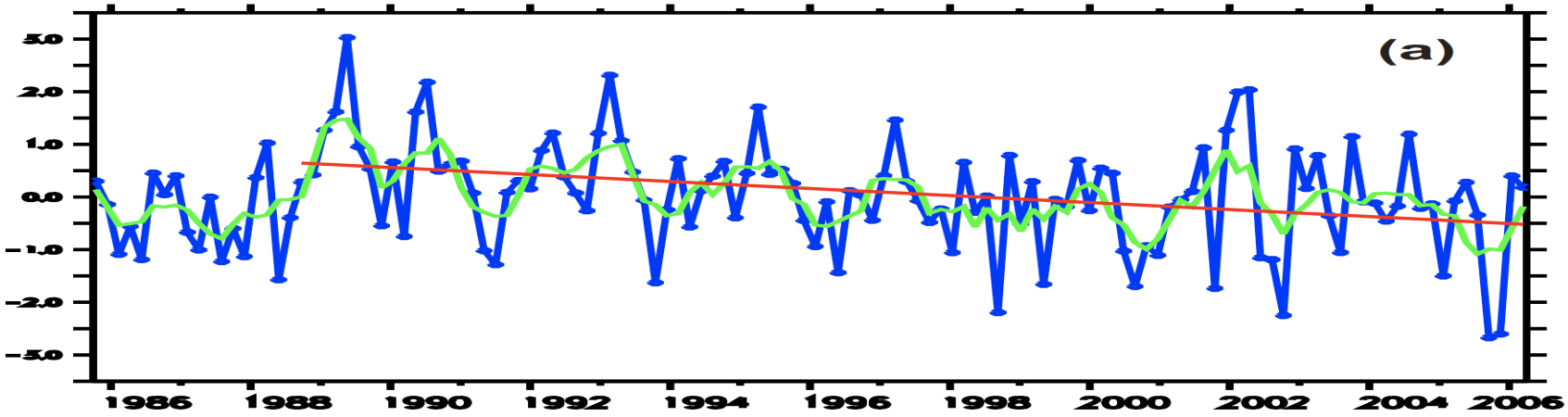
• **Atmospheric circulation shift and Arctic Rapid change Pattern (ARP)**

Statistical significance: 1000-trial Monte Carlo Simulations

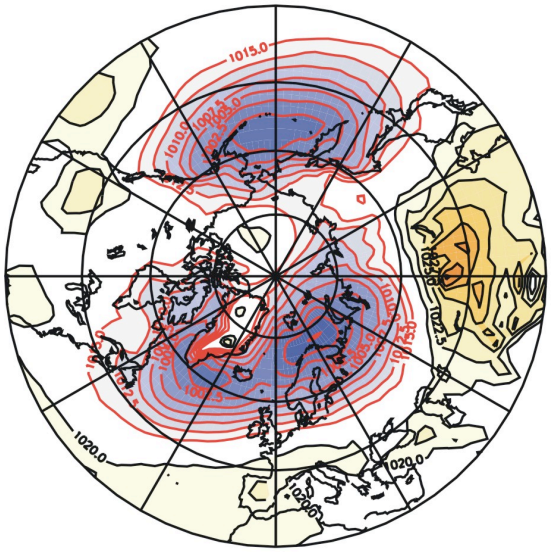
The fractions of variance (%) explained by the first EOF/PC patterns from the original MSLP anomaly data set and the maximum of fractions of variance explained by the first EOF/PC patterns from the 1000-trial Monte Carlo simulations for the selected wintertime windows

Fraction of Variance (%)	1986/87-1990/91	1989/90-1993/94	1992/93-1996/97	1995/96-1999/2000	1998/99-2002/03	2001/02-2005/06
Original Data	29.0	22.5	26.8	24.1	25.2	21.0
Scrambled Data	4.9	4.9	5.0	4.8	4.9	4.8

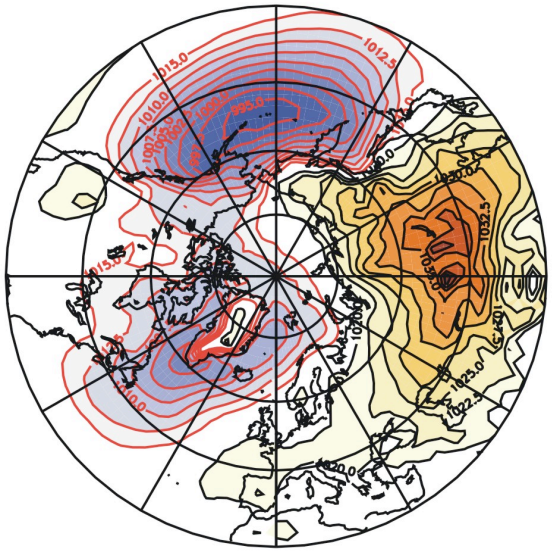
- **Atmospheric circulation shift and Arctic Rapid change Pattern (ARP)**



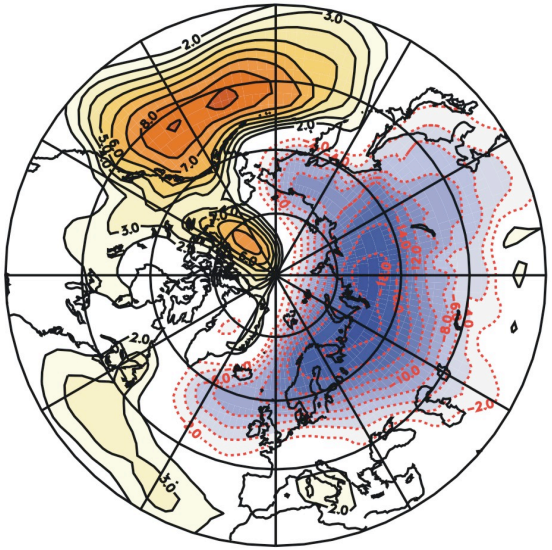
Composite Analaysis Based on ARP Index



Positive ARP

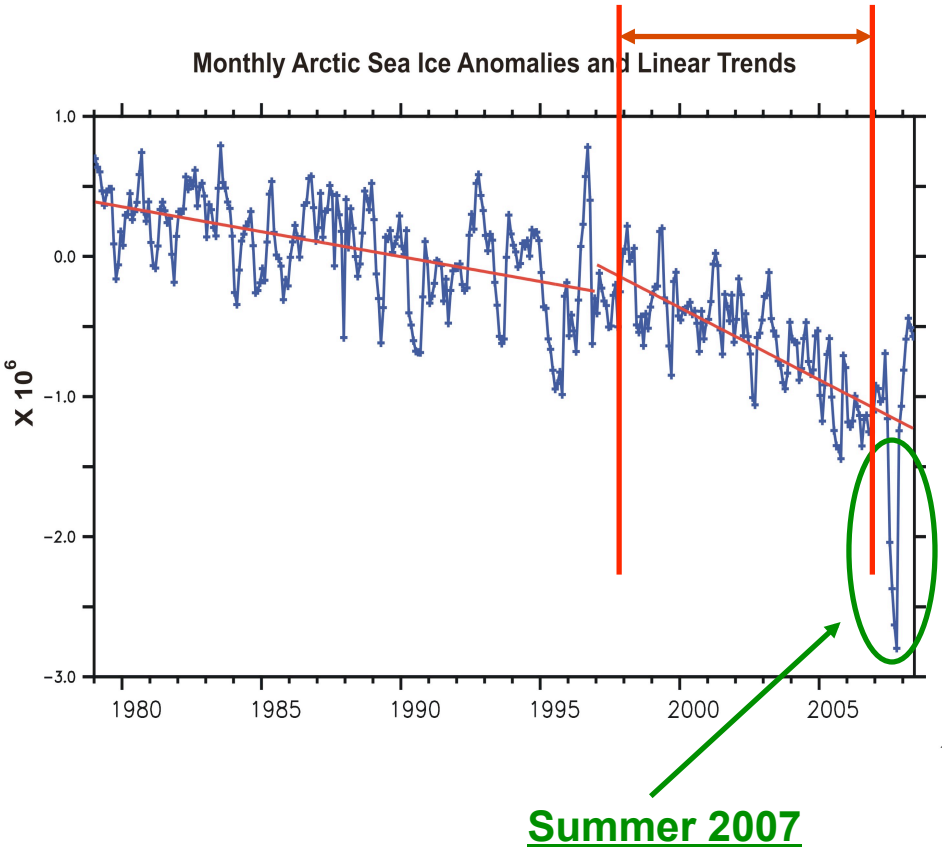


Negative ARP

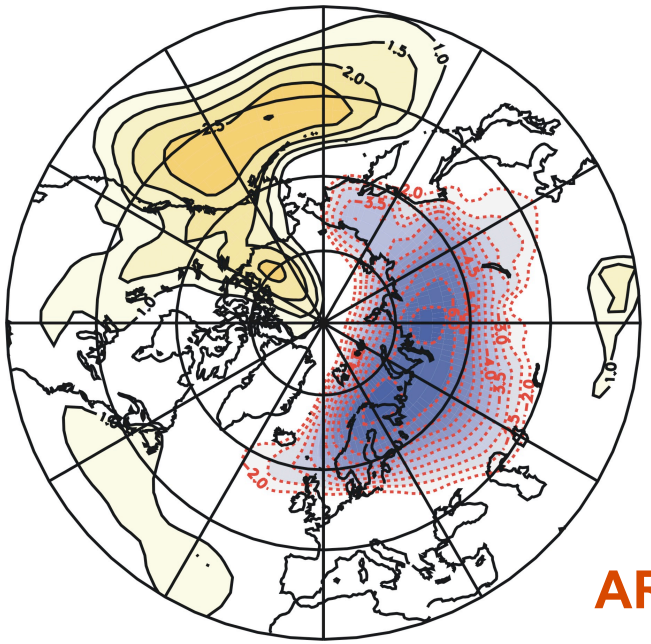


Difference

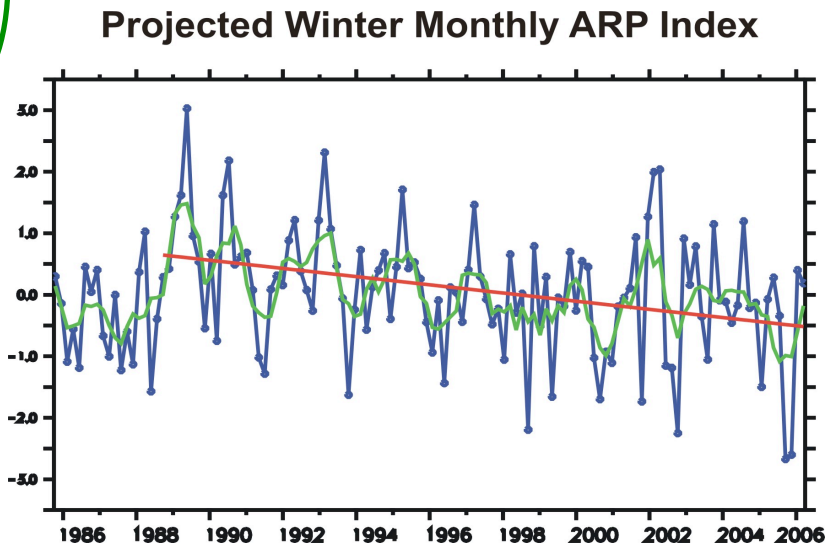
• Atmospheric circulation shift and Arctic Rapid change Pattern (ARP)



Summer 2007

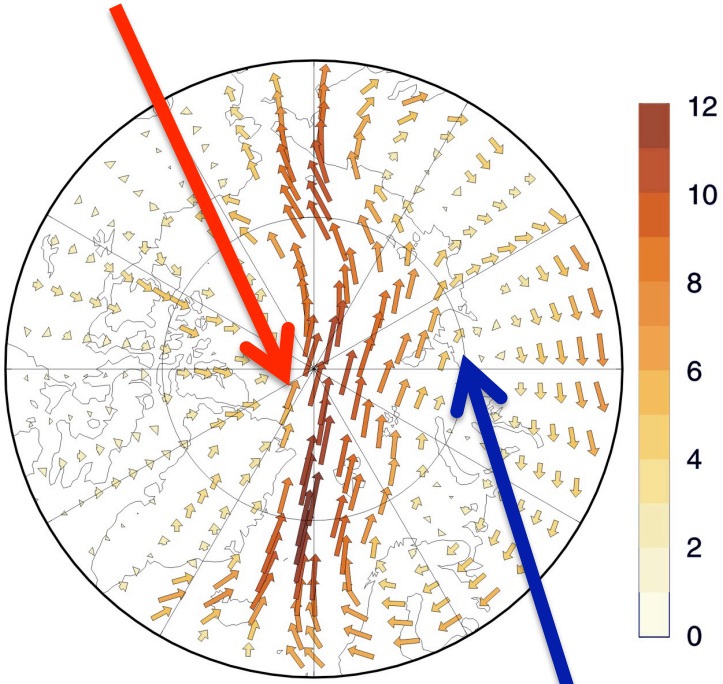


ARP

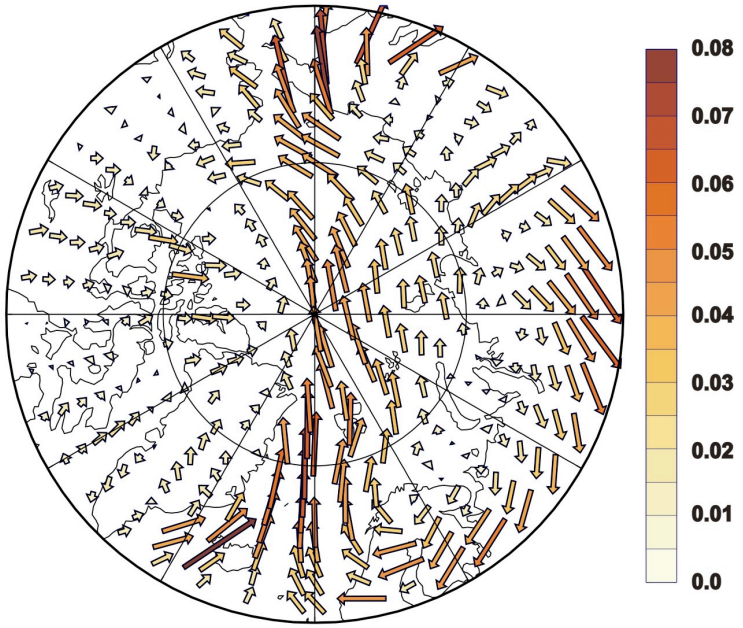


- **ARP enhanced Arctic-midlatitude interactions**

provided a shortcut of atmosphere and ocean heat transport into Arctic from the midlatitude



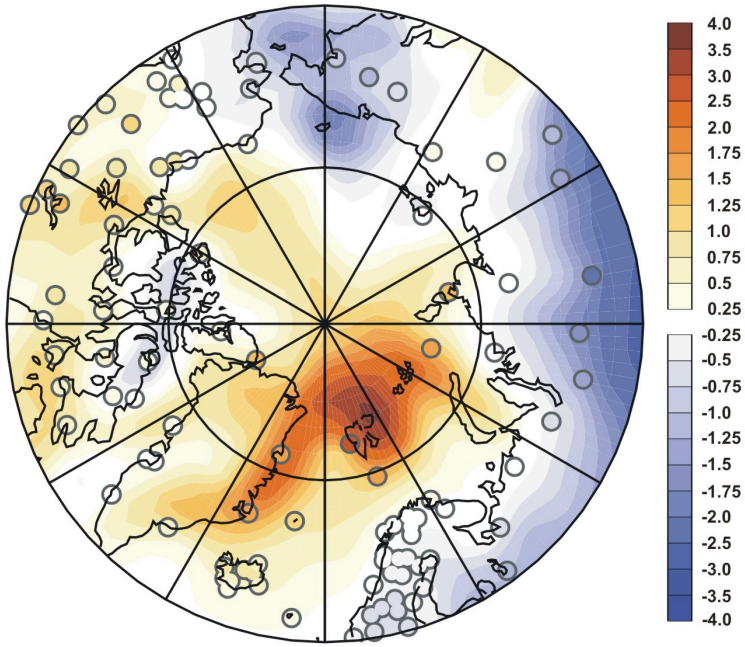
Heat transport regressed onto winter ARP index (surface - 850 hpa)



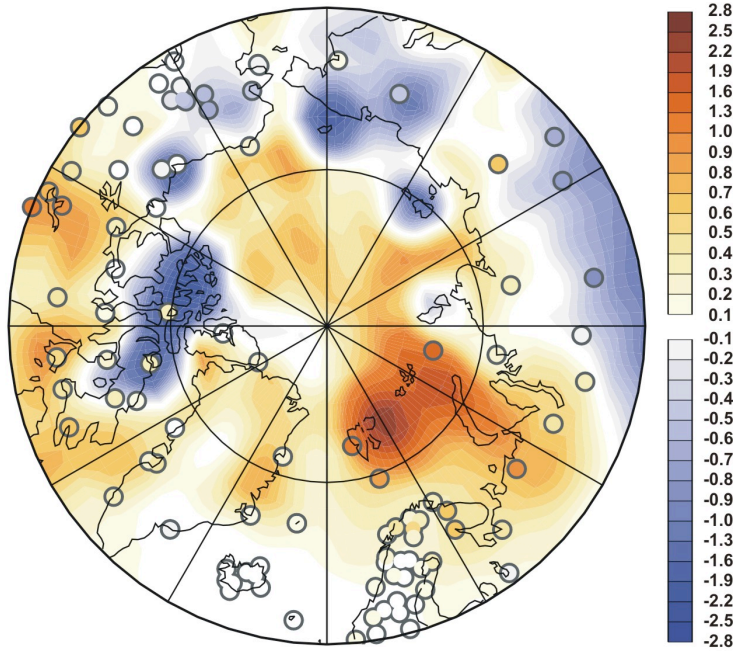
Surface wind stress regressed onto winter ARP index

re-circulate cold polar air to the midlatitude from Arctic

- **ARP caused Arctic Ocean warming and Eurasian land mass cooling**

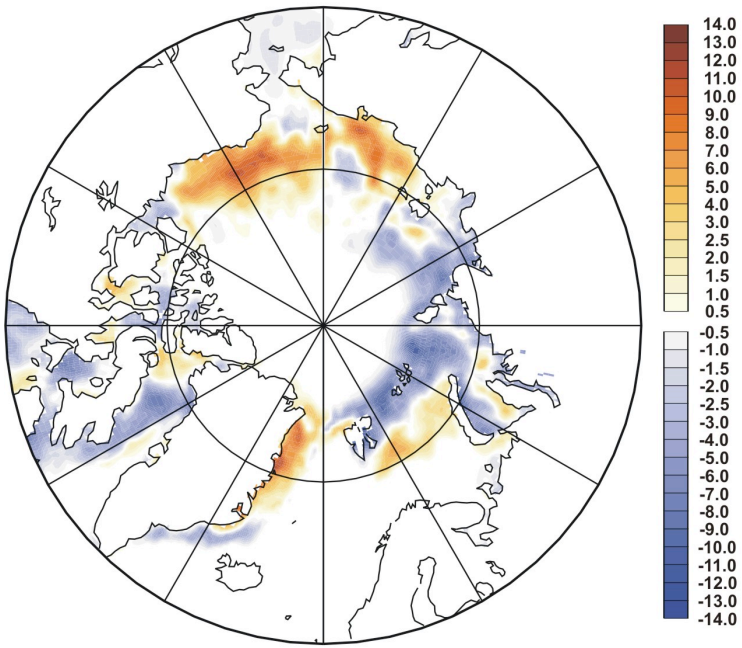


Winter Surface Air Temperature Regressed onto ARP Index

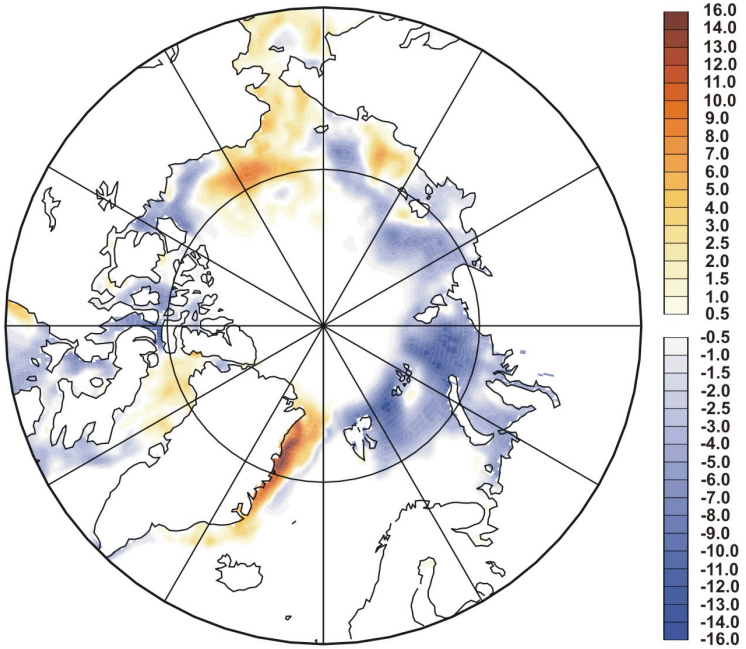


Winter Seasonal Surface Air Temperature Linear Trend

- **ARP reduced the North Atlantic Arctic sea ice coverage**

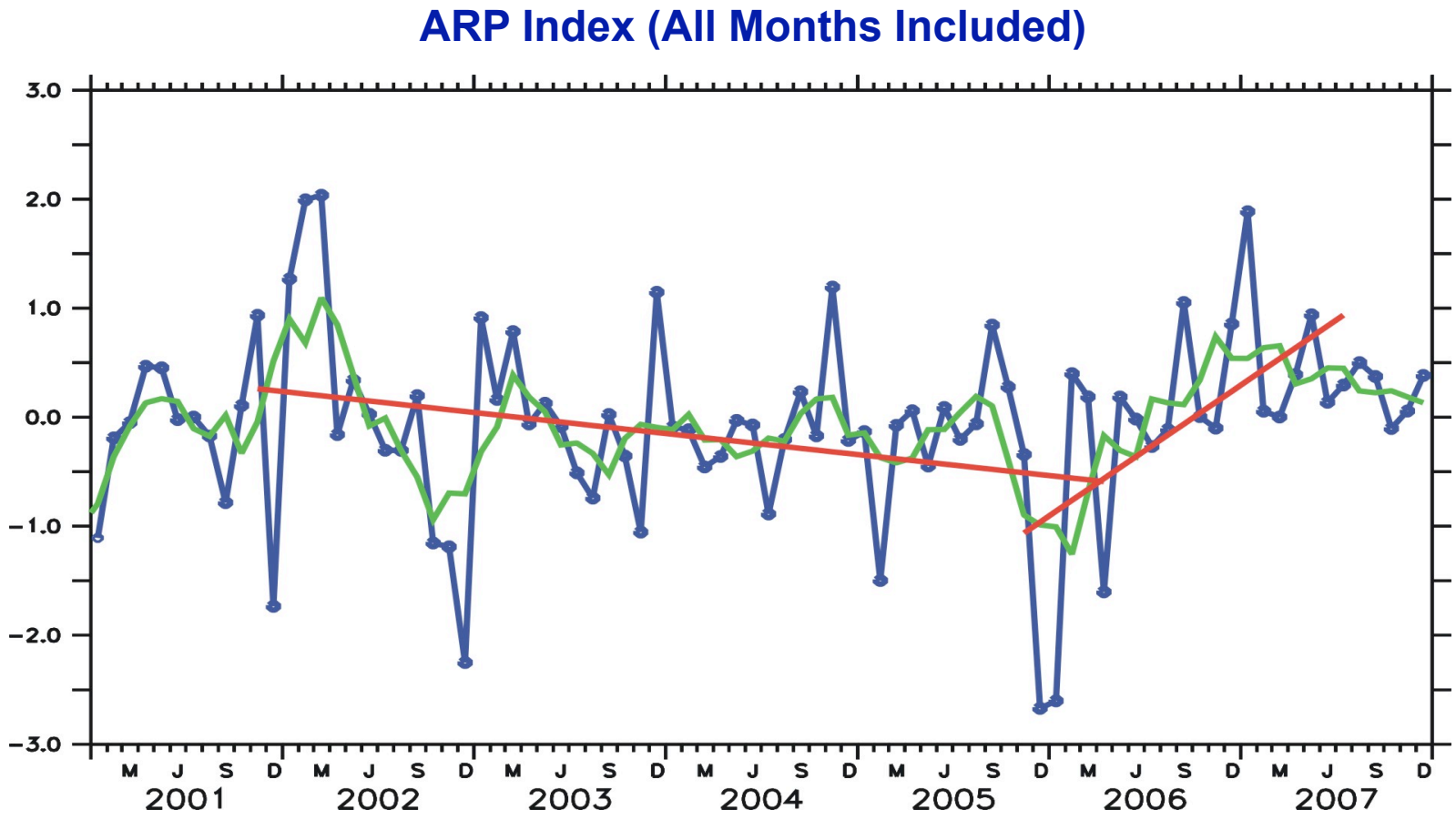


Summer Sea Ice Concentration Regressed onto ARP Index



Summer Seasonal Sea ice Concentration Linear Trend

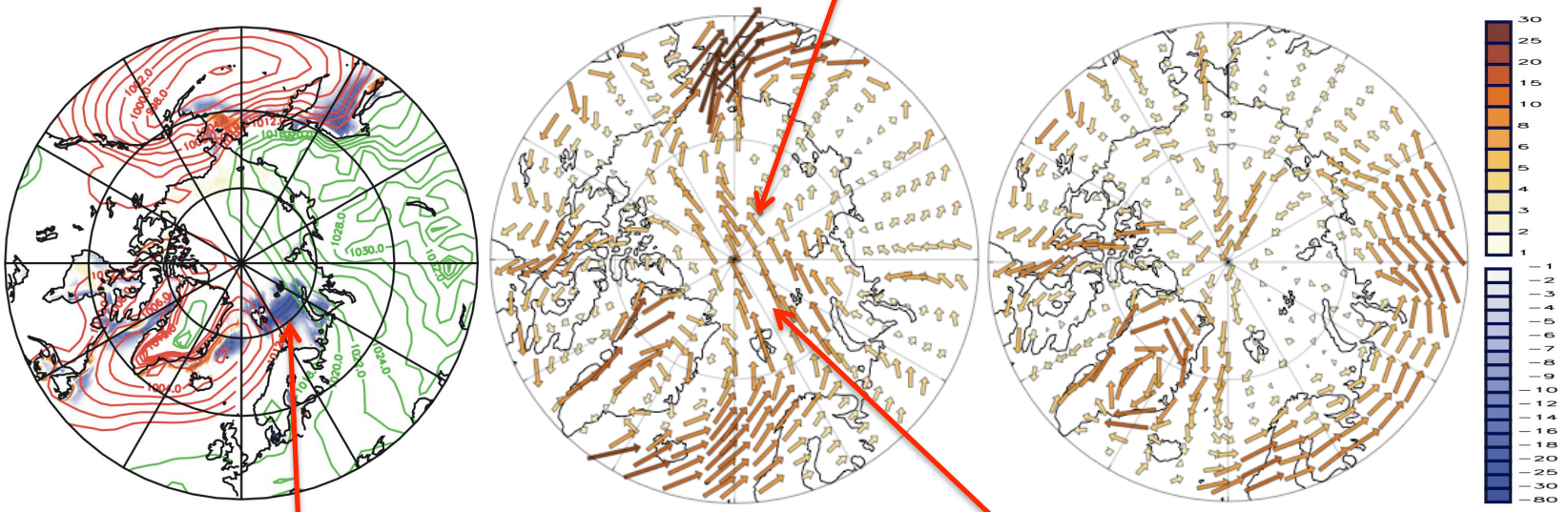
• **Swift phase change of ARP resulted in the extreme event of sea ice cover loss in summer 2007**



• **Extreme sea ice loss in summer 2007 is a result of multiyear polarity and swift phase change of ARP, not a single-time, random event**

✓The ARP phase change reversed wind pattern and reduced sea ice cover
✓The ARP phase change enhanced Pacific warm air and warm water inflow
✓The enlarged open water enhance albedo feedback

Composite Analyses of SIC and SLP Based on ARP Index



Negative ARP (mainly in winter) Before 2006

Positive ARP (mainly in summer) After 2006

Differences in SLP

The ARP associated atmospheric and oceanic heat transport reduced sea ice and enlarged open water

✓The previously warmed ocean retains the decreased sea ice
✓The enlarged open water enhance albedo feedback

Summary:

- **The atmospheric circulation pattern has shifted drastically in the latest decade and formed a new pattern – Arctic Rapid change Pattern (ARP).**
- **ARP speeded up externally-forced changes in sea ice and Arctic climate, enhanced arctic-global interaction, and caused the rapid change event.**
- **Detection of ARP may provide skillful information for predicting future occurrences of extreme or rapid climate change event in Arctic.**

GEOPHYSICAL RESEARCH LETTERS, VOL. 35, L22701, doi:10.1029/2008GL035607, 2008

Recent radical shifts of atmospheric circulations and rapid changes in Arctic climate system

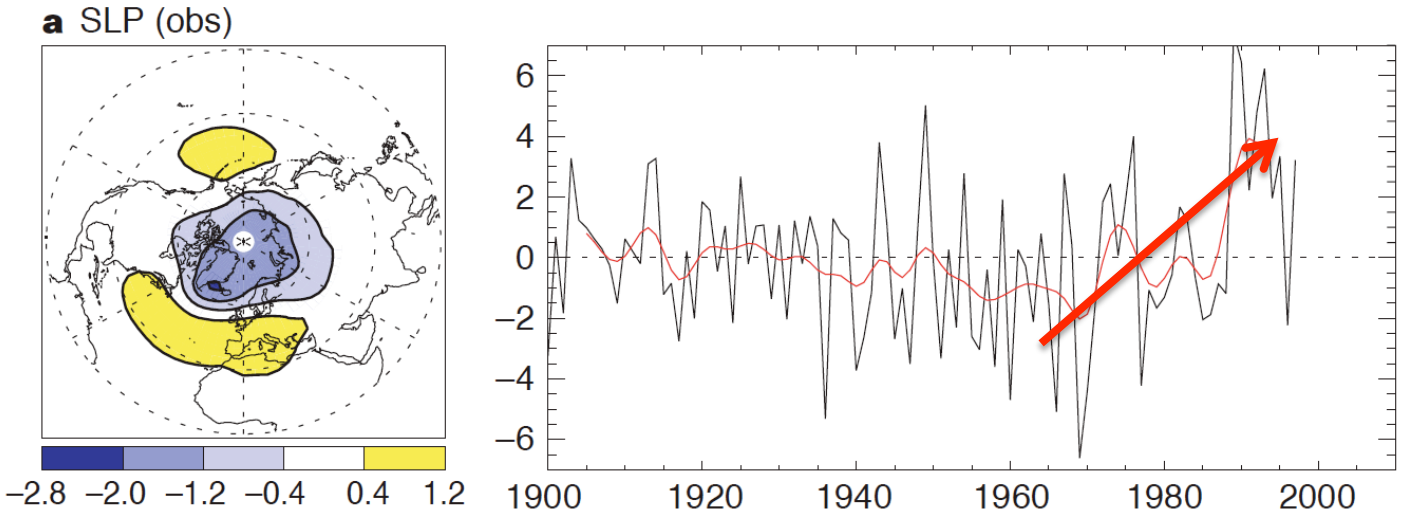
Xiangdong Zhang,[1] Asgeir Sorteberg,[2] Jing Zhang,[3] Rüdiger Gerdes,[4] and Josefino C. Comiso[5]

Received 6 August 2008; revised 22 September 2008; accepted 10 October 2008; published 18 November 2008.

[1] Arctic climate system change has accelerated tremendously since the beginning of this century, and a strikingly extreme sea-ice loss occurred in summer 2007. However, the greenhouse-gas-emissions forcing has only increased gradually and the driving role in Arctic climate change of the positively-polarized Arctic/North Atlantic tial Arctic climate system changes have been tightly associated, under conditions of global warming forcing, with the positively-polarized trend of the atmospheric circulation leading pattern, the Arctic/North Atlantic Oscillation (AO/NAO) [e.g., *Rigor et al.*, 2002; *Zhang et al.*, 2003].

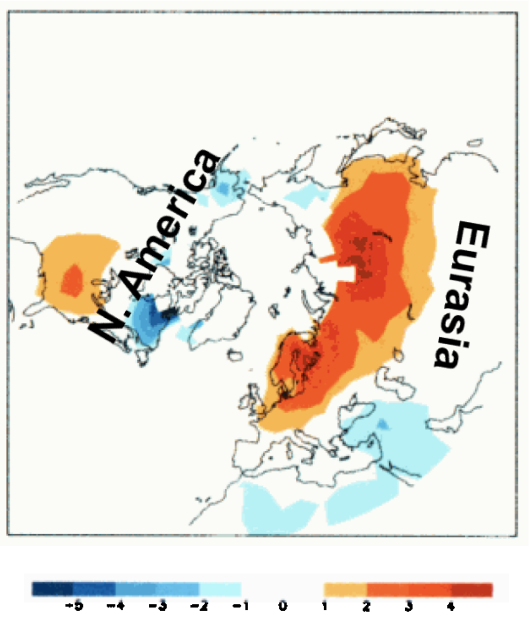
•Arctic/North Atlantic Oscillation

AO shows an upward trend from 1970s to 90s.

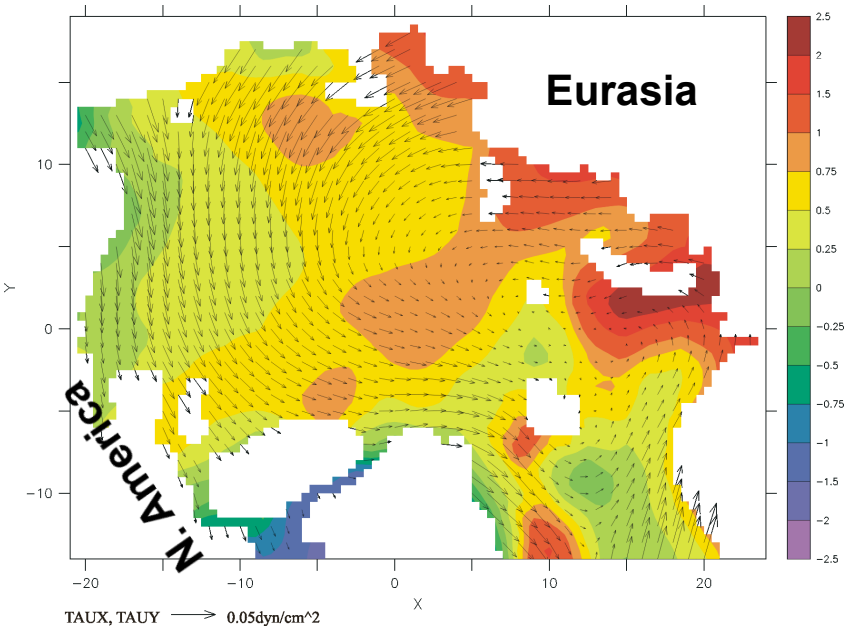


Thompson and Wallace (1998)

Positive AO and its upward trend result in an Arctic warming.

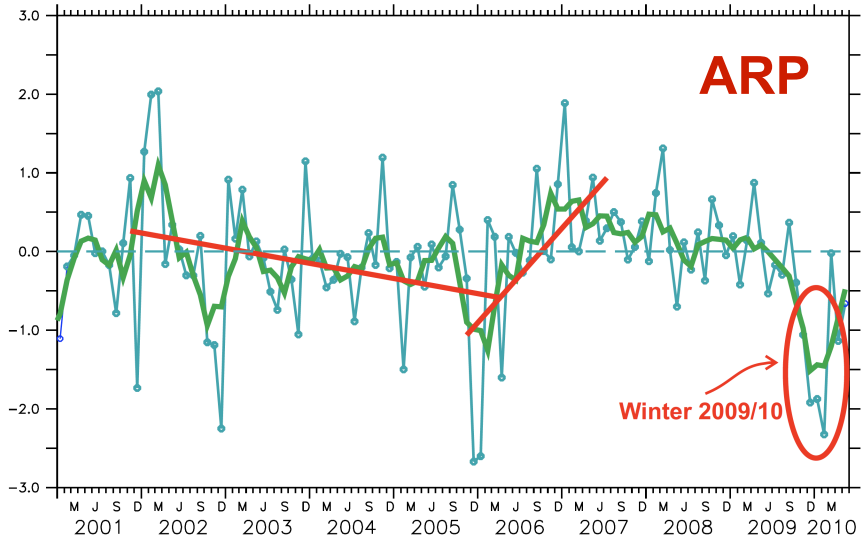


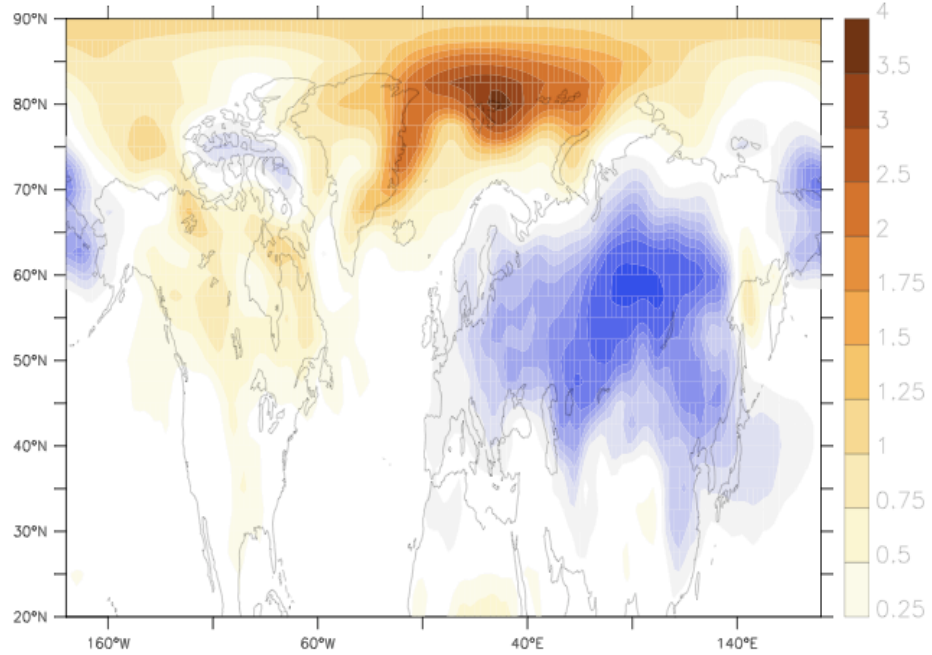
Gillett et al. (2000)



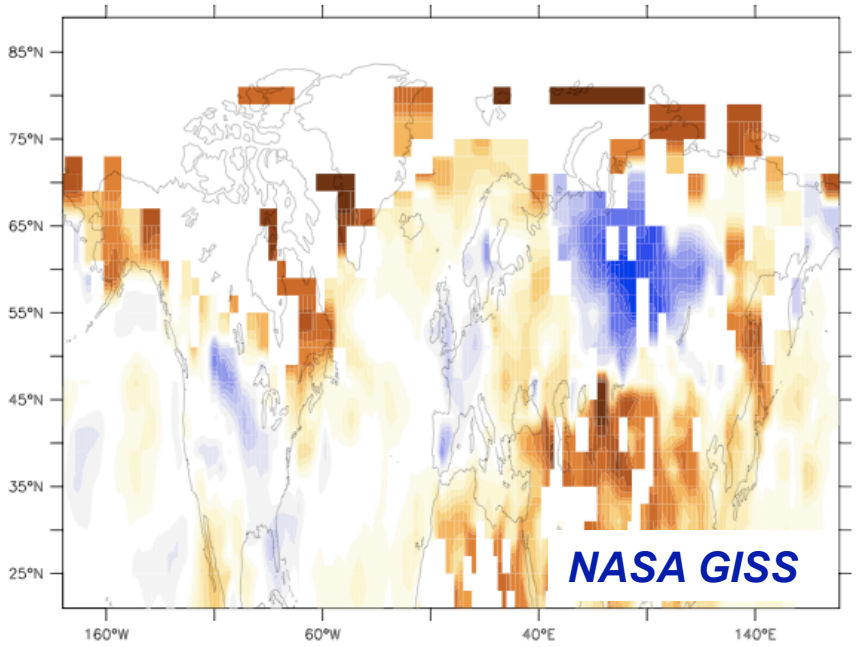
Zhang et al. (2003)

• An Update: ARP Was Negatively Polarized From Dec 2009 - Feb 2010





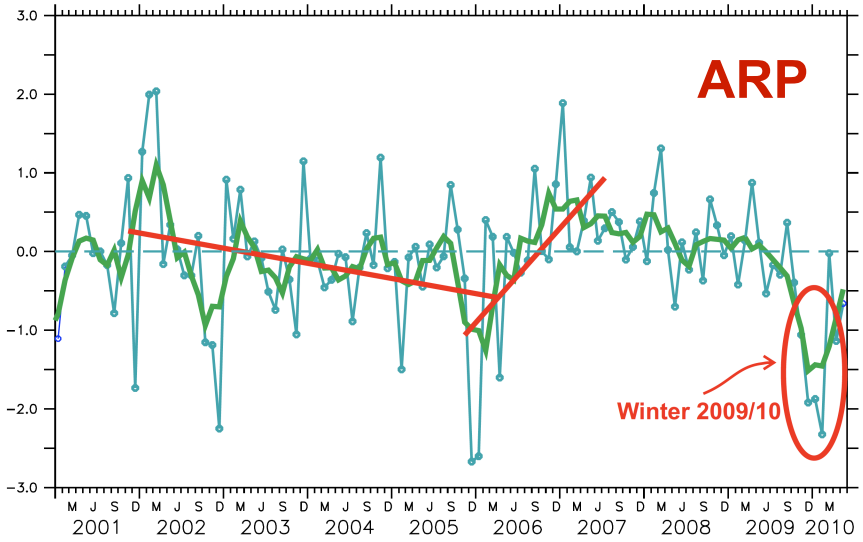
ARP driven surface air temperature Anomalies



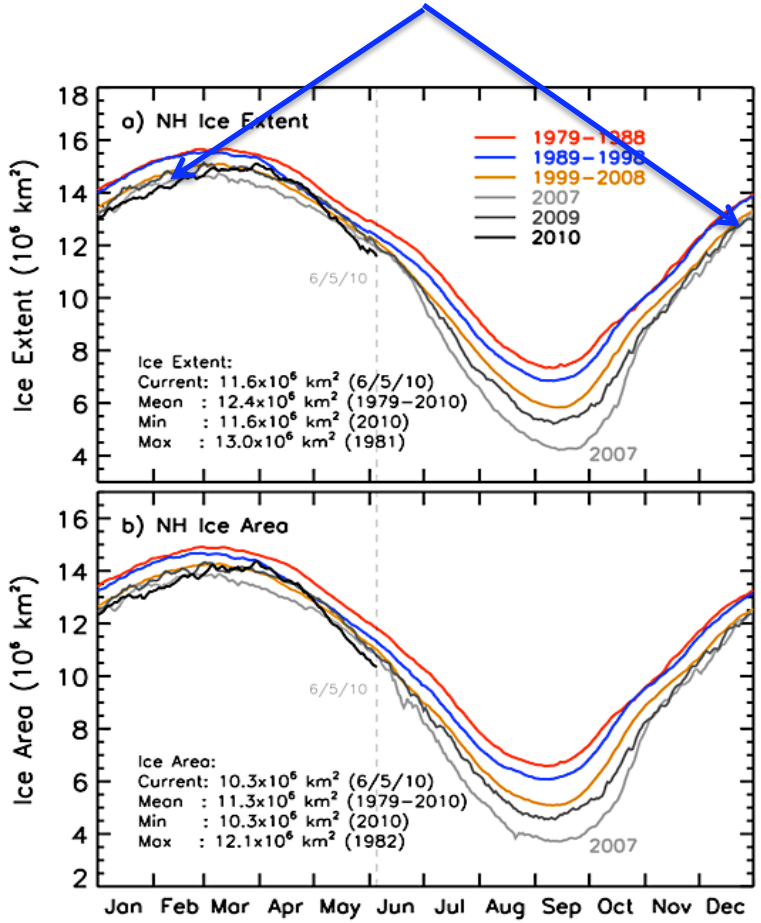
Surface air temperature anomalies Dec 2009 – Feb 2010

X. Zhang et al, 2010

• An Update: ARP Was Negatively Polarized From Dec 2009 - Feb 2010



Record Low
From Dec 2009 – Feb 2010



Negative ARP enhanced heat transport from Atlantic into Arctic

X. Zhang et al, 2010

J. Comiso