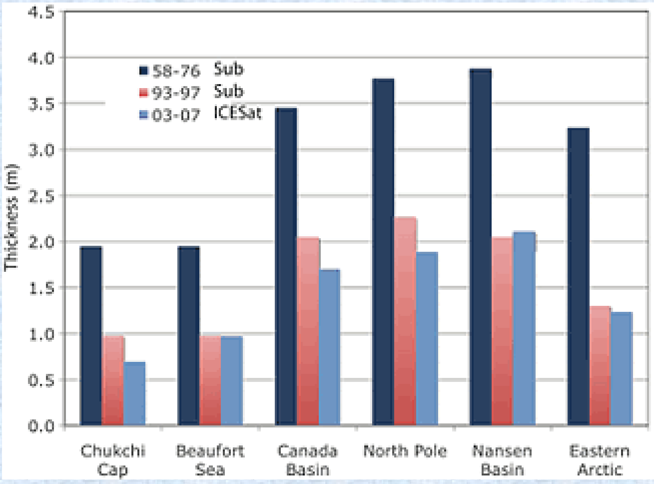
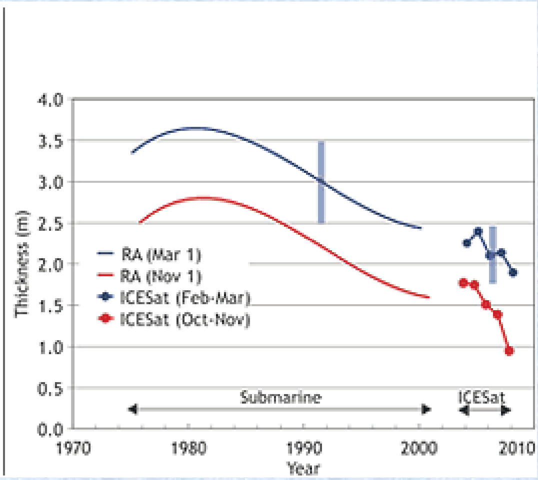
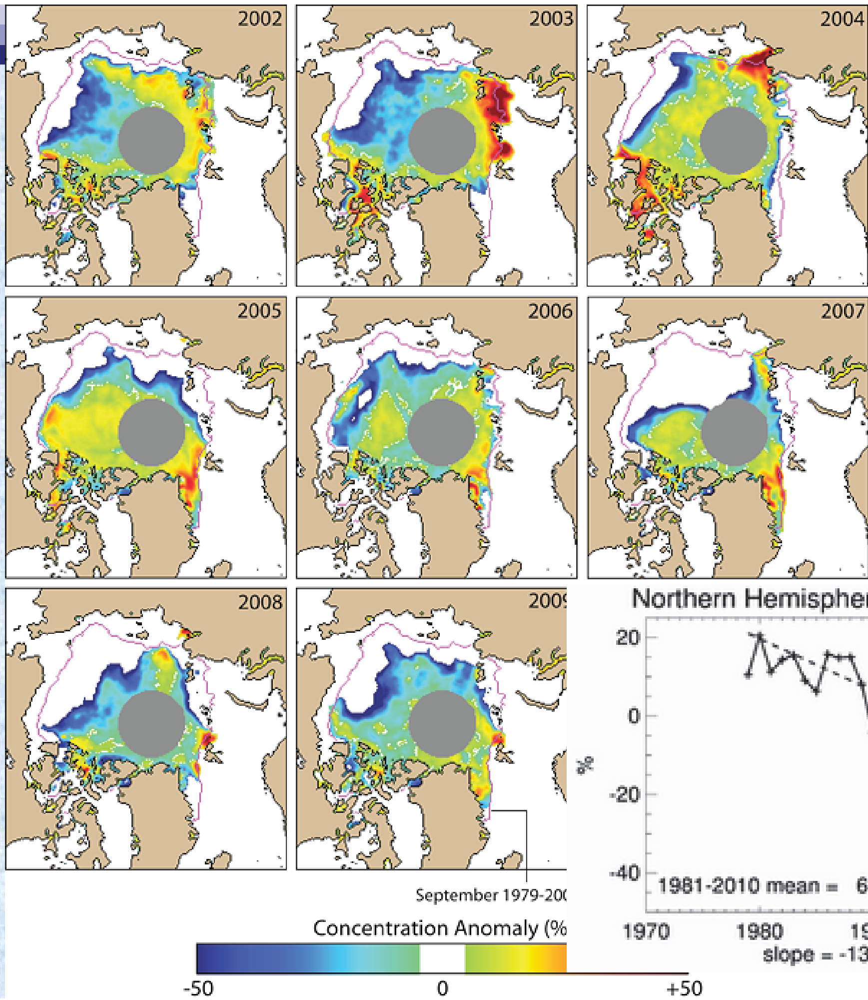
Record low sea ice concentration in the central Arctic during the summer of 2010

Jinping Zhao
Ocean University of China

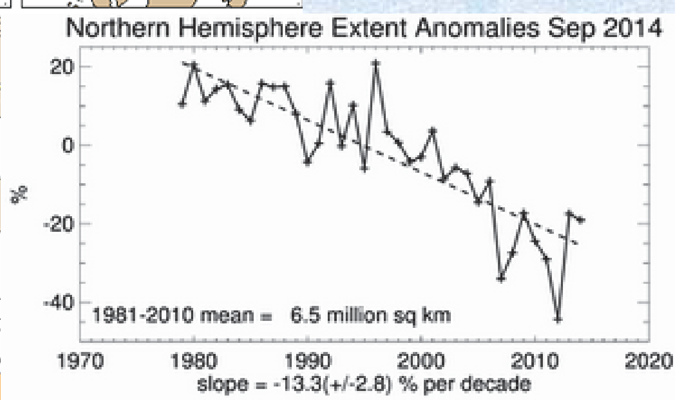
Expedition to the north pole in 1995

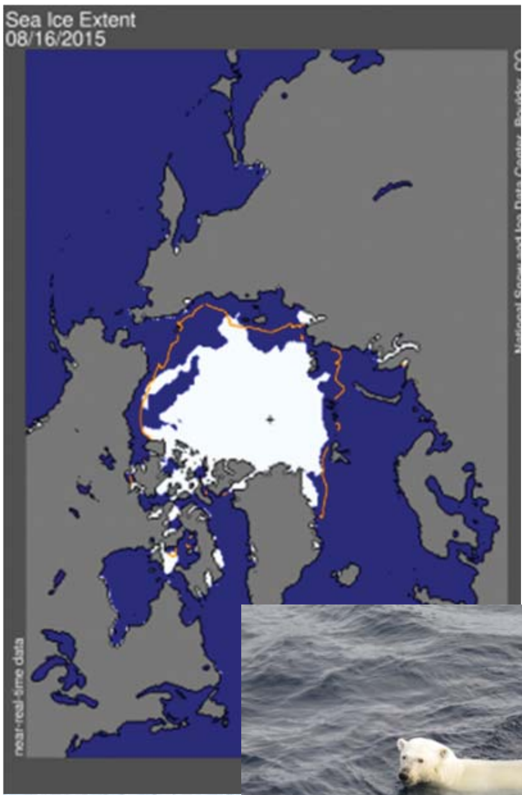


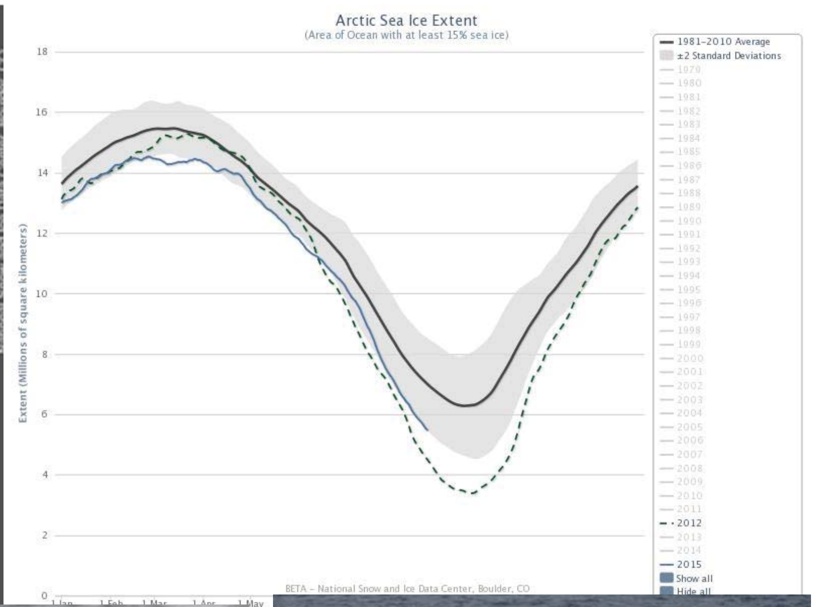




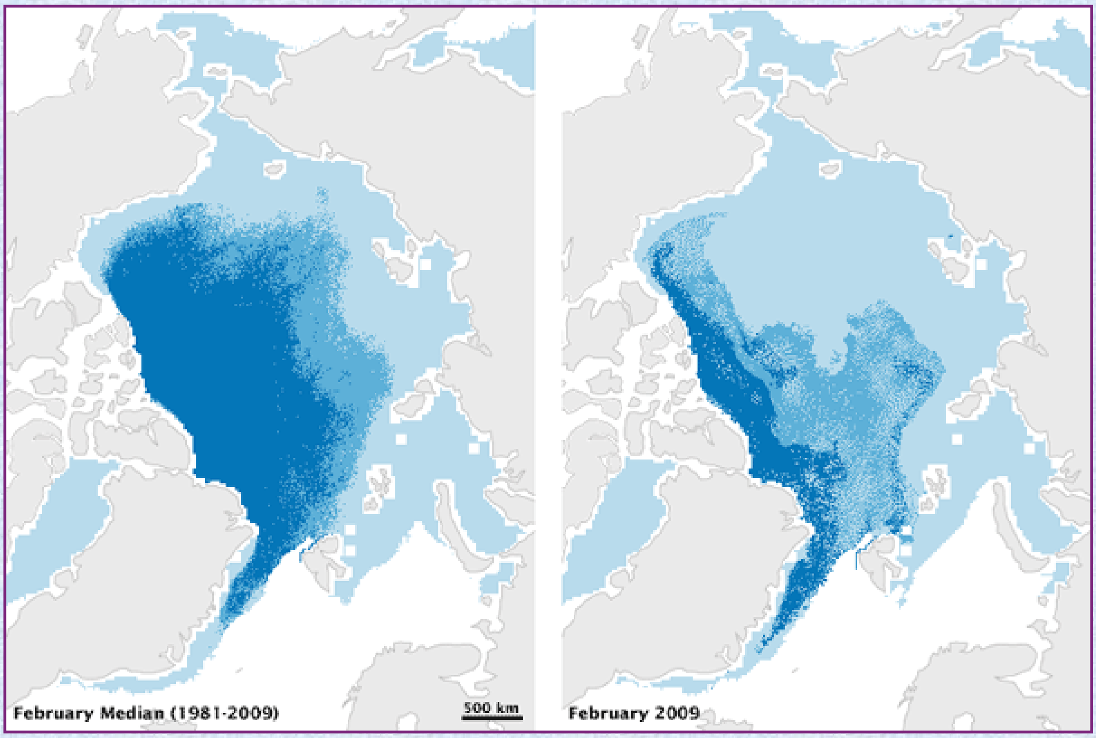
Sea ice retreat in the Arctic

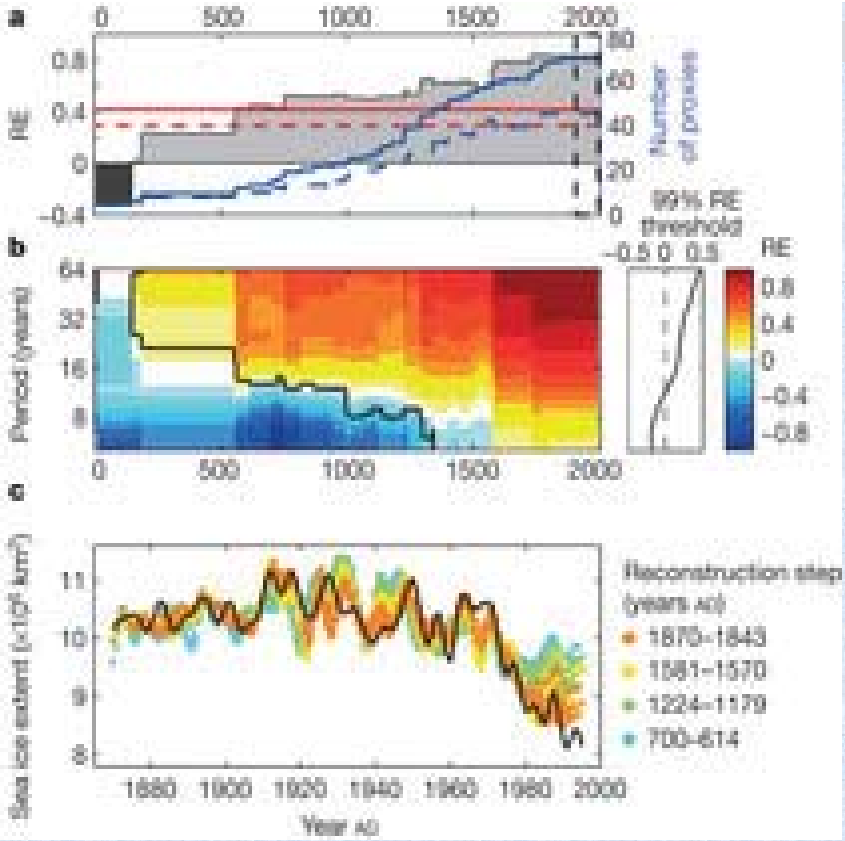






Replacement of multiyear ice by first-year ice



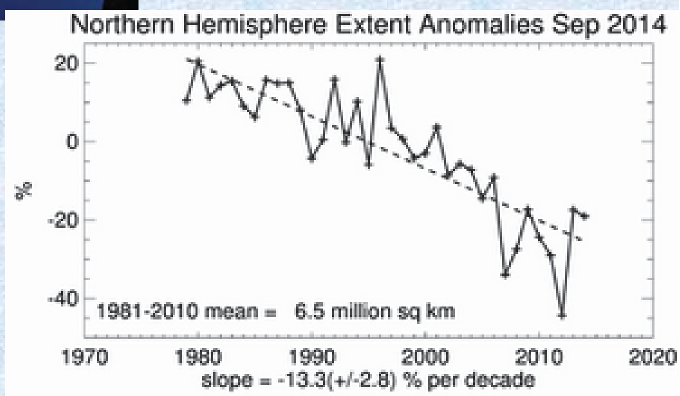


Arctic sea ice extent has been on the decline since the late 1970s and has recently been assessed to be unique over at least a 1450 year period including the relatively warm Medieval Period.

Kinnard et al., 2011, *Nature*

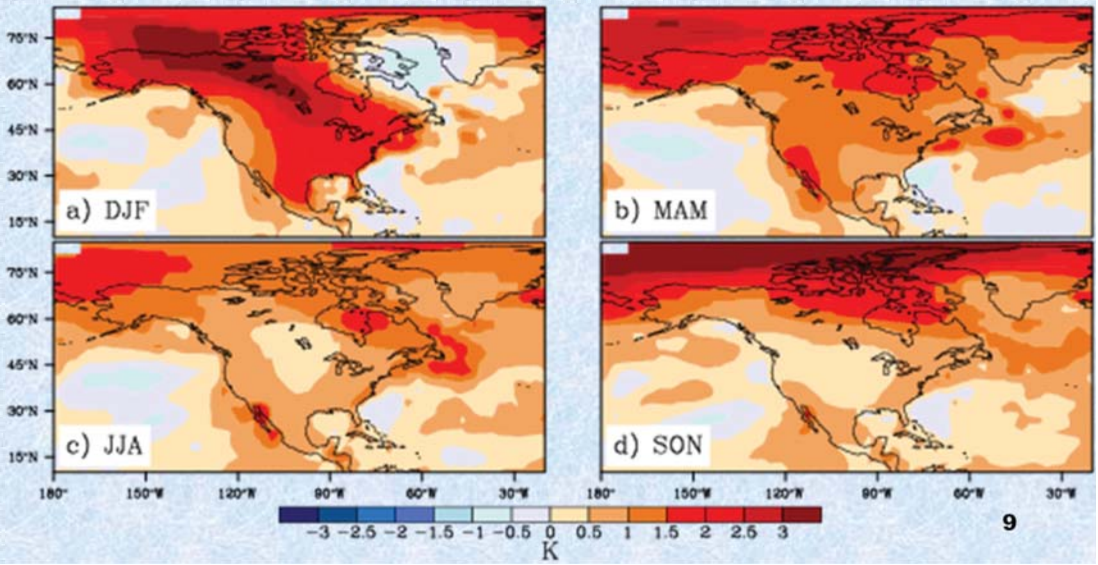
Sea ice retreat in 2040 summer

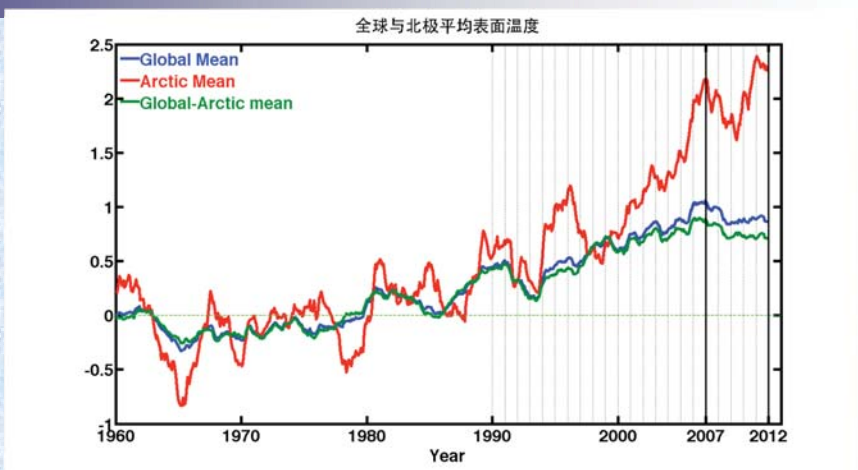
NCAR



Arctic Amplification

The rise in Arctic near-surface air temperatures has been almost twice as large as the global average in recent decades—a feature known as ‘Arctic amplification’. Increased concentrations of atmospheric greenhouse gases have driven Arctic and global average warming; however, the underlying causes of Arctic amplification remain uncertain.





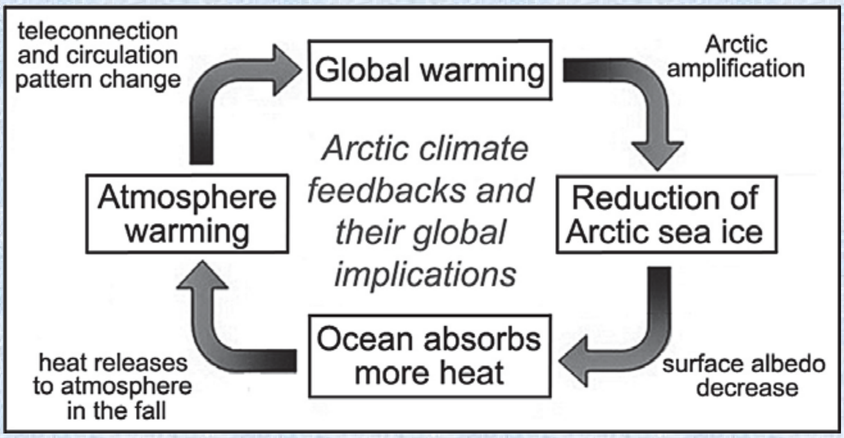
- reductions in snow and sea ice cover
- changes in atmospheric and oceanic circulation, cloud cover and water vapor are still matters of debate
- air temperature, precipitation patterns, and storm track behavior [**Budikova, 2009**]

Overland et al., 2011

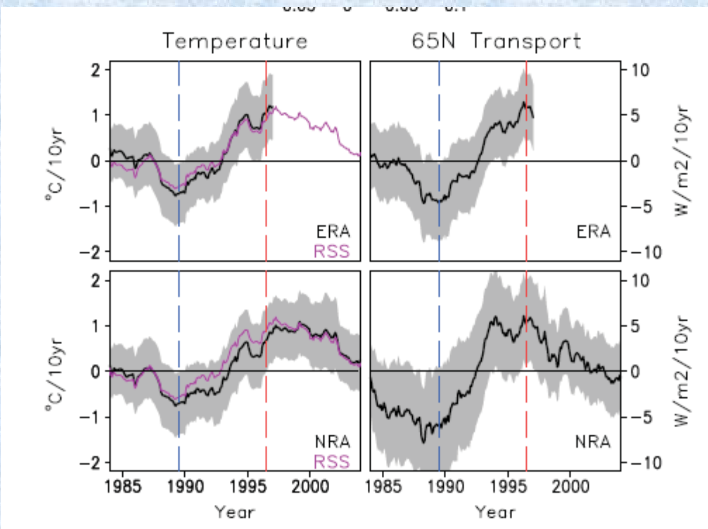
Past sea ice grew rapidly in autumn **negative feedback**

Recent
- loss of multi-year sea ice
- increased sea-ice mobility
- enhanced heat storage in ice-free ocean
- modified wind fields

positive feedback.



Polarward heat transport is variable, but no obvious trend



Transport induced changes are least important near the surface where the powerful snow/ice albedo feedback mechanism produces near-surface Arctic temperature amplification [Serreze et al., 2009; Screen and Simmonds, 2010].

Yang et al., 2010

Heat energy for Arctic warming is not coming from mid-latitude, but obtained by Arctic itself.

Main possible positive feedbacks in the Arctic

1. Snow/ice-albedo feedback → Ice–temperature feedback

2. Water vapor feedback

3. Cloud-radiation feedback

1. Snow/ice-albedo feedback mechanism

when climate warms, snow and ice cover will decrease, leading to a decrease in surface albedo and an increase in the absorption of solar radiation at the earth's surface, which would favor further warming.

Curry et al., 1996

2. Water vapor feedback mechanism

Near-surface water vapor over polar sea ice is always near ice saturation For zonal means specific humidity for all seasons typically displays a surface maximum, decreasing poleward at all levels.(Serreze et al. 1995)

Curry et al., 1996; Andreas et al., 2002

3. Cloud-radiation feedback mechanism

Trends in satellite-derived cloud and surface properties for 1982 to 1999 show that the Arctic has warmed and become cloudier in spring and summer but has cooled and become less cloudy in winter [Wang and Key, 2003, 2005]. Changes in cloud cover have not contributed strongly to recent warming.

4. ice–temperature feedbacks

- Diminishing sea ice has had a leading role in recent Arctic temperature amplification. The strong positive ice–temperature feedbacks have emerged in the Arctic, increasing the chances of further rapid warming and sea ice loss.

Ice – air temperature?
No, upper ocean

What happens in the ocean during ice retreat

Oceanic forcing

Key function of ocean is to be heat transducer and heat releaser

Haynes et al. (2010)

Six main factors to influence Arctic sea ice variation

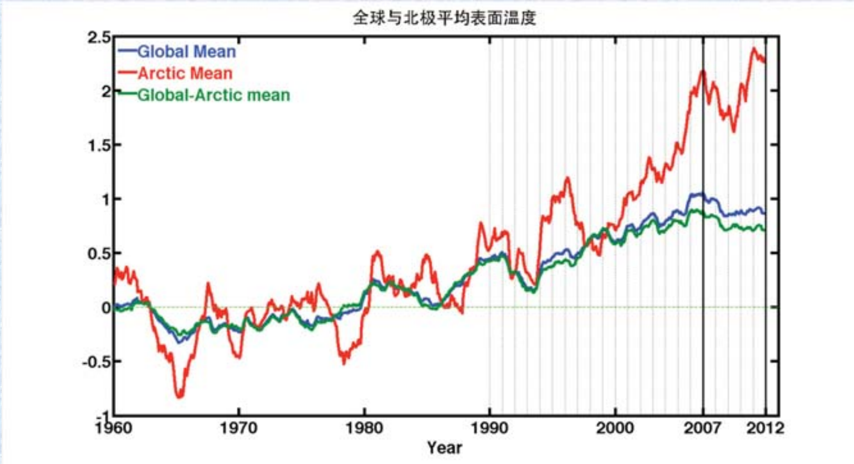
(1) Arctic warming
(2) snow cover
(3) melt pond
(4) warming in upper ocean
(5) ice drifting
(6) storm

(1) Arctic warming

Average air temperature during ice camp

1999	-11ºC
2003	-9ºC
2008	~2ºC
2010	~2ºC
2012	~2ºC
2014	~2ºC

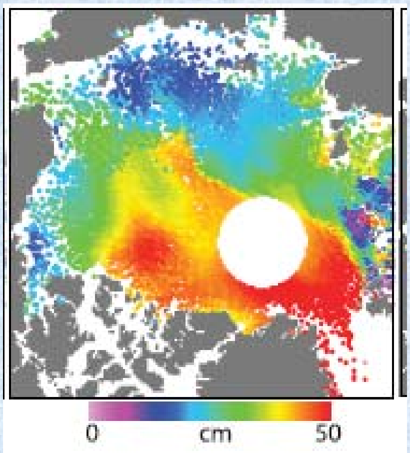
Coreless summer



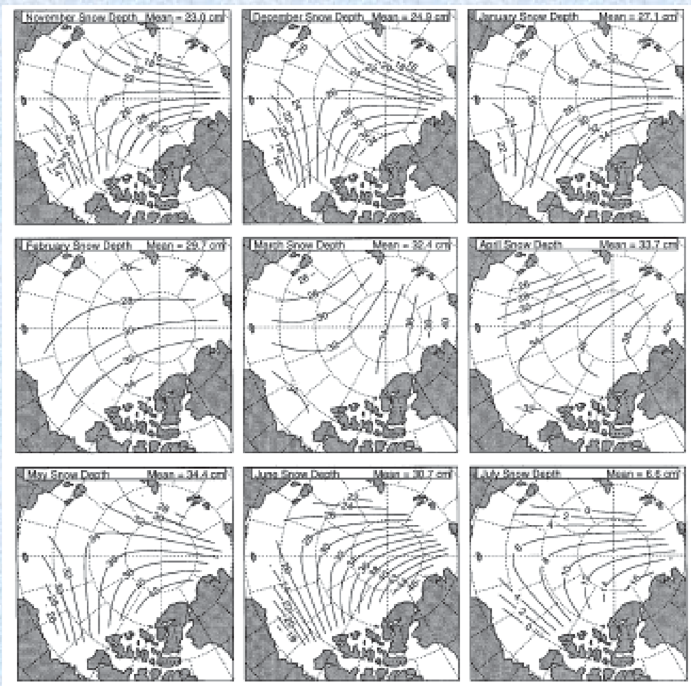
Winter ice thickness is determined by air temperature

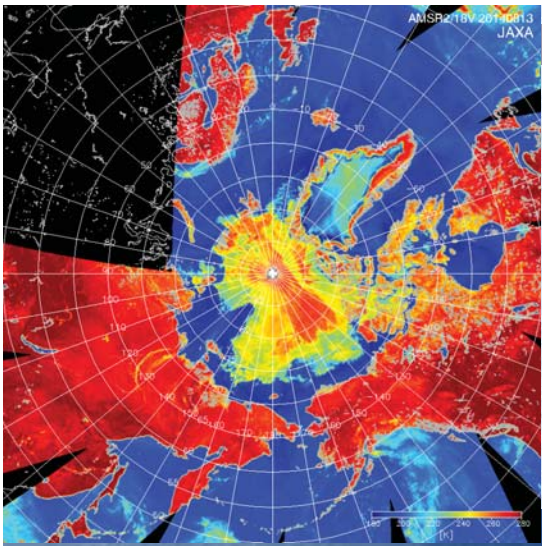
(2) snow

Stephen et al., 1999



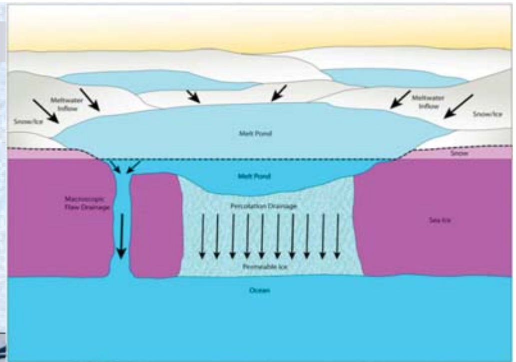
Kwok and Cunningham, 2008



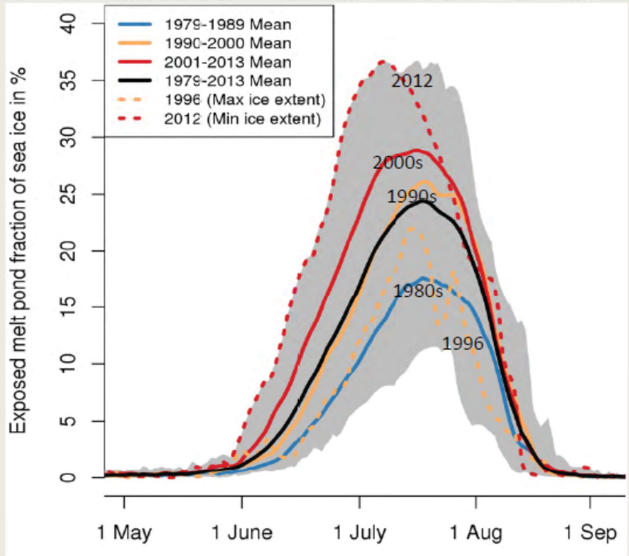


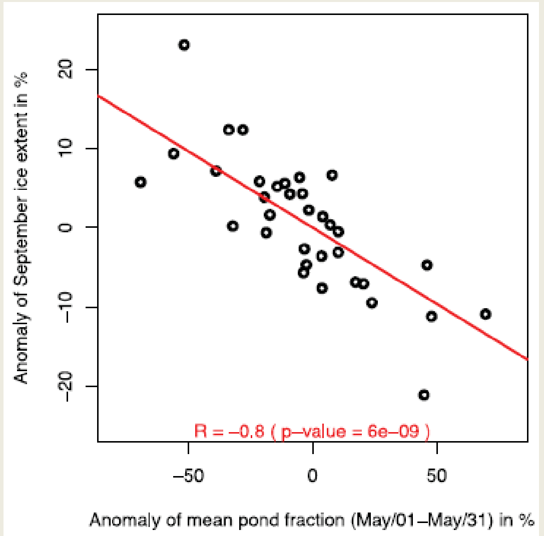
Snow in 2014 is similar with that of 2003

(3) Melt ponds on sea ice



September Arctic sea ice minimum predicted by spring melt pond fraction

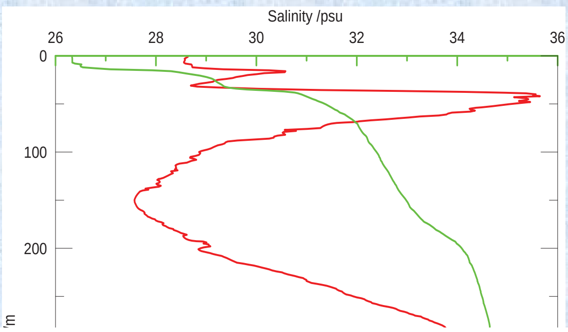




On 16 June, we predicted the 2014 sea ice minimum to be 5.4 M km2 +/- 0.5 M km2. The actual value was 5.28 M km2. So... pretty good!

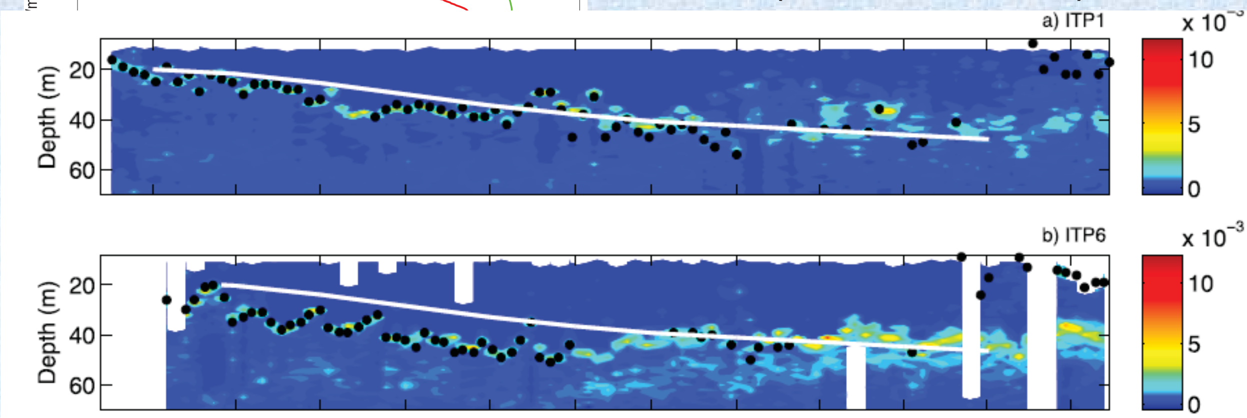
Schroder et al., 2014

(4) Near surface temperature maximum in Canada Basin



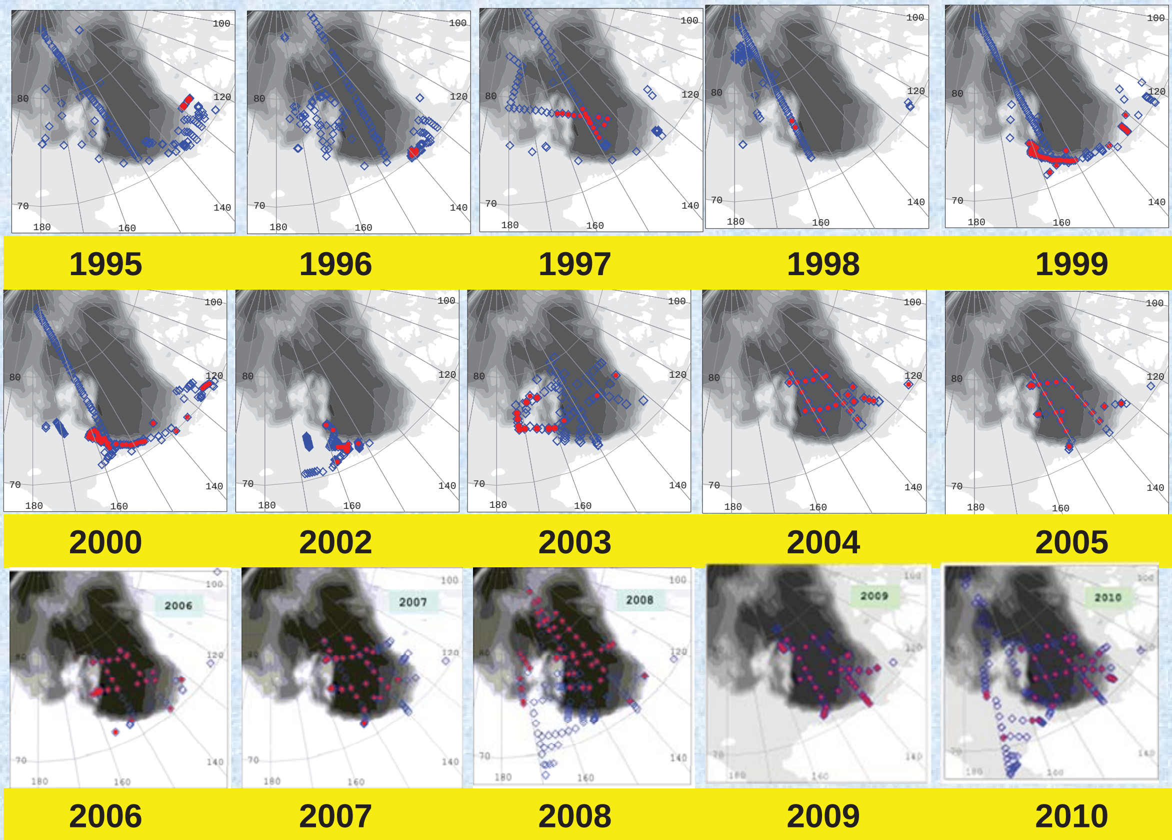
The NSTM is caused by both the solar heating and surface cooling (Zhao et al., 2003; Wang and Zhao, 2004)

Ice Tethered Profiler data could identify the temporal variation of NSTM (Jackson et al., 2010)

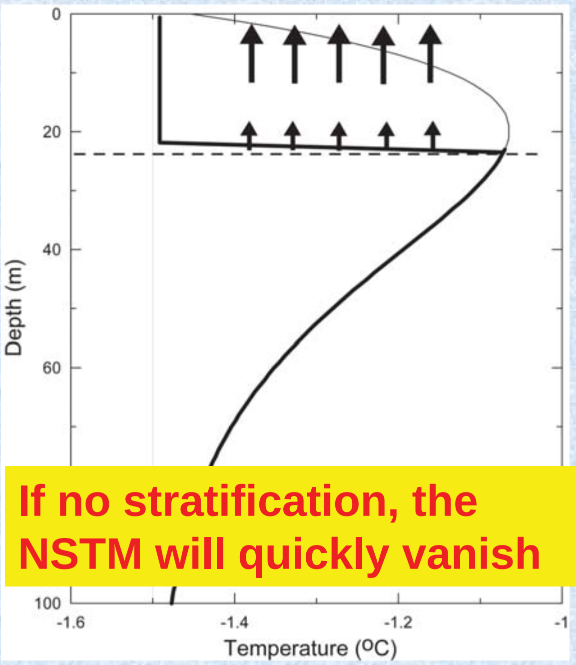


Zhao and Cao, 2011

Spatial distribution of NSTM



Sketch of the influence of the stratification on the upward heat flux and the sharpening NSTM

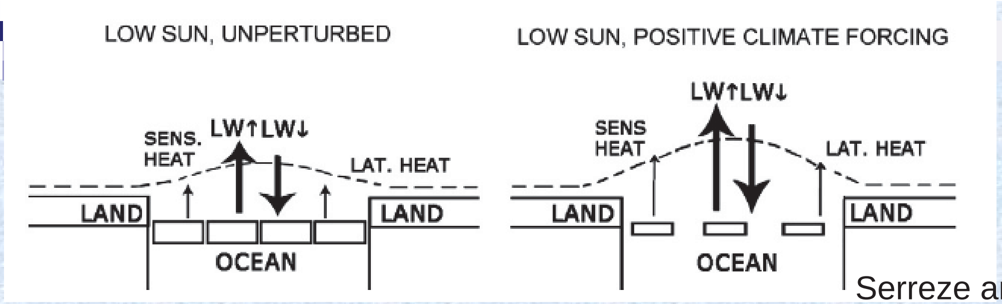


20.4 W/m^2, temperature anomaly is 1ºC

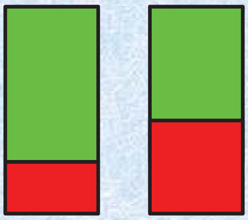
0.8 W/m^2

Above the pycnocline the solar energy is mostly transported to sea ice by turbulent diffusion

Under the pycnocline the solar energy is mainly used to increase the temperature maximum;

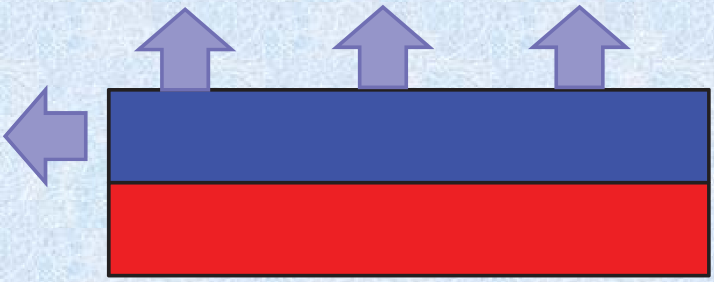


Serreze and Barry, 2011

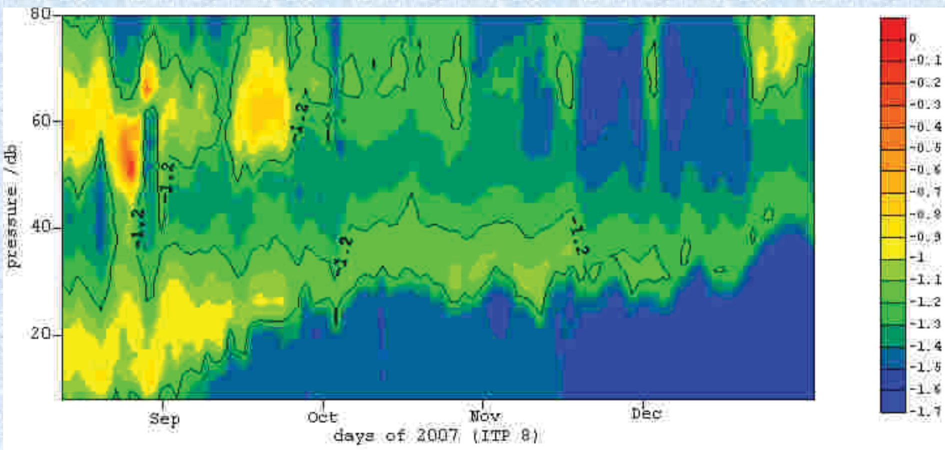


Heat for Arctic Amplification is mostly is newly increased with albedo positive feedback.

The heat is absorbed by ocean. Ocean is a heat exchanger and a heat releaser.



The heat stored in the NSTM is very few, but its main function is to keep the ocean open longer until sunset



As long as the water is opening, the solar energy will persistently penetrate into the water and heating the water and atmosphere.

When ice-free summer comes, the water will open longer and the climatologic effect will be normalized.

Changing Arctic Ocean influences during Summer and Autumn

Summer

- Coreless summer
- Low concentration of sea ice
- Enhanced surface stress and curl
- Increasing freshwater
- Shallower Ekman layer
- Stratification and barrier layer
- Near surface temperature maximum
- Enhanced Beaufort Gyre

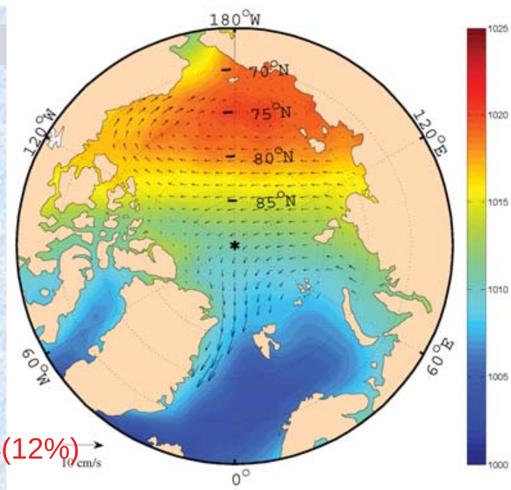
Autumn

- Low albedo increasie heat from ocean
- Increasing low cloud
- Increased humidity
- Changing ice drifting patterns
- Longer opening in Autumn
- Slower convection
- Heat release from NSTM

(5) Sea ice drifting patterns

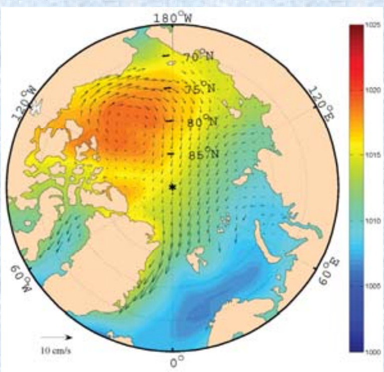
There are four primary sea-ice drifting types in the Arctic Ocean:

(1) Beaufort Gyre+Transpolar Drift,
(2) Anticyclonic Drift,
(3) Cyclonic Drift and
(4) Double-gyre Drift.

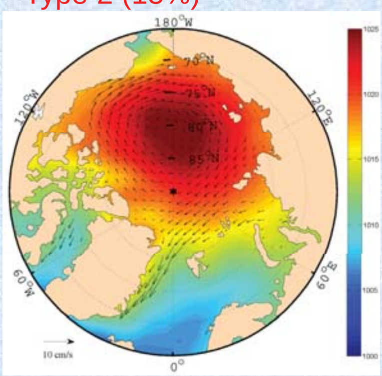


Type-4(12%)

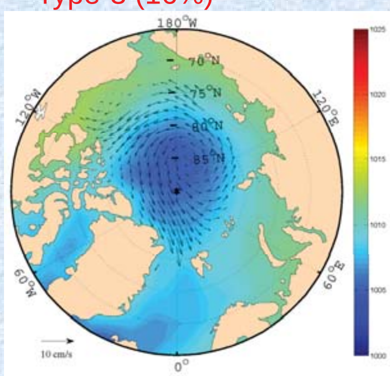
Type-1 (38%)

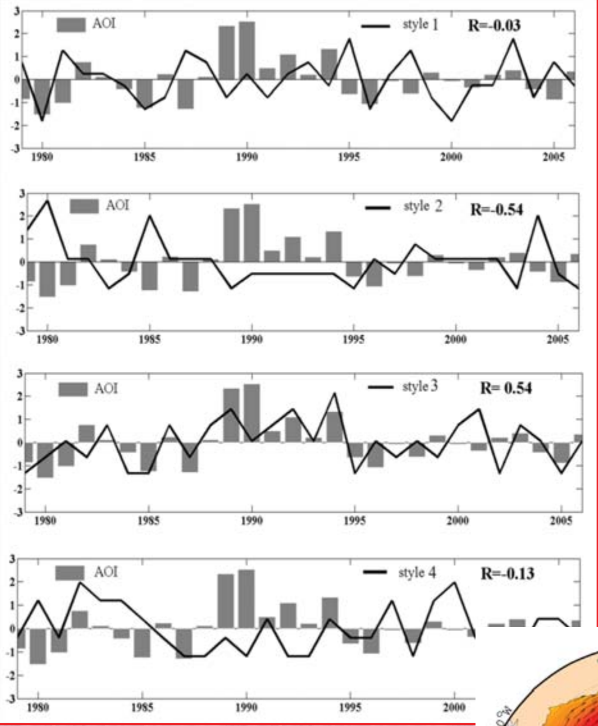


Type-2 (15%)



Type-3 (16%)





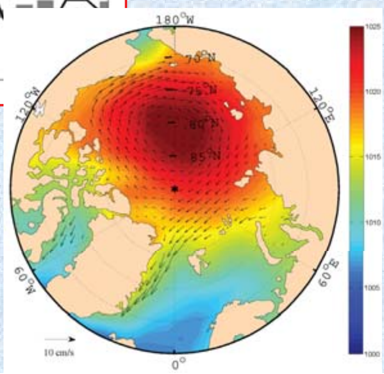
Wang and Zhao (2012)

Correlation of ice drifting patterns with AO index

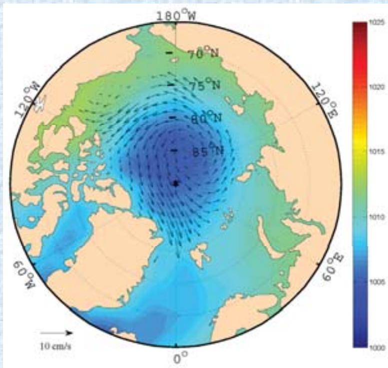
Type 2 and Type 3 correlate well with the AO index, with a correlation coefficient of -0.54 and 0.54, respectively.

While the variations of Type 1 and Type 4 have much lower correlations with the AO index.

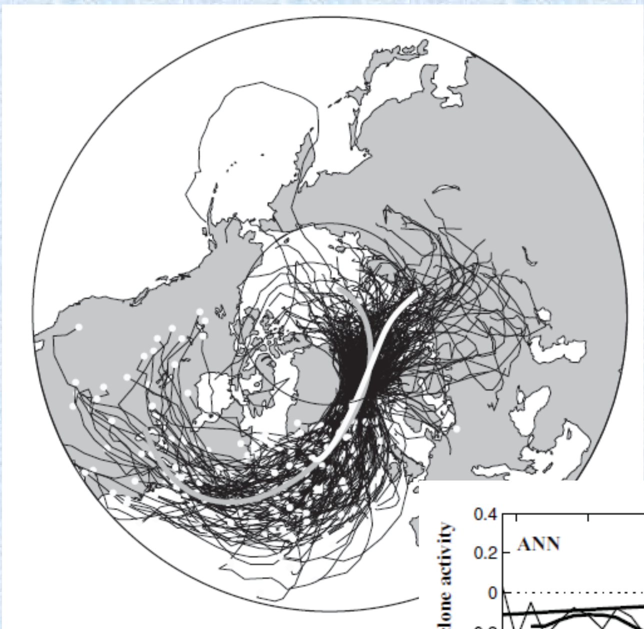
Type-2 (15%)



Type-3 (16%)



(6) Storm

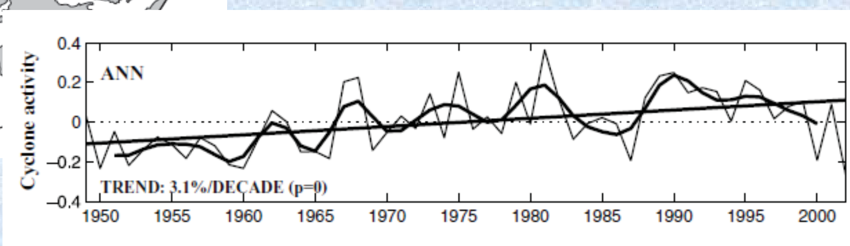


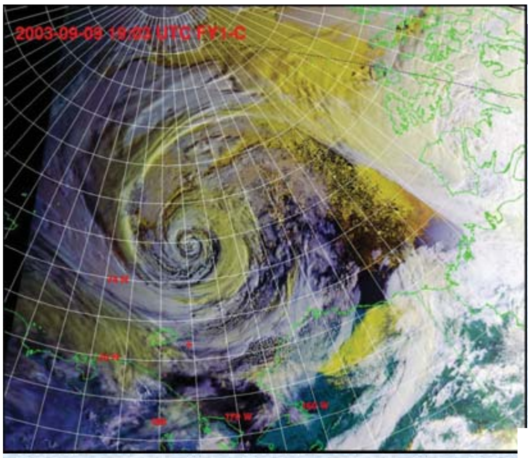
Sorteberg and Walsh (2008)

Cyclones entering the Arctic and their role in transporting moisture into the Arctic

205.8 mm yr^{-1}

72% of the annual Arctic precipitation
35.1% summer

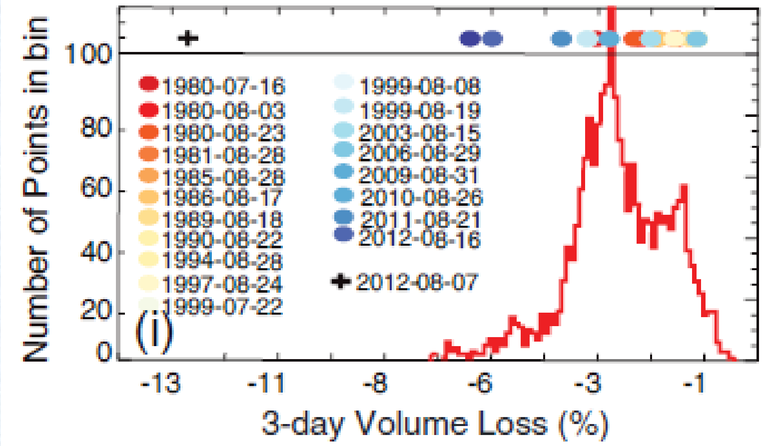




Strong air-sea interaction Storms in the Arctic

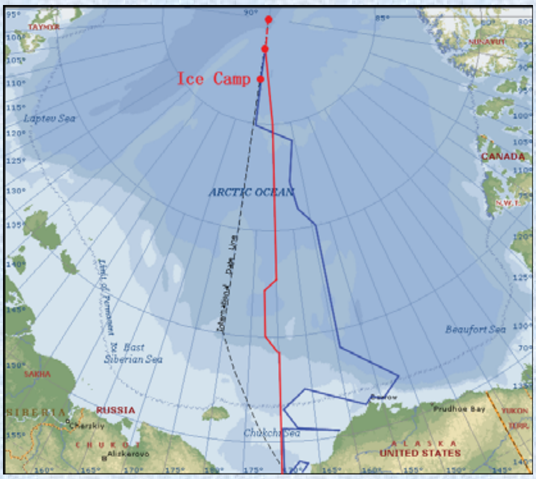
This model study examines the impact of an intense early August cyclone on the 2012 record low Arctic sea ice extent.

We find that the 3 day storm-related volume loss is 1.7 times greater than any prior 3 day loss during July and August of 1979–2011.



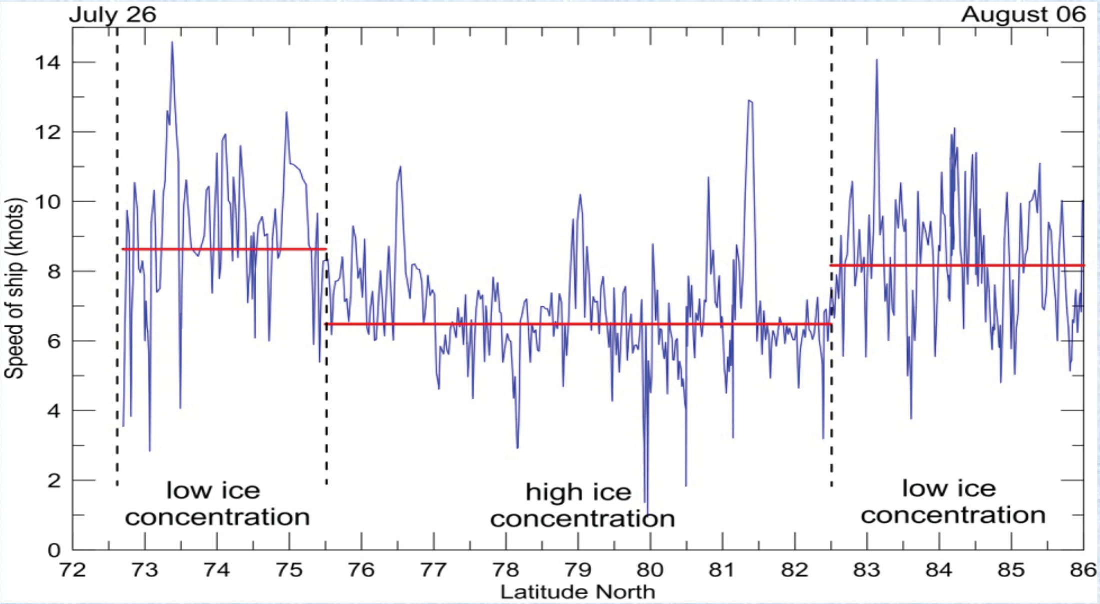
Zhang et al., 2013

Record low sea ice concentration in the central Arctic during the summer of 2010



Xuelong, the Chinese ice breaker reached 75ºN difficultly in 1999. However, it traveled to 88º26’N easily in 2010. If there is enough fuel, it could travel to the Eurasia Basin. It reflects the much weaker strengthen of sea ice.

Navigation speed of Snow Dragen



Lots large water areas in pack ice

Leads appeared in pack ice. It was unusual in such high latitude before

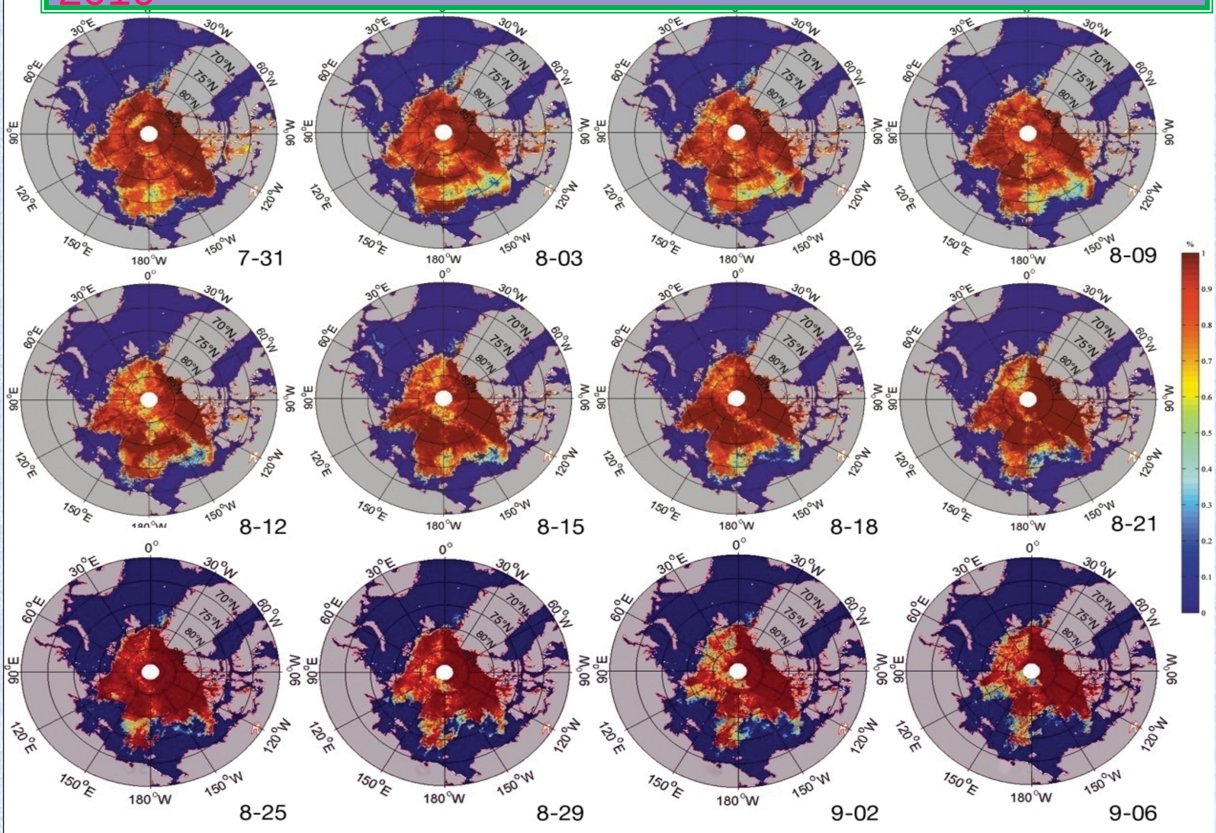
Photo taken over the North Pole

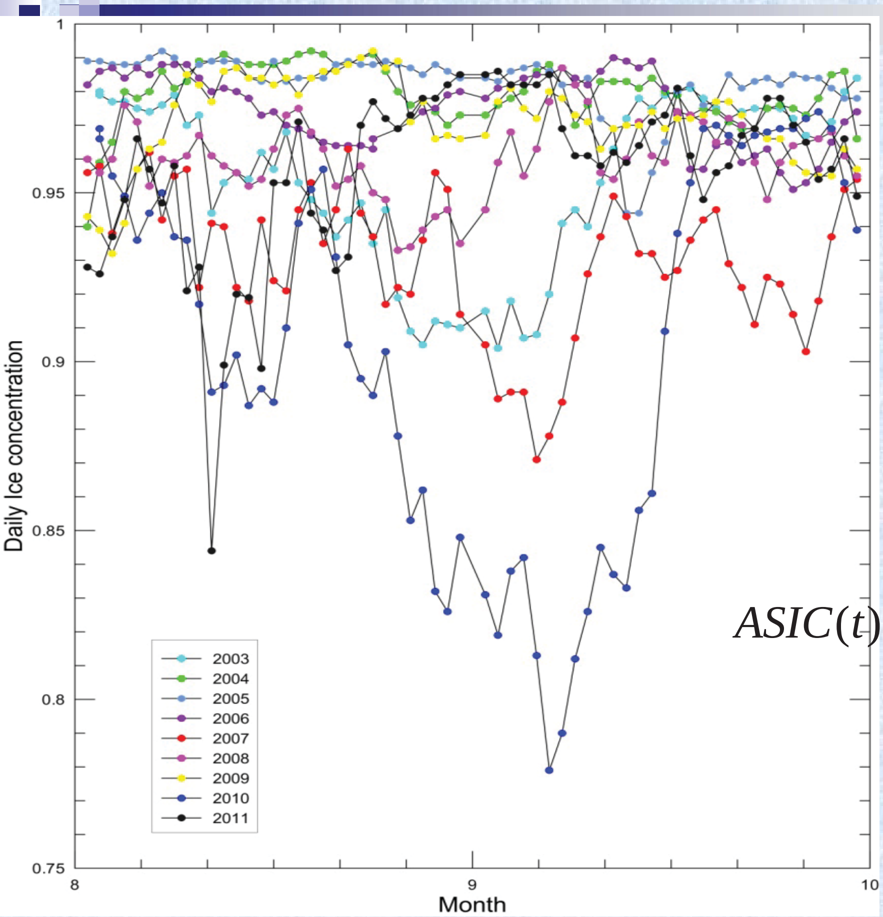
Large area of water near North Pole

The water area will induce

Less albedo
More heat absorption
More feed back

Record low ice concentration in central Arctic in August 2010

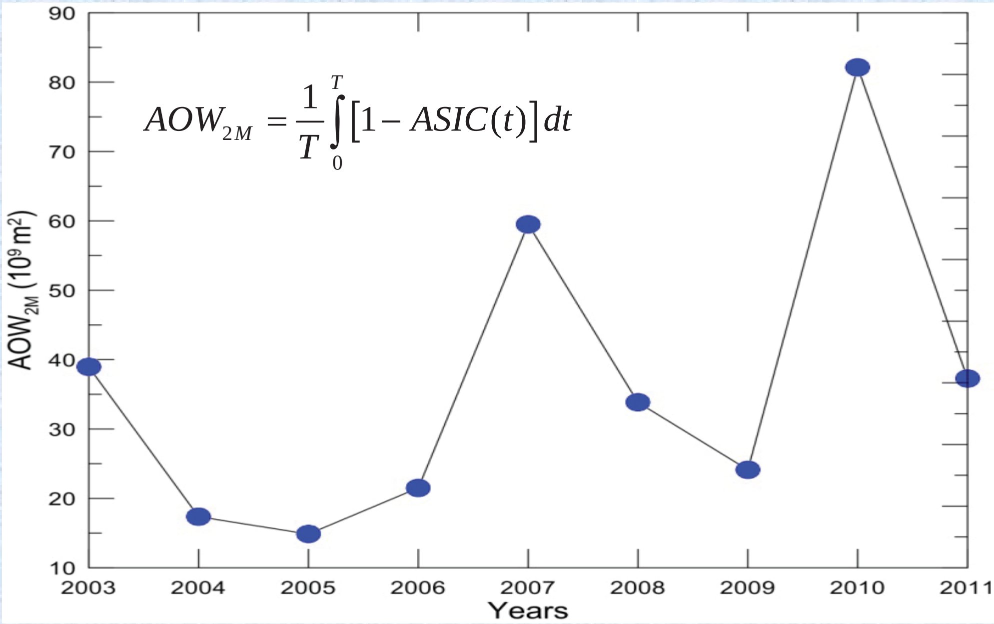




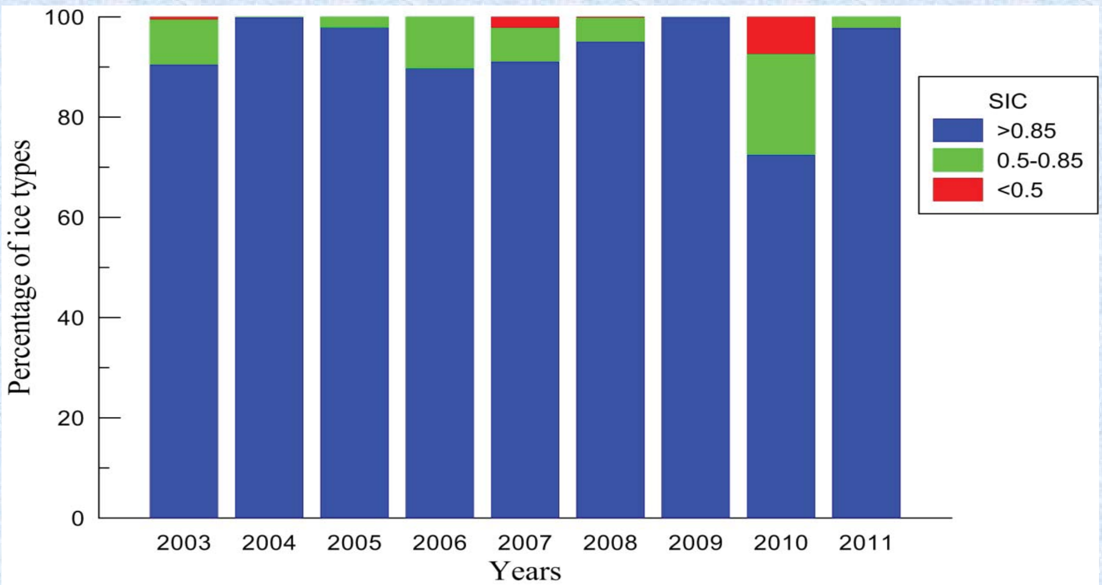
Daily average sea ice concentrations north of 85°N from August 1 to September 30 from 2003 to 2011.

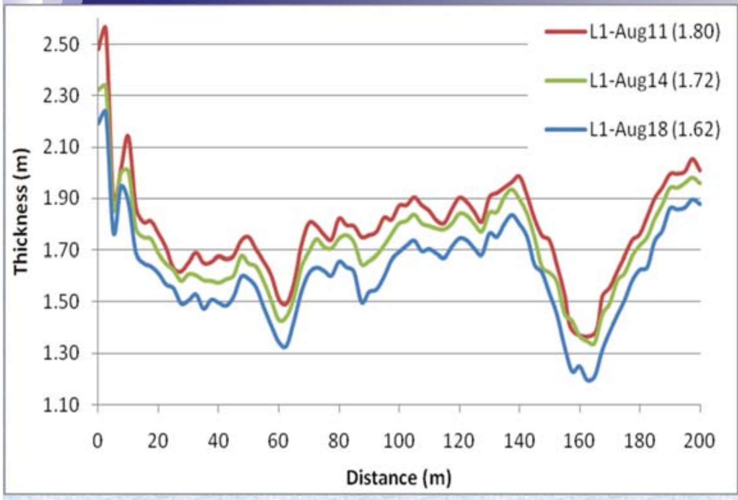
$$ASIC(t) = \frac{1}{S}\iint_S C(x,y,t)\,dxdy$$

Two-month averaged area of open water in the central Arctic surrounded by 85ºN from 2003 to 2011



The percentage of three types of ice concentration at the date each year with the minimum averaged SIC north of 85ºN





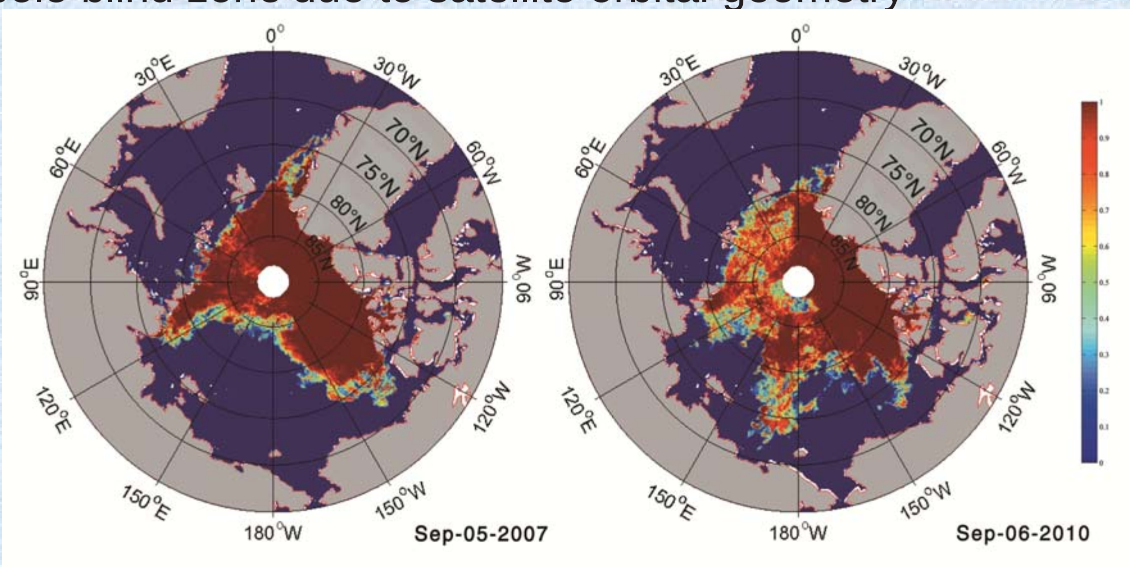
Ice melting during
Aug. 11-18, 2010

During the ice camp, the ice melted 1-2 cm/day.

So the open water in pack ice was not caused by ice melting, but by ice movement. We call the phenomenon as “open before melting”

Distribution of ice concentration in Arctic Ocean with the lowest Daily average sea ice

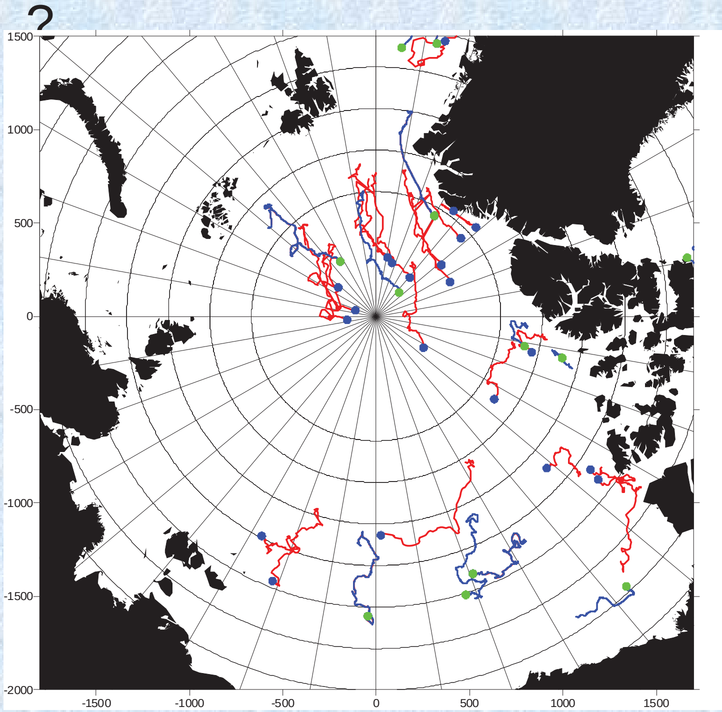
concentrations north of 85°N in 2007 (a) and 2010 (b). The white circle around the pole is defined here as the ‘north pole blind zone’due to satellite orbital geometry



In 2008 and 2011 winter and spring, serious frozen rain in southern China and draught in northern China

The drought in 2011 was the extreme within 100 years

Interrupt of Arctic Transpolar Drift in 2010 summer ?



Discontinuity

It is usual for discontinuity of ice drifting for few days.

But it is unusual for several months.

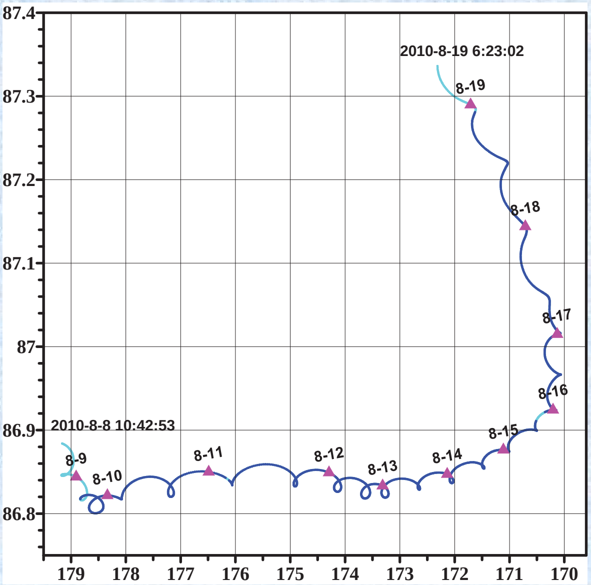
Interrupt ?

Data shows the Arctic Transpolar Drift interrupted.

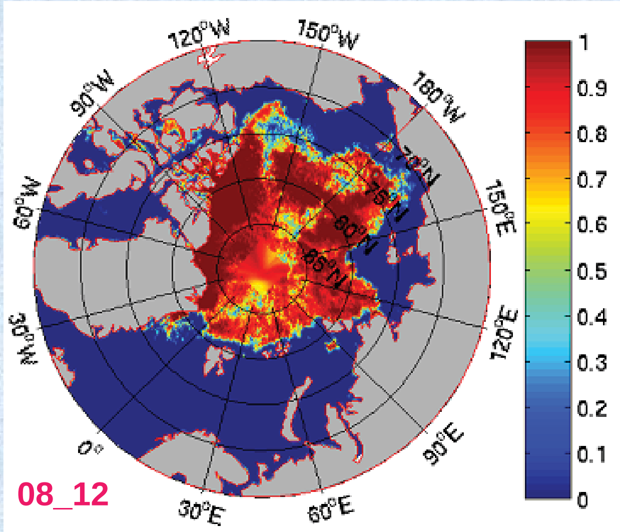
It caused the very low ice concentration in central Arctic

Divergence in Sea ice drifting

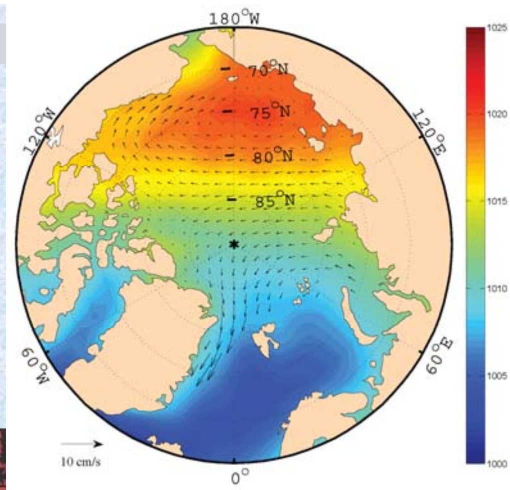
Ice camp drifting during August 8-19

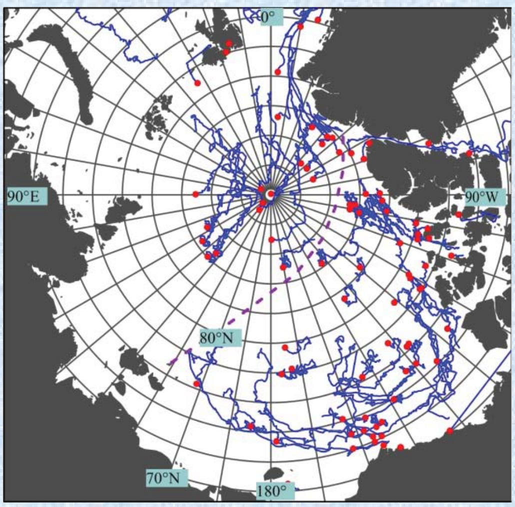


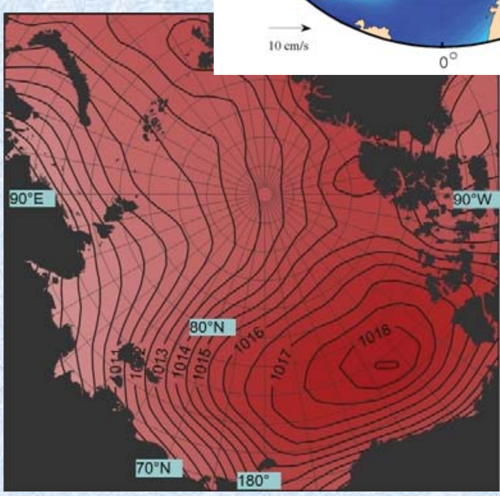
The ice camp drifted eastward for 8 days, then shift to the north.



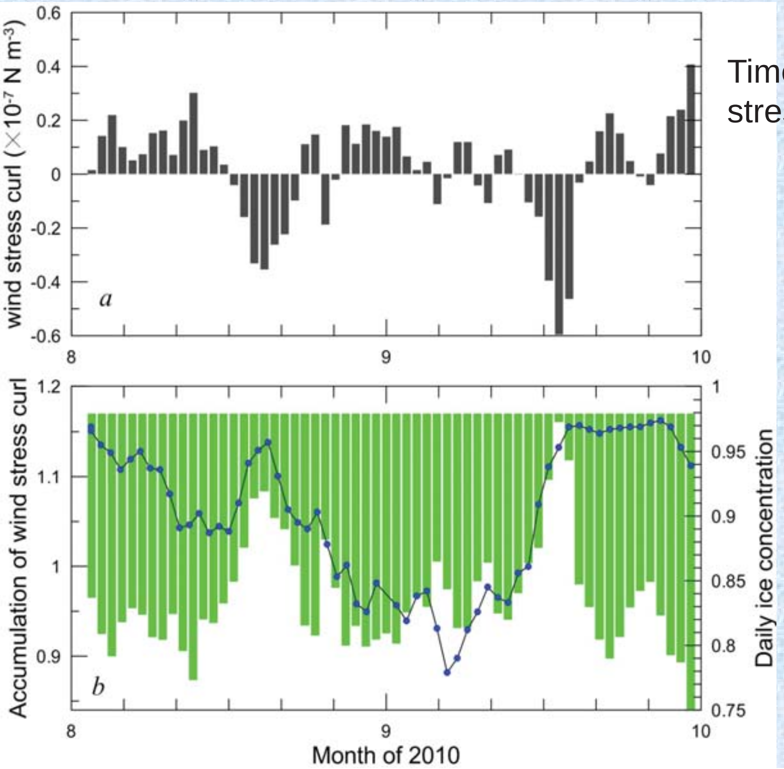
Changing surface circulation







Response of sea ice concentration to wind stress curl

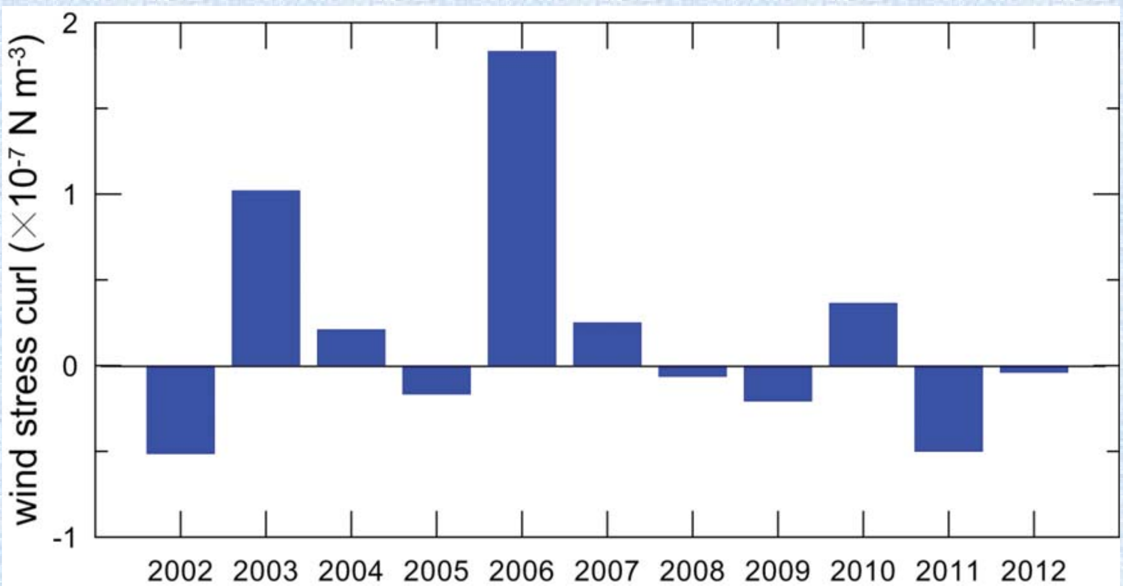


Time series of averaged wind stress curl

$$\frac{dASIC(t)}{dt} \approx -\frac{1}{\rho f h S}\iint_S (\nabla\times(\nabla\cdot\boldsymbol{\sigma}) + curl\boldsymbol{\tau}_a + curl\boldsymbol{\tau}_w)dxdy$$

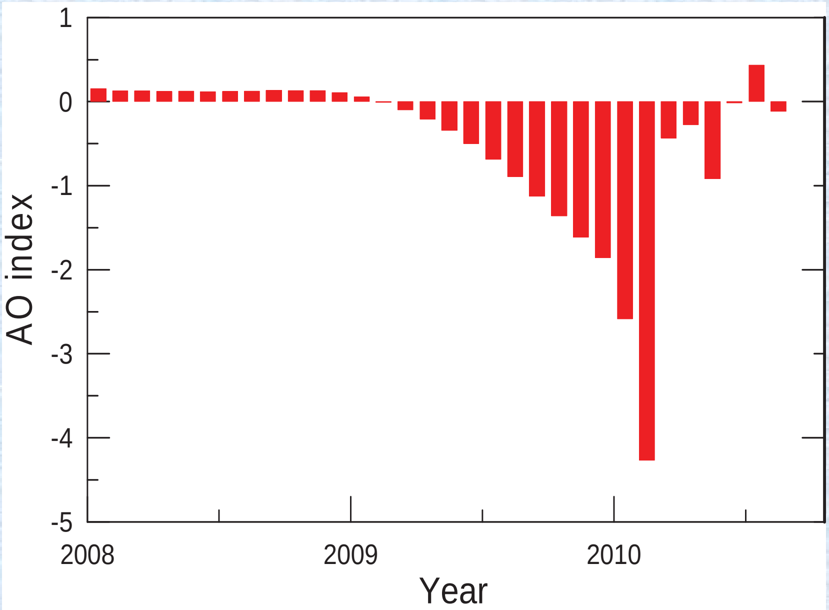
Time series of accumulated wind stress curl (AWSC, green bars) and averaged sea ice concentration (blue dots) north of 85ºN.

Averaged wind stress curl of August each year

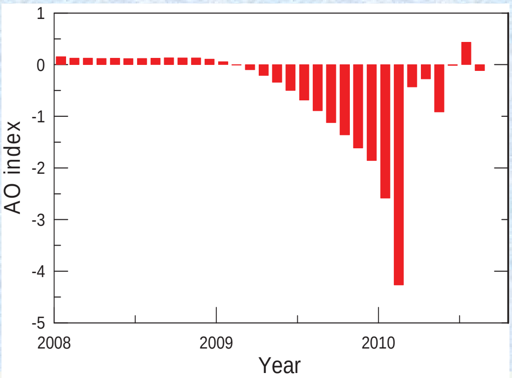


Shift of Arctic Oscillation Index

AO index trended to a negative phase, but it is interrupted on March, 2010

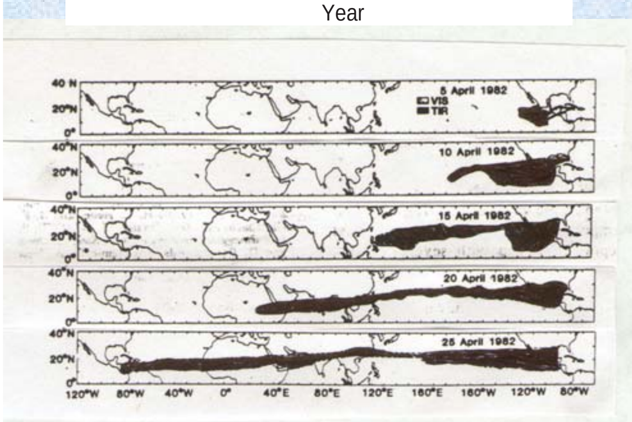


Icelandic volcano terminated the negative AO



Iceland volcano erupted since March 21, 2010

The second eruption was at April 16.



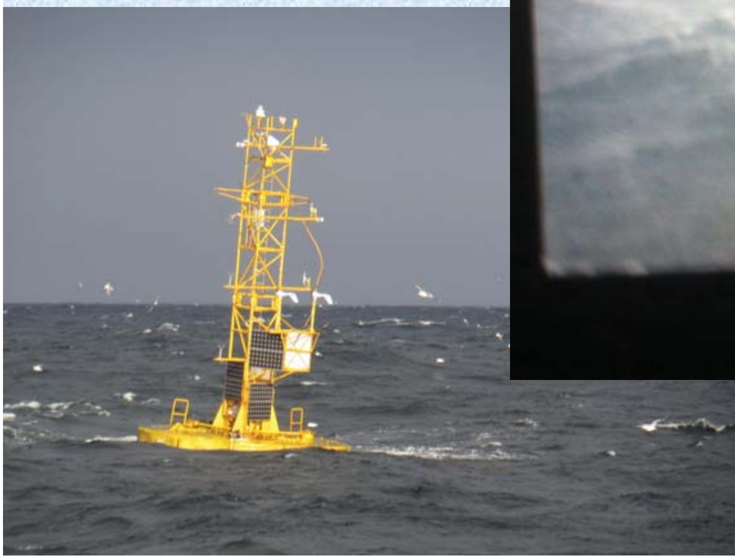
Two possibilities

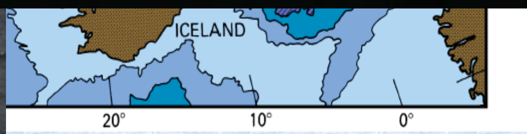
(1) It is a result of volcanic eruption

(2) A new summer circulation pattern appears

2012

Air-sea co

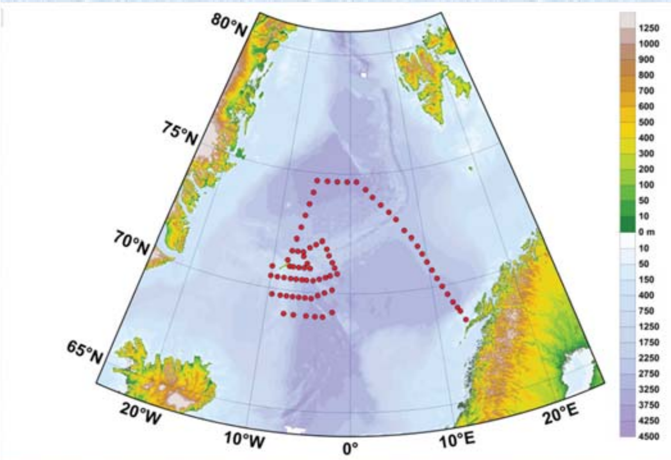


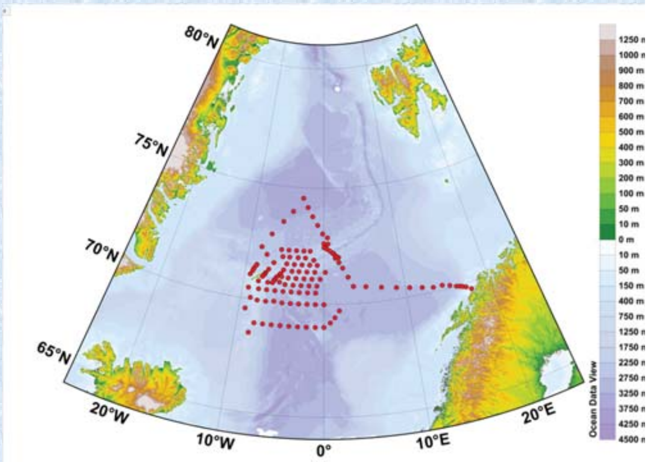


Nordic Seas' cruises in 2014 and 2015 of OUC

2014

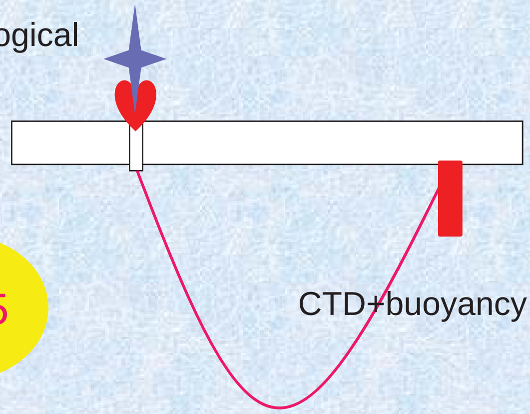
2015

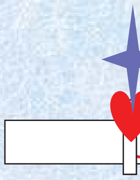




ITP for upper ocean---- a tailed buoy

Meteorological sensors

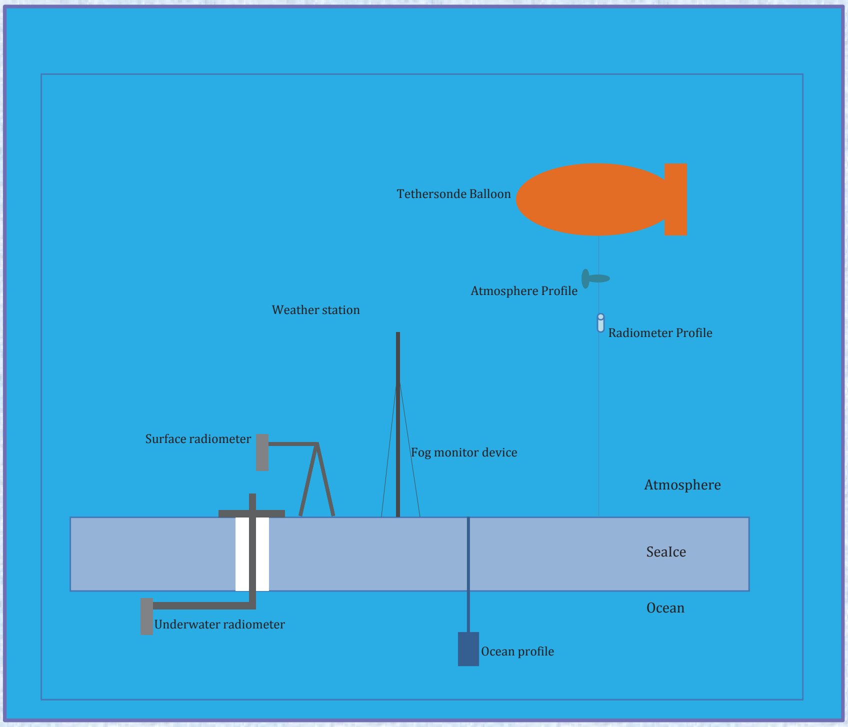




2015

Cable length: 120 m
- 109 m for drifting speed of 0.1 m/sec
- 65 m for drifting speed of 0.5 m/sec
- 1-2 times per day

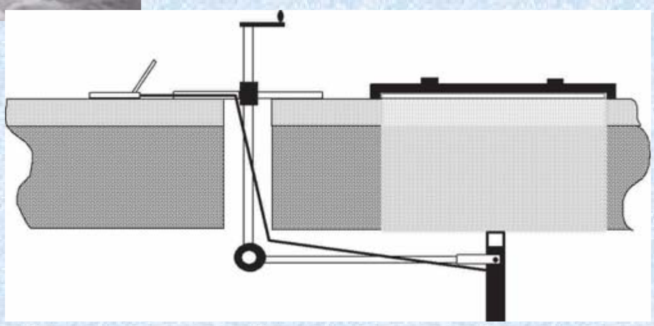
Belmont Forum
Arctic Fog Variability in a Warming Arctic and Its Impact on Maritime Human Activities



2014

Field vertical observation for fog

Sea ice optic experiment in winter Arctic

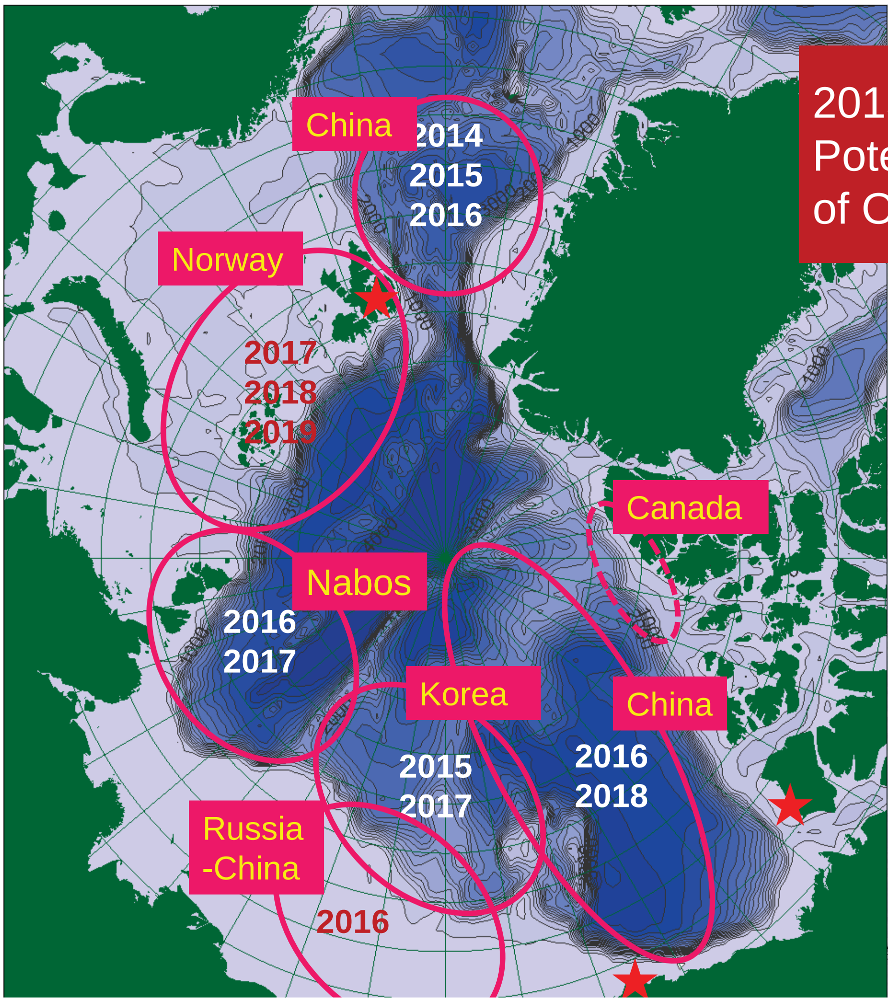


Ocean profiling under multiyear ice supported by airplane

Arctic expeditions of Ocean University of China

1995	**China – North pole**
1999	**Chinare-1**
2003	**Chinare-2**
2006	Canada-JOIS
2007	US-Bering Sea
	Canada-CFL
2008	**Chiare-3**
	US-Bering Sea
	Canada-CFL
2009	US-Bering Sea
2010	**Chinare-4**
	China-OUC

2011	**Korea-Medelev ridgr**
2012	**Chinare-5**
	Korea-Mendeleev Ridge
2013	China-Svalbard
2014	**Chinare-6**
	China-OUC-Barrow fog
	China-OUC-Nordic Sea
	Korea-Mendeleev Ridge
2015	China-OUC-Nordic Seas
	Korea-Mendelee
2016	**Chinare-7**
	China-OUC-Nordic Sea



2015-2019
Potential Arctic cruises of OUC

Main funding of Ocean University of China

	Projects	by
	Exploration and assessment for Arctic and Antarctic environment	CAAA
	Mechanism of Arctic Amplification and its global climate effects caused by Arctic sea ice retreat	MOST
	Coupling variation of Arctic sea ice with upper ocean circulation and its effect on climate	C-NSF
	Arctic Fog Variability in a Warming Arctic and Its Impact on Maritime Human Activities	Belmont

Summary

Thank you

- The Arctic Transpolar Drift was disrupted for a long time in 2010 summer.
- Low concentration sea ice appeared in central Arctic Ocean.
- The low ice concentration may
  - weaken surface albedo
  - enhance heat absorption of sea water
  - speed up ice melting
  - feedback atmosphere
- The drifting pattern is speculated to cause
  - by the eruption of Iceland volcano.
  - by changing surface circulation pattern.