The Northern Hemisphere Sea ice Trends: Regional Features and the Late 1990s Change

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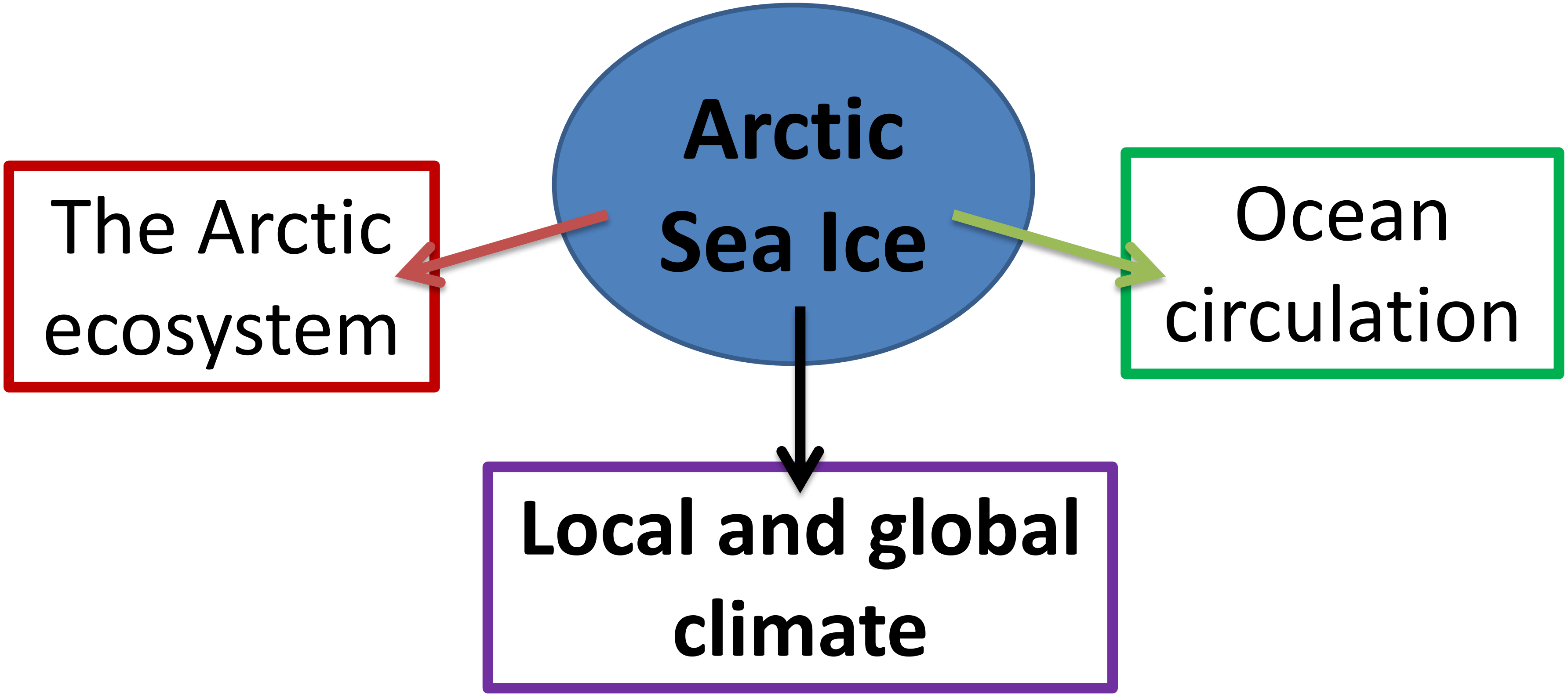
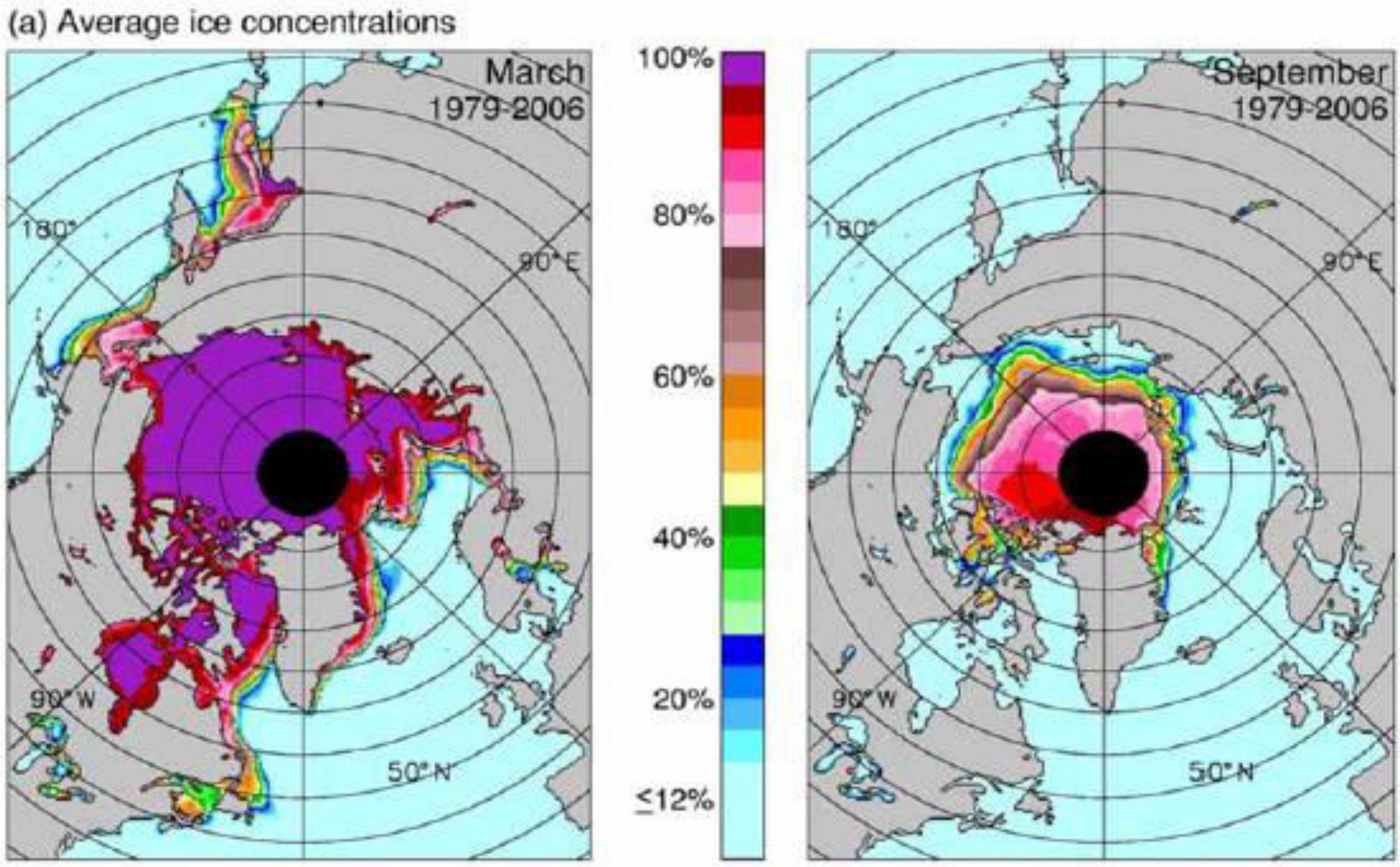
The Importance of Sea Ice Change



The amplified warming in the Arctic is likely related to the sea ice loss (e.g., Screen and Simmonds, 2010).



Parkinson and Cavalieri, 2008, JGR

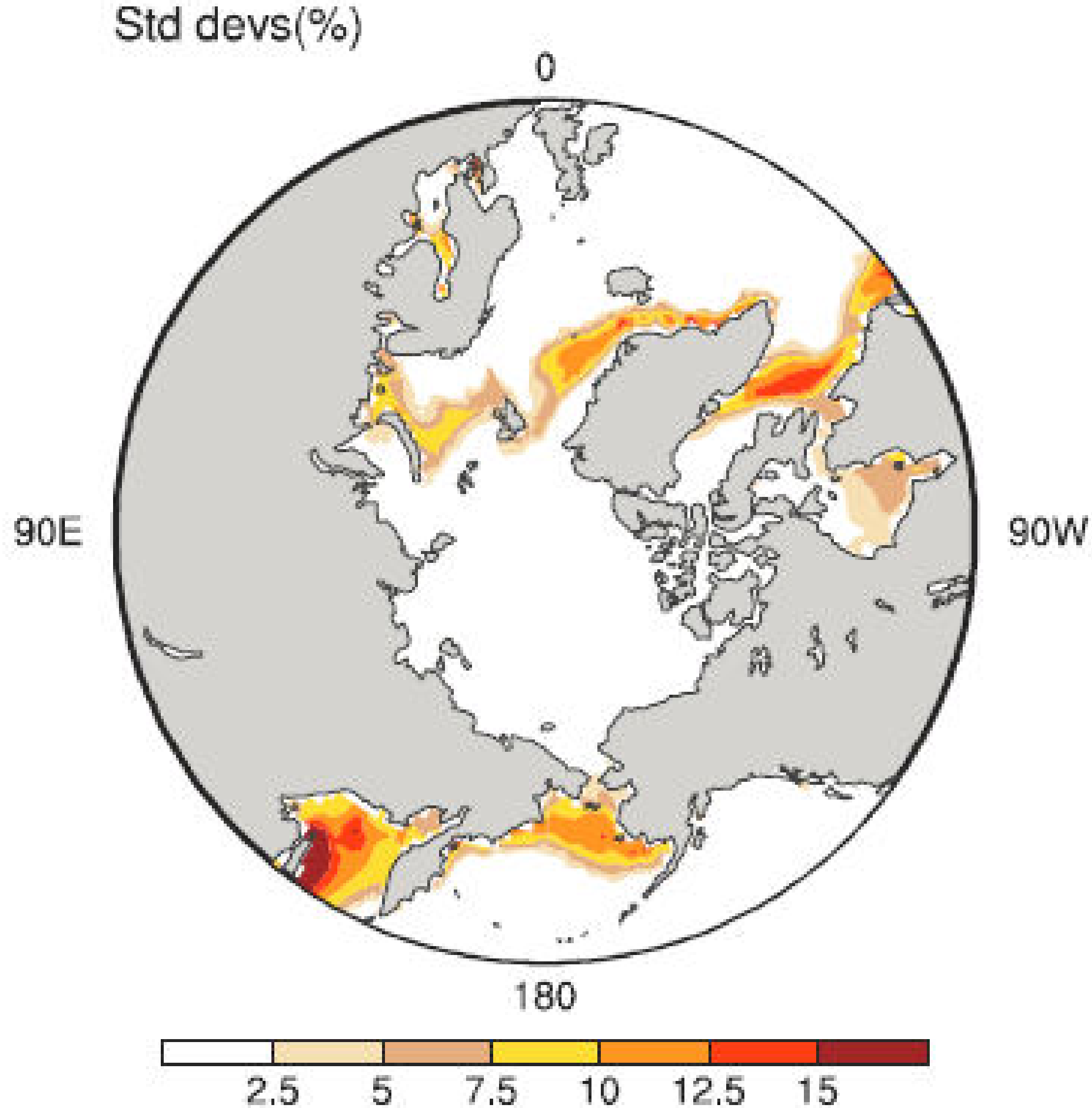
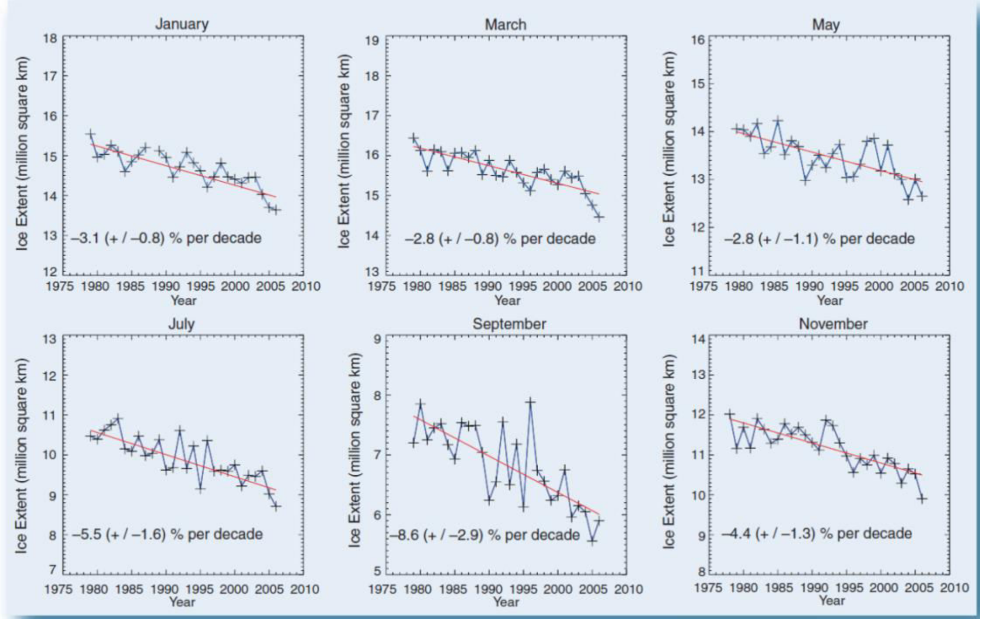


Fig. 1. Standard deviations (%) of the wintertime (December–February) Arctic sea ice cover for the period 1969–2001.

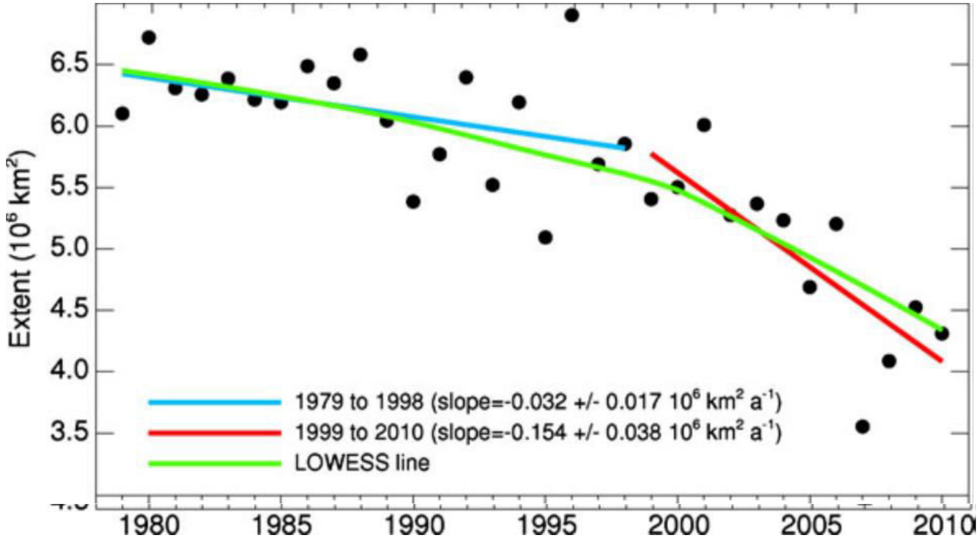
Li and Wang 2013 AAS

Sea Ice Variability and Trends

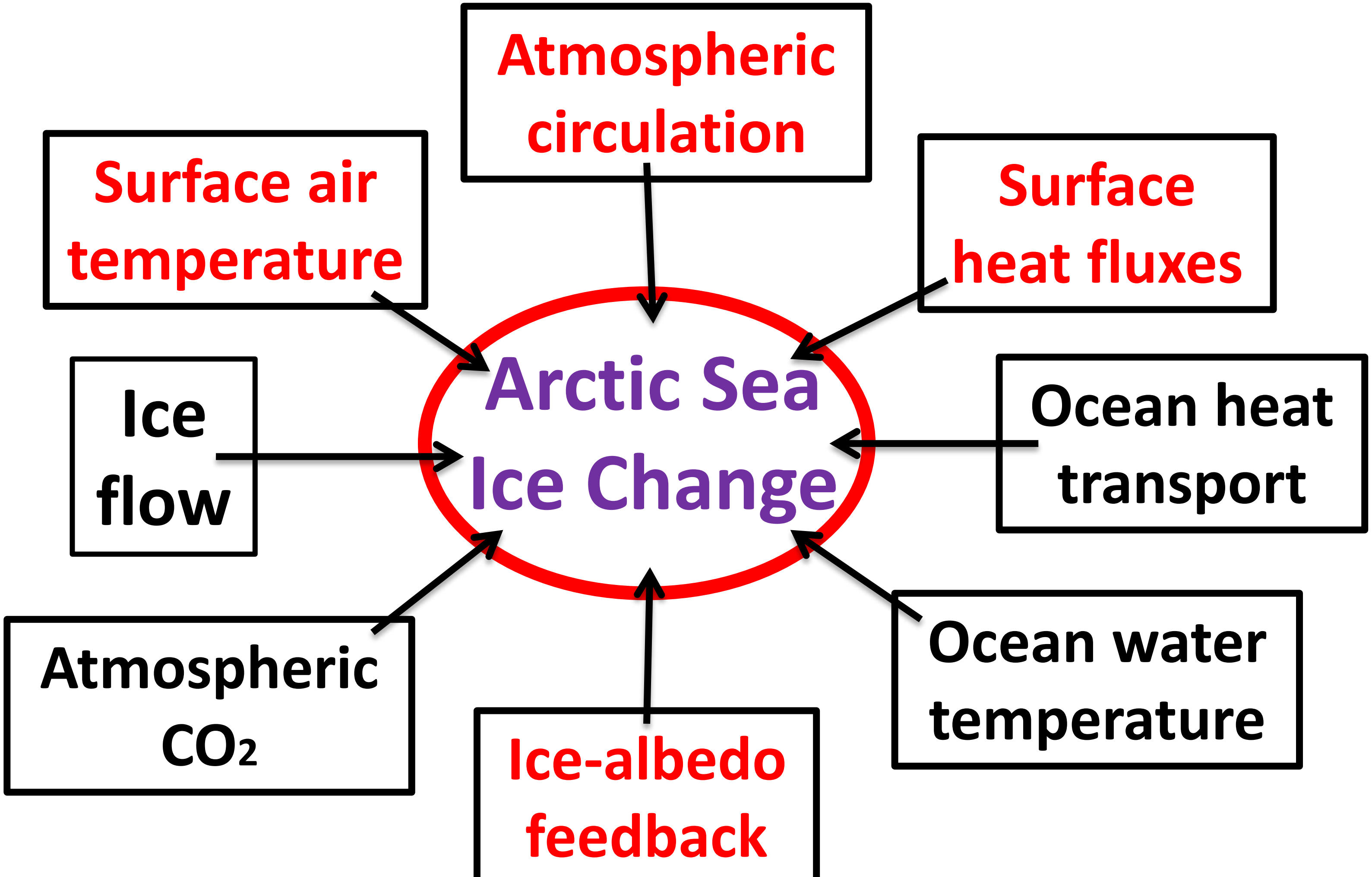
The Arctic sea ice cover has declined in all months since 1979 (e.g., Serreze et al. 2007).



The ice loss in September has been accelerated in recent years (e.g., Stroeve et al. 2012).



Factors for Sea Ice Changes



The sea ice change is not uniform, displaying regional features.

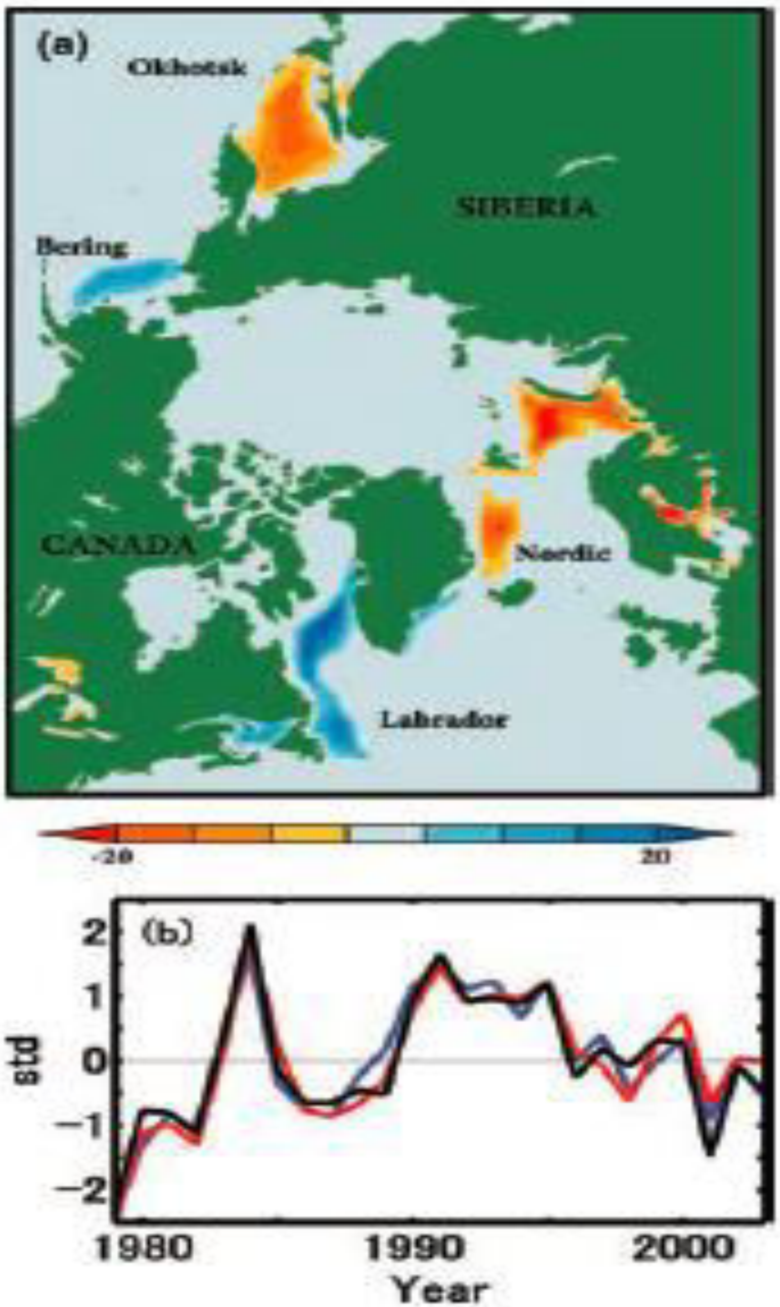


Fig. 1. Leading mode of sea-ice variability. (a) First EOF of the winter (February–March) mean NH SIC field. The colour indicates the local change in SIC in per cent for one unit standard deviation increase in the PC1 time-series. (b) Normalized principal component time-series for the first EOF modes of the SIC field (blue) and the four-region SIE field (PC1-SIE; red), and the normalized algebraic mean of the North-Atlantic and North-Pacific SIE seesaw indices (black). The time-series prior to de-trending are shown.

Ukita et al. 2007 Tellus

The aims of the present study

- Investigate the spatial characteristics of the Arctic sea ice trends
- Explore the change in the sea ice trends around the late 1990s and its possible reasons.

Focus on both March and September ;

summer sea ice is sensitive to the sea ice condition in the previous winter (e.g., Stroeve et al. 2012).

Data

- Sea ice variables from the National Snow and Ice Data Center (NSIDC)

  e.g. sea ice concentration (SIC), sea ice age

- Sea ice extent (SIE)

  the cumulative areas of all grid cells having at least 15% sea ice concentration.

- Monthly mean datasets from NCEP/NCAR

  e.g. surface air temperature, surface winds, net shortwave radiation

- 1979-2014, March and September

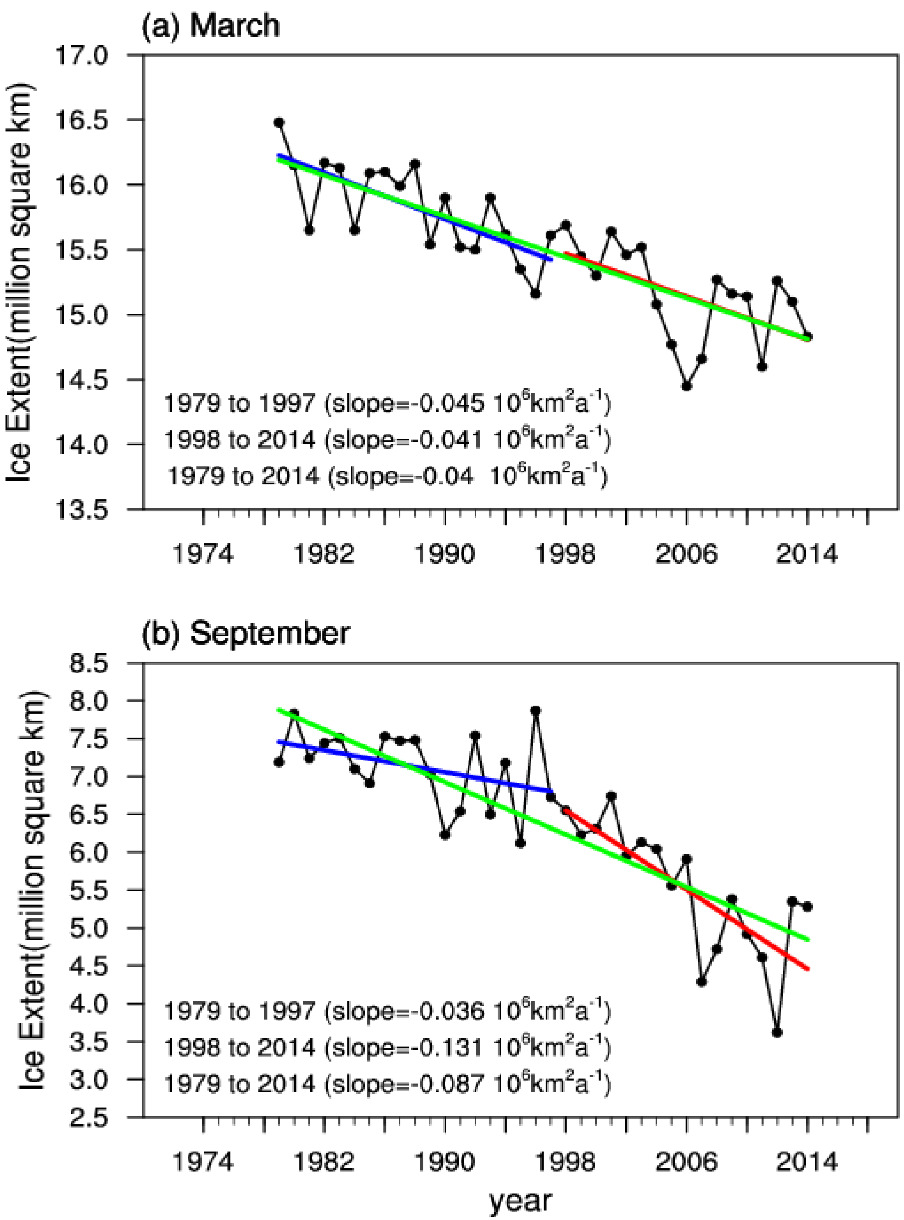
Results

- Sea ice trends in March and September

- Formation of the sea ice trends and their changes in March
  - *Surface air temperature*
  - *Surface wind*

- Formation of the sea ice trends and their changes in September
  - *Surface air temperature*
  - *Surface wind*
  - *Self-acceleration of sea ice loss*

Sea ice trends in March and September

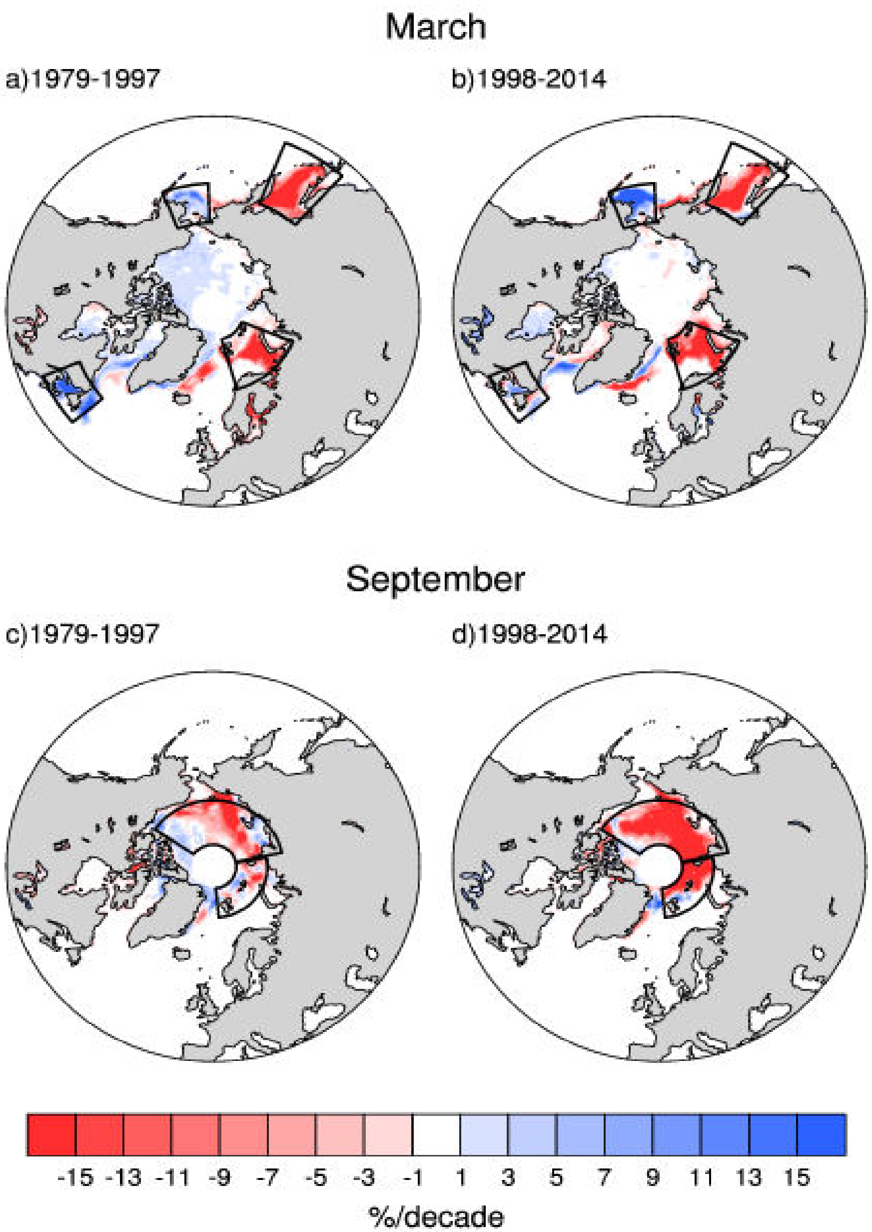


[1979-1997] vs [1998-2014]

The sea ice extents for the Northern Hemisphere are declining in both March and September, but only the negative slope for September is steepened with time.

Fig. The Northern Hemisphere sea ice extent in March (a) and September (b) from 1979 to 2014 with lines for linear trends based on the full record (green), 1979-1997 (blue), and 1998-2014 (red).

Sea ice trends in March and September

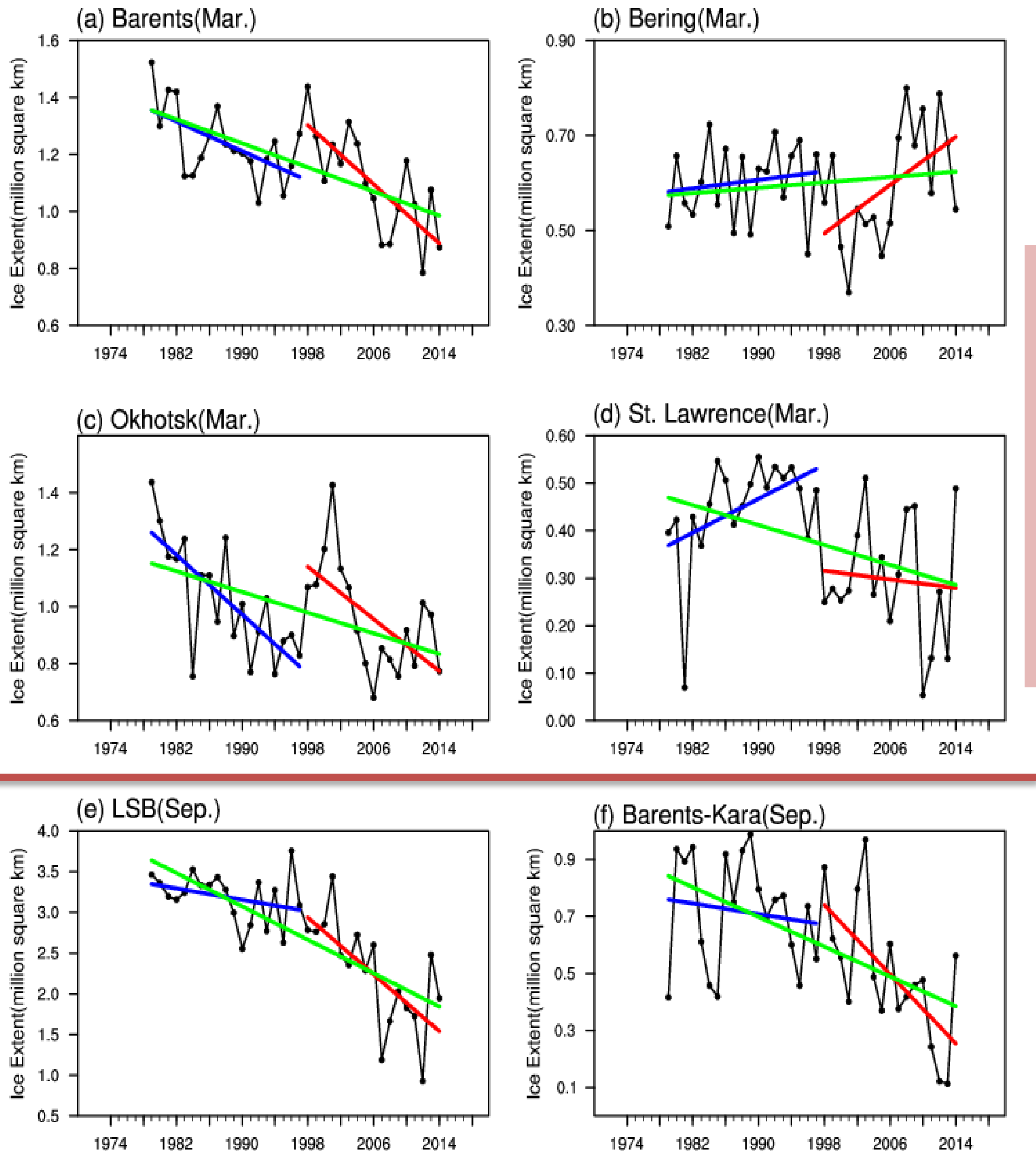


There are regional differences in March sea ice trends;
The sea ice trends show decrease over most regions in September.

Fig. Linear trends for March (top) and September (bottom) sea ice concentration during 1979-1997 (a, c) and 1998-2014 (b, d). The unit is % per decade. The six domains enclosed by thick-lines denote the key regions used in the analysis.

March: The Barents Sea; The Bering Sea; The Sea of Okhotsk; The Gulf of St. Lawrence

September: LSB regions (Laptev-East Siberian-Beaufort Seas); The Barents-Kara Seas



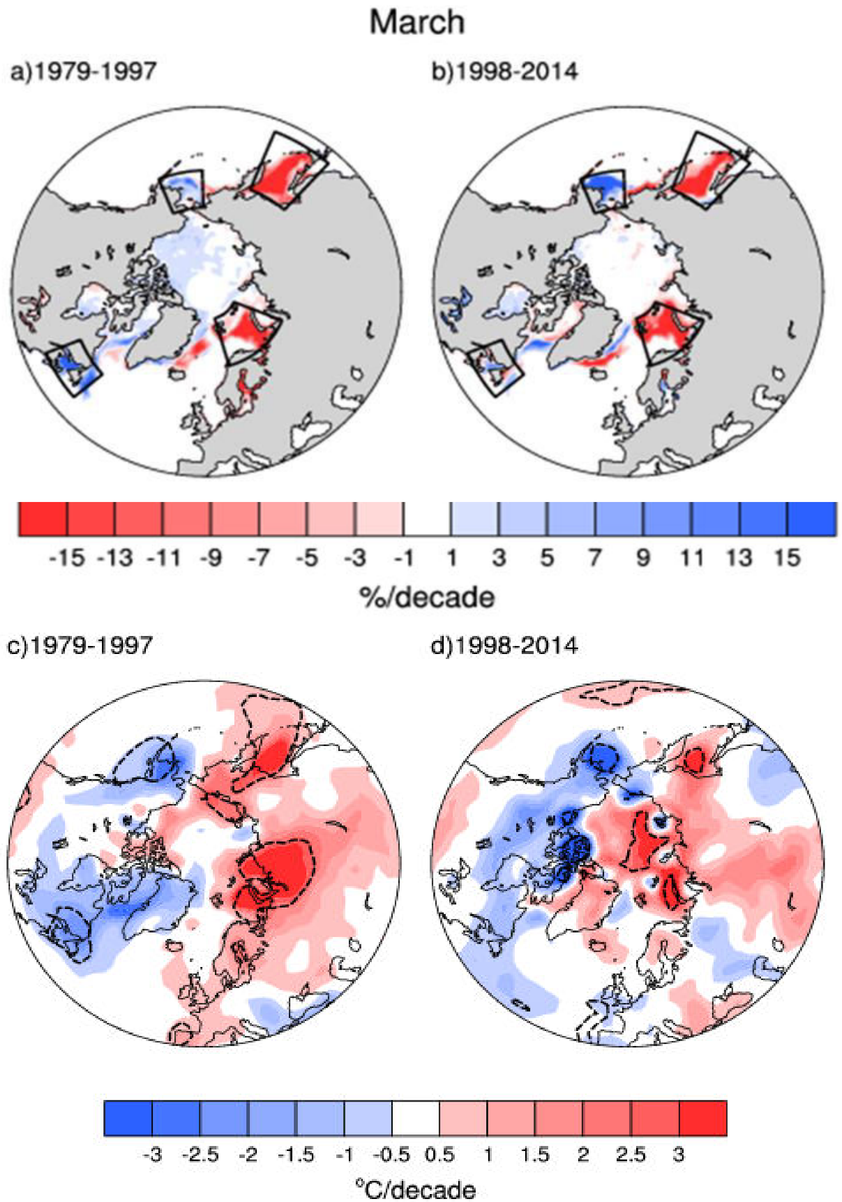
The trends of regional sea ice extents in March differ greatly from the earlier period to the later period, e.g., the Barents Sea, the Bering Sea.

Fig. Area-mean sea ice extent in six key regions.

Table 1 Slopes of the linear trends for sea ice extent in the six key regions over three time-periods (unit: million km^2/a; * denotes that the slope is statistically significant at the 95% confidence level)

	1979-1997	1998-2014	1979-2014
Barents(Mar.)	-0.013*	-0.026*	-0.011*
Bering(Mar.)	0.002	0.013*	0.001
Okhotsk(Mar.)	-0.026*	-0.023*	-0.009*
St. Lawrence(Mar.)	0.009*	-0.002	-0.005*
LSB(Sep.)	-0.018	-0.087*	-0.051*
Barents-Kara(Sep.)	-0.005	-0.03*	-0.013*

Formation of sea ice trends in March



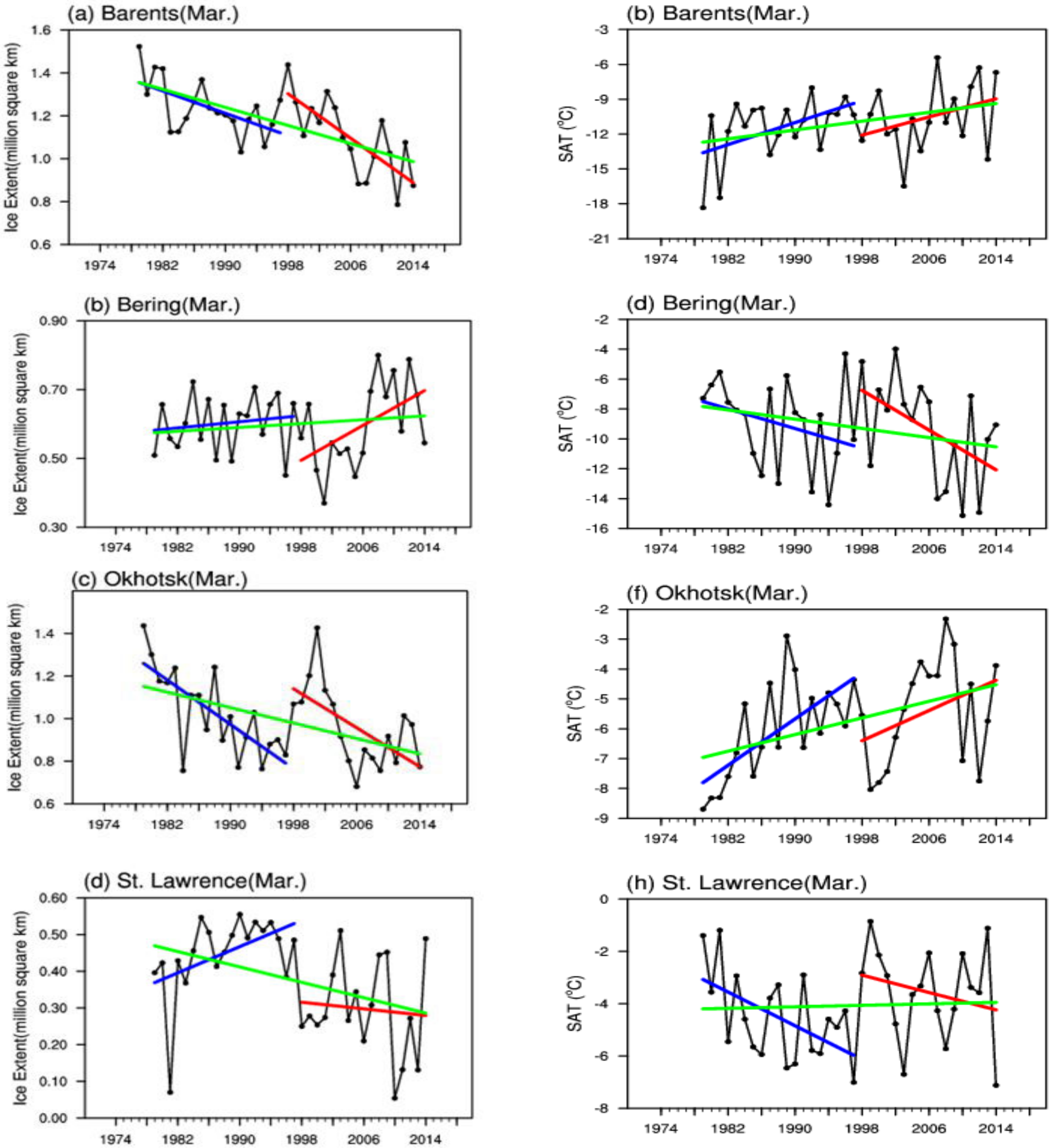
SAT vs SIC

SAT increase ~ SIC decrease
SAT decrease ~ SIC increase

Fig. Linear trends of March sea ice concentration and surface air temperature during 1979-1997 (a, c) and 1998-2014 (b, d).

Formation of sea ice trends in March

SAT vs SIE



SAT increase ~ SIC decrease
SAT decrease ~ SIC increase

Fig. Area-mean SIC and SAT in March over four key regions.

Formation of sea ice trends in March

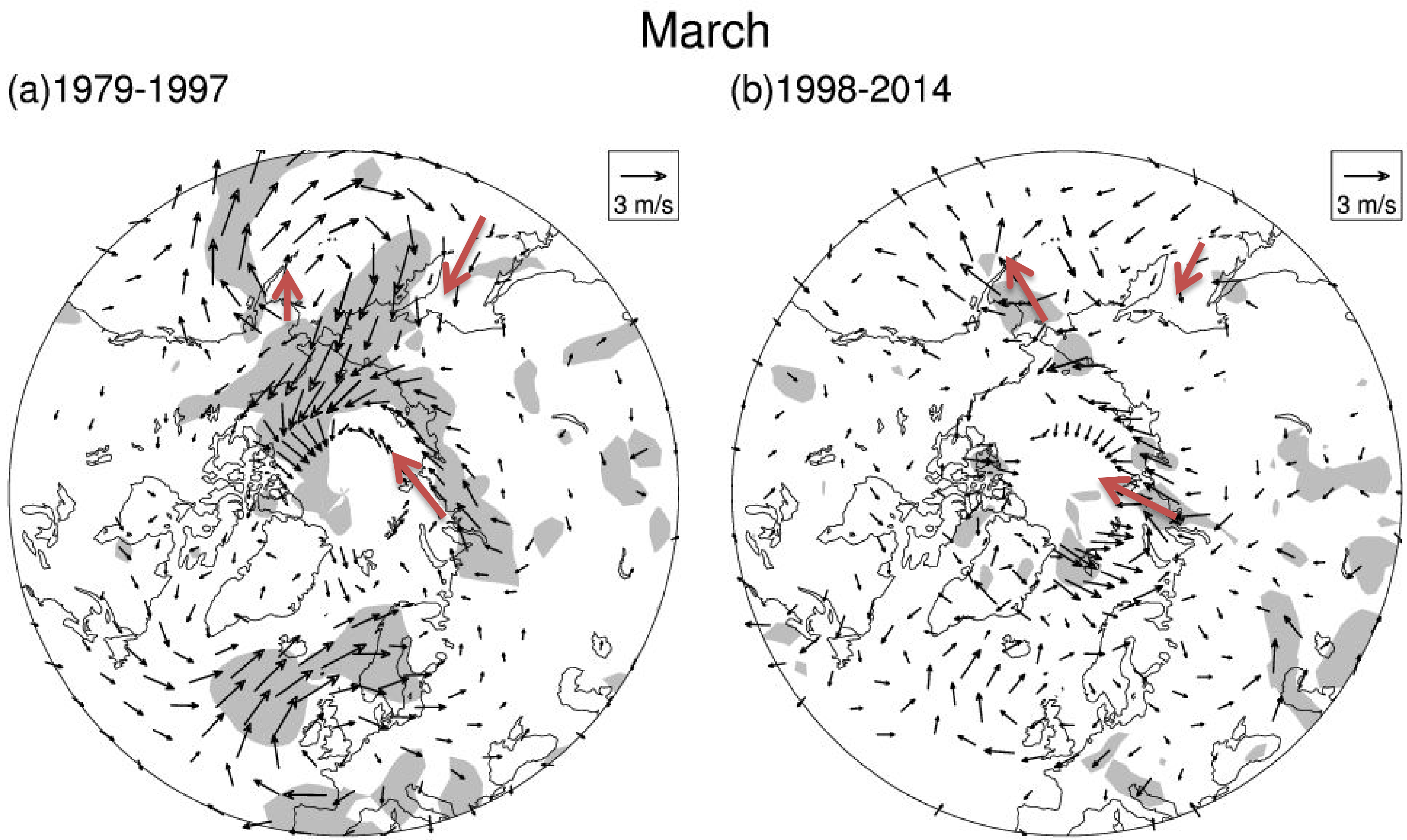


Fig. Linear trends of March surface wind during 1979-1997 (a) and 1998-2014 (b).

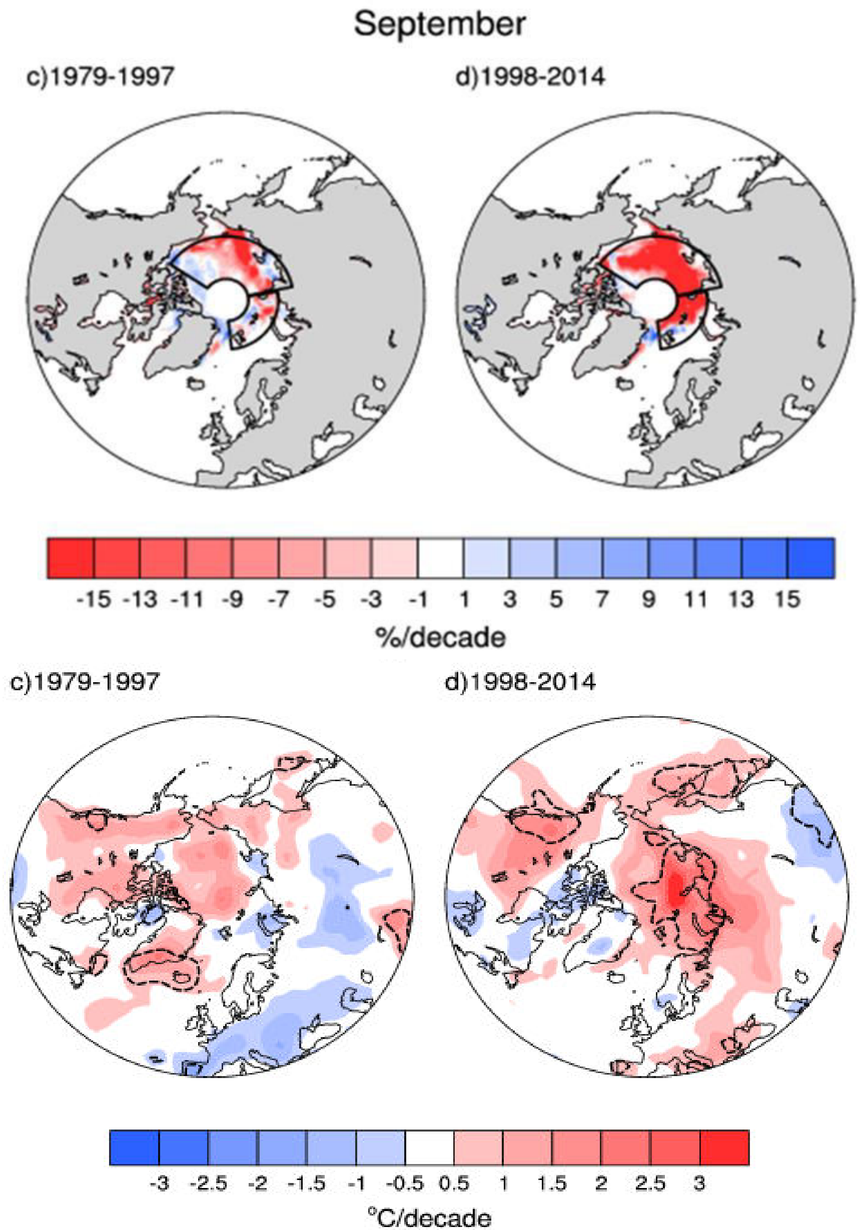
Formation of sea ice trends in March

- The sea ice trends in March and their changes at late 1990s may be attributed to the effects of SAT and atmospheric circulation change.

- The SAT trends in March display regional differences and there is a good correspondence in the sea ice and SAT trends.

- The surface wind changes may contribute to sea ice changes through modulating SAT.

Formation of sea ice trends in September

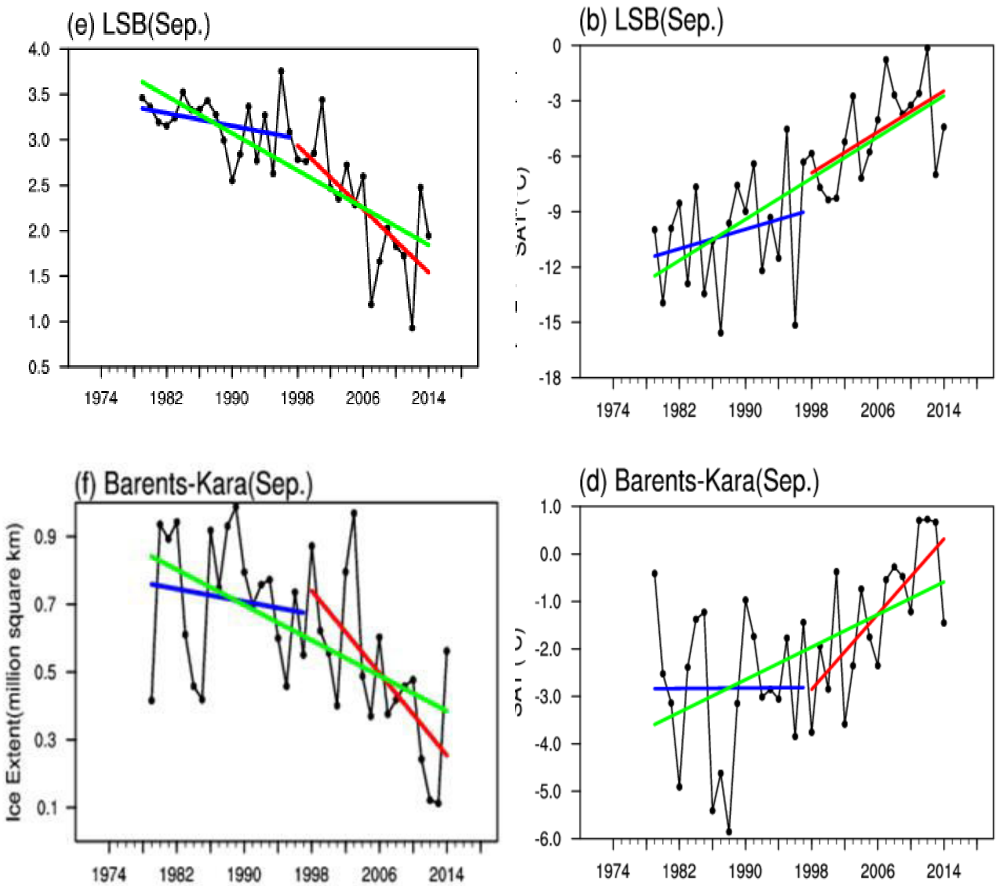


SAT vs SIC

SAT increase ~ SIC decrease

Fig. Linear trends of September sea ice concentration and surface air temperature during 1979-1997 (a, c) and 1998-2014 (b, d).

Formation of sea ice trends in September



SAT vs SIE

SAT increase ~ SIC decrease

Fig. Area-mean SIE and SAT in September over two key regions.

Formation of sea ice trends in September

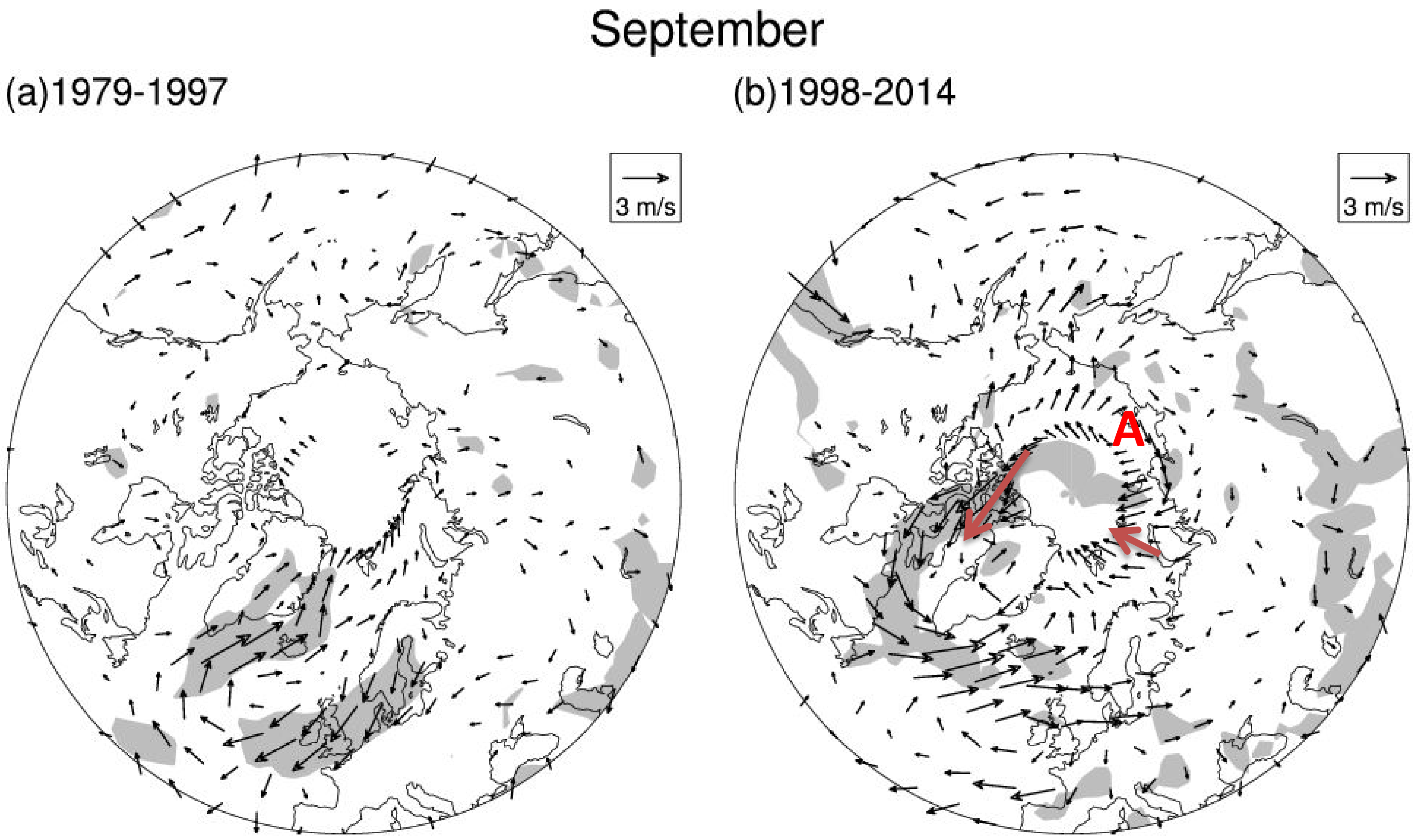


Fig. Linear trends of September surface wind during 1979-1997 (a) and 1998-2014 (b).

Formation of sea ice trends in September

The self-acceleration of sea ice loss

- **Ice age**

  The summer sea ice extent is sensitive to the sea ice conditions in the previous winter (e.g., Rigor et al. 2002; Stroeve et al. 2012).

  The younger the ice in winter, the more ice loss in summer.

- **The ice-albedo feedback**

  A positive feedback process acts to *reinforce the initial alteration in ice cover.*

Formation of sea ice trends in September

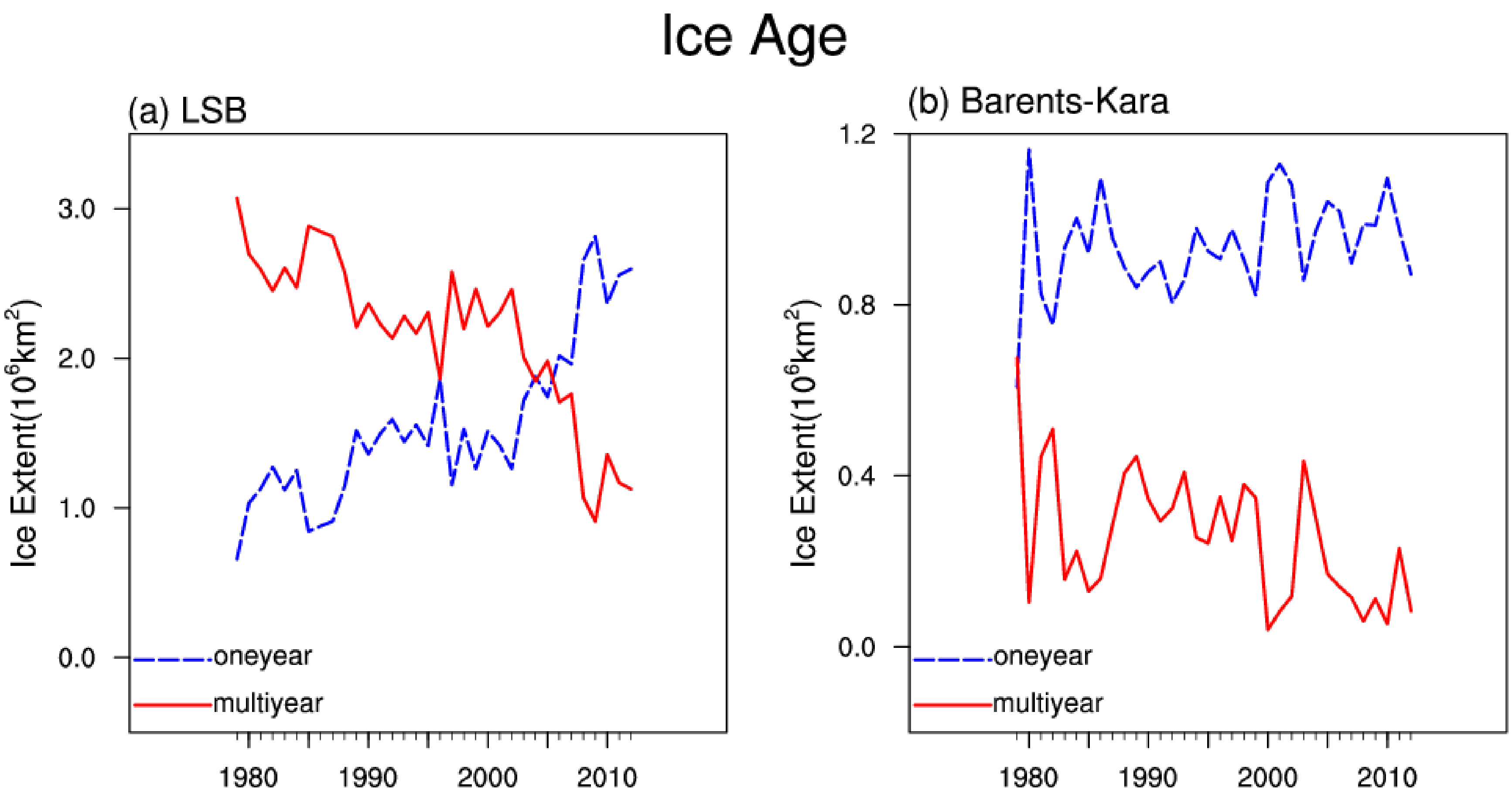
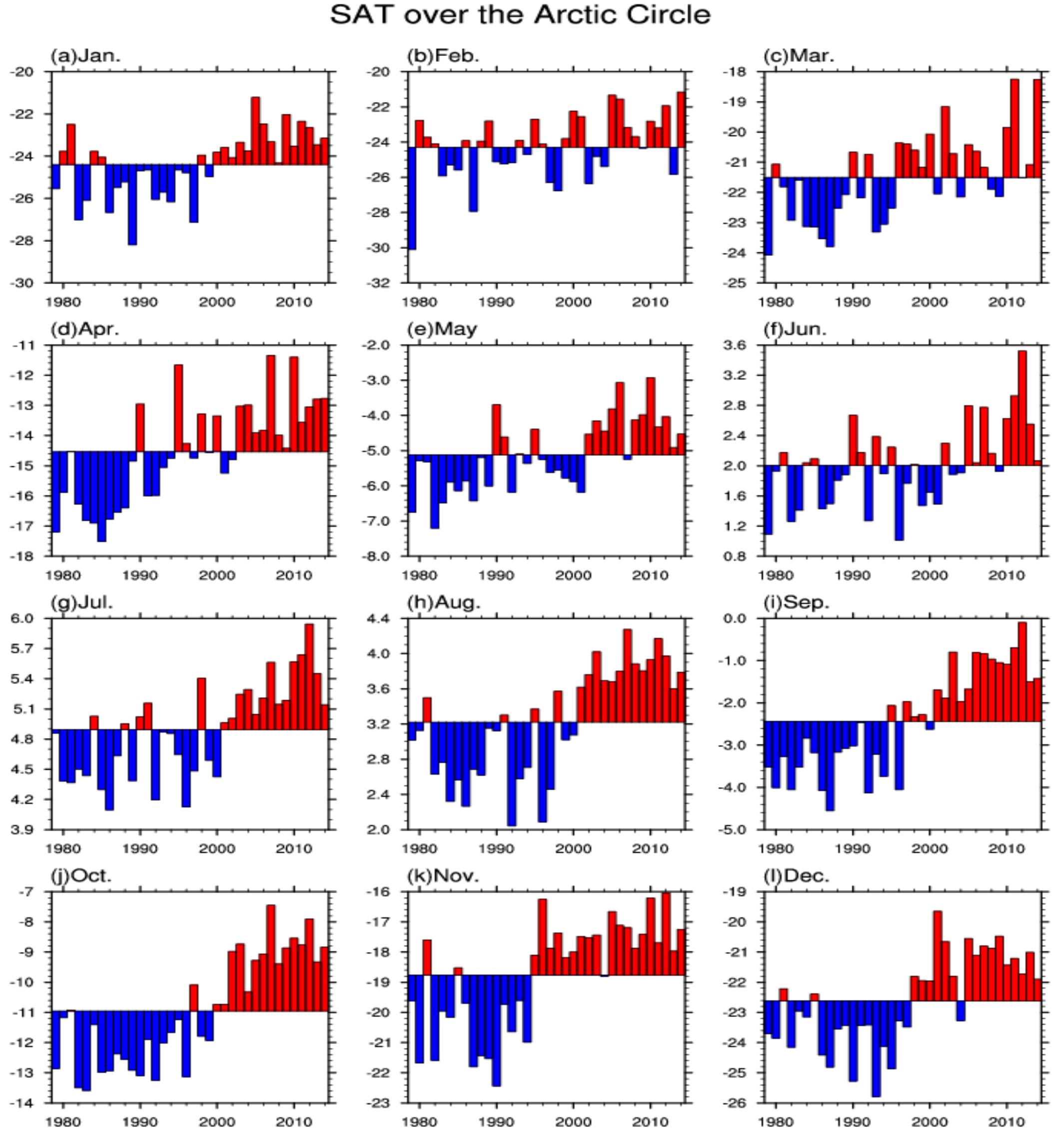


Fig. Multiyear and one-year ice extent in the Laptev Sea-East Siberian Sea-Beaufort Sea (a) and the Barents-Kara Seas (b) in March during 1979-2012.

The effects of SAT on the ice age



Fostering an earlier onset of ice melt (spring)

Accelerate the ice melting (summer)

Delay the freeze of water (autumn)

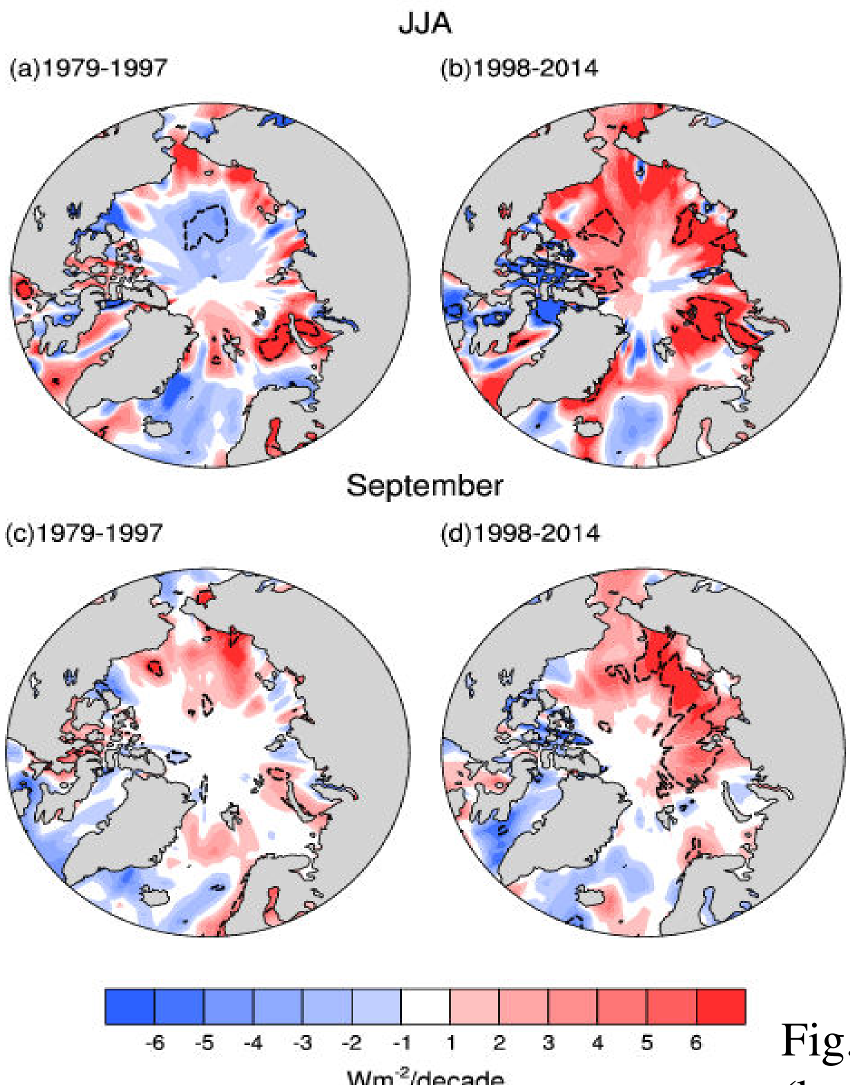
Shorten the time for ice growth

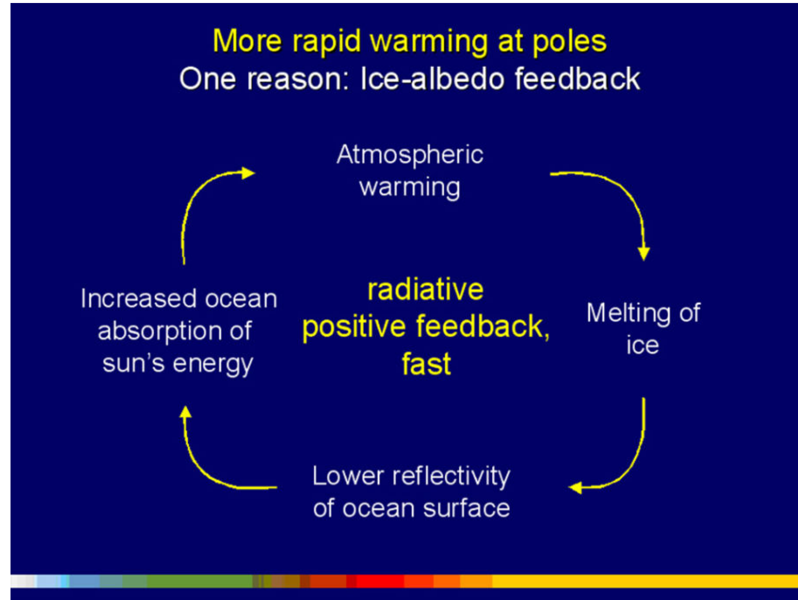
Thinner ice

Fig. The time series of monthly surface air temperature averaged over the Arctic Circle for the period 1979-2014. The horizontal line represents the climatological mean temperature.

Formation of sea ice trends in September

➢The ice-albedo feedback





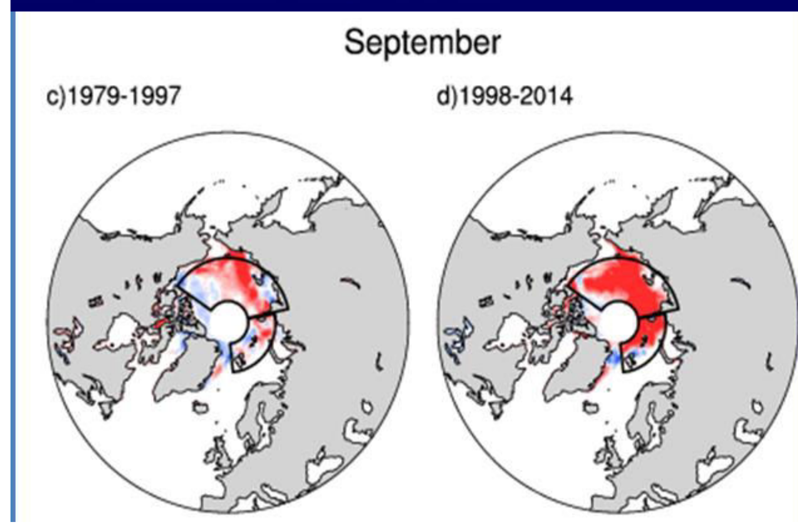


Fig. Linear trends of JJA (top) and September (bottom) downward surface net shortwave radiation.

Formation of the sea ice trends in September

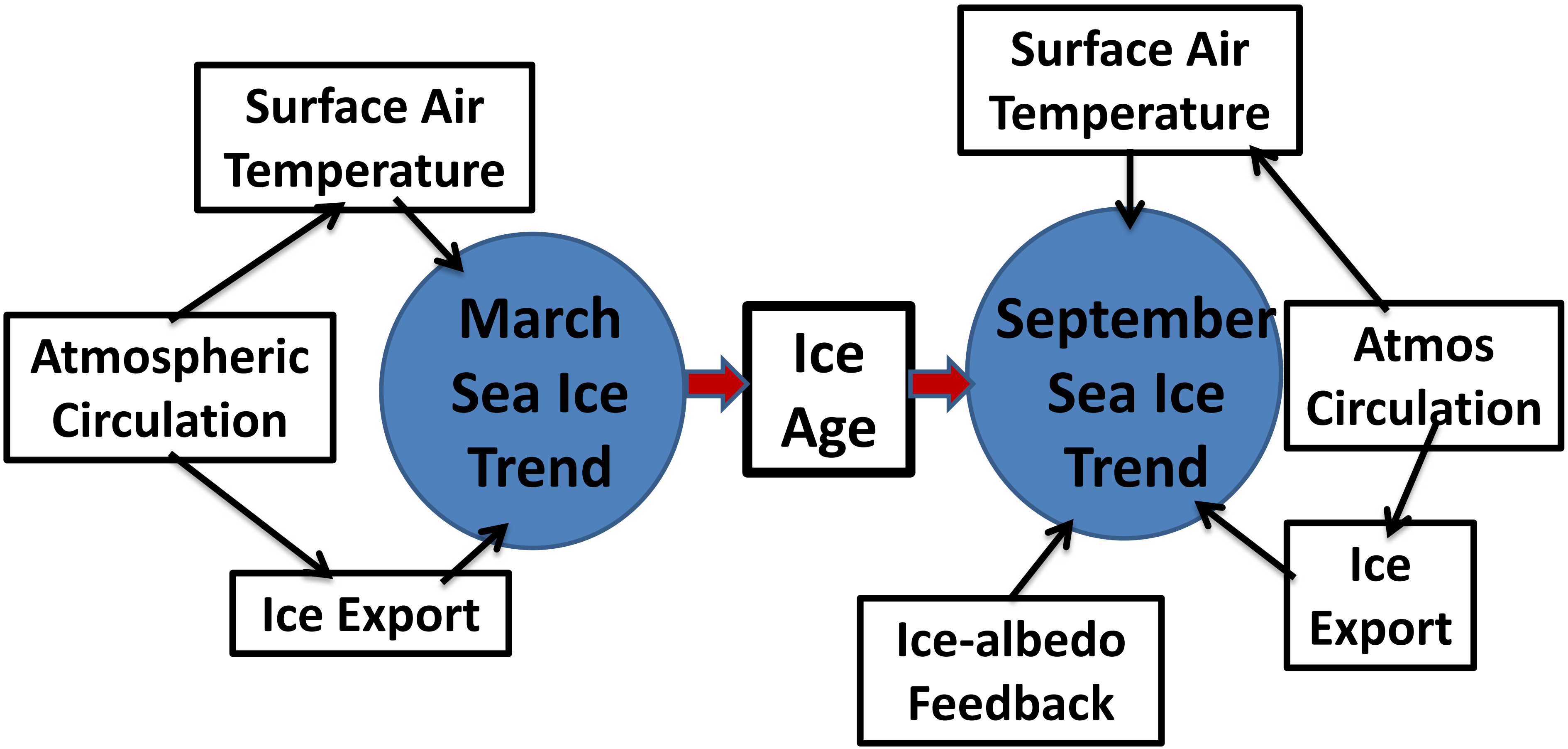
- The accelerated downward trend of sea ice cover in September is attributed to several factors, including *increased air temperatures, changes in ice age and ice-albedo feedback*.

- The Arctic SAT is considerably warmer in the recent decades than the earlier decades. *The accelerated sea ice loss in September may be partly attributed to this rapid Arctic warming*.

- *The March ice cover becomes much younger and thinner in recent decades*. *The multi-year ice in March is declining at a larger rate in recent decades, which may account for the larger rate of ice loss in September.*

- *The ice-albedo feedback plays a growing important role in the sea ice loss in summer. The absorption of solar radiation in the Arctic Ocean in summer has increased rapidly in recent decades*.

Factors for the Arctic Sea Ice Decline



Summary

- The sea ice extents for the Northern Hemisphere total are declining in both March and September, and only the negative slope in September is steepened after late 1990s.

- There are regional differences in March sea ice trends. The ice trends in March may be attributed to the effects of anomalous surface air temperatures and atmospheric circulation.

- The accelerated sea ice loss in September is attributed to several factors, including increased air temperatures, surface wind change, multi-year ice reduction and ice-albedo feedback.

Discussion

- There could be a close interaction between sea ice and SAT changes.
- We showed that the SAT trends are partly induced by atmospheric wind changes.
- At least part of the recent cold-season warming is driven by the loss of ice (e.g., Serreze et al. 2007).
- Further studies are needed to address the contributions of different factors in the sea ice trends and their changes, such as the ocean conditions.

The end!