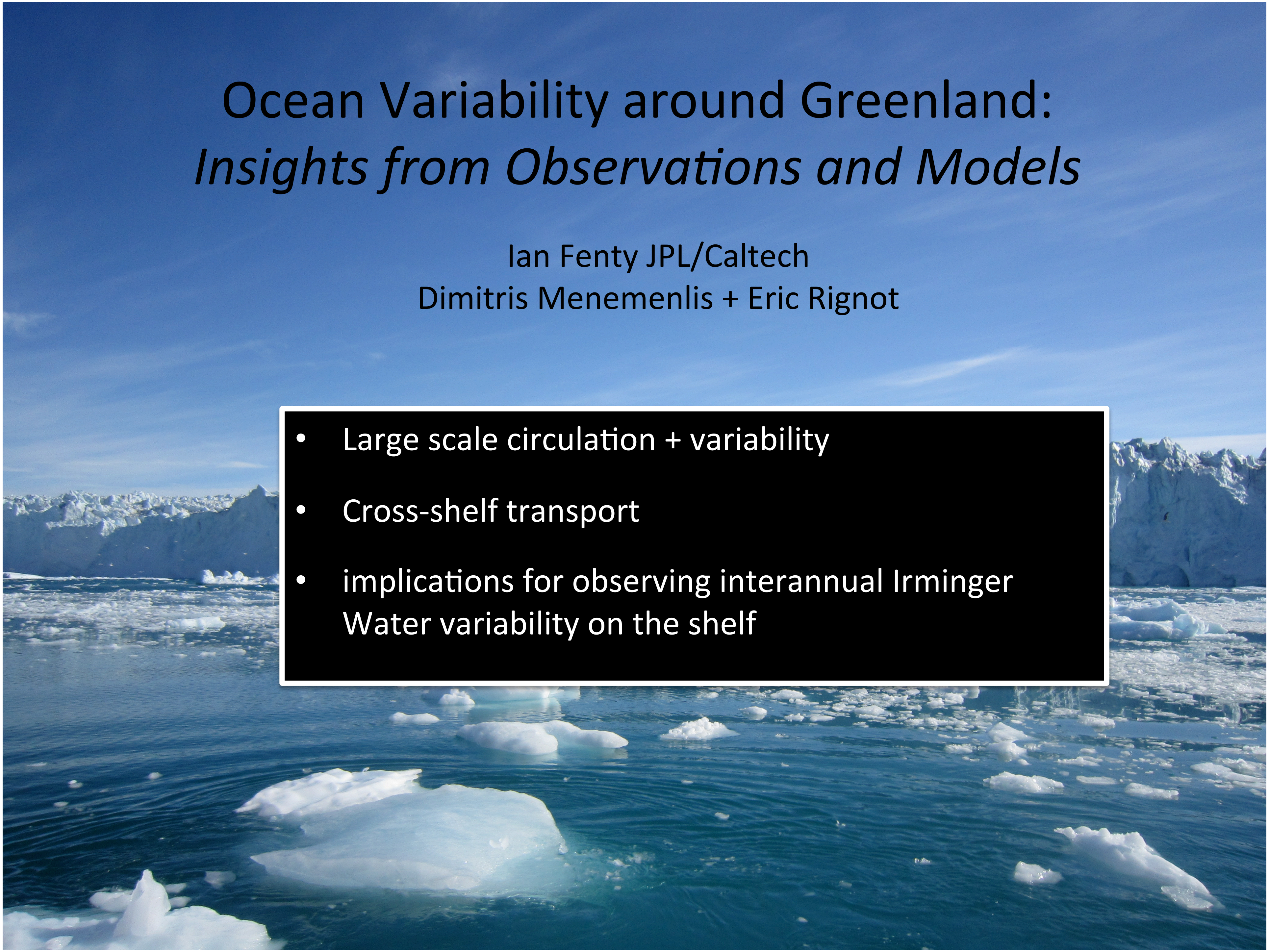


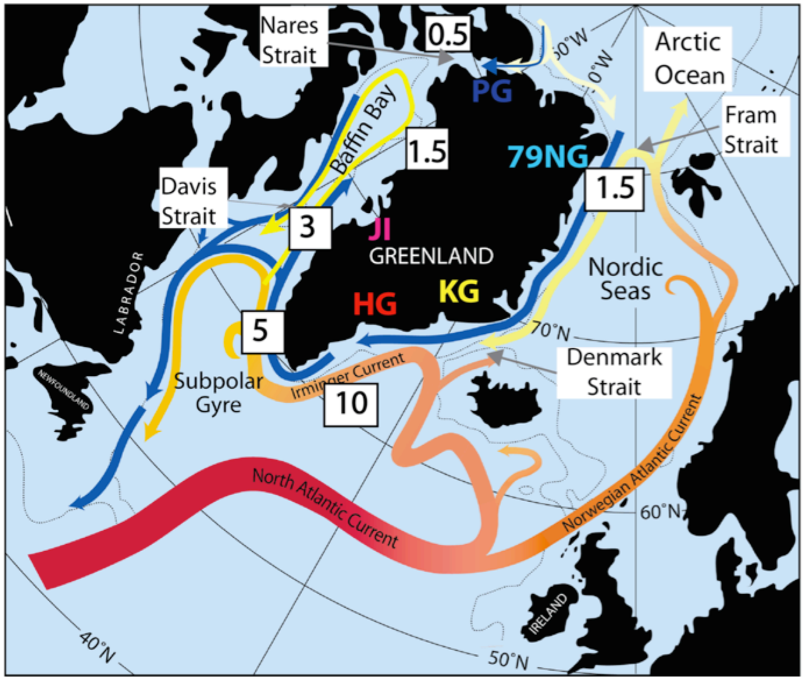
Ocean Variability around Greenland:
Insights from Observations and Models

Ian Fenty JPL/Caltech
Dimitris Menemenlis + Eric Rignot

- Large scale circulation + variability
- Cross-shelf transport
- implications for observing interannual Irminger Water variability on the shelf

What is conveyed by this schematic for **upper ocean temperature** and **circulation**?

- Poleward transport of warm waters on the NAC
- Birfurcation to the Subpolar Gyre
- Flow along the E/WGC
- Bifurcation in LS to Baffin Bay
- Bifurcation to the Nordic Seas, recirculation at Fram Strait
- *Gradual, smooth cooling of a relatively warm source of subtropical original waters (IW) along well-defined pathways*

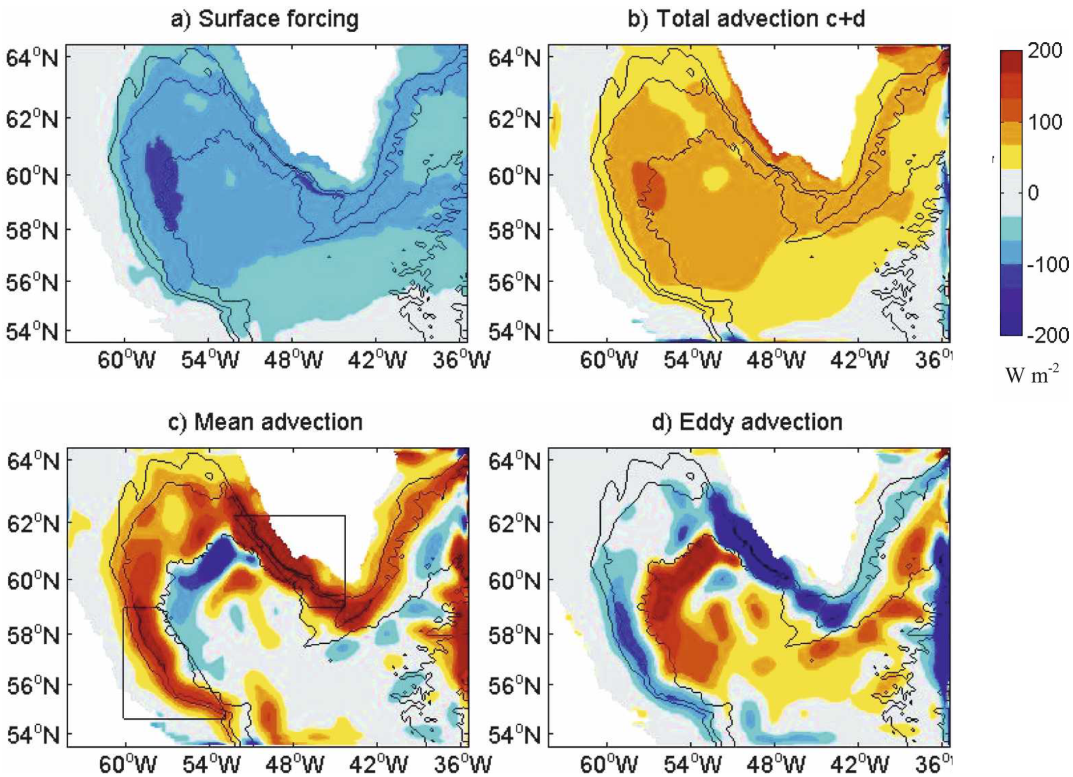


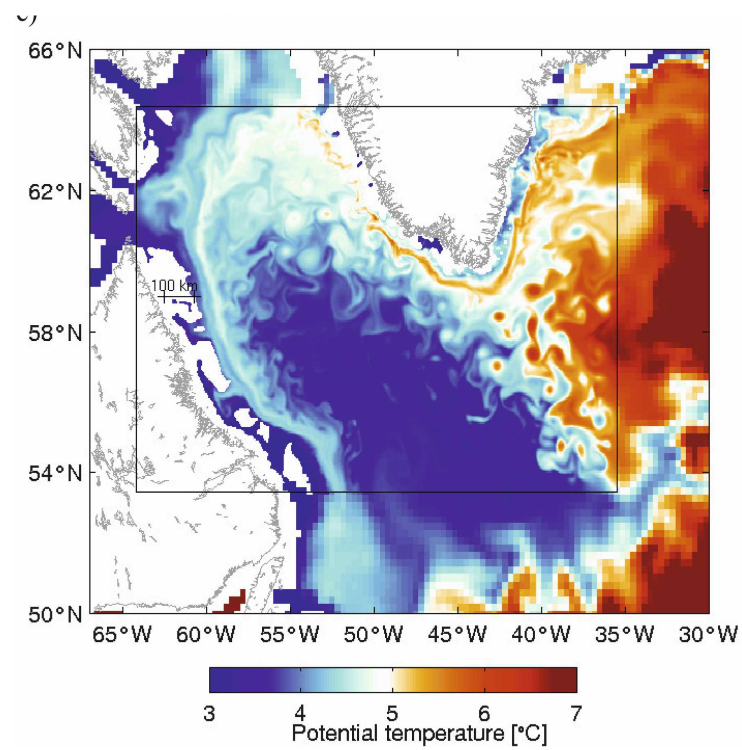
…what is not conveyed that is relevant to understanding IW variability in glacial fjords?

1. processes whereby heat is lost from the boundary currents
2. seasonal + interannual variability
3. advective timescales

1. Processes whereby IW heat is lost from the boundary currents

4 km ocean process model by Chanut et al, 2008

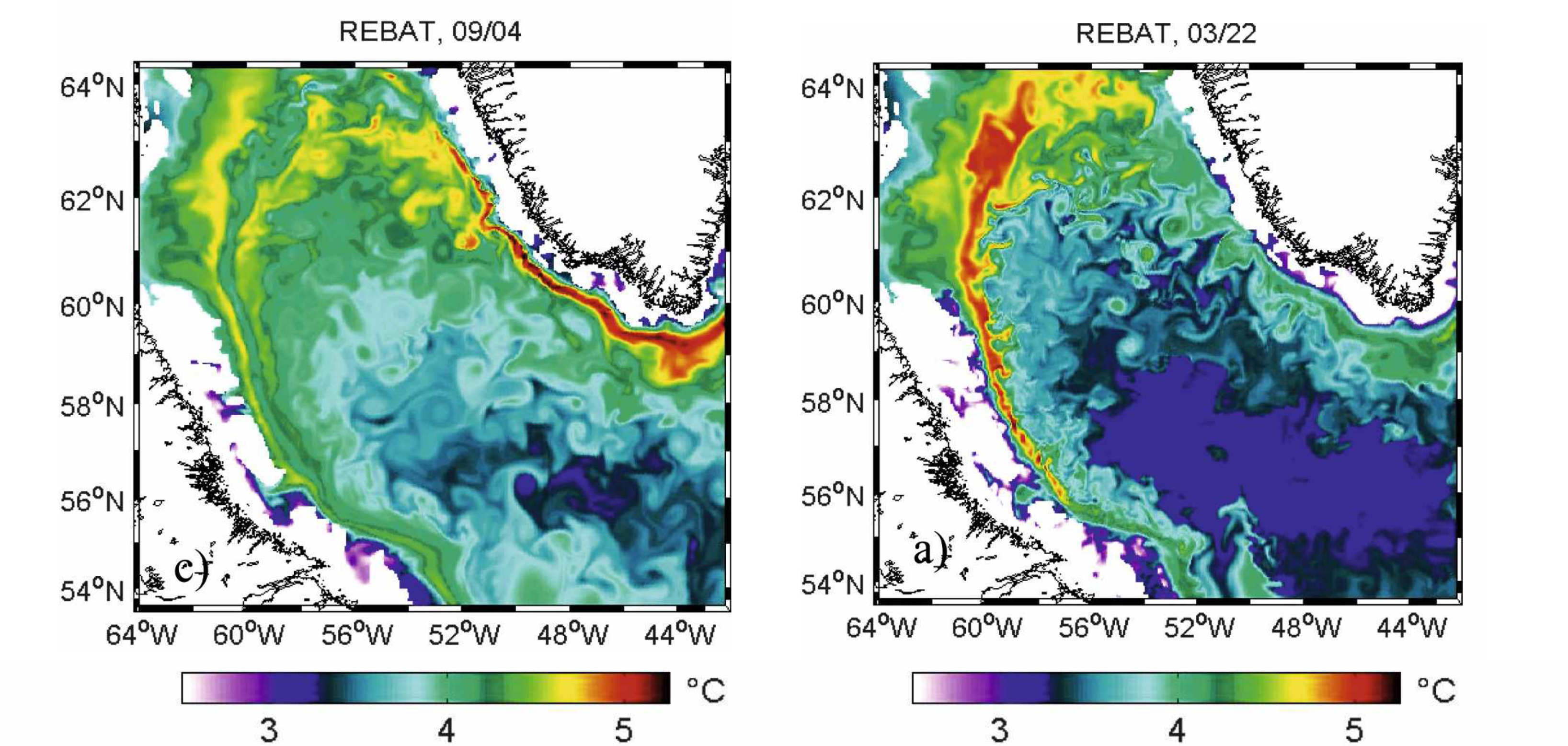




- In equilibrium, surface heat flux divergence (air-sea heat loss) in the central SPG is balanced by the lateral transport of heat from the boundary current.
- Lateral heat transport from the boundary current is due to a combination of mean flow (in the northern Labrador Sea) and eddies (everywhere else)

2. What drives seasonal variability of the IW temperatures?

T at 180 m at the end of summer and winter



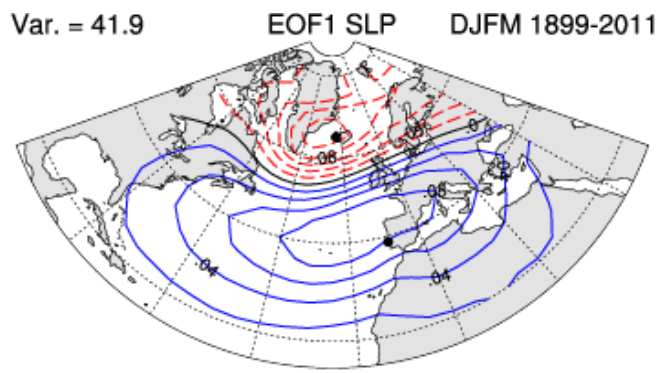
- Air-sea heat loss and induced horizontal eddy transports are highly seasonal
- Seasonal fluctuations of T of the IW on the boundary current is ~ 1 degree
- Warm IW core is restored < 0.5 year timescale

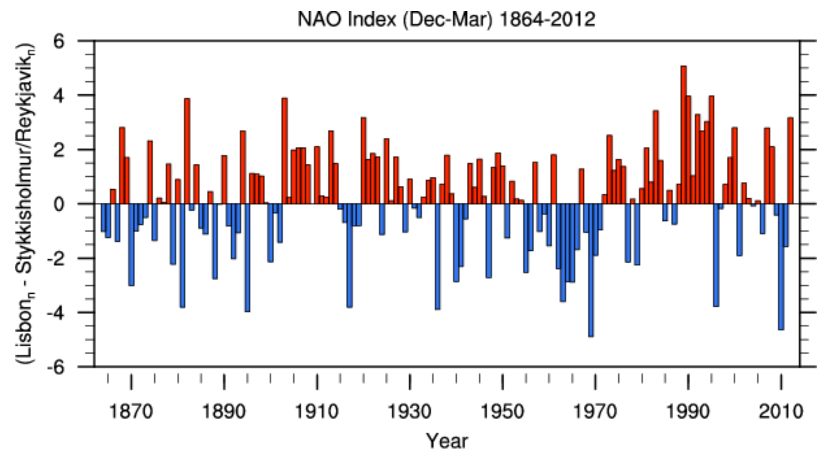
2. What drives interannual variability of the IW temperatures?

NAO

- Large-scale SLP pattern exhibits decadal variability across a relatively long instrument record
- Multi-year excursions in + or – regimes
- Switch from a positive excursion in late 1980s-mid 1990s to a mixed phase thereafter

Positively correlated with **air-sea heat loss** and **wind stress** anomalies in the Baffin Bay, Subpolar Gyre and, GIN Seas

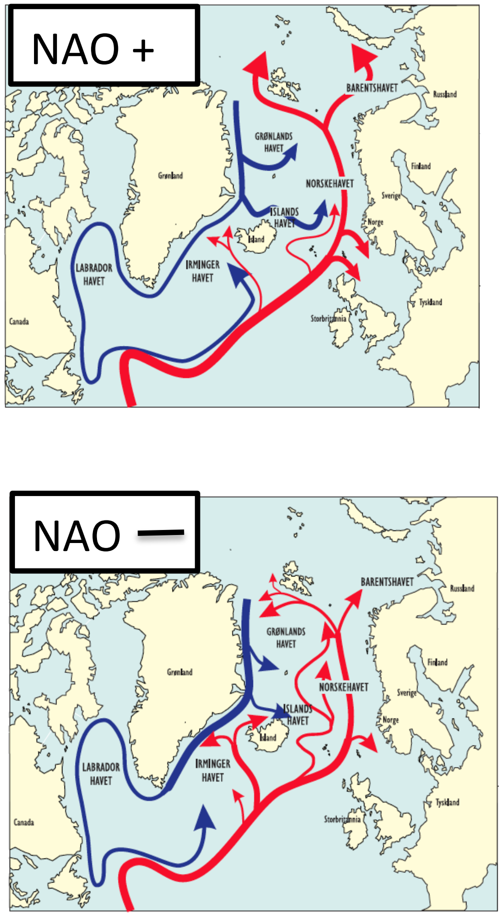




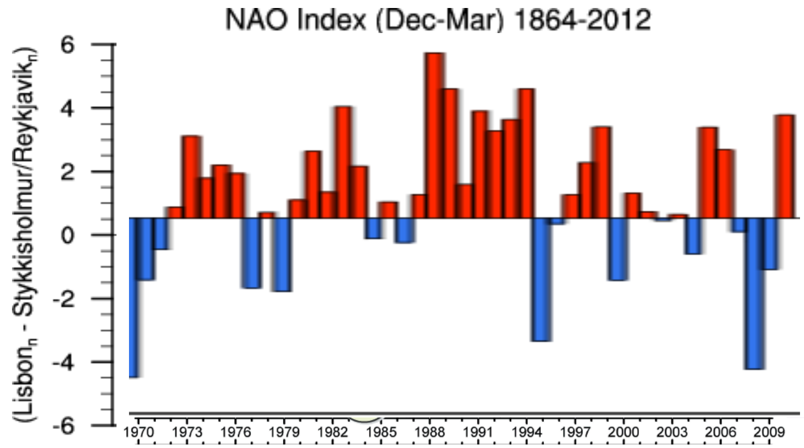
What are the effects changing atmospheric conditions from those associated with NAO + to – conditions on the IW?

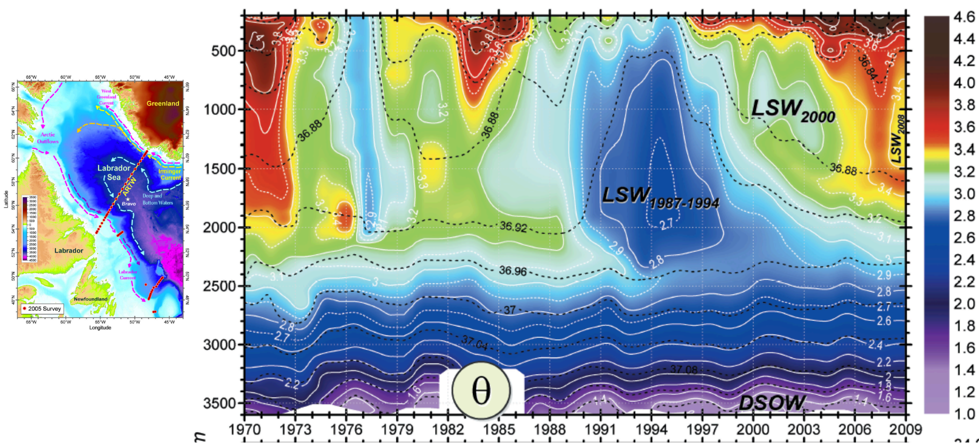
Effect 1: more warm subtropical-origin waters diverted to SPG and GIN seas
warmer IW source water

Effect 2: reduced air-sea heat loss in the SPG, Baffin Bay, and GIN Seas
less extraction of heat from the IW



Blindheim et al., 2001



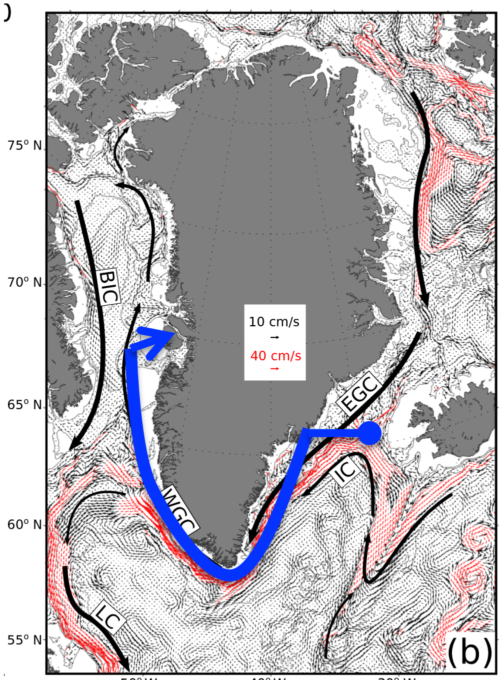


Yashayaev et al 2009

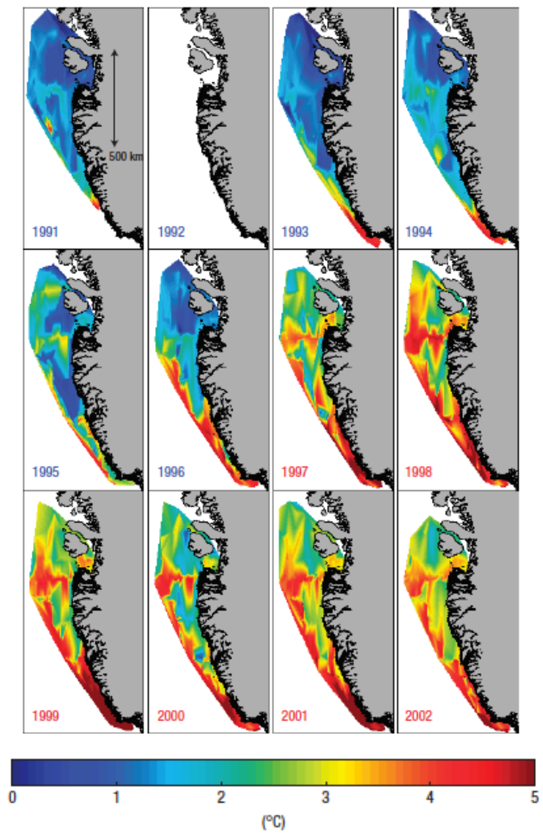
- A decrease in net heat flux divergence in the SPG interior leads to an overall reduction (over several years) in eddy heat flux divergence from the IW in the boundary current to the interior.
- Following mid-90's switch away from NAO+ conditions, both effects led to a warming of IW.
- Which effect is dominant in warming the IW in the fjords?

3. What are some advective timescales?

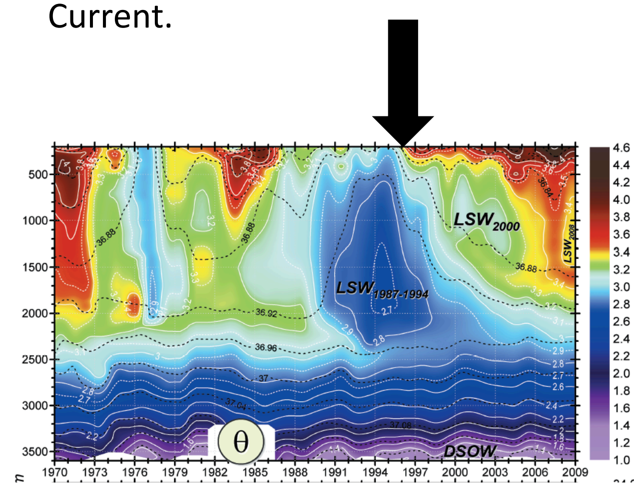
From Denmark Strait to Disko Bay ~ 1 year



What about the arrival of the ‘pulse’ that ‘travelled along the W. Greenland coast during the 1990s’? arriving in 1997 reported by Holland et al 2008?



Perhaps there was no advective pulse. After the intense winters of the NAO+ early 1990s ended, the LS interior warmed, which then reduced the lateral eddy heat flux divergence from the IW on the W. Greenland Current.



Consequently, in each following summer observation period, the T of the IW on the WGC was warmer when arriving in Disko Bay, giving the appearance of a slowly propagating advective pulse.


Large scale circulation + variability
Cross-shelf transport
implications for observing interannual Irminger Water variability on the shelf

The seafloor topography around Greenland determines whether and how warm ocean waters flow up to the glacial fjords.

Physically, the leading order balance for a geostrophic, weakly stratified, quasi-barotropic flow is approximately,

$$\vec{u}_h \cdot \nabla_h \left(\frac{f}{H}\right) = 0$$

Where

u_h horizontal velocity

f Coriolis parameter

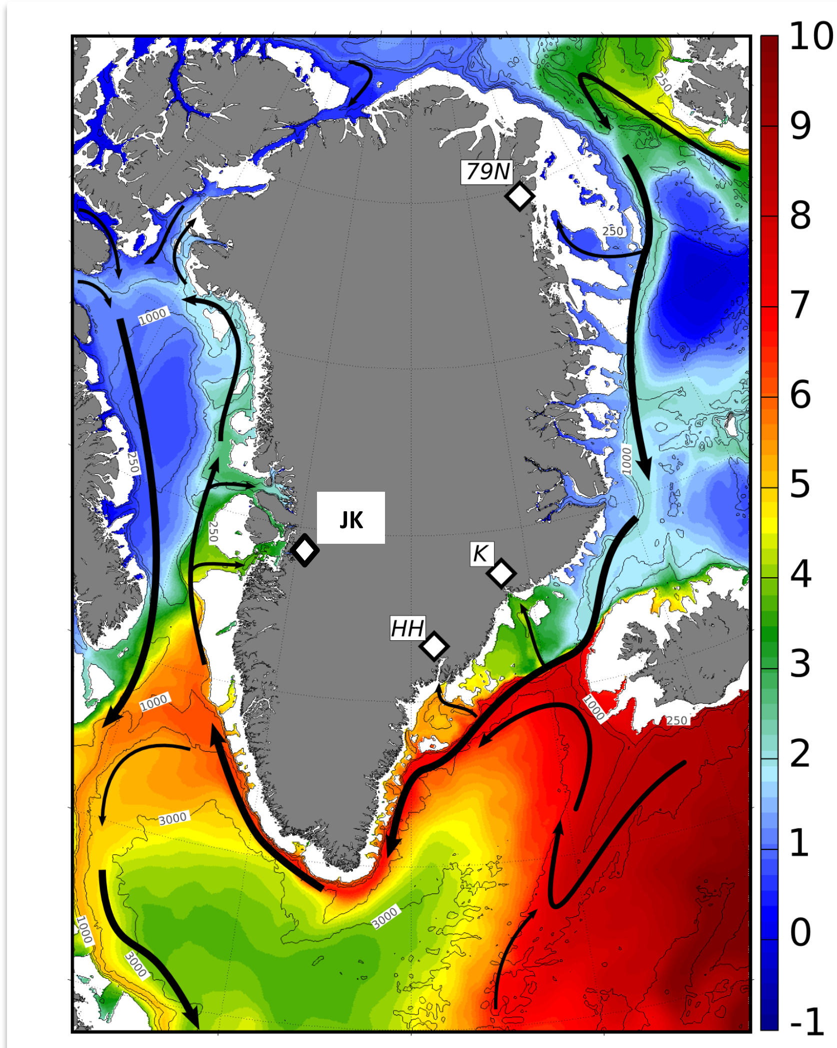
H fluid depth

For Greenland boundary currents, variations of f << H

Subject to other restrictions: e.g.,

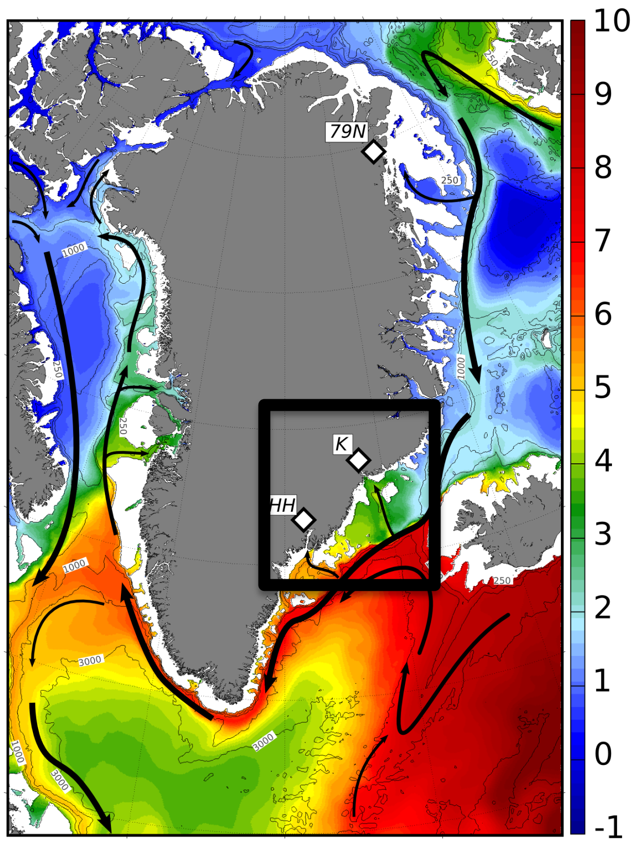
Length scale of along-flow bathymetric variations must be greater than the Rossby deformation radius

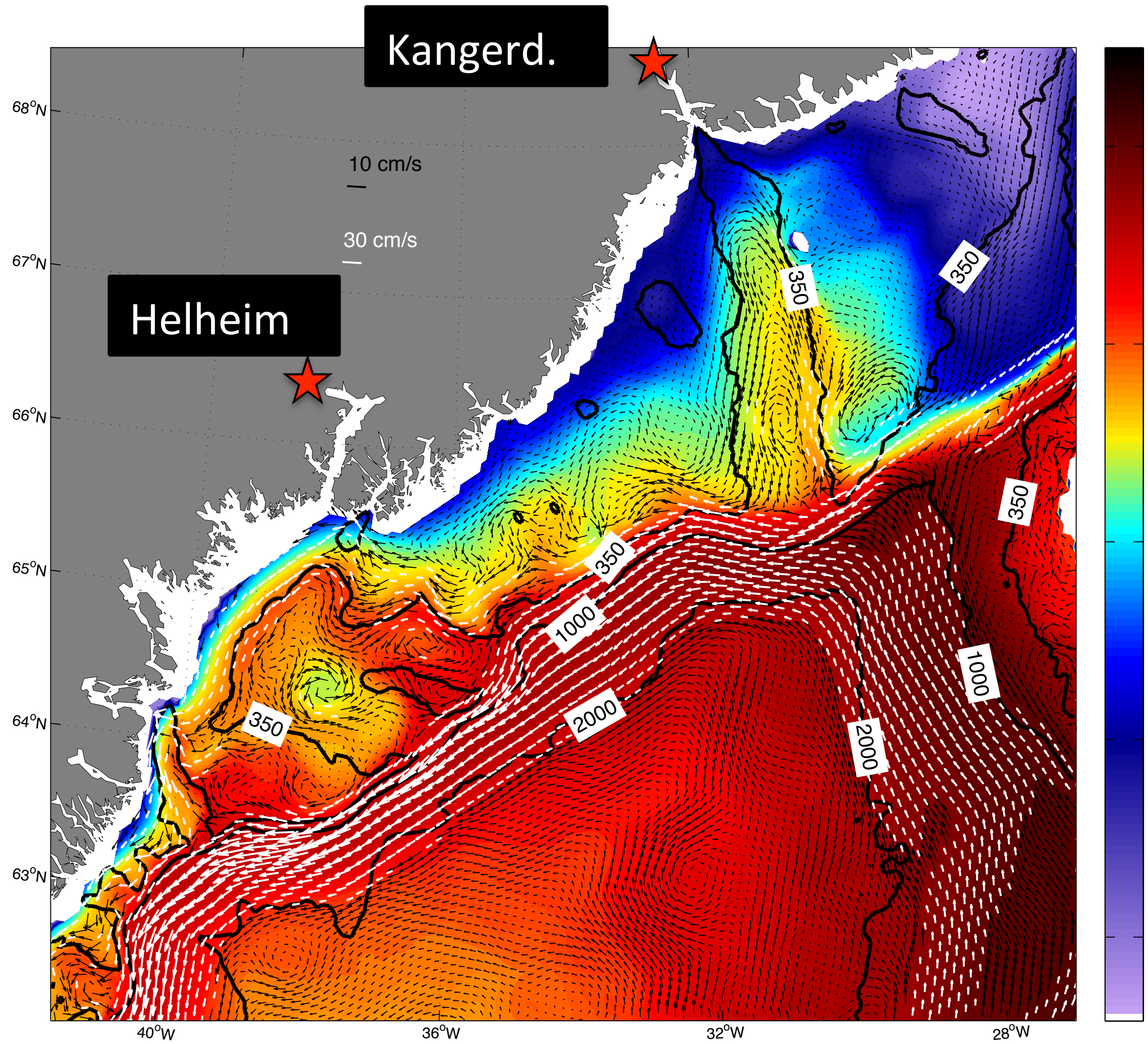
(approx 5-10 km) in region



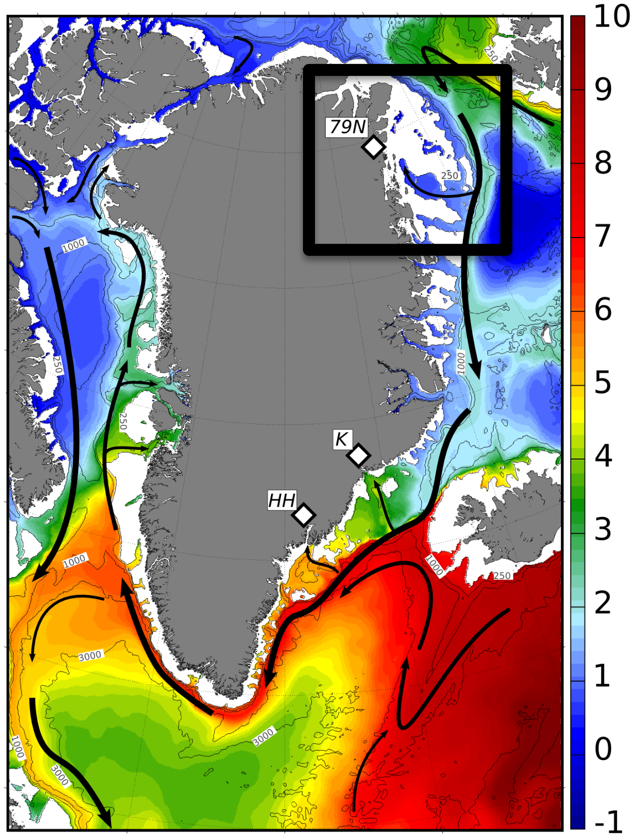
In SE Greenland, mean subsurface circulation (200 m) follows f/H contours, bringing IW up submarine troughs towards Kanger and Helheim

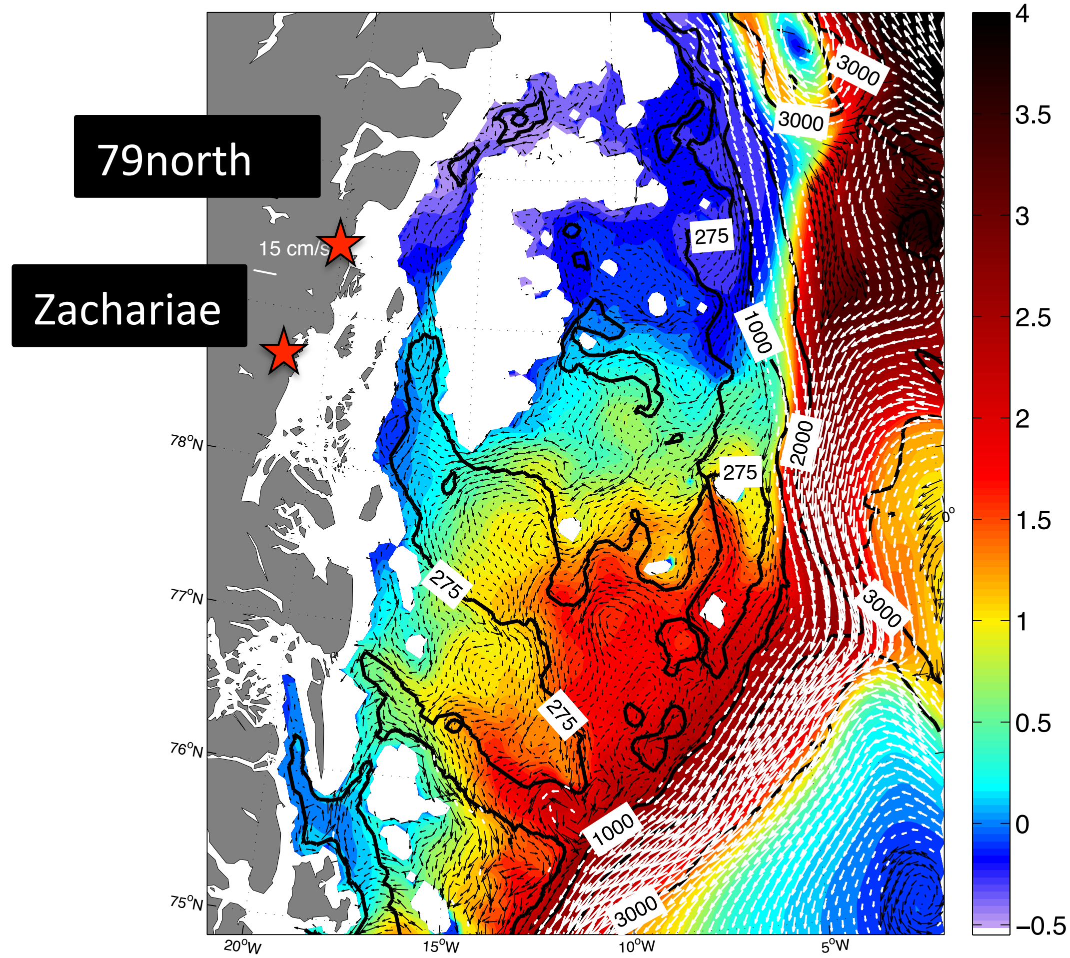
6 km MITgcm configuration of Arctic/North Atlantic ocean-sea ice model from D. Menemenlis





In NE Greenland, mean subsurface circulation (200 m) follows f/H contours, bringing modified Atlantic Waters up submarine troughs towards Zachariae Isstrøm and 79north



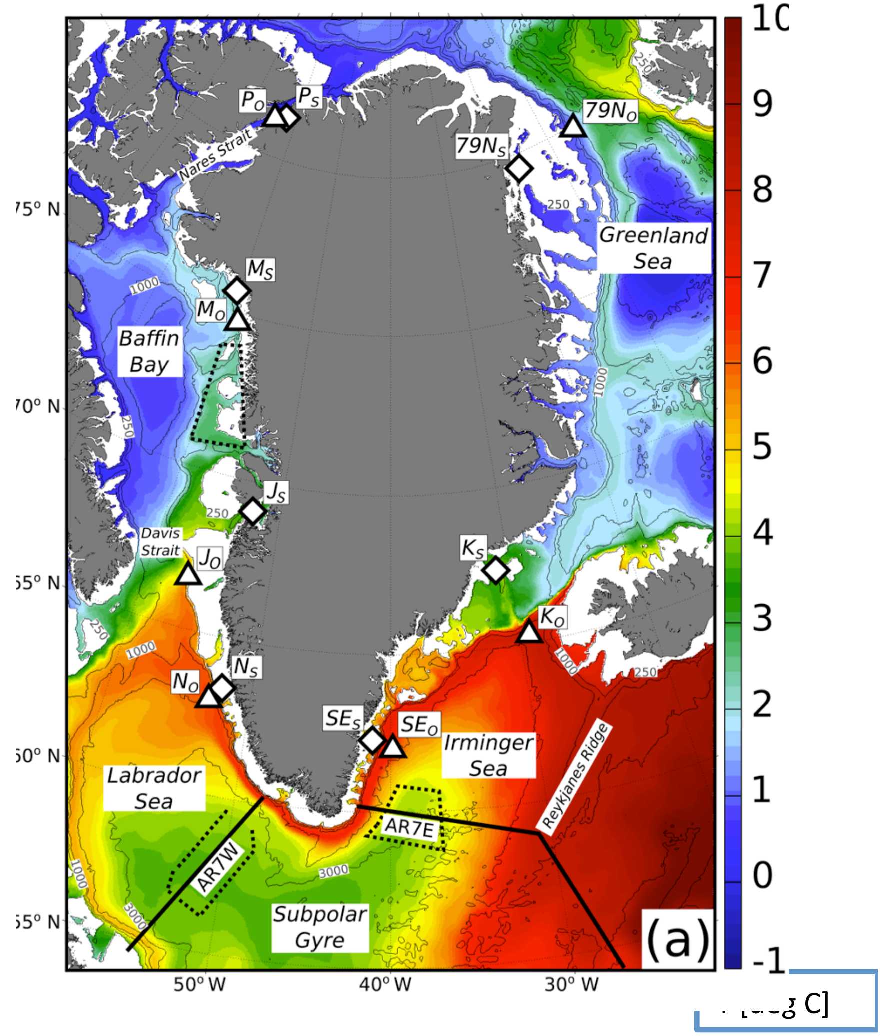


Q1) *Can a state-of-the-art ocean model reproduce a propagating ocean warming signal around Greenland that is consistent with ocean observations and synchronous with the observed thinning and acceleration of tidewater glaciers?*

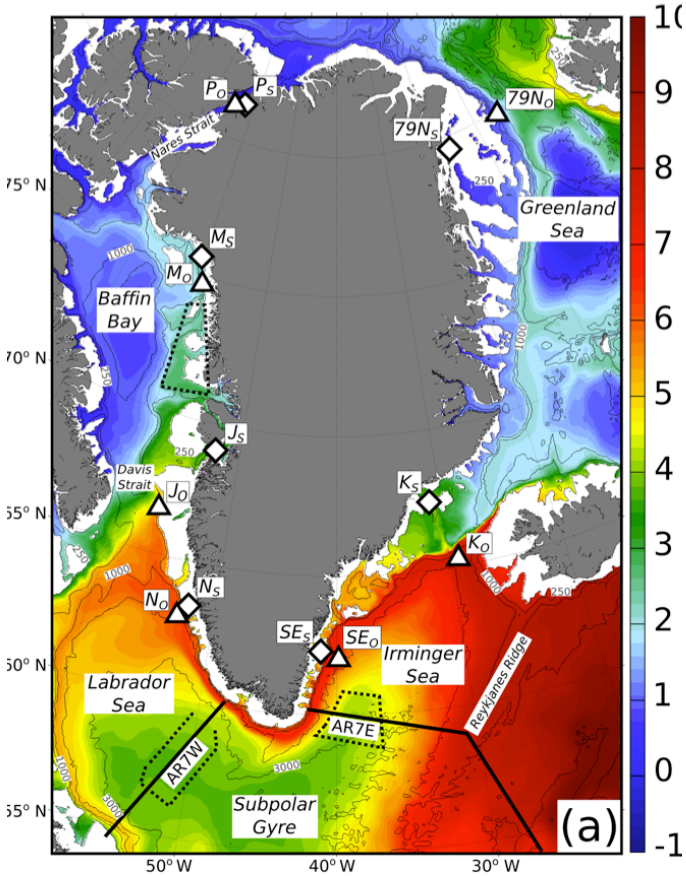
Method:
Force a pre-optimized configuration of a high-resolution ocean model with NCEP/NCAR atmospheric reanalysis over the period 1992-2010 and compare model output to *in situ* ocean observations in the region.

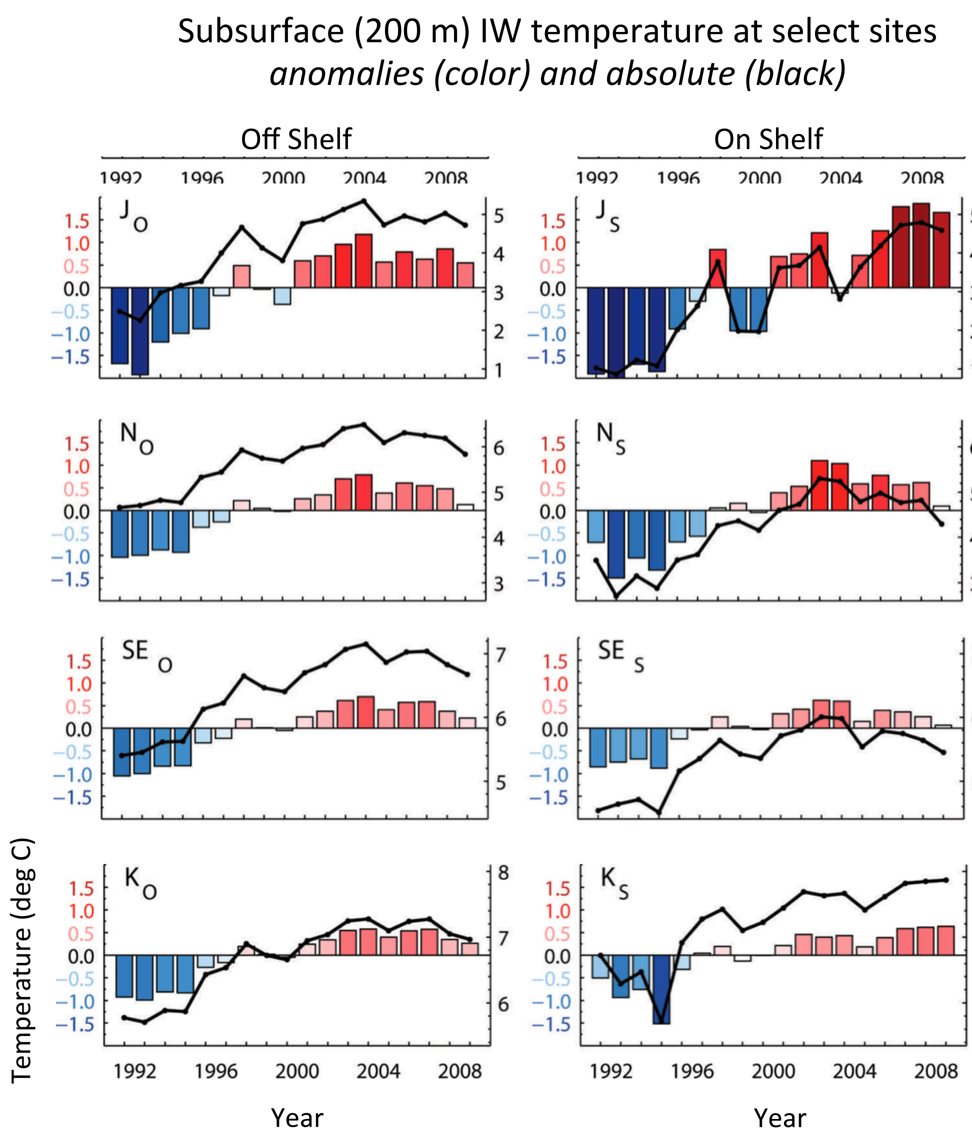
Q2) ***Is the propagating ocean warming signal communicated onto the shelf to the entrance of the outlet glacier fjords?***

Method:
Simultaneously analyze the ocean temperatures at the **mouths of tidewater glacial fjords** and at **nearby locations off the shelf**.



The model shows that warm ocean temperature anomalies are rapidly transmitted onto the shelf towards the fjords at each site.



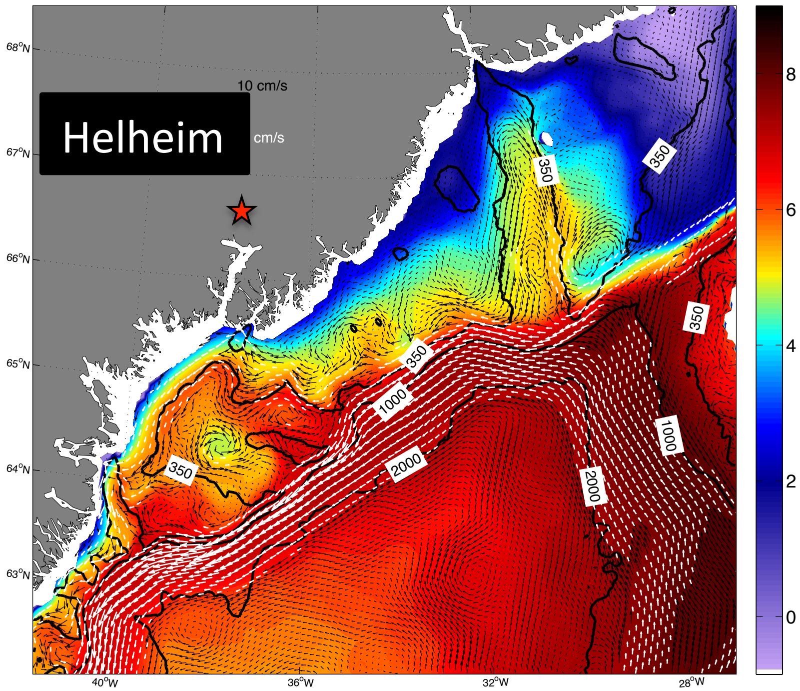


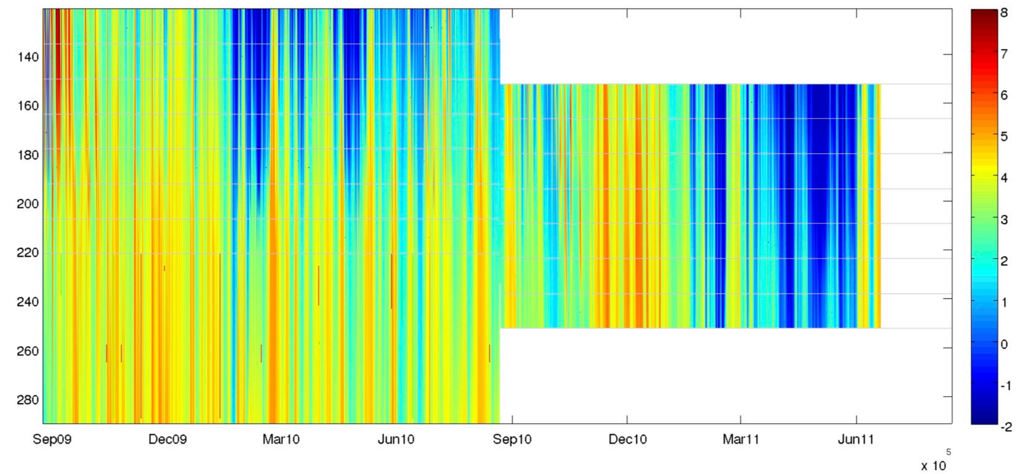
Conclusions

- A state-of-the-art ocean model can reproduce a propagating ocean warming signal around Greenland that *is consistent with many in situ ocean observations* and *synchronous with the observed thinning and acceleration of tidewater glaciers*.
- Propagating ocean warming signals are *communicated onto the shelf to the entrance of the outlet glacier fjords*.
- However, considerably more work needs to be done at higher model resolutions to study how these warm waters propagate up the fjords to the glacial termini.

• Large scale circulation + variability
• Cross-shelf transport
• implications for observing interannual Irminger Water variability

IW temperatures in Sermilik exhibit large seasonal and high-frequency variability
~6 degrees at 240 m





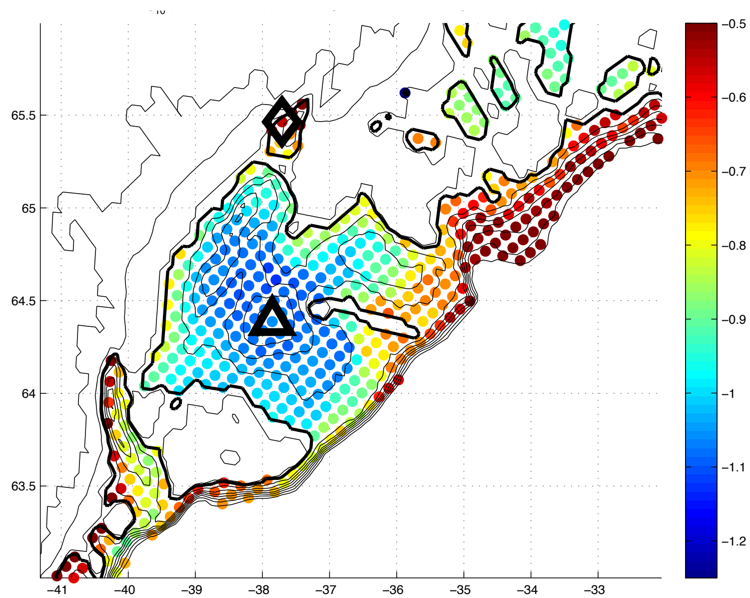
Straneo pers. comm

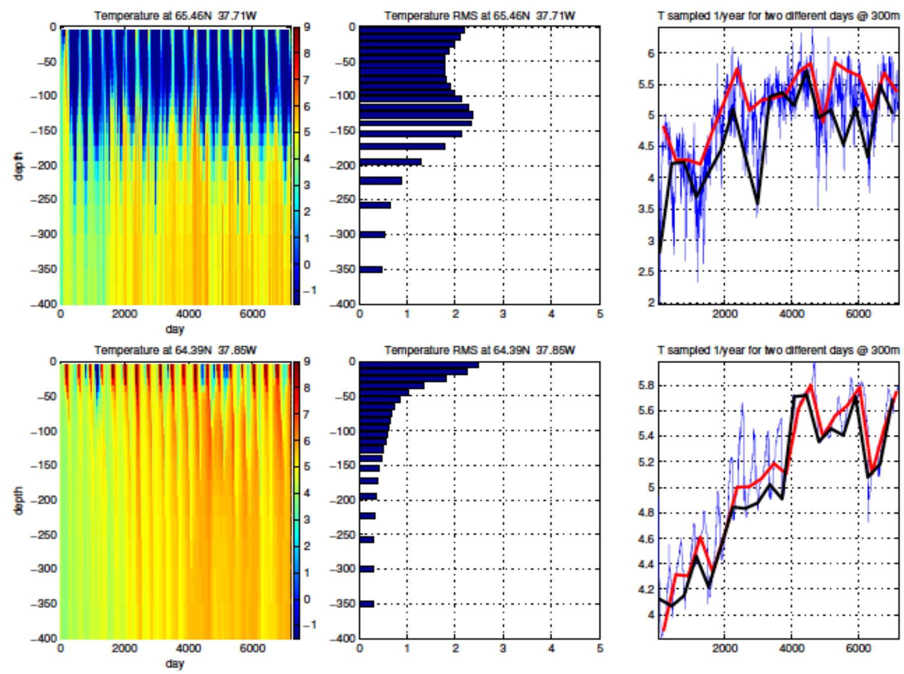
- Instrumenting each of Greenland's fjords with moorings to monitor their interannual temperature variability is unfeasible.
- Can we use the model to identify sites on the continental shelf that (1) do not exhibit high-frequency temperature variability and (2) are highly correlated with the mean fjord temperature?
- If so, then sampling those sites may be a cost-effective way of getting a handle on the fjord temperature variability

Infrequent sampling at the mouth of fjords with high temperature variability may miss interannual trends.

However, there may be nearby sites with less high-frequency variability that do reliably capture them.

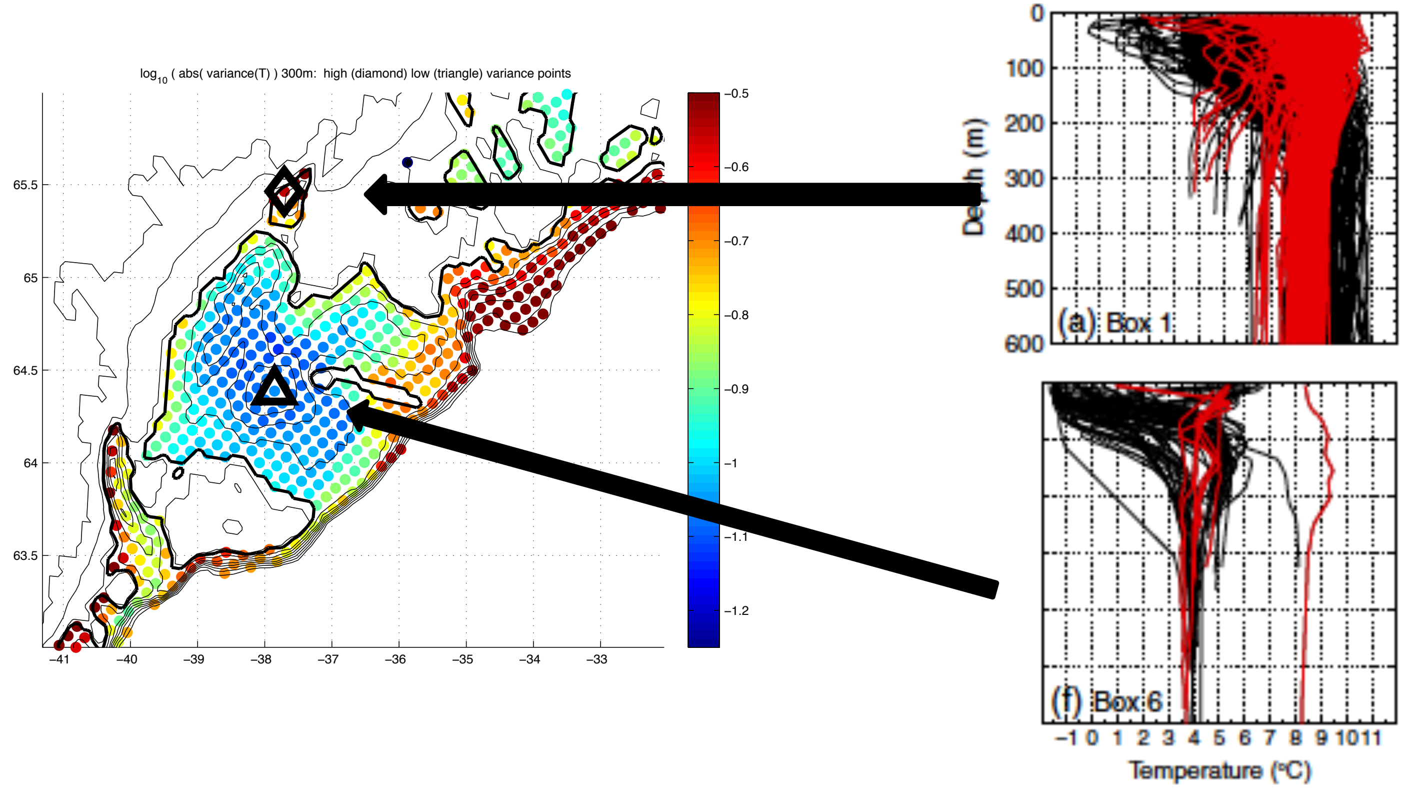
Log10(| temperature variance |) at 300 m





Top Row: High variance site near the fjord mouth. (Diamond)
Bottom Row: Low variance site on the shelf (Triangle)
Left column: ocean T vs. depth over the simulation period;
Middle column: temperature RMS vs. depth;
Right column: 3-day T at 154 m (blue), and the T time series corresponding to hypothetical annual measurements for two different days of the year (red and black).

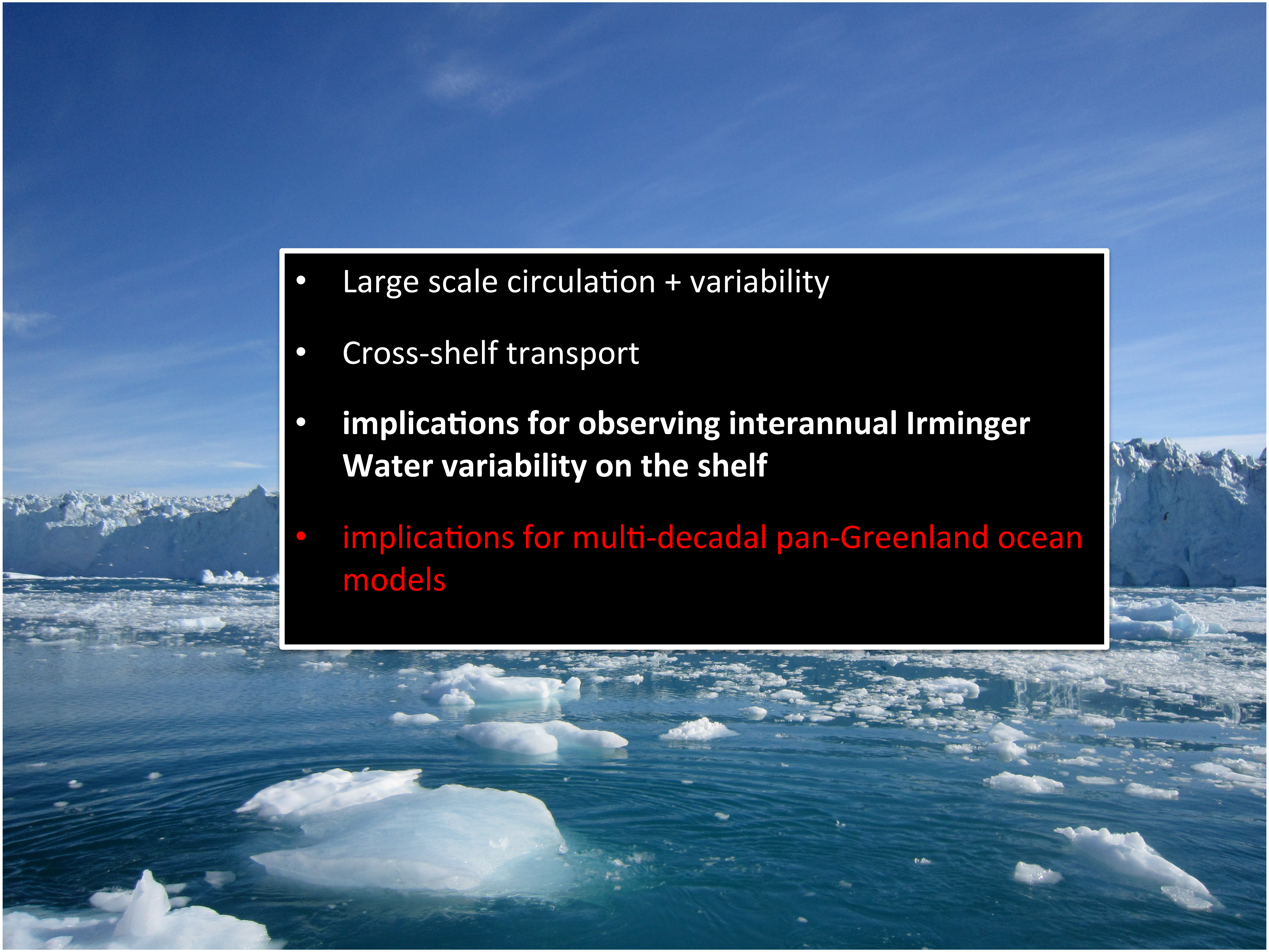
In situ sampling from instrumented seals shows that the model is capturing the spatial pattern of IW temperature variance on the shelf.



Sutherland et al 2013

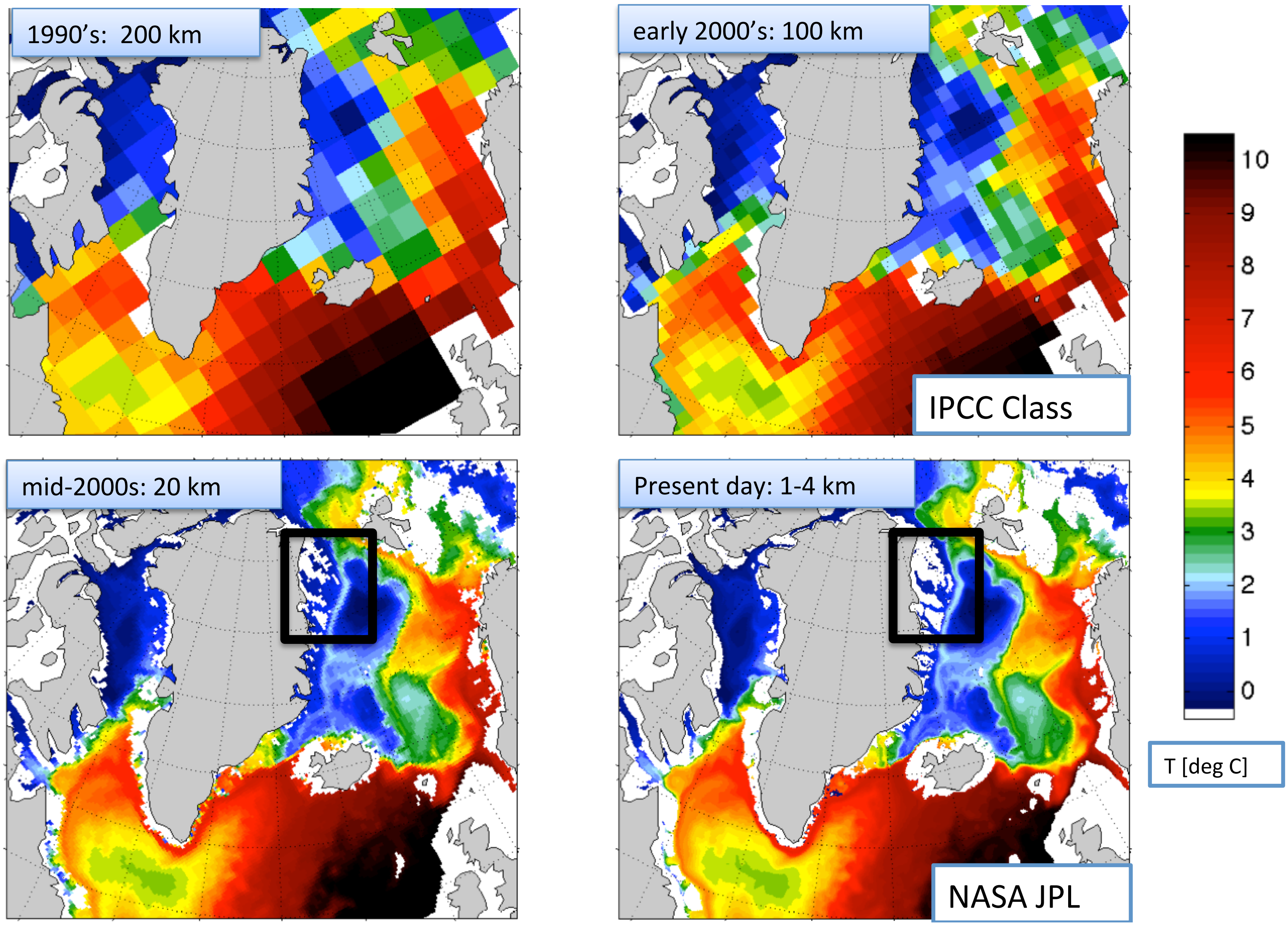
More work is needed to determine to what extent the mean fjord temperatures predict actual ice-ocean melt rates


End.

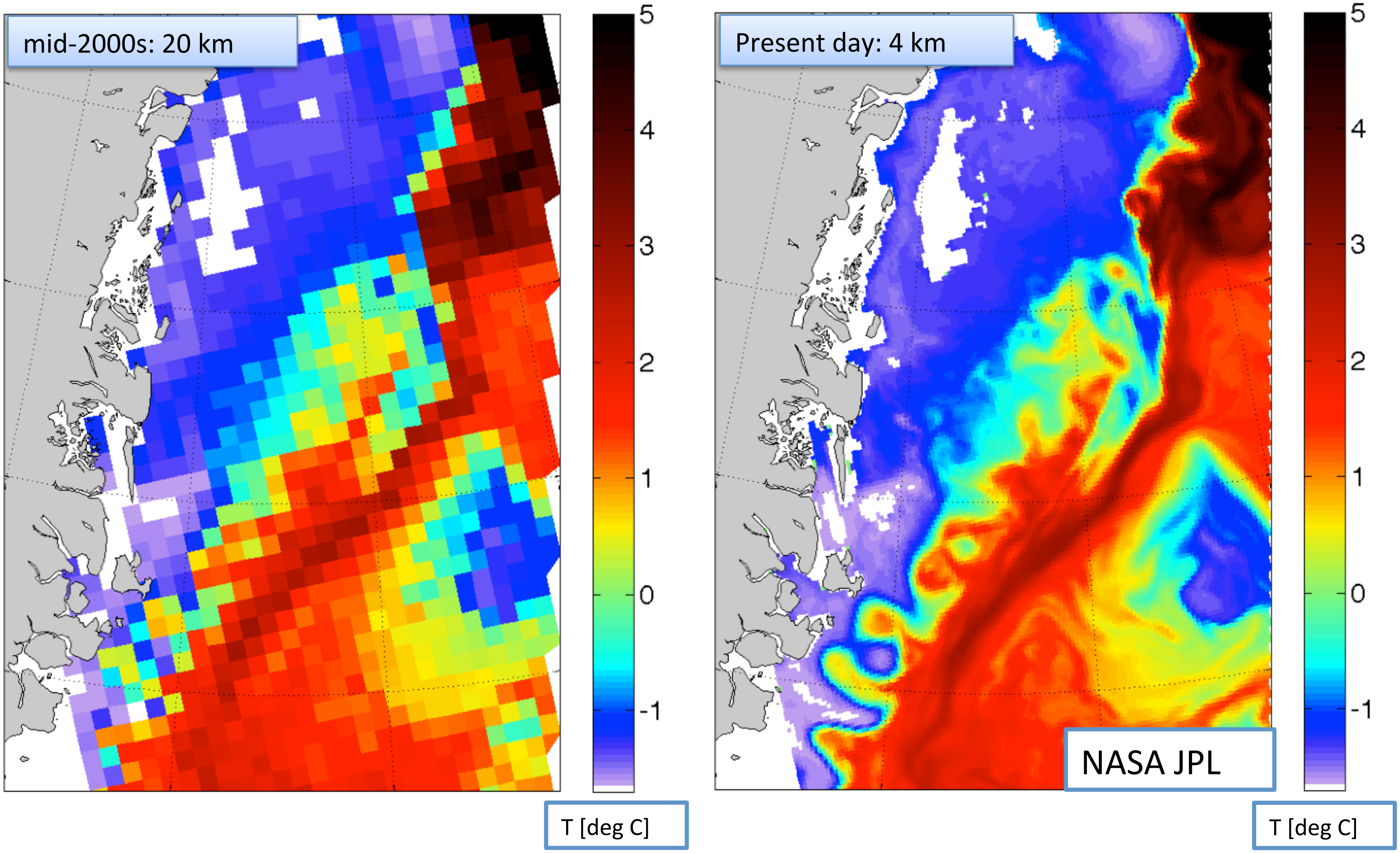


- Large scale circulation + variability
- Cross-shelf transport
- **implications for observing interannual Irminger Water variability on the shelf**
- implications for multi-decadal pan-Greenland ocean models

Contemporary ocean models can now realistically simulate the ocean currents and temperature around Greenland.

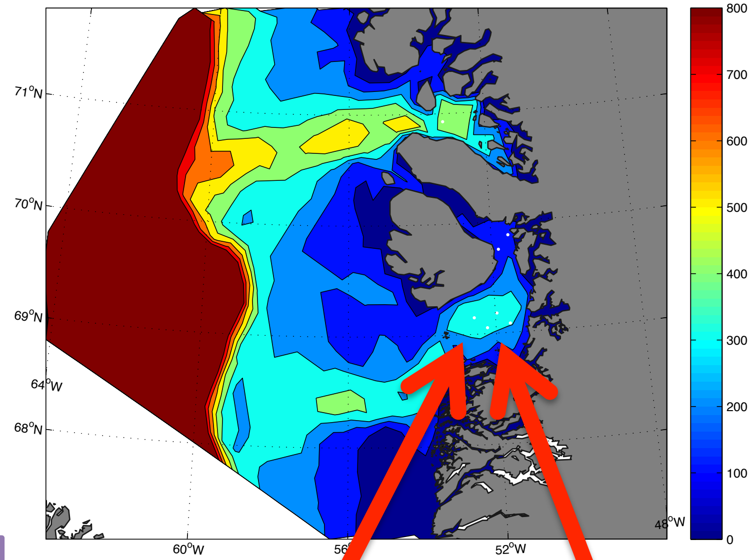


The recent advances in our available ocean modelling tools permits the investigation of ocean-ice sheet interaction for the first time.

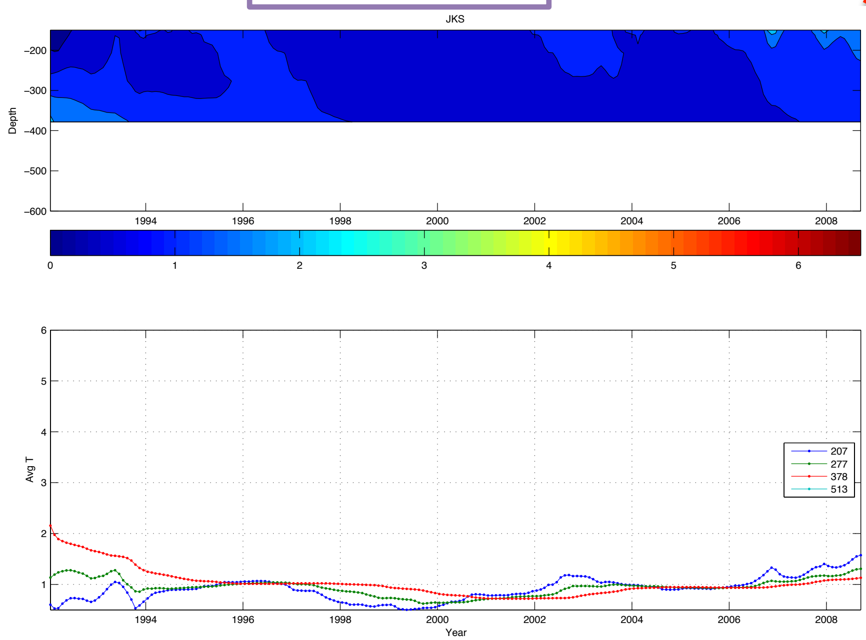


Warming but *far* lower than 9 km and Holland 2008

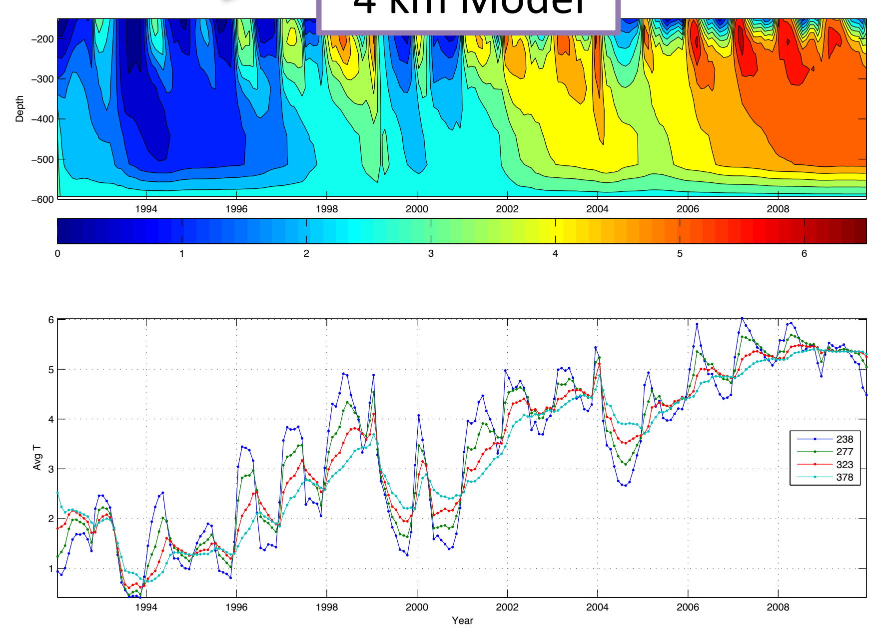
Here, maximum colorbar is 1.5 degC whereas Holland's is 5 degC



18 km Model



4 km Model



Implications for modelling