Impact of Sea Ice Retreat on Open Ocean Convection in the Greenland and Iceland Seas

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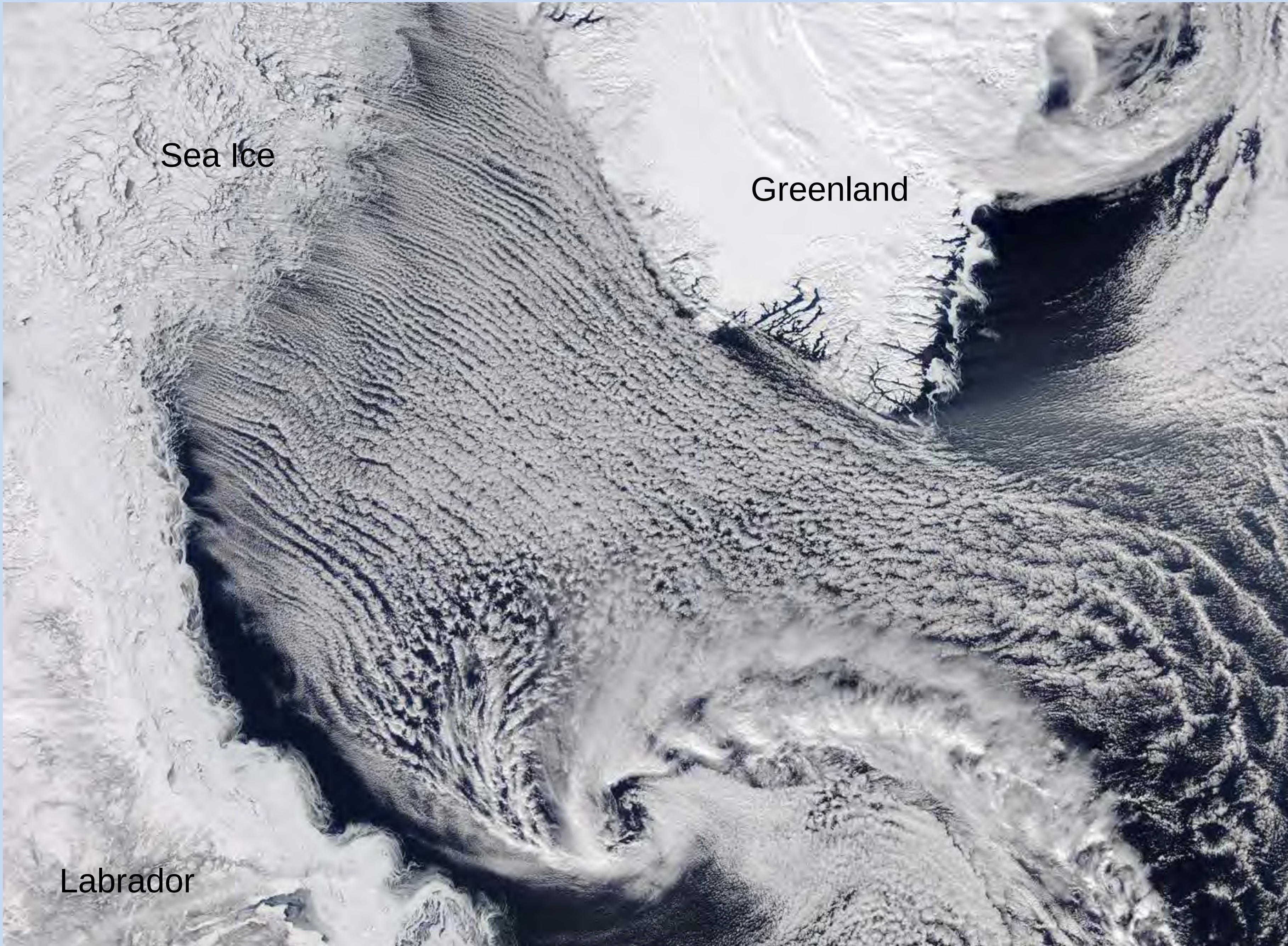
In collaboration with K. Våge, R. Pickart & I. Renfrew



Cold Air Outbreak and Polar Low over the Labrador Sea April 6 2014

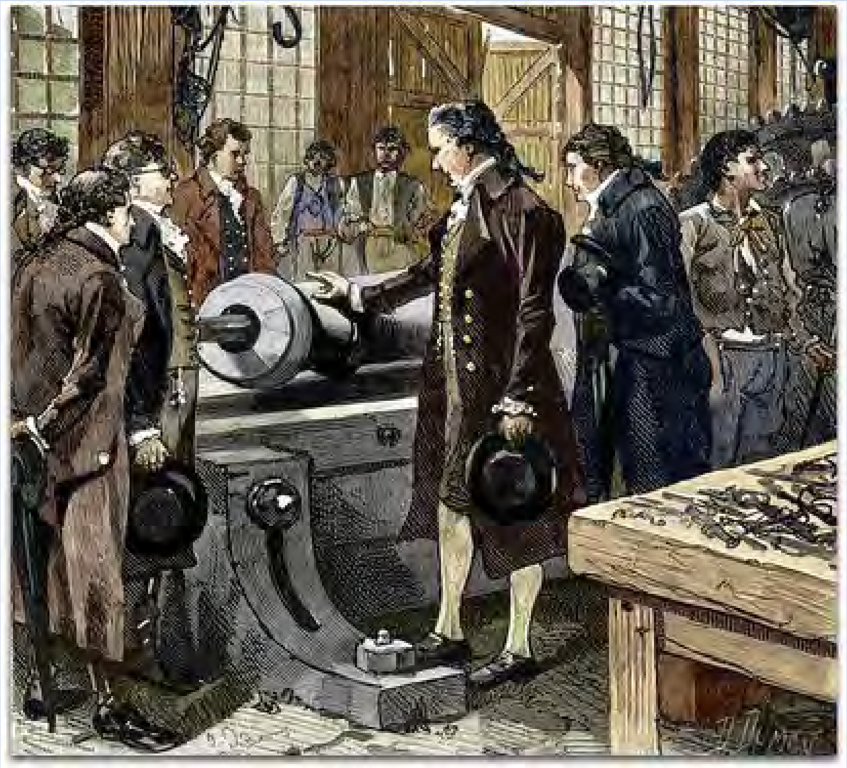
Background

- In the mid-18th century, Stephen Hales invented a device that allowed one to collect water samples from the deep ocean.
- He convinced Henry Ellis, the Captain of a British merchant ship, to take this device to sea and to collect water samples from the deep ocean.
- Ellis collected deep water samples (~1200m depth) in the tropical Atlantic (sea surface temperature ~24^{o}C) that were quite cold (~ 10^{o}C).

Replica of Hales' 'Bucket Sea-Gauge'

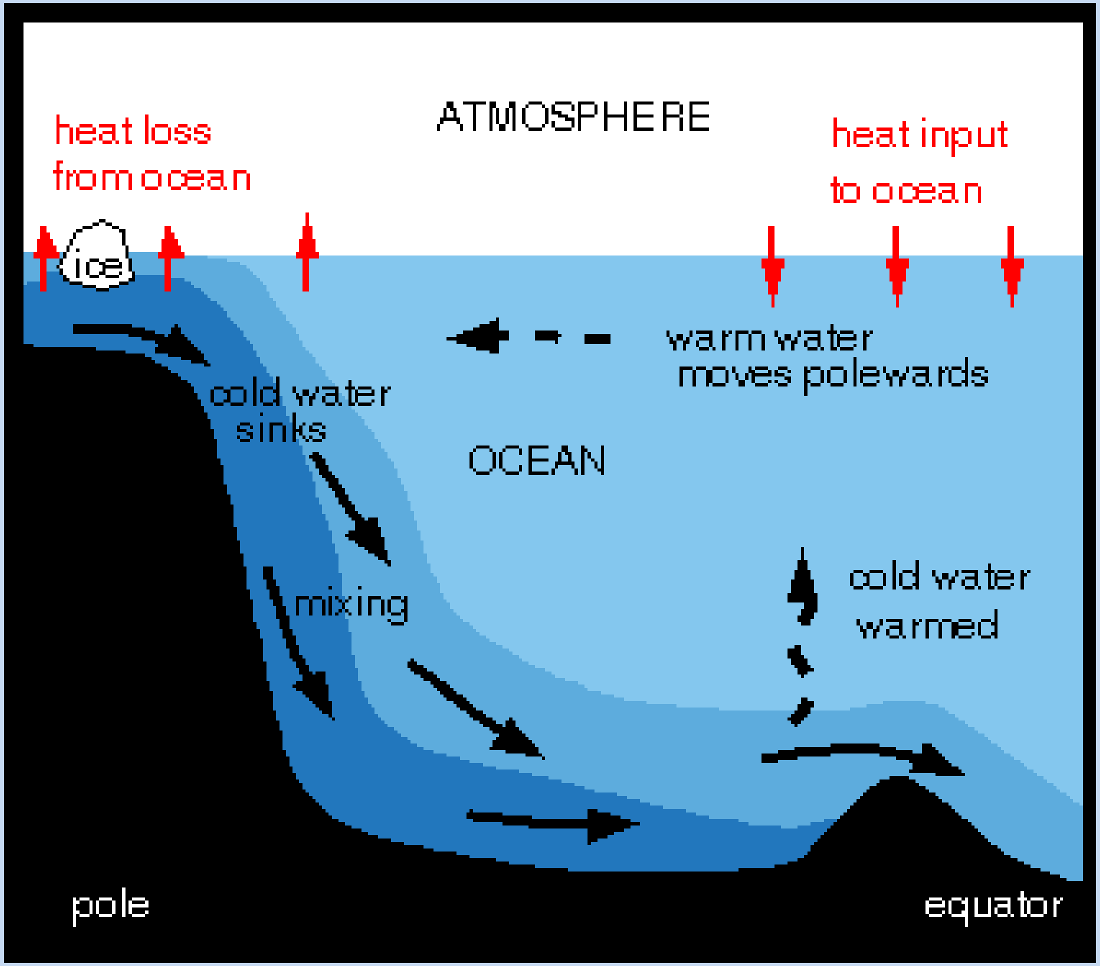
Background

- This observation lingered for ~50 years until 1797 when Count Rumford (Benjamin Thompson) came across it and asked the question:
  - Why was the water at great depth so cold? *(Conduction should have eliminated/reduced the vertical temperature gradient unless there was a source of cold water at great depth)*

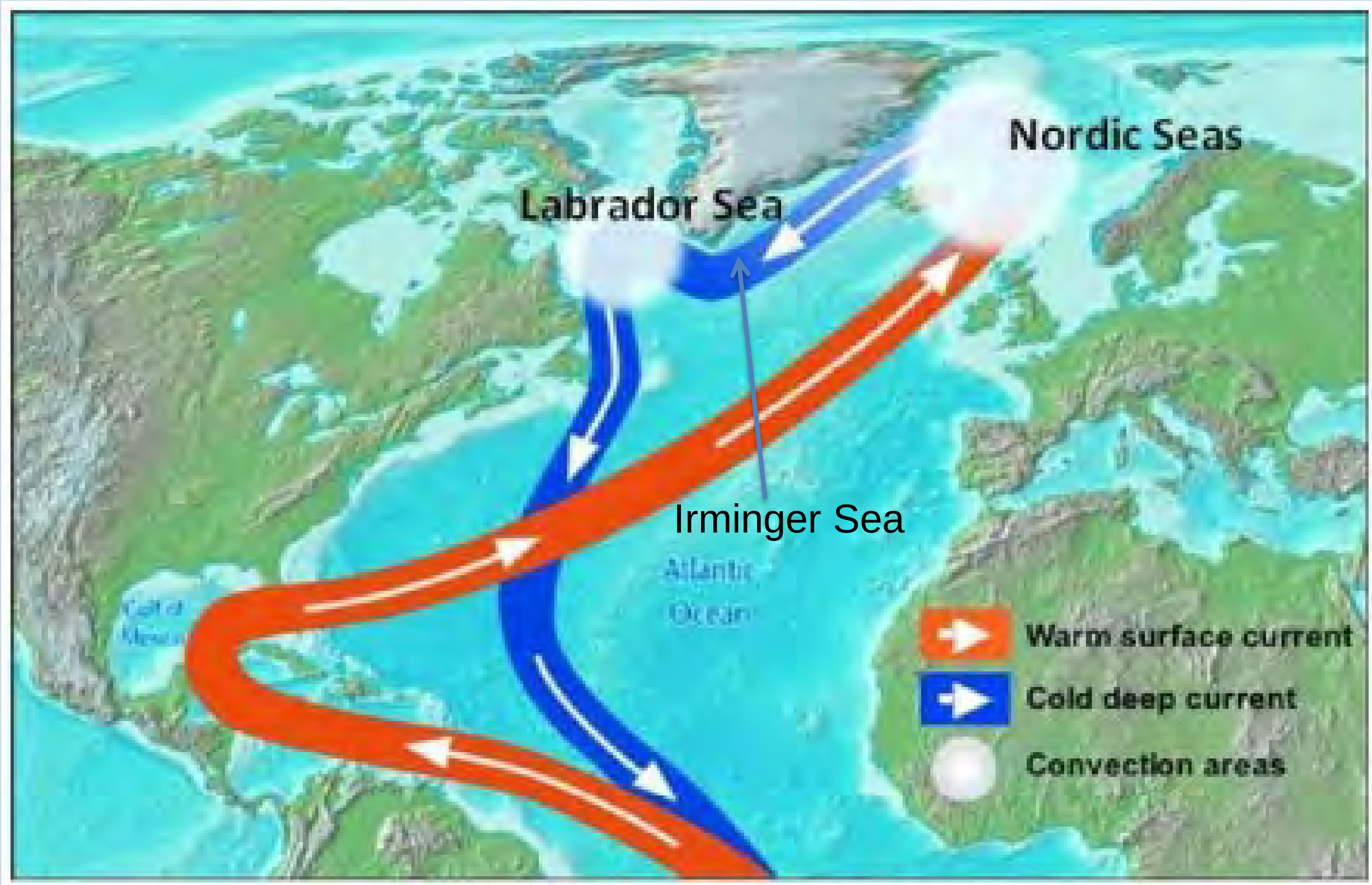


Background

- With a single data point, Rumford had discovered one of the most important components of the climate system - **The Atlantic Meridional Overturning Circulation (AMOC).**



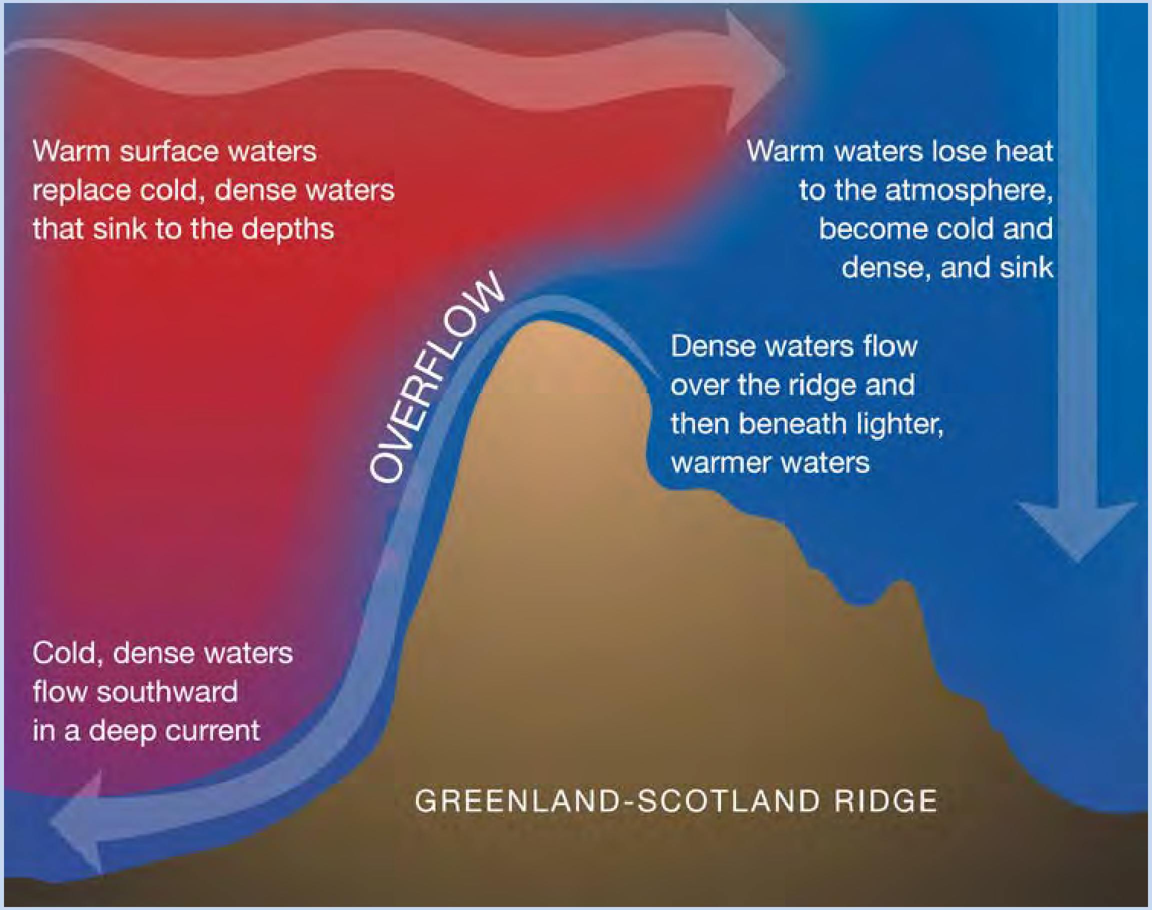
Background



Modern(ish) Schematic of AMOC with 2 main convection sites
(Another site exists in the Irminger Sea to the east of Cape Farewell)

The Nordic Seas

- Convection in the Nordic Seas is complicated by the Greenland -Scotland Ridge that limits the ability of the convected water to head south (aka Denmark Strait Overflow Water or DSOW).

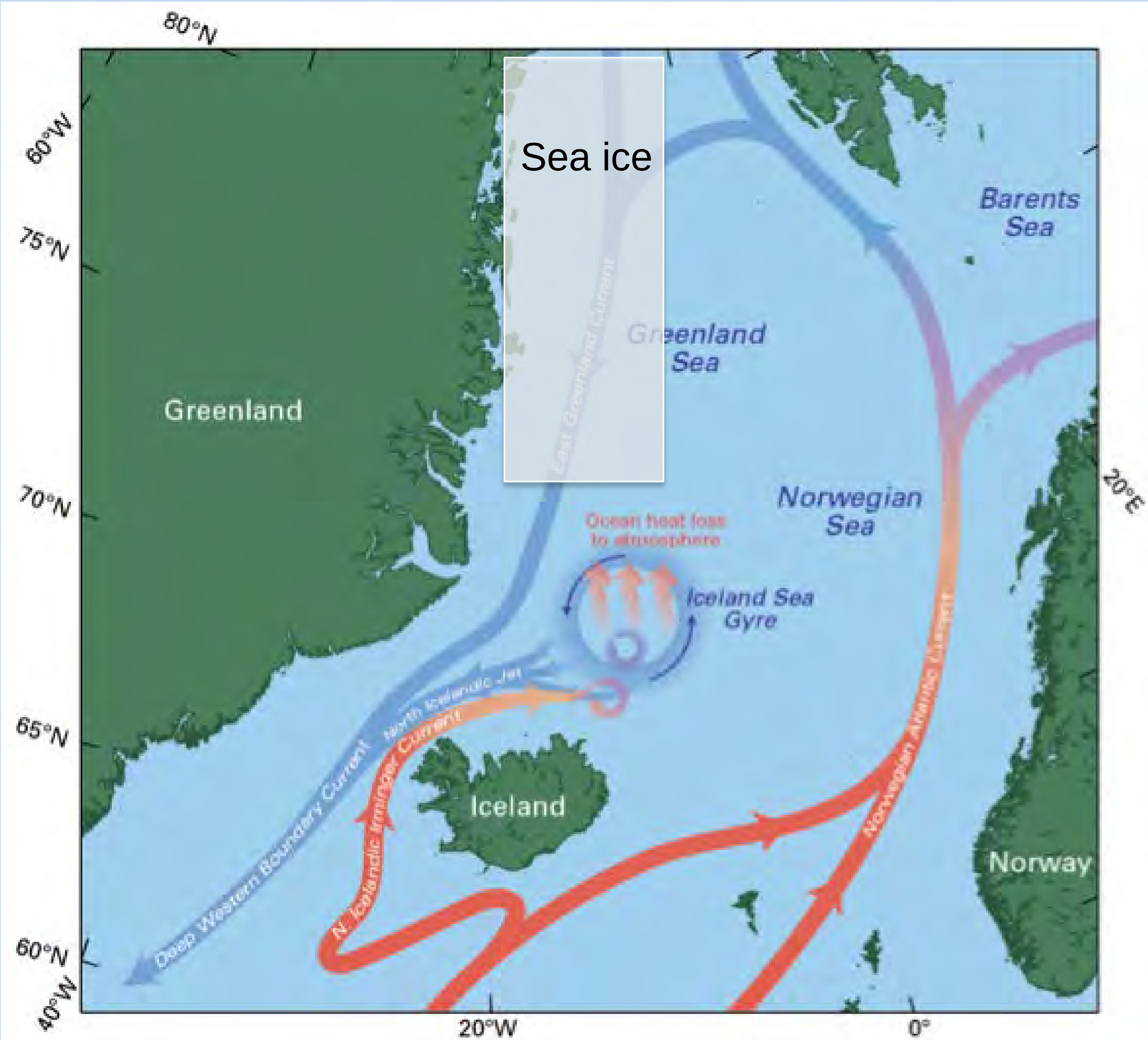


Schematic of the DSOW

The Nordic Seas

•Swift , Aagaard and others in the 1980s proposed that convection in the Iceland and Greenland Seas contributed to the DSOW.
•Mauritzen (1996) and others steered the community towards the view that water mass transformation around the boundary currents of the Nordic Seas was responsible for the DSOW.

The Nordic Seas



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the Iceland Sea
~30-50% of the

of all rivers.

EGC (water mass transformation on the eastern side of the rim current) and NIJ (convection in the Iceland Sea) both contribute to the DSOW.

The Role of the Atmosphere

- For at least a century, it has been acknowledged that the atmosphere plays a crucial role in ocean convection by providing the loss of buoyancy that drives the convective overturning.
- How to characterize this loss?
- Convection occurs in remote regions during the depth of winter when winds are strong and air-sea temperature difference is large (Gascard and Clarke observed convection in the Labrador Sea in 1976 with wind speeds >20m/s and DeltaT ~10^{o}C).

The Role of the Atmosphere

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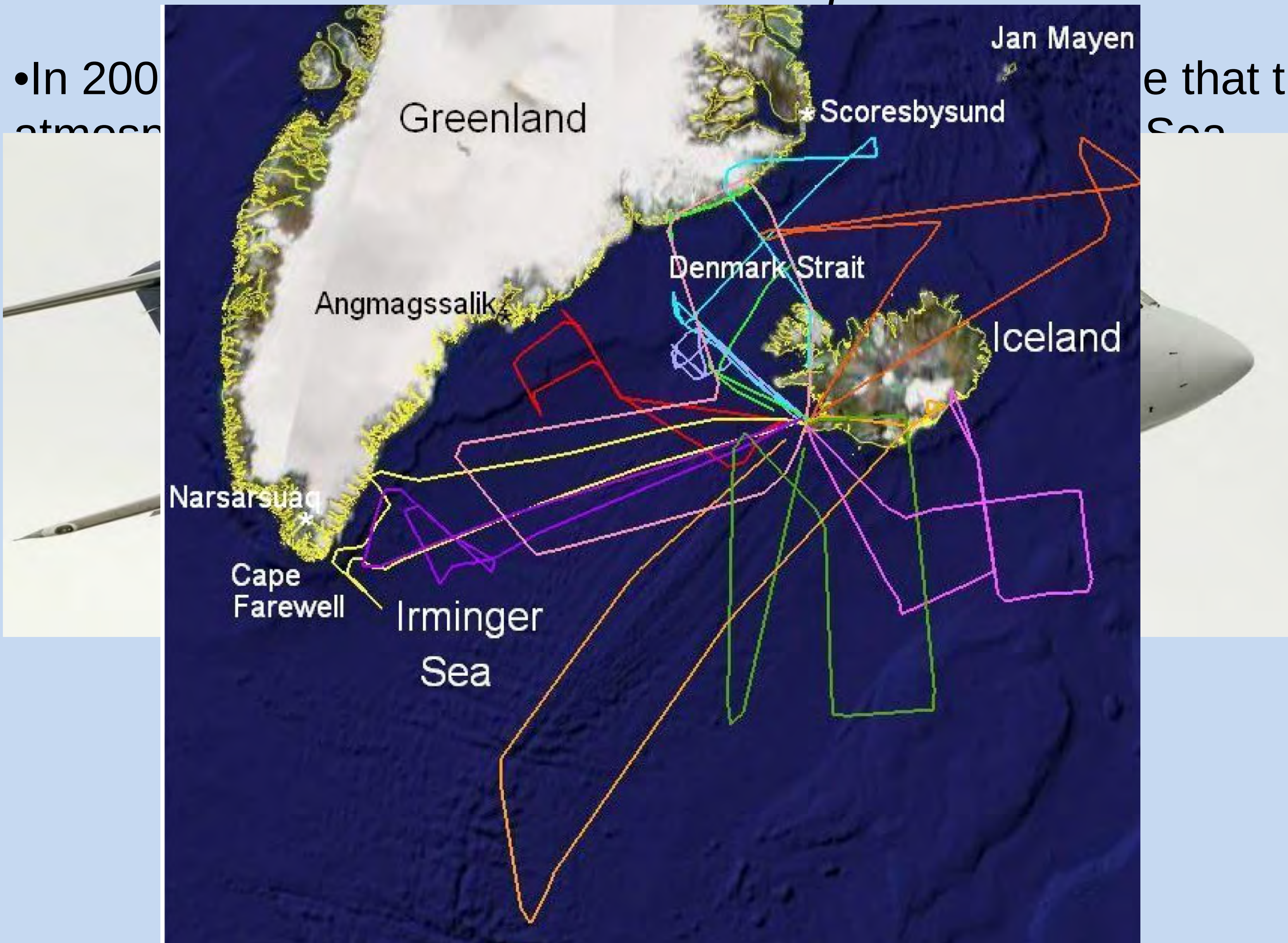
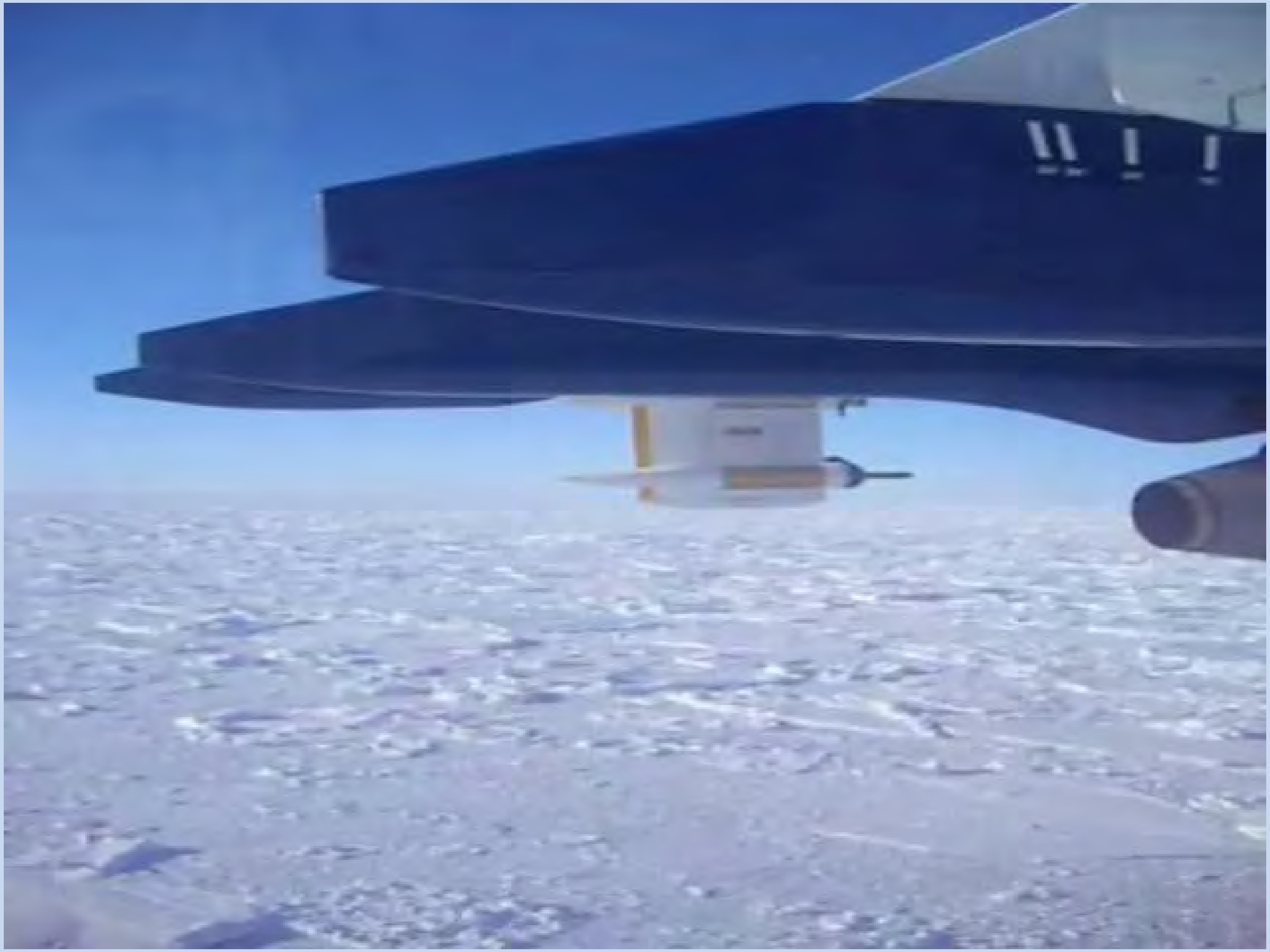


The Role of the Atmosphere

- Aircraft flight at 30m above sea-level over the Irminger Sea in 30 m/s winds.

The Role of the Atmosphere

- Aircraft flight at 30m above sea-level over the Denmark Strait's MIZ.

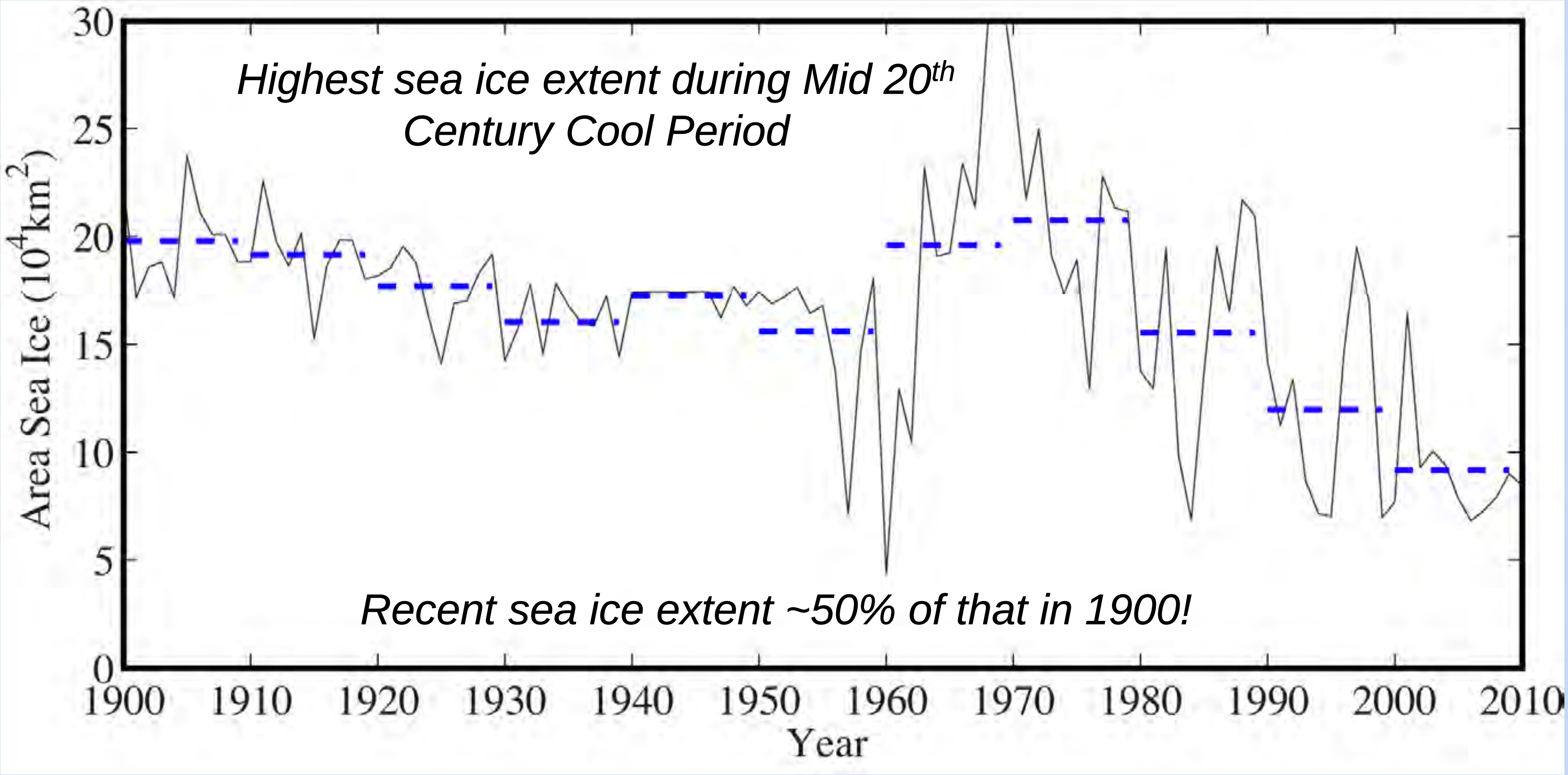


The Role of the Atmosphere

•In 2008, there was a winter cruise to the Iceland Sea. During one event, wind speeds were in excess of 30 m/s

Impact of Climate Change on the Atmospheric Forcing of Nordic Seas Ocean Convection

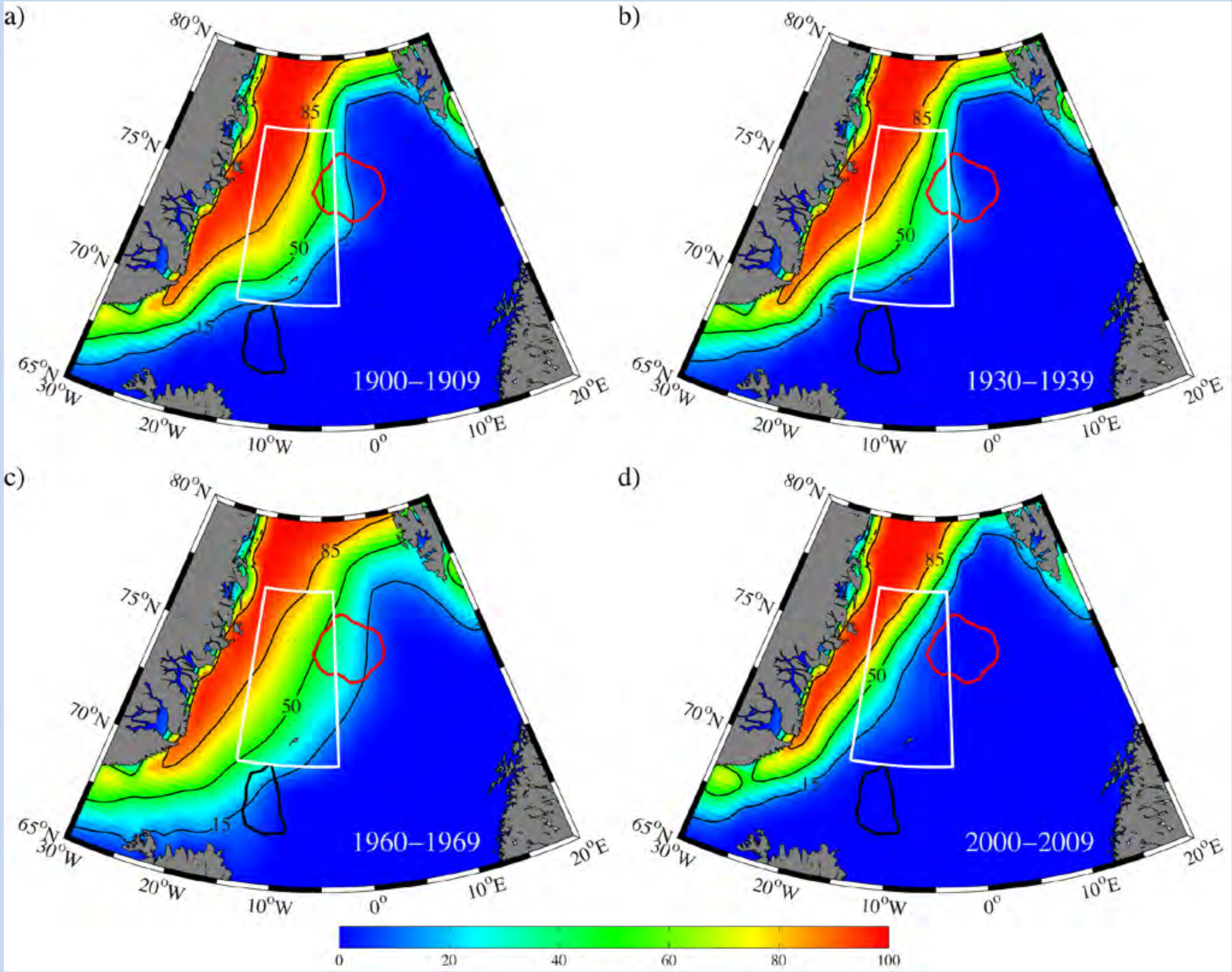
- Sea ice retreat is occurring during the winter and as I will argue, this may be reducing the forcing that drives ocean convection in the Nordic Seas.



Winter Sea Ice Concentration (%) with decadal means
Nordic Seas 1900-2009 (HadISST2.1)

Impact of Climate Change on the Atmospheric Forcing of Ocean Convection

- Sea ice retreat is occurring during the winter along the East Greenland coast.

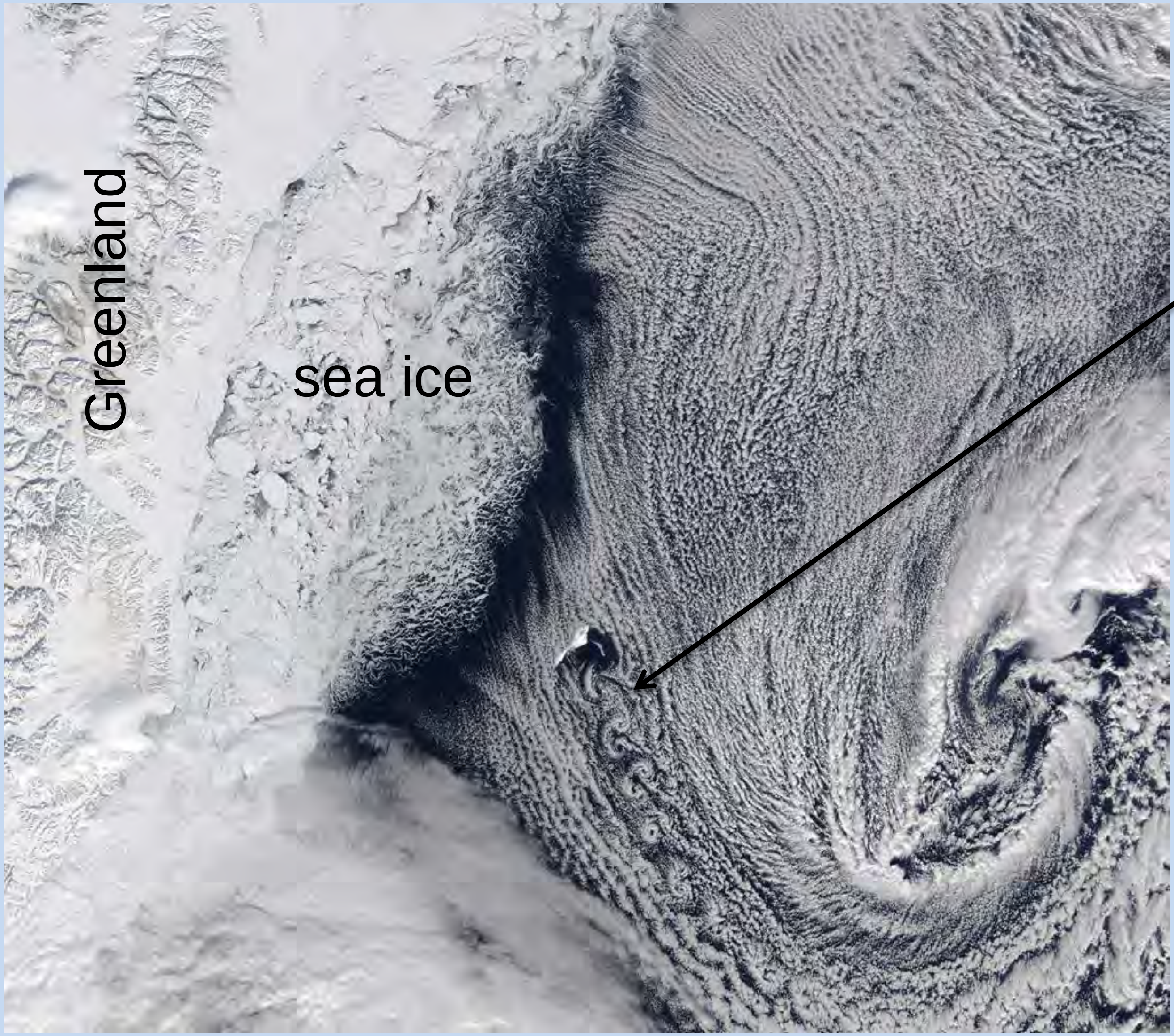


Red: Greenland Sea Convection Site
Black: Iceland Sea Convection Site

Over the period of the 20th Century, the ice edge has retreated away from the convection sites.

Winter Sea Ice Concentration (%) 1900-2009 (HadISST2.1)

Why is Sea Ice Important to Ocean Convection?



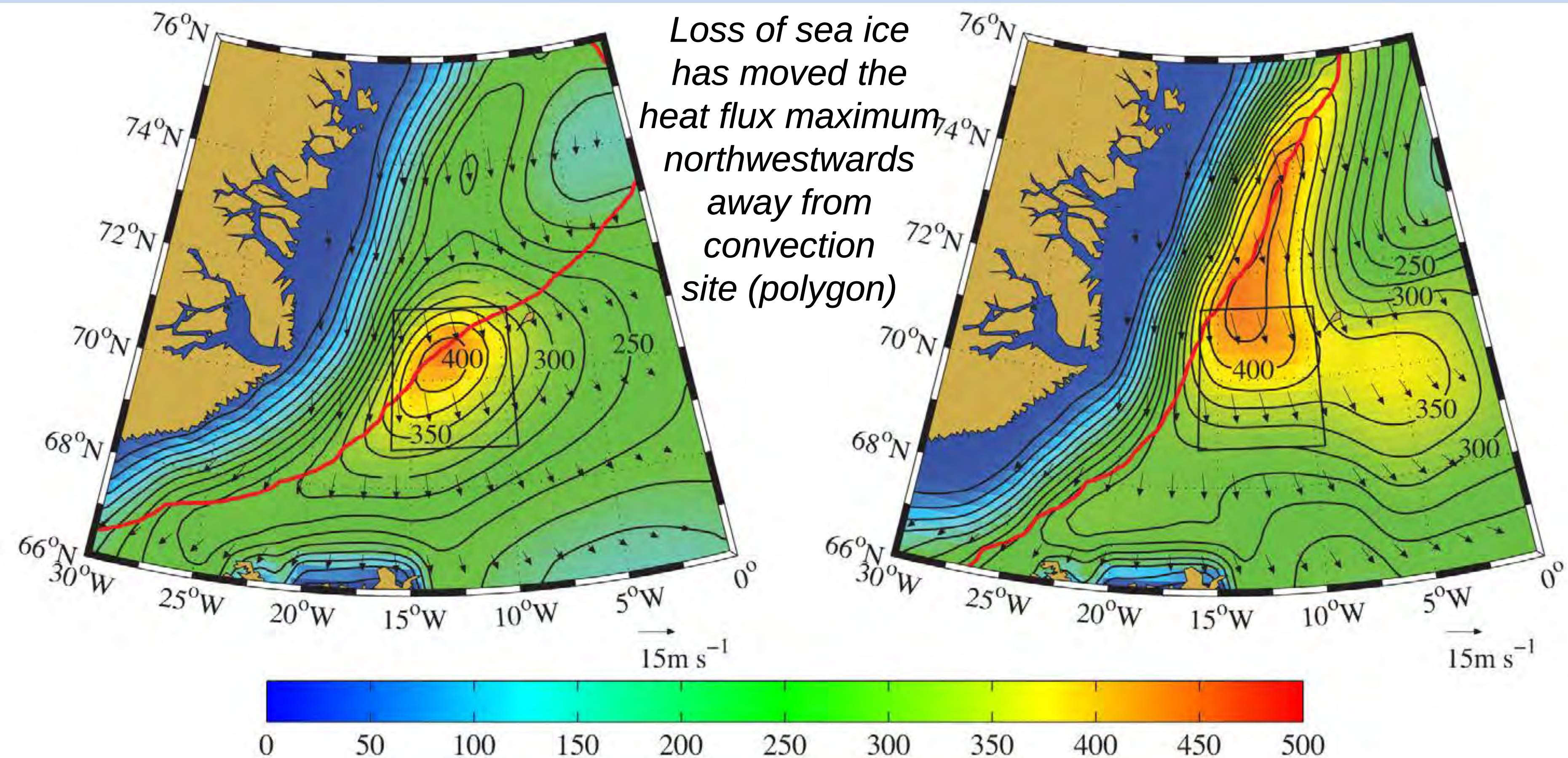
Kármán vortex street shed by Jan Mayen

Air-Sea Interaction is largest near the ice edge where cold Arctic air flows over warm open water

Cold Air Outbreak over the Greenland Sea

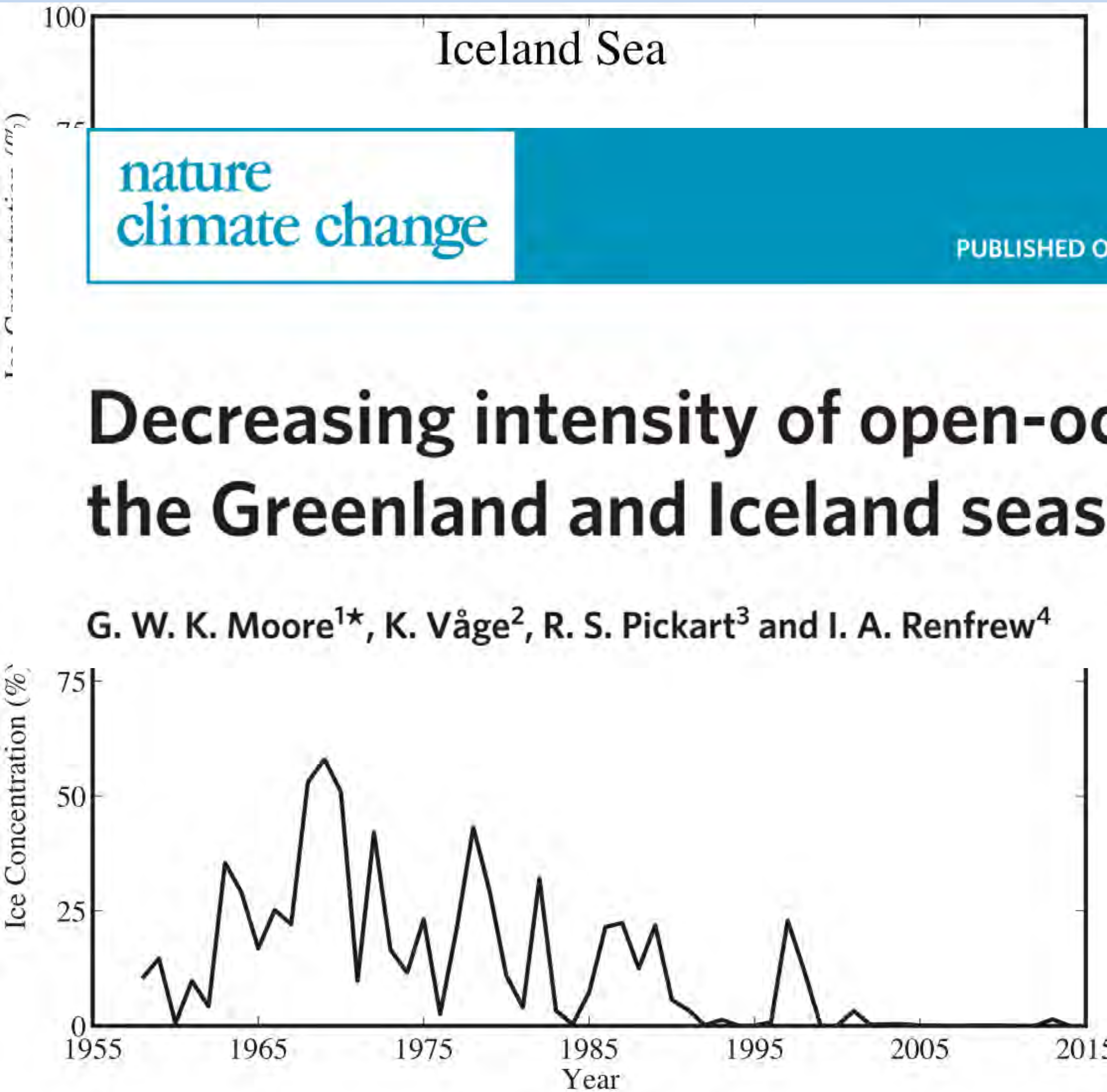
Impact of Sea Ice Loss on Atmospheric Forcing over the Iceland Sea

1979-1988 2004-2013



Composite High Heat Flux Event (W/m²) over the Iceland Sea
(red curve 50% sea ice concentration contour)

Trends in Surface Meteorology and Air-Sea Flux Fields over the Greenland and Iceland Sea Convection Sites



Winter mean sea ice concentration (%)

nature climate change

LETTERS

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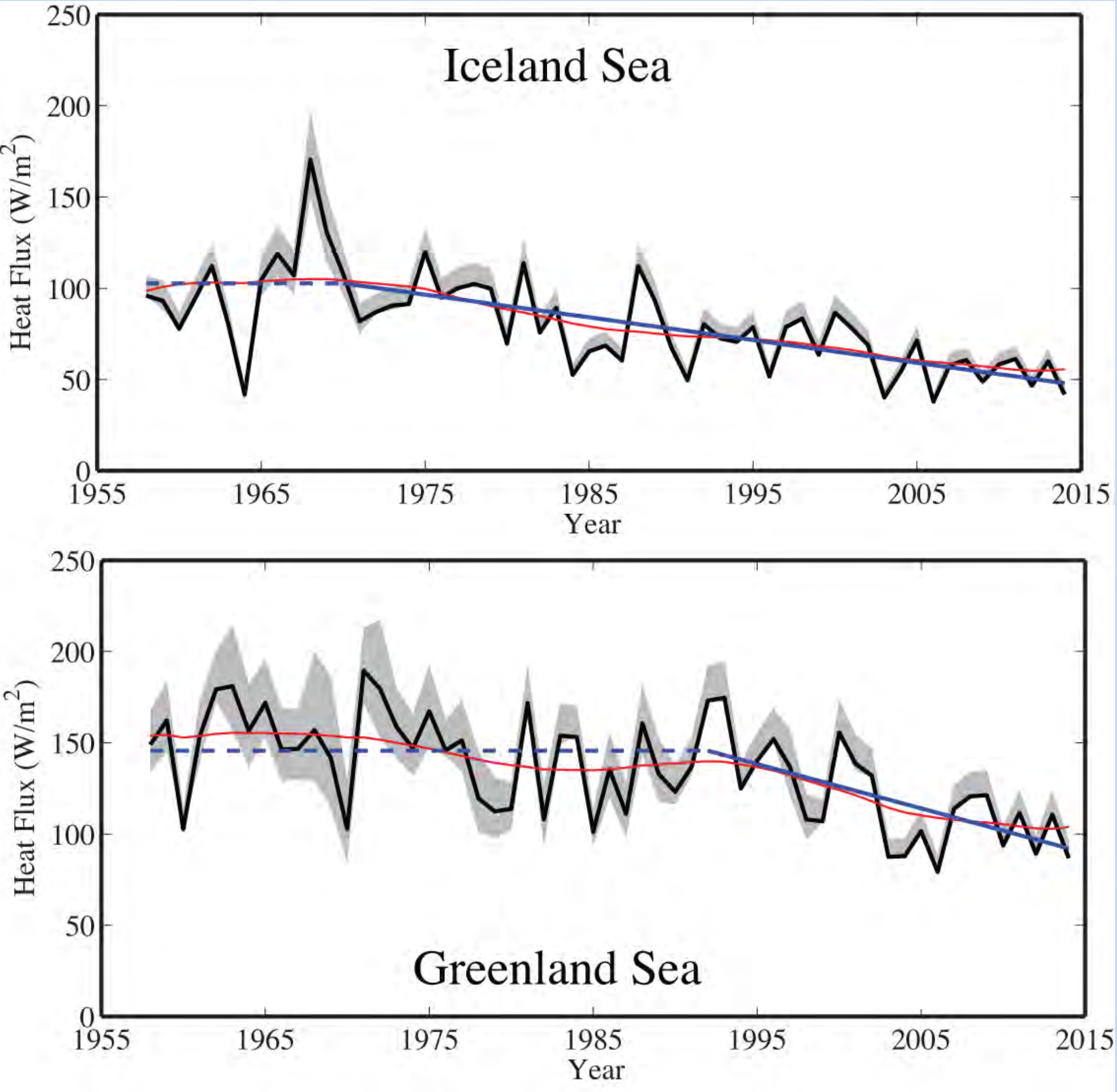
Decreasing intensity of open-ocean convection in the Greenland and Iceland seas

G. W. K. Moore[1*], K. Våge[2], R. S. Pickart[3] and I. A. Renfrew[4]

Iceland Sea convection site had sea ice present during the late

site had sea ice present until 1980s.

Trends in Surface Meteorology and Air-Sea Flux Fields over the Greenland and Iceland Sea Convection Sites



Winter mean heat flux (W/m^2)

The air-sea heat flux over the Iceland Sea convection site has been in decline since the 1960s.

The air-sea heat flux over the Greenland Sea convection site has been in decline since the 1980s.

Impact of Trend in Air-Sea Heat Flux on Convection in the Iceland and Greenland Seas

- Over the past 30 years, the Iceland and Greenland Seas have seen reductions of ~20% in the magnitude of the air-sea heat flux over the convection sites.
- The trend towards a reduced air-sea temperature difference responsible for this reduction.
- The retreat of sea ice has contributed to this loss by shifting heat flux maximum away from convection sites.

Impact of Trend in Air-Sea Heat Flux on Convection in the Iceland and Greenland Seas

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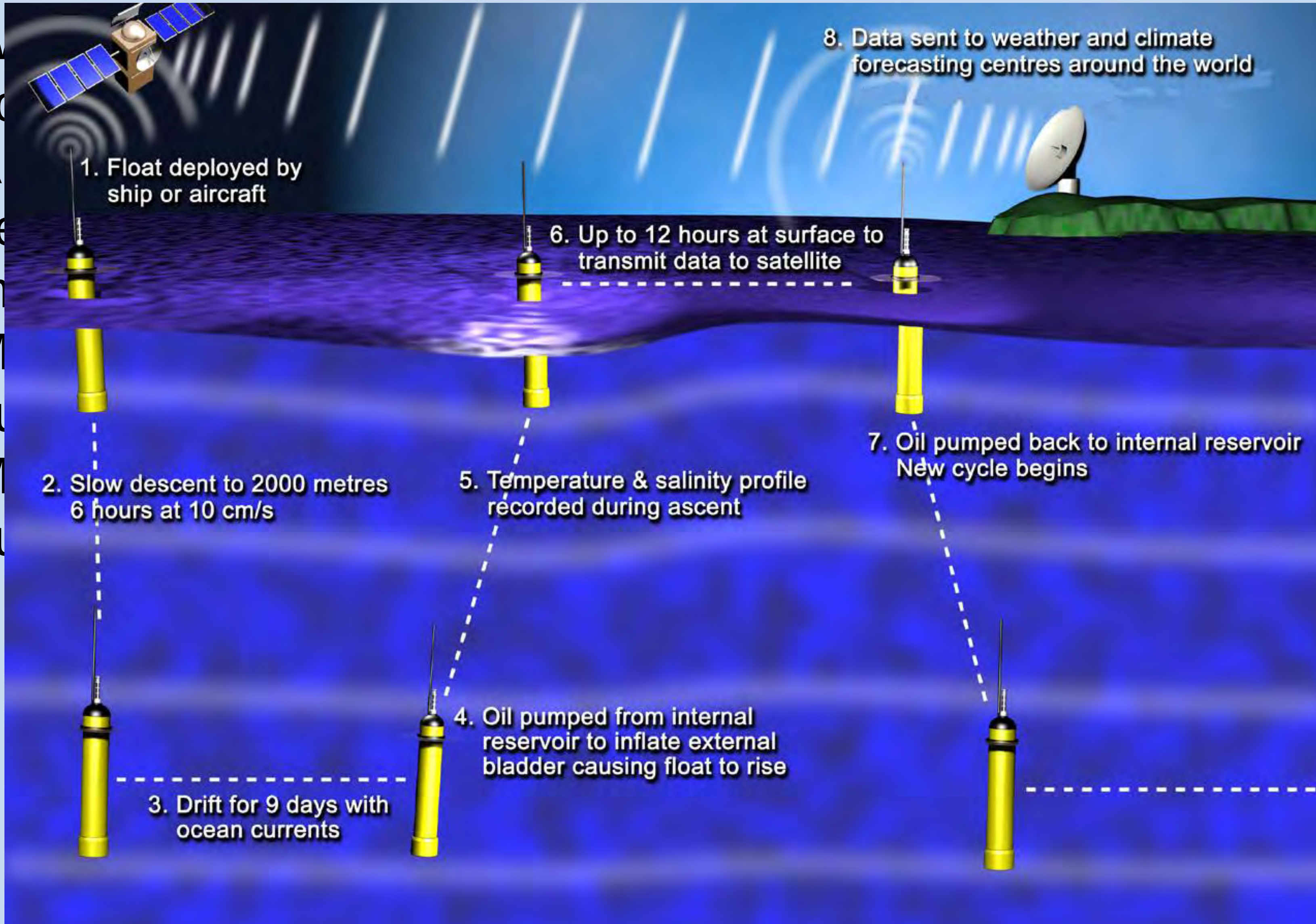
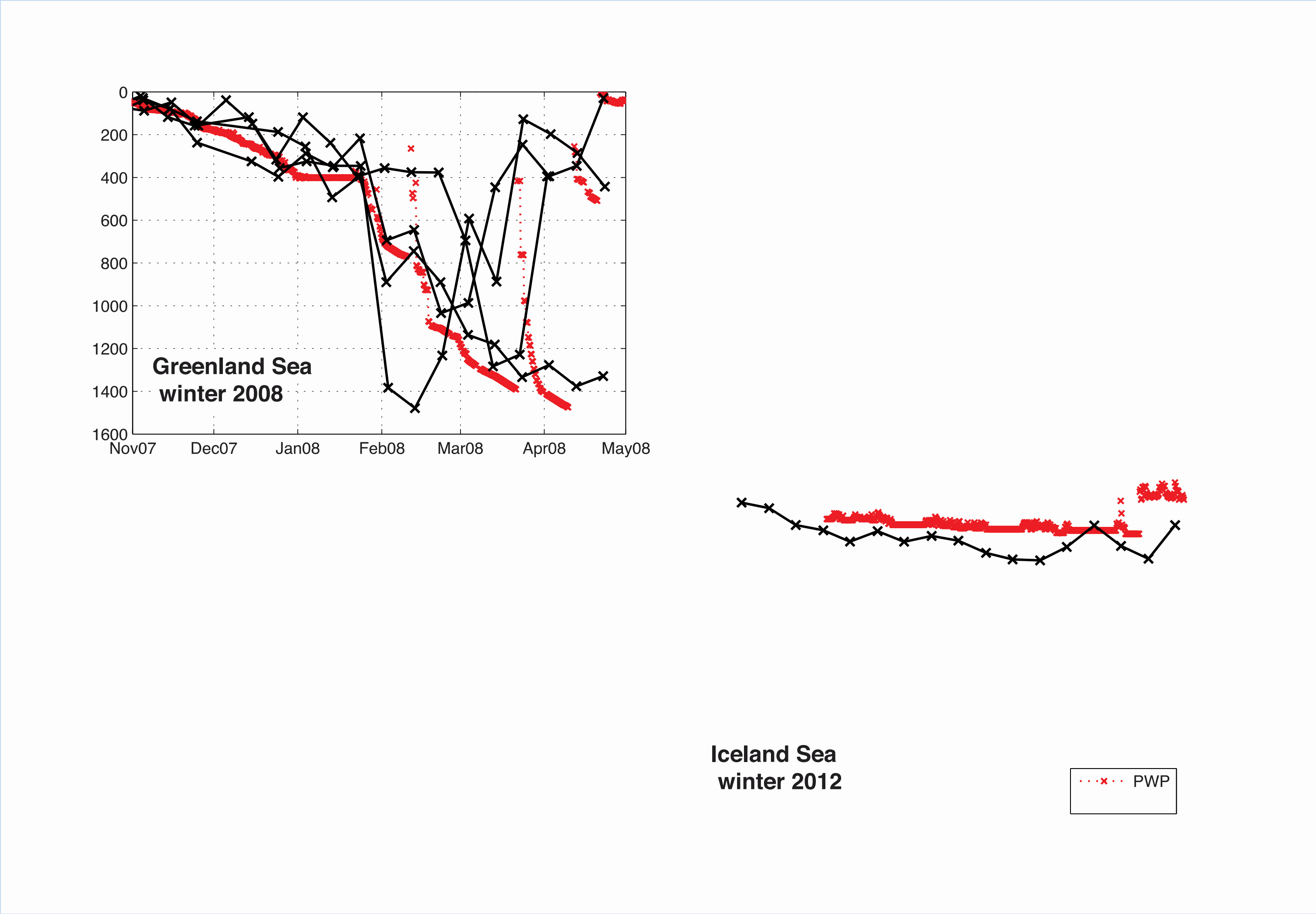


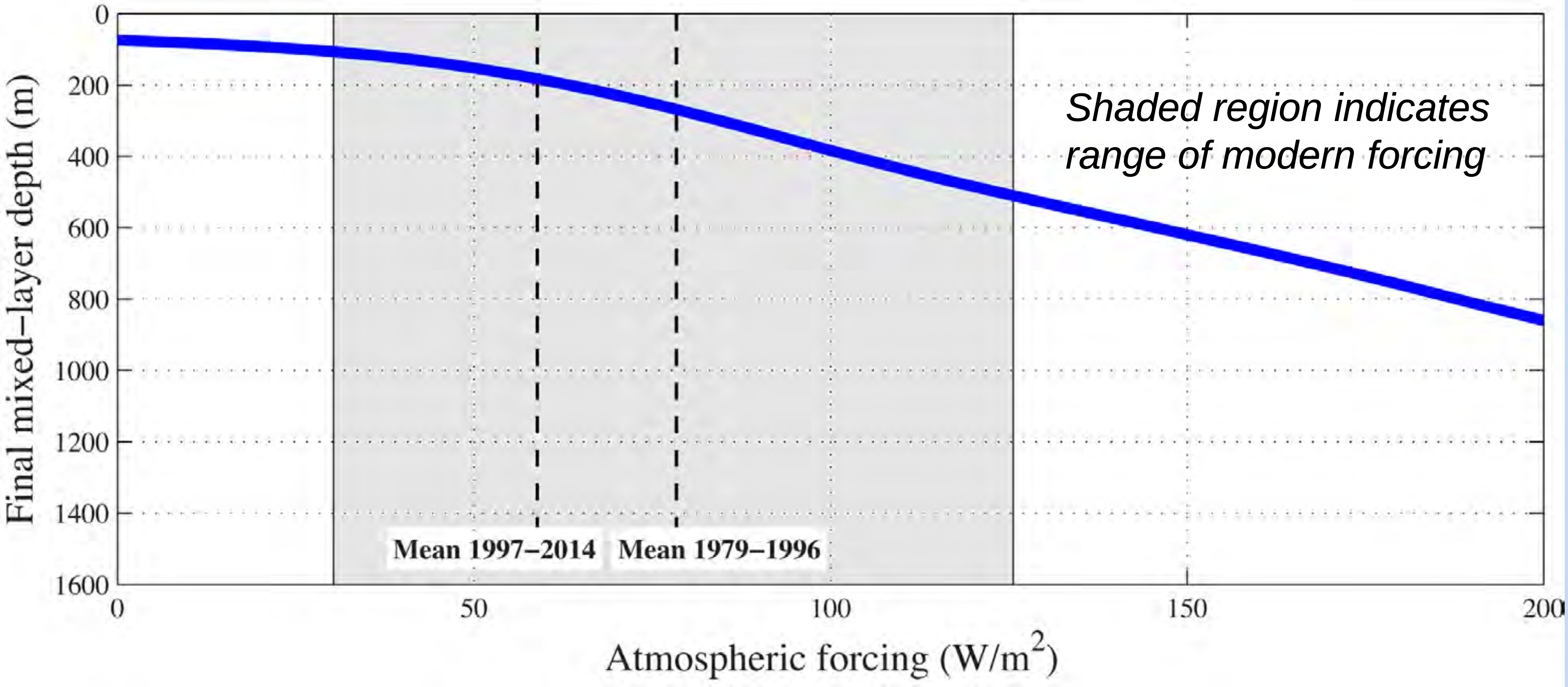
Verification of PWP Model (red) with Argo Data (black)



Note: change in vertical scale between Iceland and Greenland Sea plots

Significant inter-annual variability in the depth of convection in the Greenland Sea
Convection in the Greenland Sea typically deeper than that in the Iceland Sea

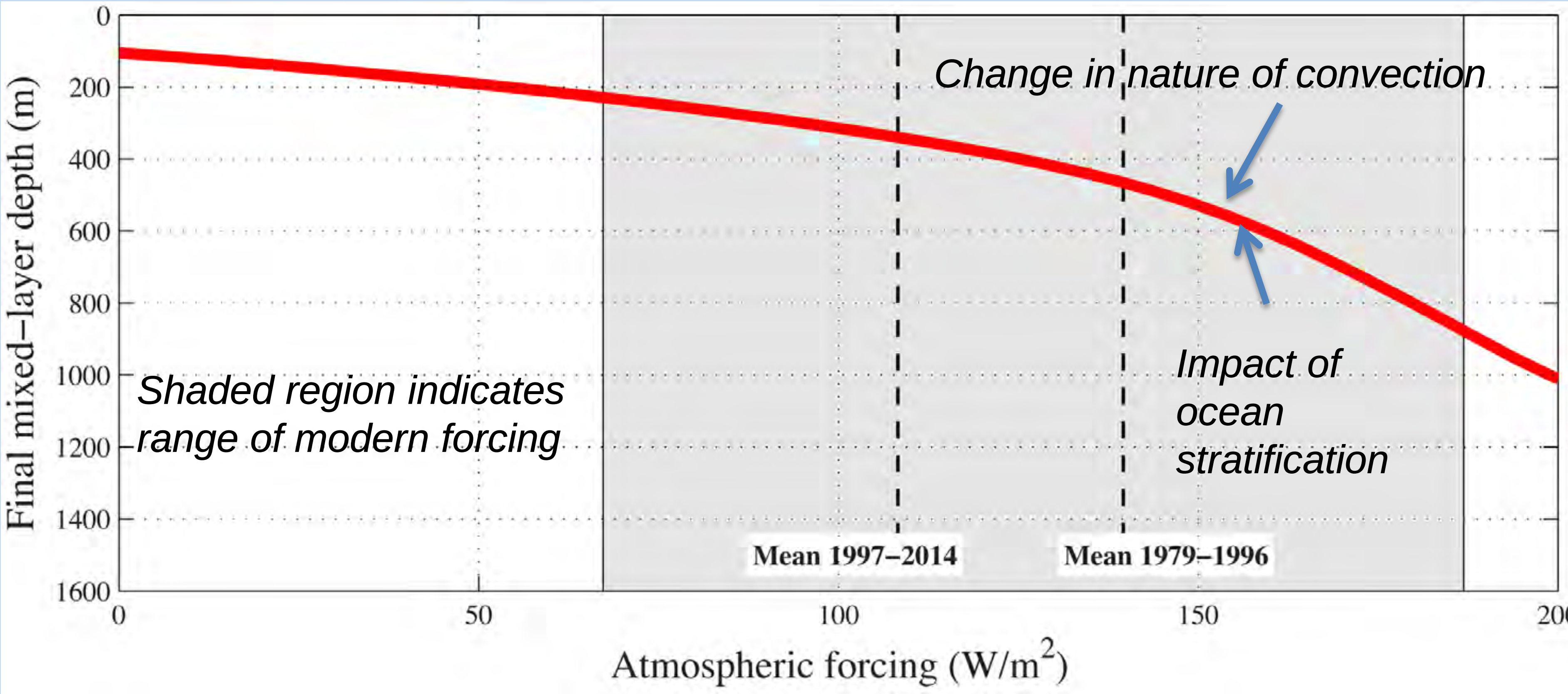
Sensitivity to Atmospheric Forcing



Final Iceland Sea Mixed Layer Depth as a Function of Winter Mean Forcing

Depth of convection in the Iceland Sea is a linear function of atmospheric forcing (~5m increase in depth for every 1 W/m^2 increase in the forcing or v.v.)

Sensitivity to Atmospheric Forcing



Final Greenland Sea Mixed Layer Depth as a Function of Winter Mean Forcing

Two distinct convection regimes in the Greenland Sea

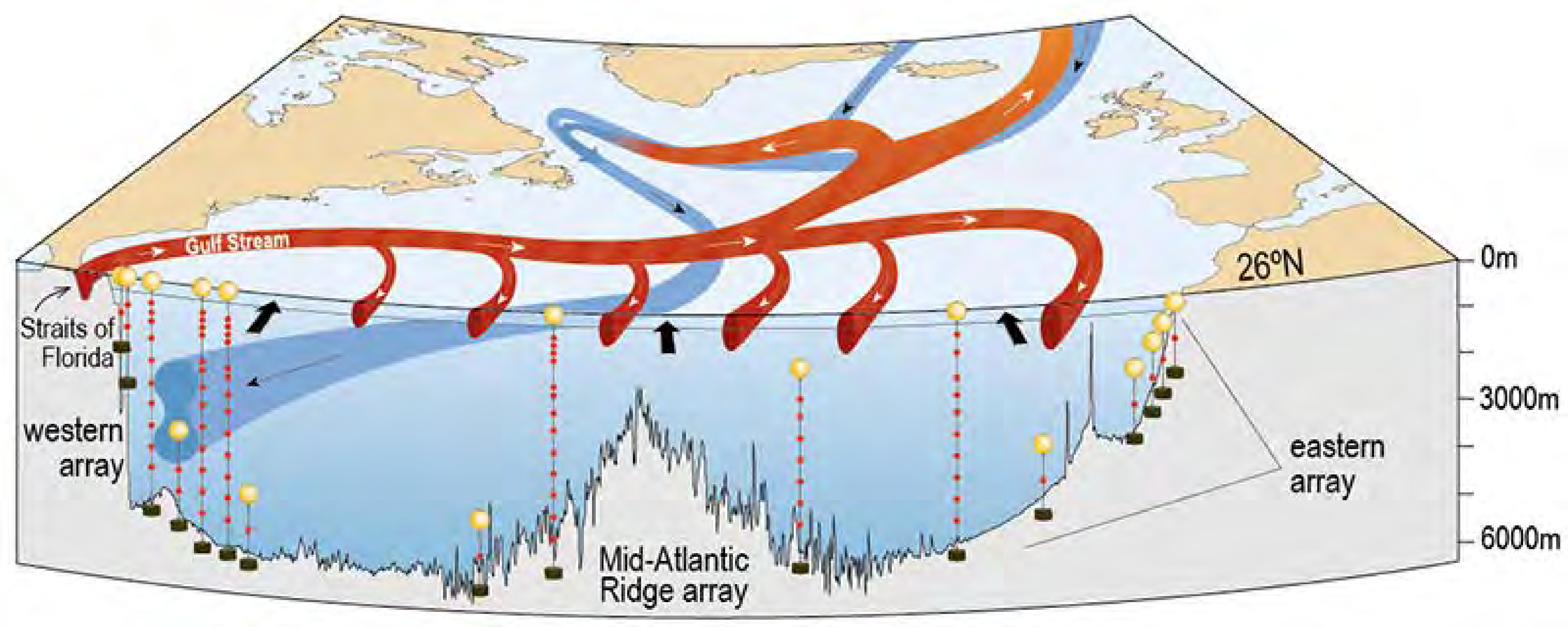
Above ~150 W/m² (~3m increase in depth for every 1 W/m² increase in the forcing or v.v.)

Below ~150 W/m² (~10m increase in depth for every 1 W/m² increase in the forcing or v.v.)

Sensitivity to Atmospheric Forcing

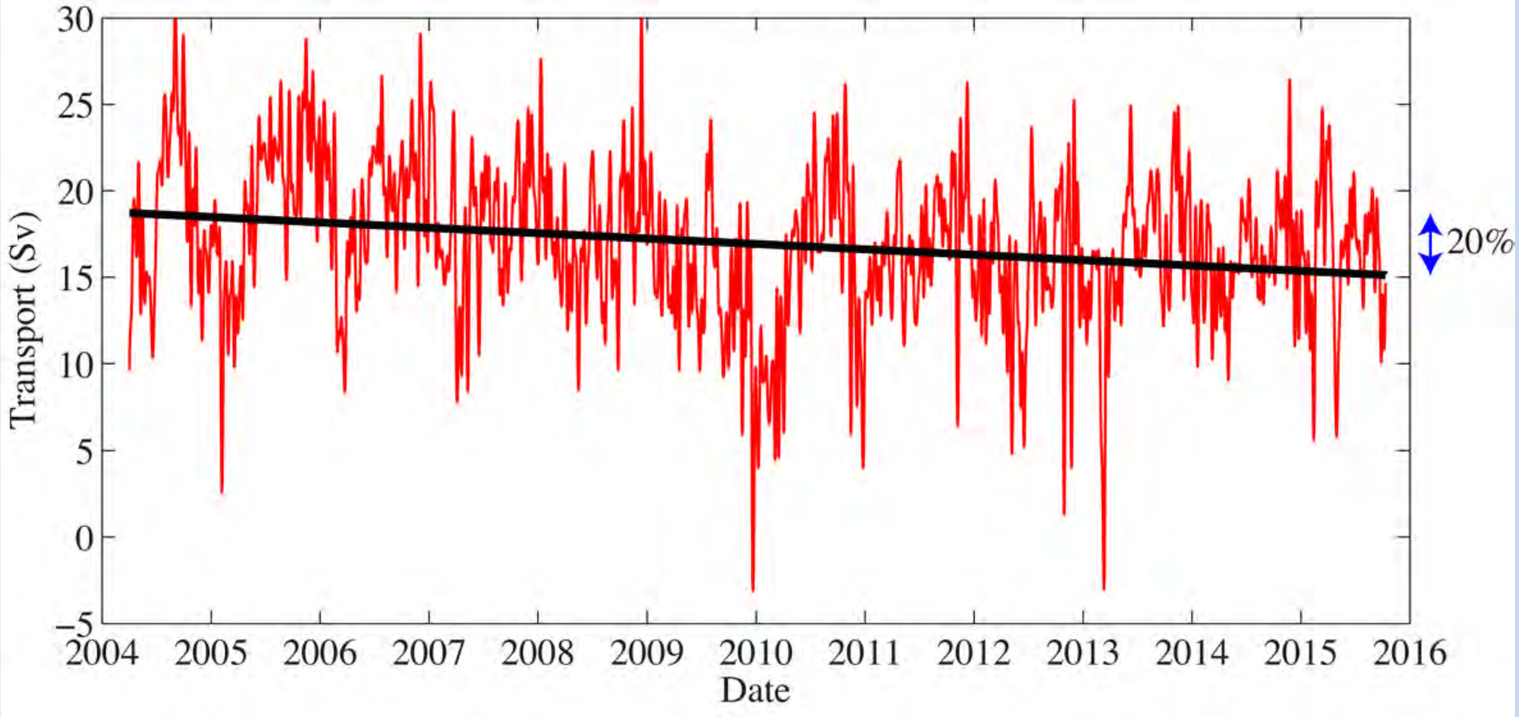
- Reduction in the strength of the forcing over the Greenland and Iceland Sea convection sites tends to produce shallower mixed layers.
- This is a signal of a reduction in the intensity of ocean convection at these sites.
- This should be associated with a weakening of the ocean conveyor belt that transports heat polewards.

Is there Evidence of a slowdown in the AMOC?



The RAPID mooring array has been monitoring the transport associated with AMOC since 2004.
Mooring array across 26ºN captures the surface and deep flow.
Deep flow not as well constrained due to presence of deep western boundary current (rotational constraint).

Is there Evidence of a slowdown in the AMOC?



Time series of the northward surface transport across 26ºN 2004-2016

Statistically significant reduction of ~0.3Sv/year in the northward transport =>over the ~12 year dataset, the transport has weakened by ~20%

Impact of Sea Ice Retreat on East Greenland Current

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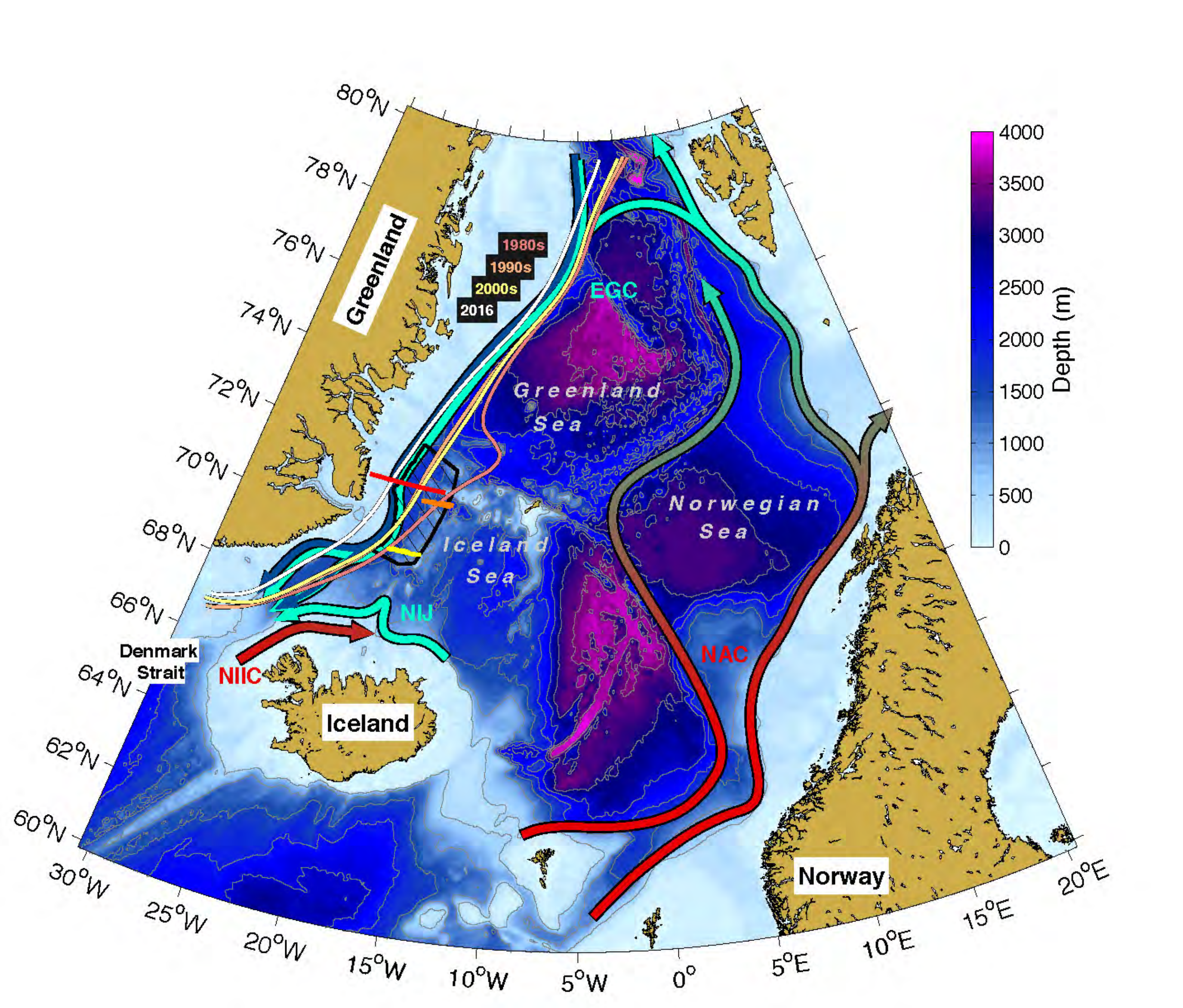

Conclusions

- The Iceland Sea is again recognized as a potentially important site that may make a significant contribution to the DSOW.
- This is the result of the discovery of the North Iceland Jet, an ocean current that links the Iceland Sea and the DSOW.
- The retreat of sea ice over the Nordic Seas appears to be reducing the atmospheric forcing over the Iceland and Greenland Seas.
- This weakening may impact the ventilation of the mid-depth waters of the Nordic Seas.
- A continuation of the trend towards lower atmospheric forcing over the Iceland Sea may decrease the supply of densest water to the return flow of the AMOC.
- We may be seeing a reduction in the intensity of the AMOC.

Conclusions

- Retreat of sea ice may also lead to enhanced water mass modification along the rim current of the Nordic Seas partially compensating for the changes in the interior.
- An example of the complex inter-related nature of the coupled climate system.

Conclusions

- We will return to the Iceland Sea next winter with an ice-strengthened research vessel and an instrumented aircraft along with a suite of moorings to close the circle with respect to the role that the Iceland Sea plays as a source for the DSOW.


Thank-You