(Some evidences of the) Importance of scale interactions for the Arctic dynamics

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Polar climates workshop – November 2018

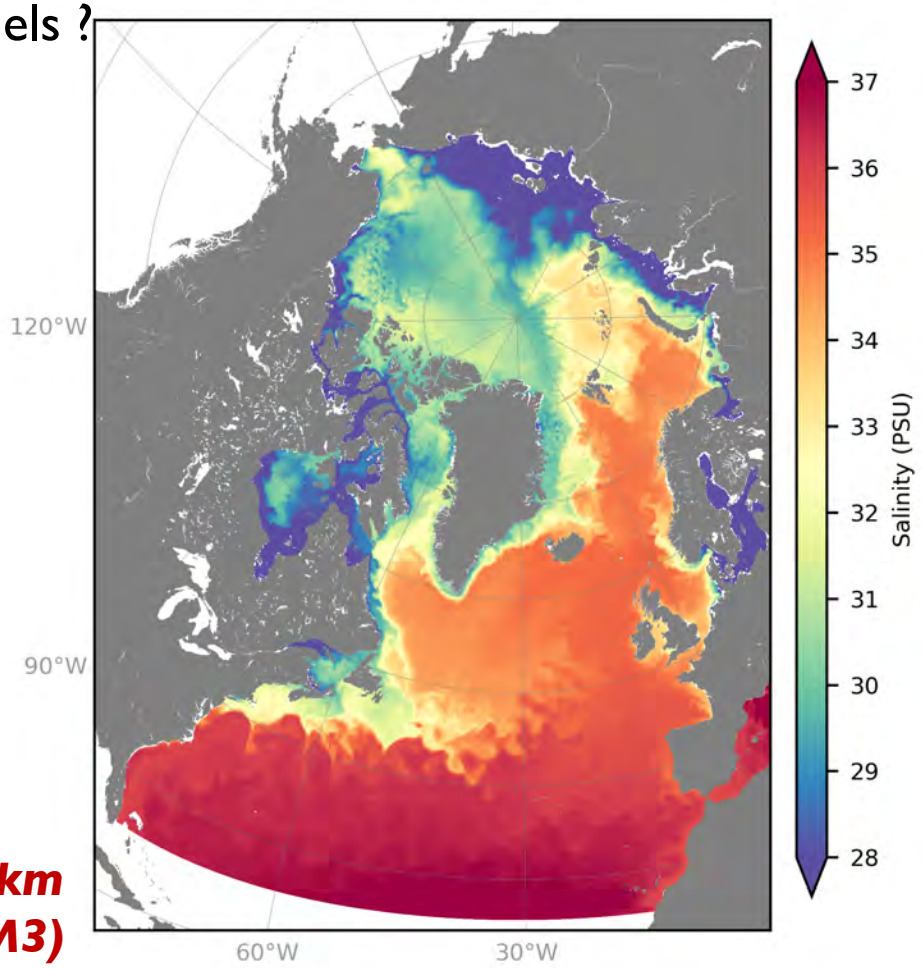
Motivating questions

- How does bathymetry influence the ocean circulation (at all depths, at large and small scales) and sea ice ?
- How does the mesoscale ocean dynamics interact with the large scale ocean circulation and sea ice?
- What are we potentially missing by not representing the mesoscale dynamics and scale interactions in state-of-the-art models ?

Aim of this talk:

Discuss some specific examples, *from observations or process models*, showing the importance of scale interactions :

- *Bathymetry, front and sea ice in the Barents Sea*
- *Bathymetry, eddies, and the dynamics of the Beaufort Gyre*
- *Interplay between mesoscale and sea ice*



Snapshot (18/08/2000) of SSS from a 4 km resolution simulation (NEMO-LIM3)

Bathymetry, front and sea ice

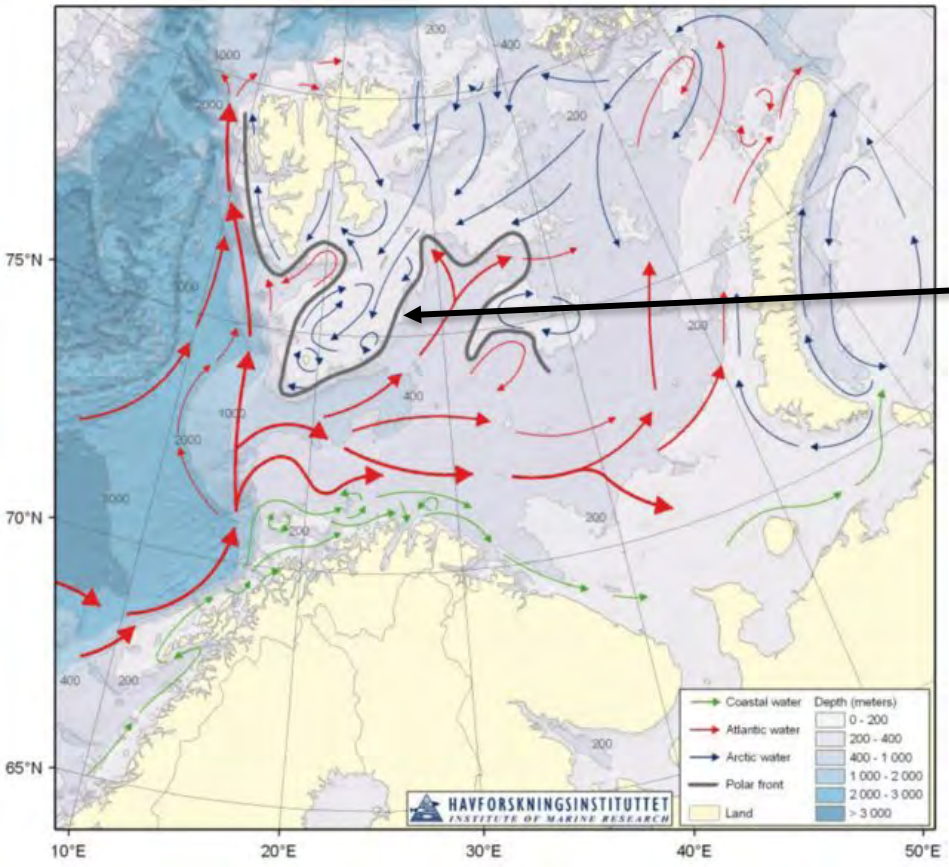
Important features in the Barents Sea:

> *formation of 'Barents Sea Water' through exchange with the atmosphere.*

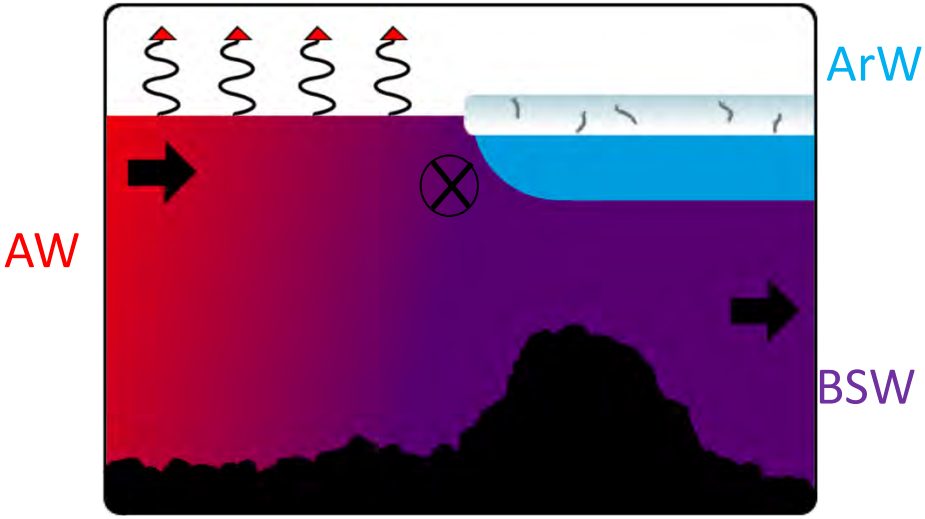
> *BSW contributes to AMOC (eventually)*

> *largest loss of winter sea ice since 1850 (Onarheim & Arthun 2017)*

> *Seasonal forecast relatively easy (Sigmond et al. 2016)*



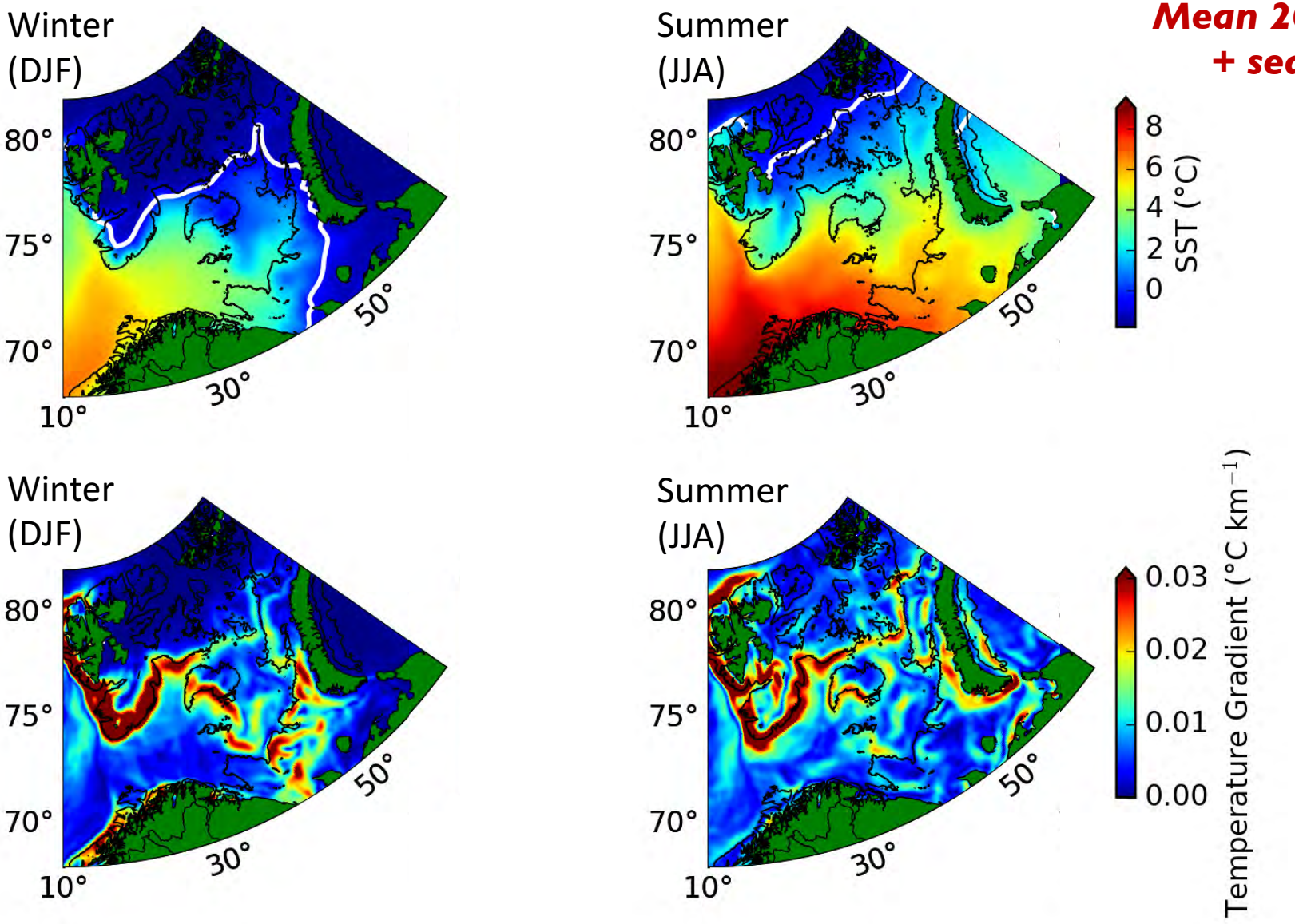
Schematic of the polar front



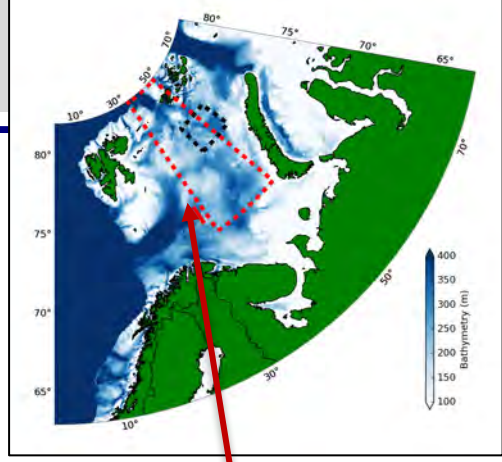
Bathymetry, front and sea ice

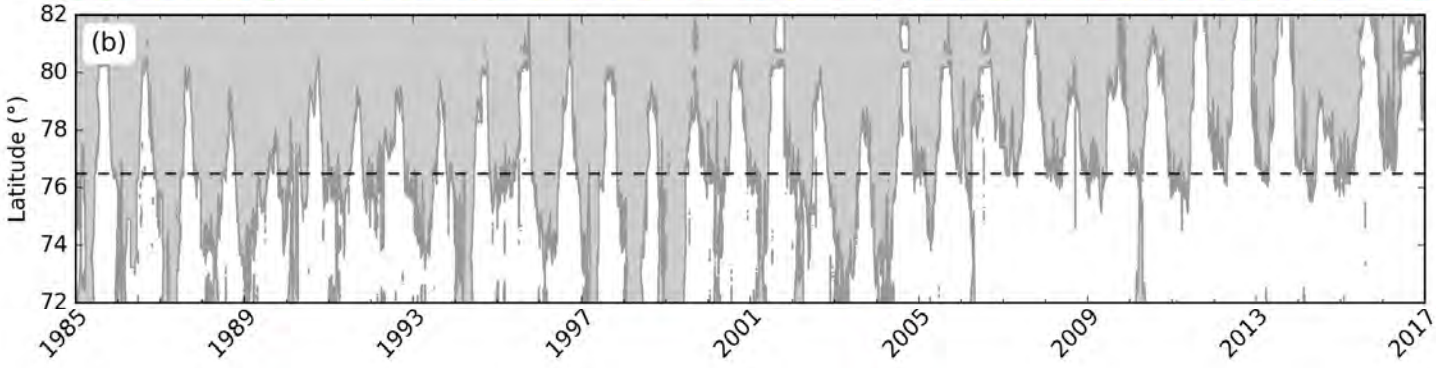
Detection of the Polar front from SST observations (HR OSTIA dataset – Donlon et al. 2012)

Mean 2005-2017
+ sea ice edge



Bathymetry, front and sea ice





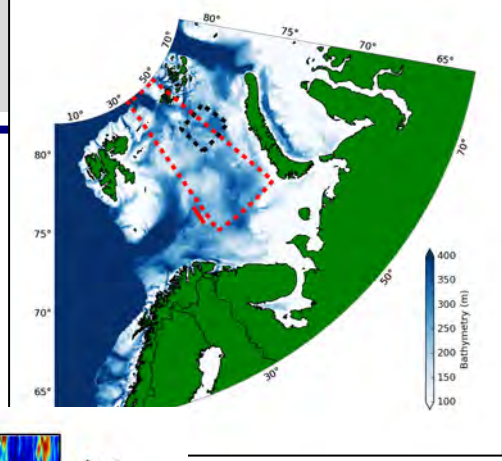
Position of the sea ice edge

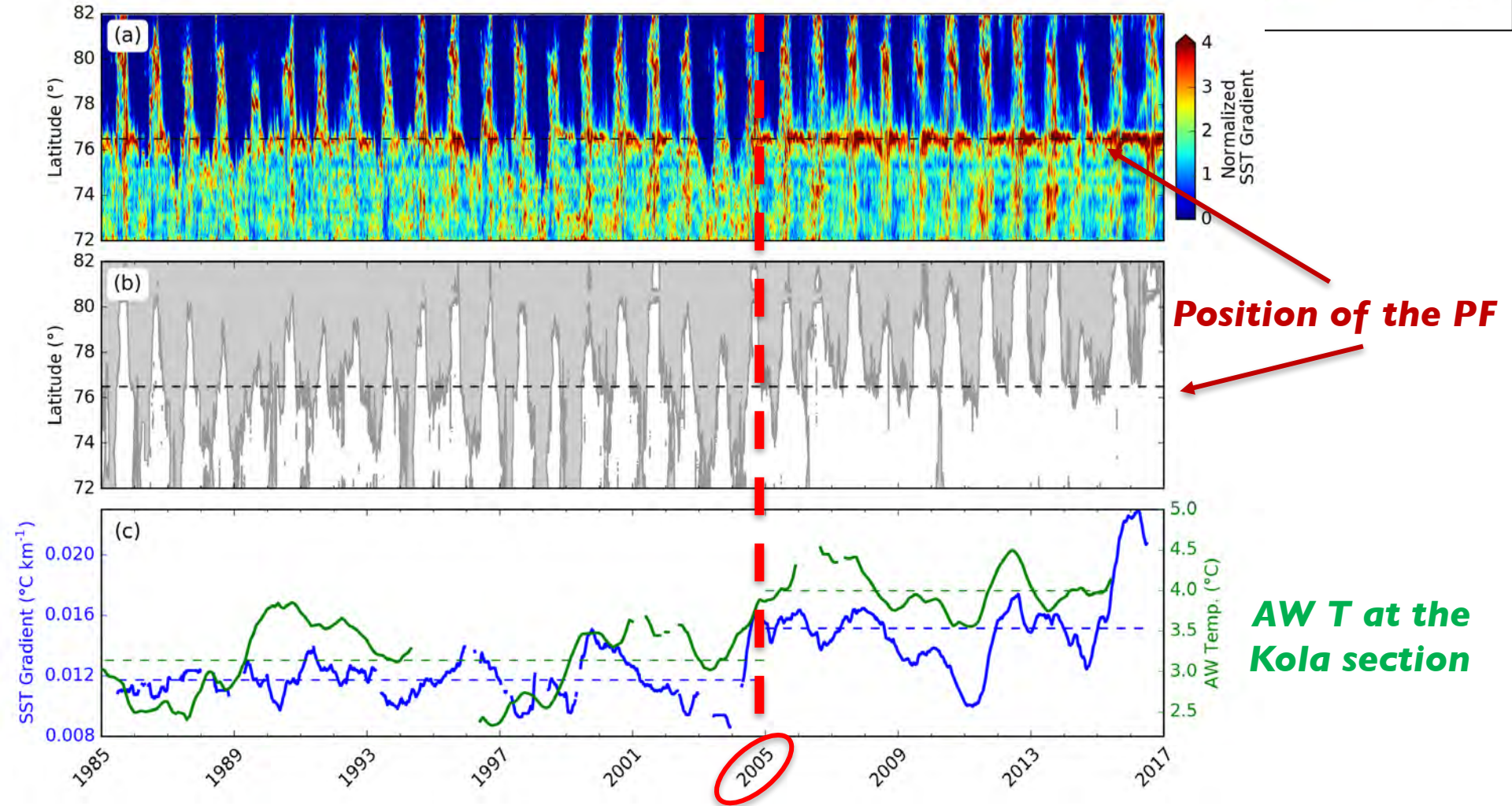
Bathymetry, front and sea ice

Regime shift in 2005!

> *Intensification of the SST gradient*

> *winter sea ice expansion limited by the PF*

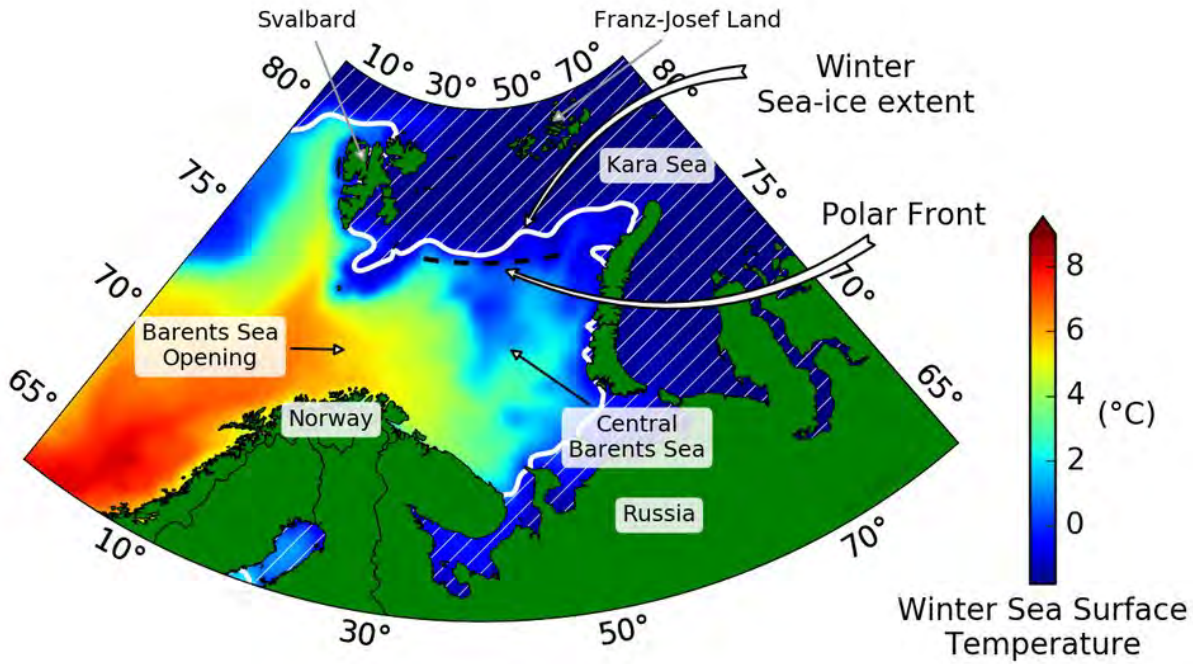




Bathymetry, front and sea ice

- *The Polar Front is fixed to the ~220m isobath*

  > shelf slope current constrained by potential vorticity

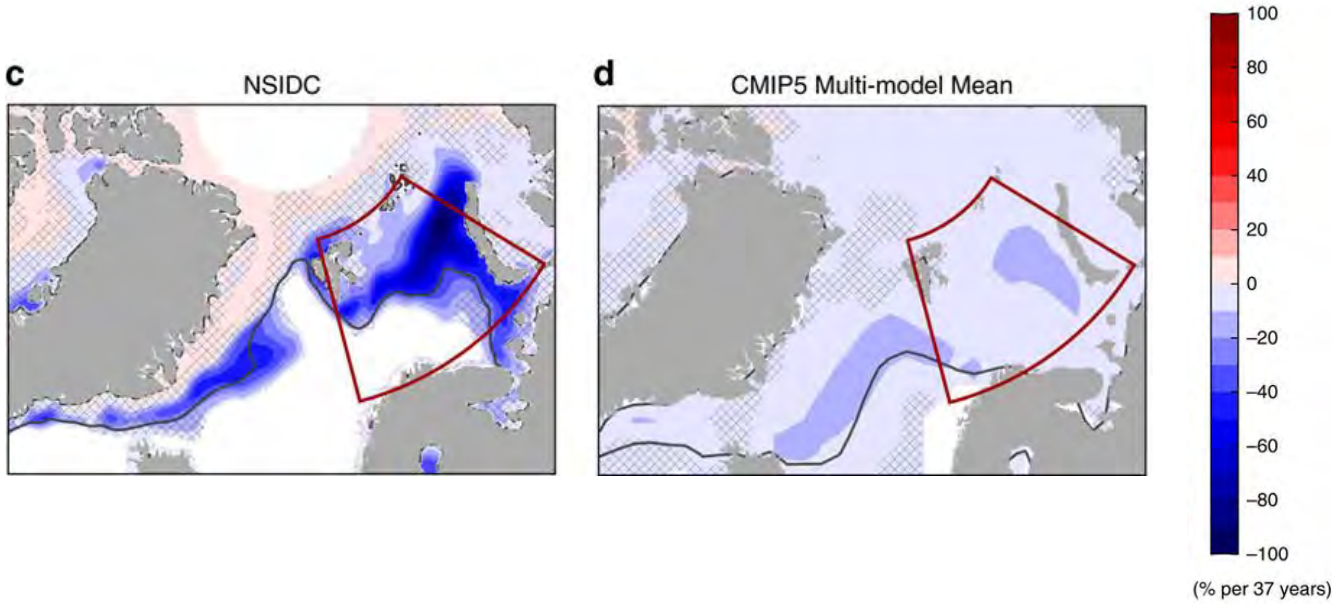


- *Intensification of the PF contrains the winter extention of sea ice, with potential implications for the BSW (warmer saltier and denser)*

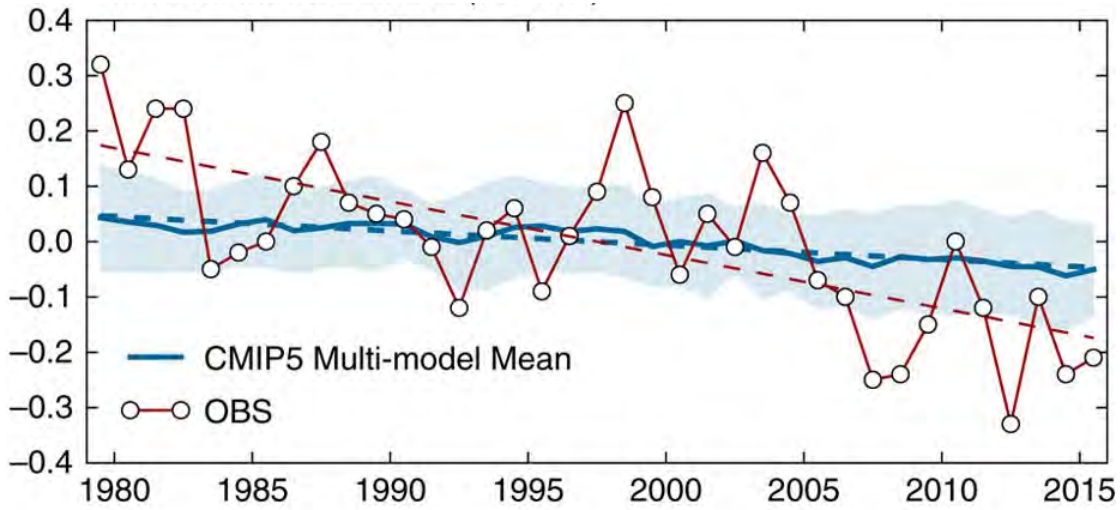
  … and for sea ice seasonal and (multi-) decadal projections ?

Bathymetry, front and sea ice

Winter sea ice retreat in the Barents Sea from CMIP5 models:



March SIC trend over 1979–2015.



March extent in the Barents Sea.

Li et al. 2017

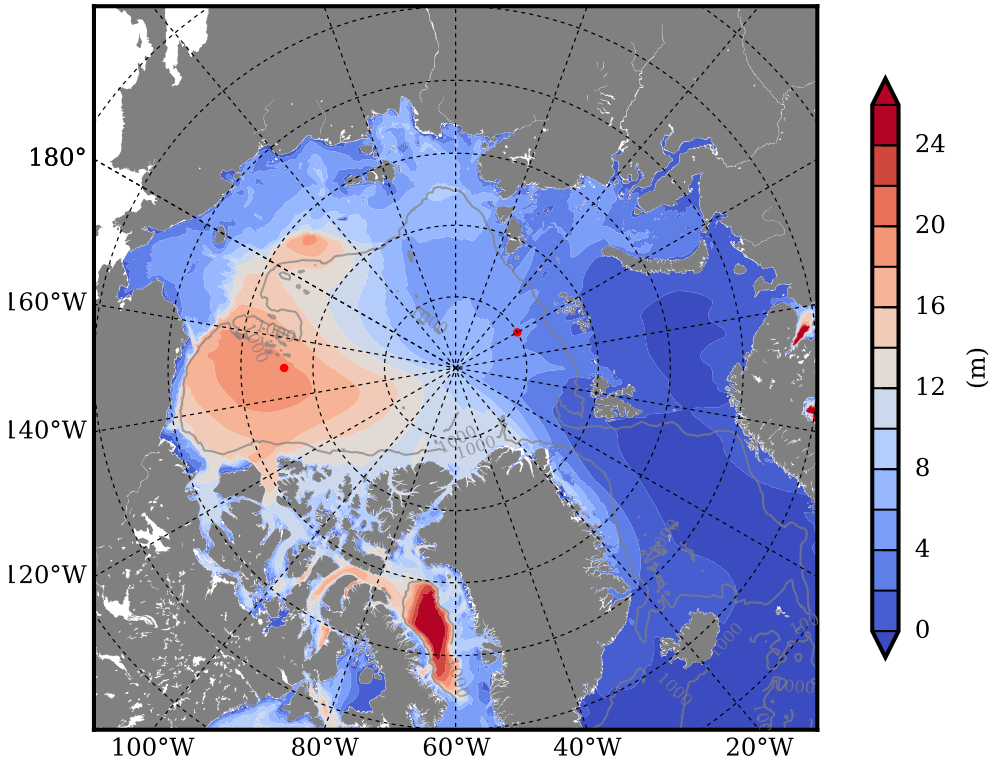
Bathymetry, gyre and eddy

Main features of the Beaufort Gyre:

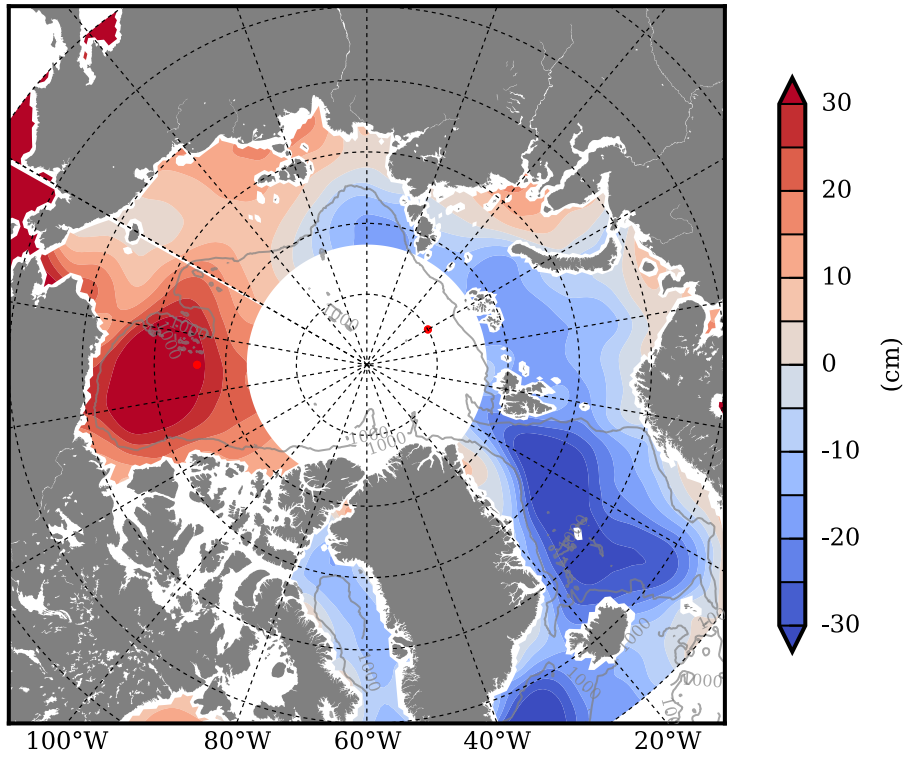
> Large reservoir of FW, large signature in SSH constrained by the slope on its southern side

> Potentially controls FW export to the N. Atlantic, with effect on SSS downstream, and potentially deep convection and AMOC (Jahn & Holland 2013)

FW content (ref 34.8 psu)
WOA climatology



Mean SSH (2003-2014)
Armitage et al. 2017



Bathymetry, gyre and eddy

Functionning of the Beaufort Gyre:

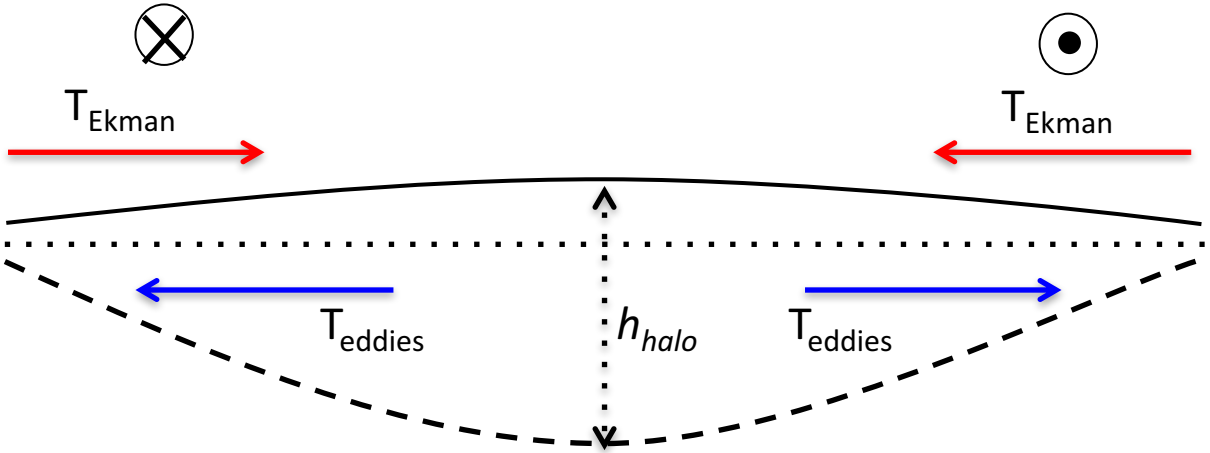
> *The leading order balance has been determined from theory and simple process models*

> *Main balance between Ekman convergence and eddy-induced volume flux:*

$$\frac{\partial h_{halo}}{\partial t} = \nabla \times \frac{\tau}{\rho f} - \kappa \nabla^2 h_{halo},$$

Ekman (from wind and ice, modulated by surface current)

Eddies



Scale analysis suggests adjustment timescale due to eddies is

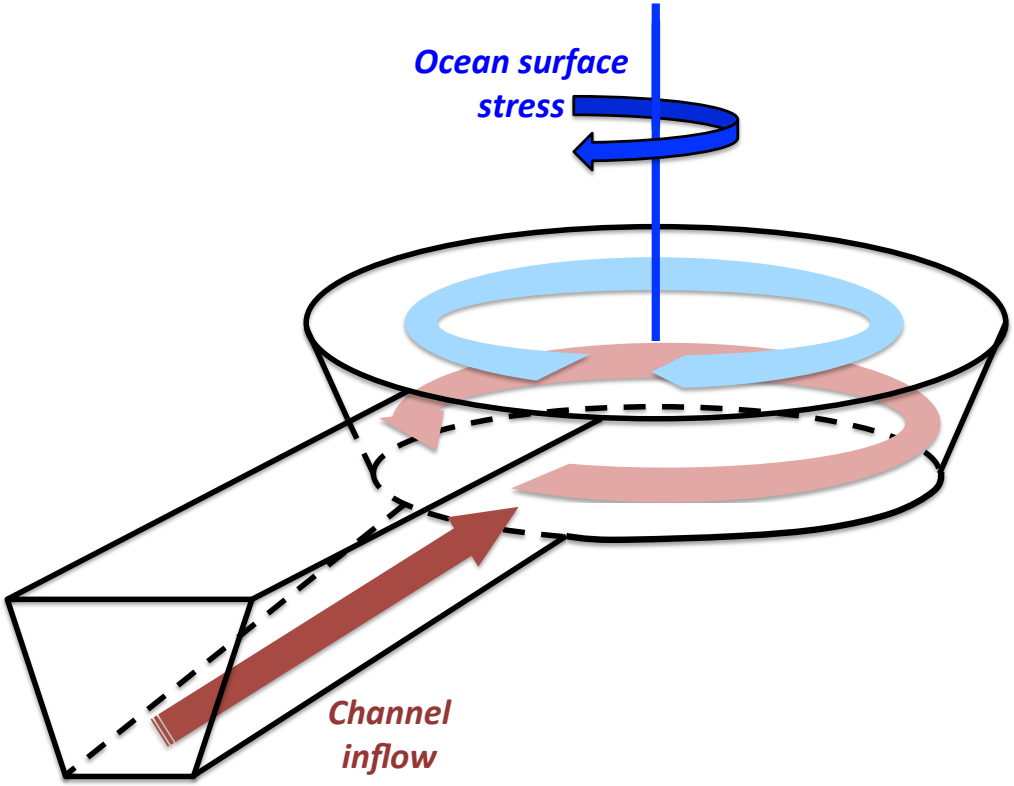
$$\tau \sim \frac{rA}{\kappa\lambda} \sim \frac{r^2}{\kappa} \sim 10 \text{ years}$$

Imply a memory of the forcing over 10 years!

Davis et al. 2014, Manucharyan & Spall 2016, Meneghello et al. 2018

Bathymetry, gyre and AW boundary current

Caveats of the process models : no bathymetry, constant and symmetrical forcing, the Arctic is not just a fresh surface layer…



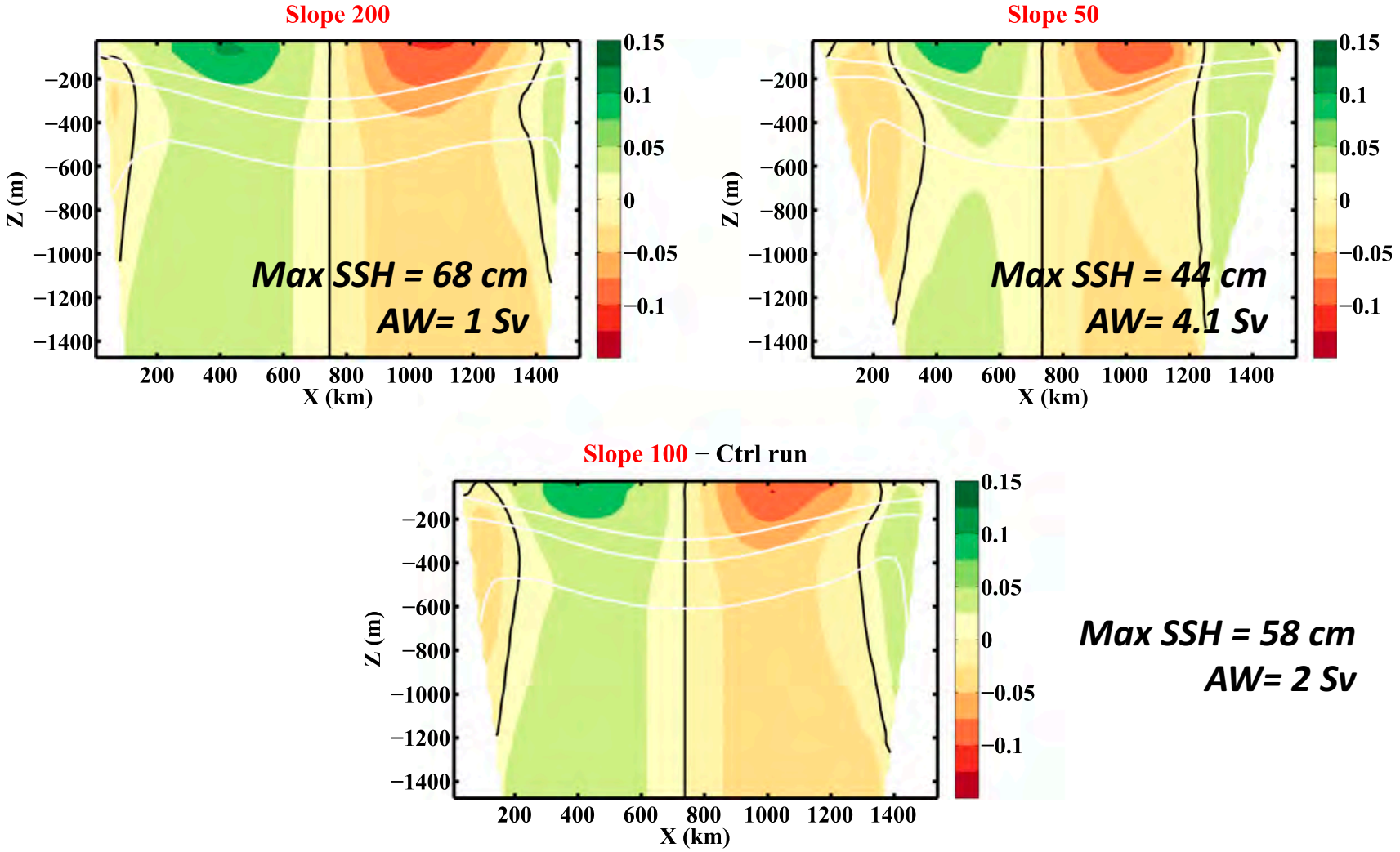
Set up

- *MITgcm in a circular basin*
- *…with a sloping boundary*
- *Forced by an annular surface stress, and an AW inflow*

Lique et al. 2015, Lique & Johnson 2015

Bathymetry, gyre and AW boundary current

Under similar forcing, a change of slope modifies the intensity of the circulation in both the intermediate and the surface layers!



Lique et al. 2015, Lique & Johnson 2015

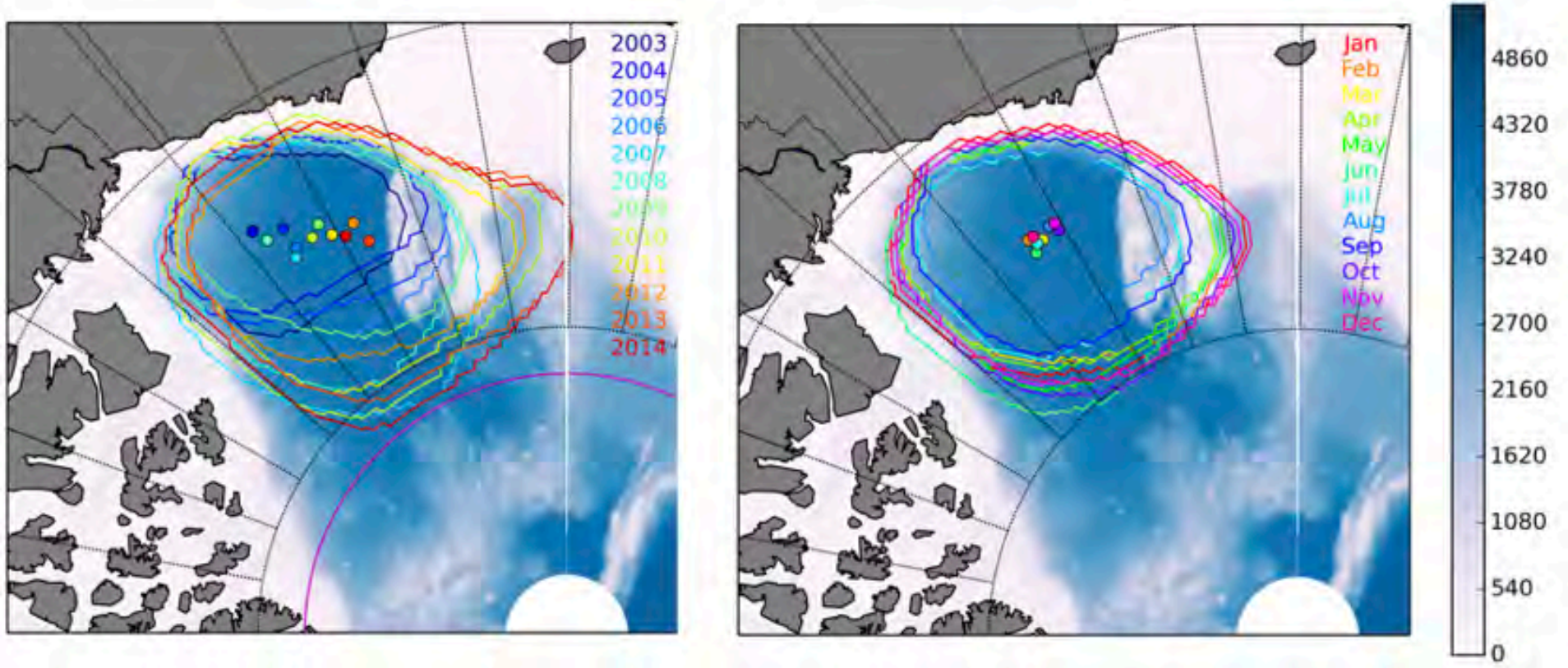
Bathymetry & gyre

Variability of the Beaufort Gyre:

> *Satellite observations of SSH in the ice-covered Arctic allow a description of the gyre*

> *large seasonal, interannual variability + trend!*

> *… the gyre interacts more or less with bathymetry …*



Regan, Lique and Armitage (in rev. JGR)
Dataset: Armitage et al. 2016, 2017

Bathymetry & gyre

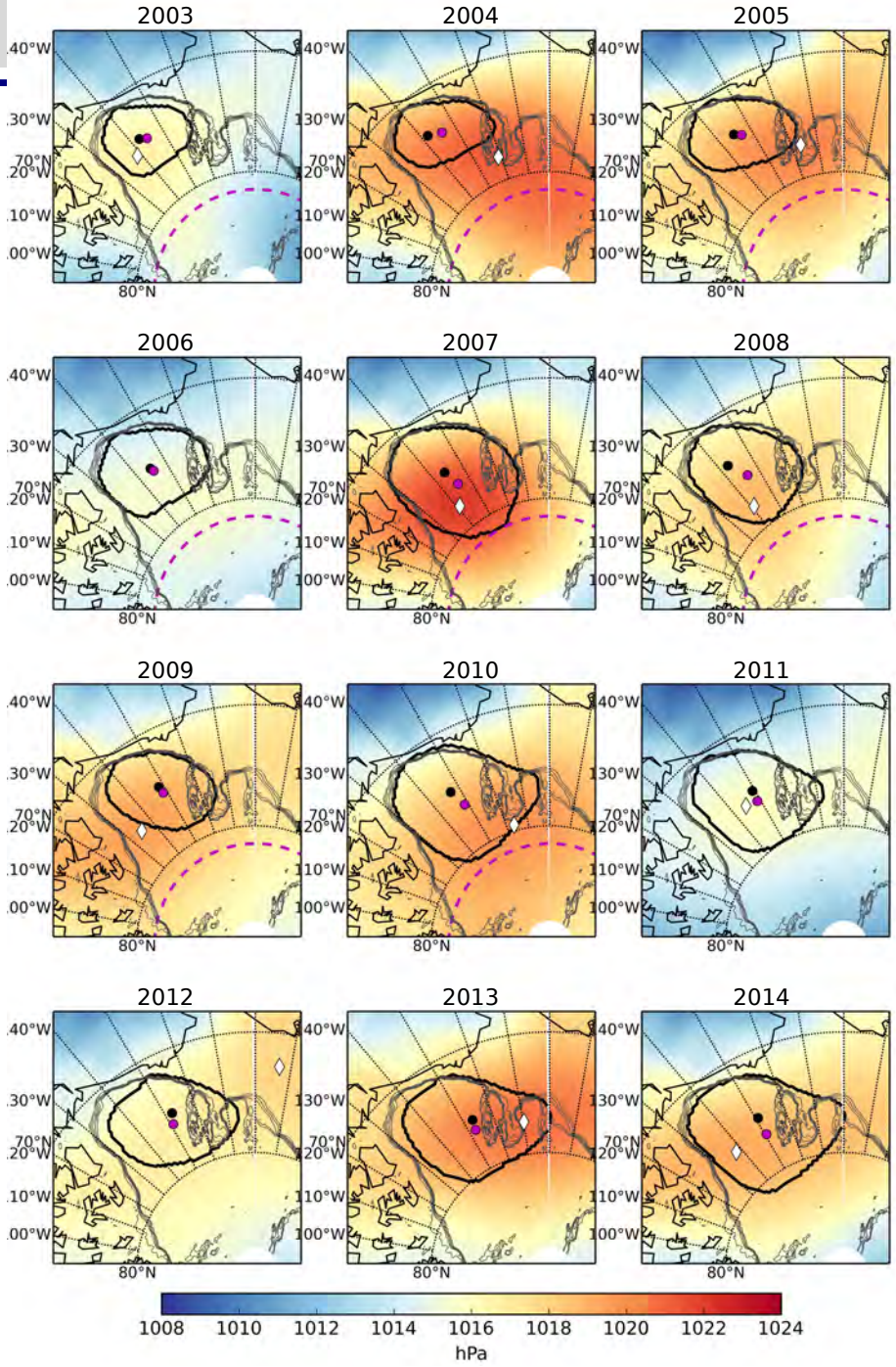
Variability of the Beaufort Gyre:

> *the position, size and intensity of the gyre are determined by the forcing (partly independetly)*

> *Depends on* ***both*** *the intensity and the position of the atmospheric forcing (Beaufort Sea Height)*

+ memory of the forcing over a decade or more (Johnson et al. 2018)

SLP - max: ◊
Max SSH: ●



Bathymetry & gyre

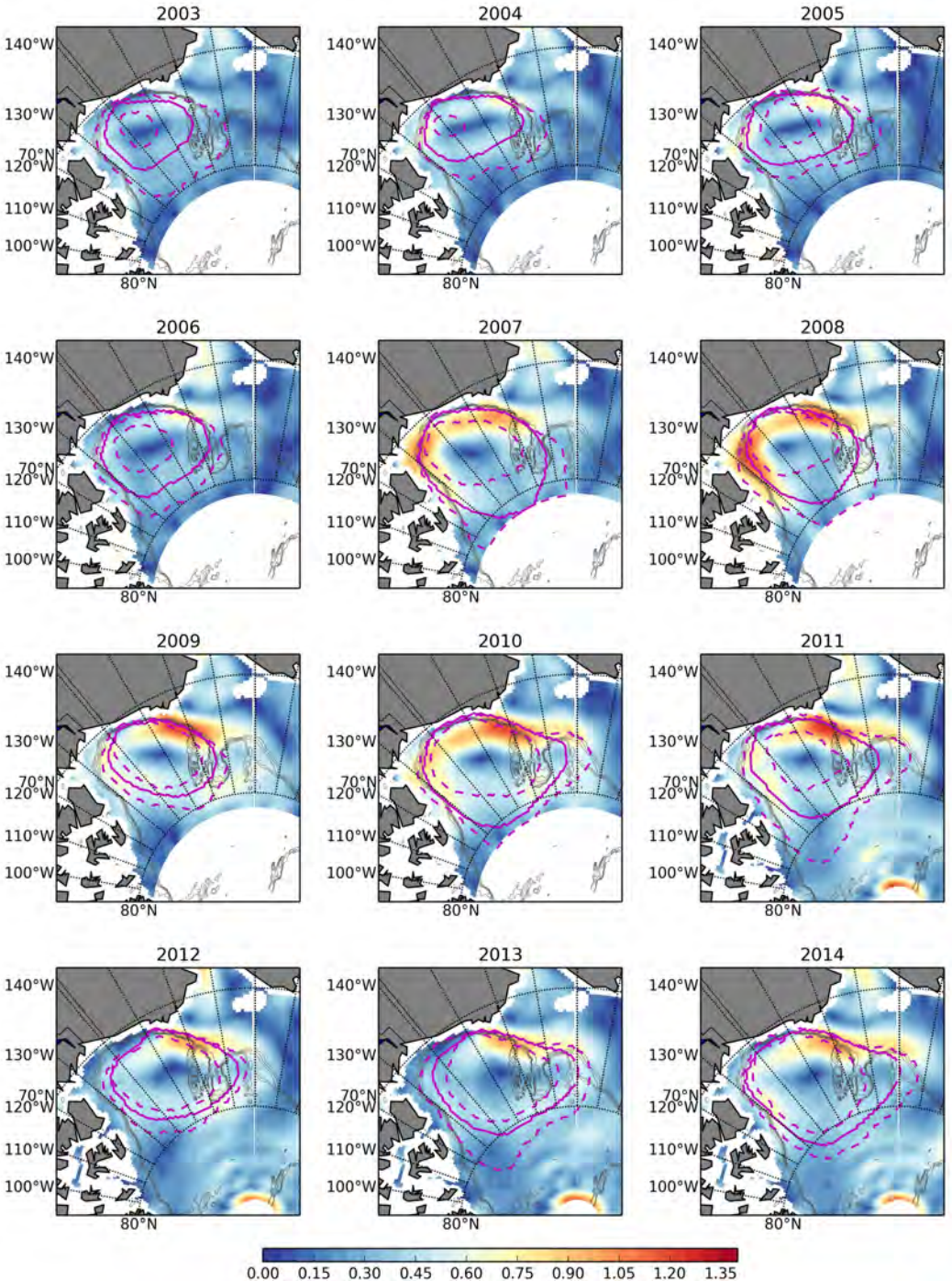
Variability of the Beaufort Gyre:

> *the position, size and intensity of the gyre are determined by the forcing (partly independetly)*

> *Depends on* ***both*** *the intensity and the position of the atmospheric forcing (Beaufort Sea Height)*

> *SSH gradient gets steeper (i.e the gyre spins up) when the gyre encounters the slope/shelf… and the gyre eventually breaches over*

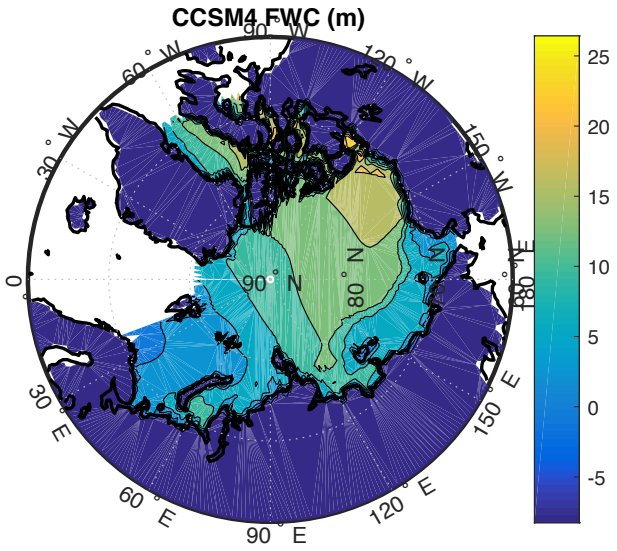
Gradient of SSH [x 10^6 $m.m^{-1}$]



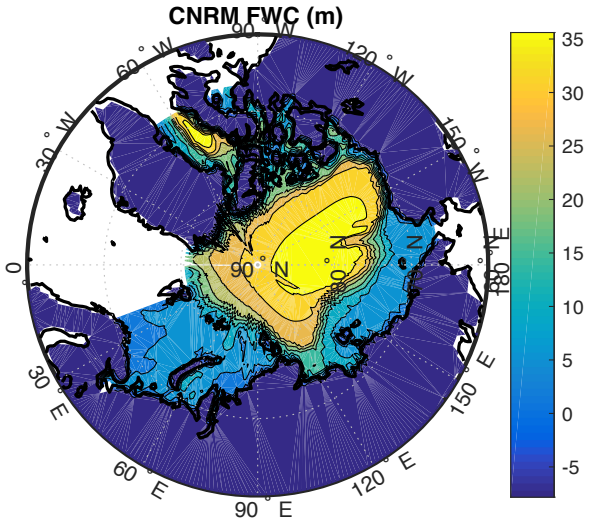
Bathymetry, gyre and eddy

Beaufort Gyre and FW content in CMIP5 models:

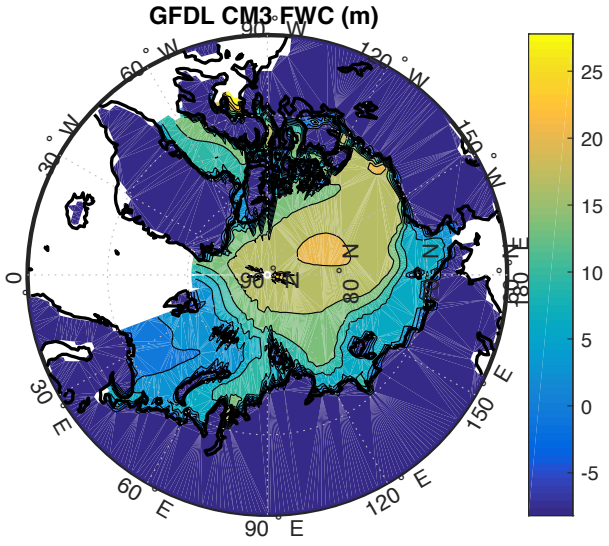
CCSM4



CNRM



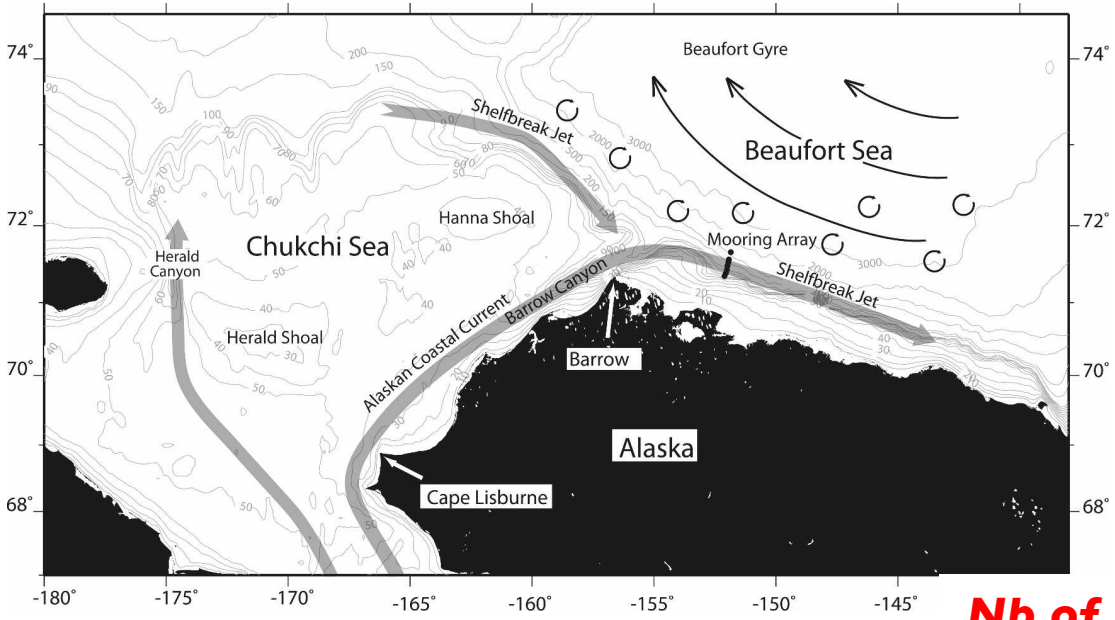
GFDL CM3



Sam Cornish PhD project, Oxford

Bathymetry, gyre and eddy

> Interaction of the gyre with bathymetry promotes the generation of eddies ?



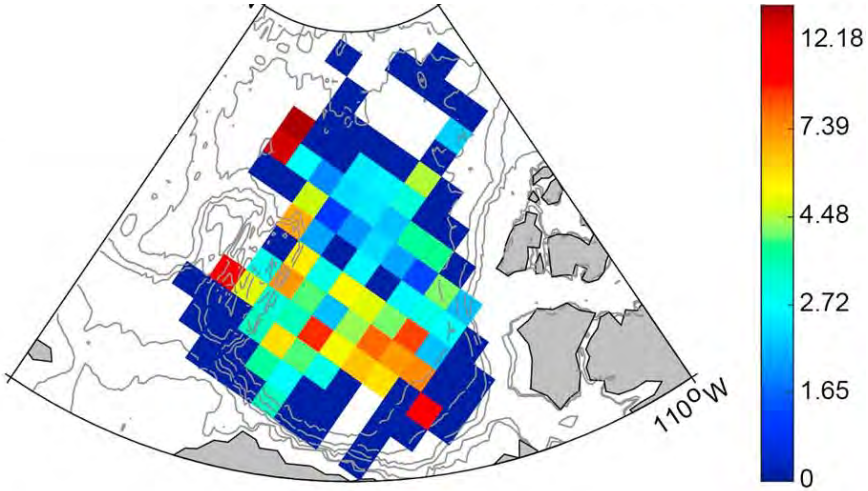
'Anticyclonic eddies are commonly observed offshore of the shelfbreak jet and in the Canada Basin within the Beaufort gyre.'

Spall et al. 2008

Nb of eddies per 10^6 km of ITP track 2005-2015

'The highest concentration of eddies was found […] close to topographic margins and boundaries of the Beaufort Gyre.The number of eddies approximately doubled from 2005–2012 to 2013–2014 […] suggesting more active baroclinic instability of the Beaufort Gyre.'

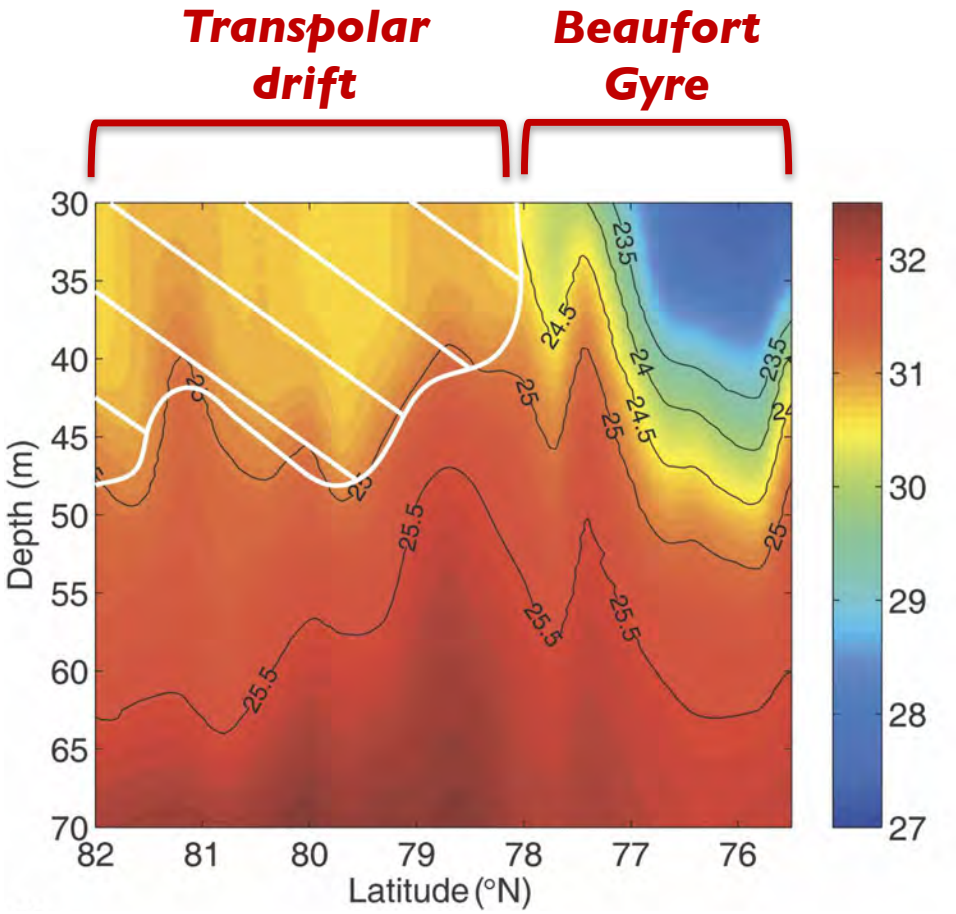
Zhao et al. 2016



Beaufort Gyre, surface front and eddy generation

> The northern limit of the Beaufort Gyre corresponds to a surface salinity front

> where eddies (dipoles) grow out of instabilities in two layers



Salinity along SCICEX 2000

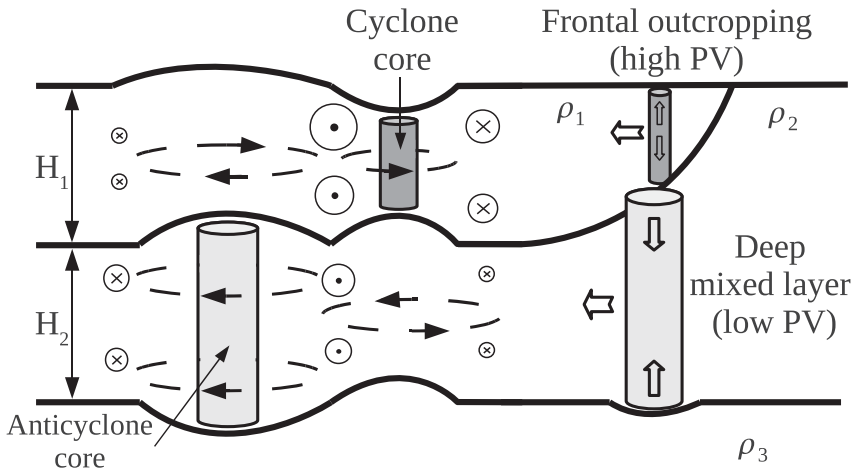


FIG. 6. Schematic of dipole formation indicating the water mass origins of the cyclone and anticyclone.

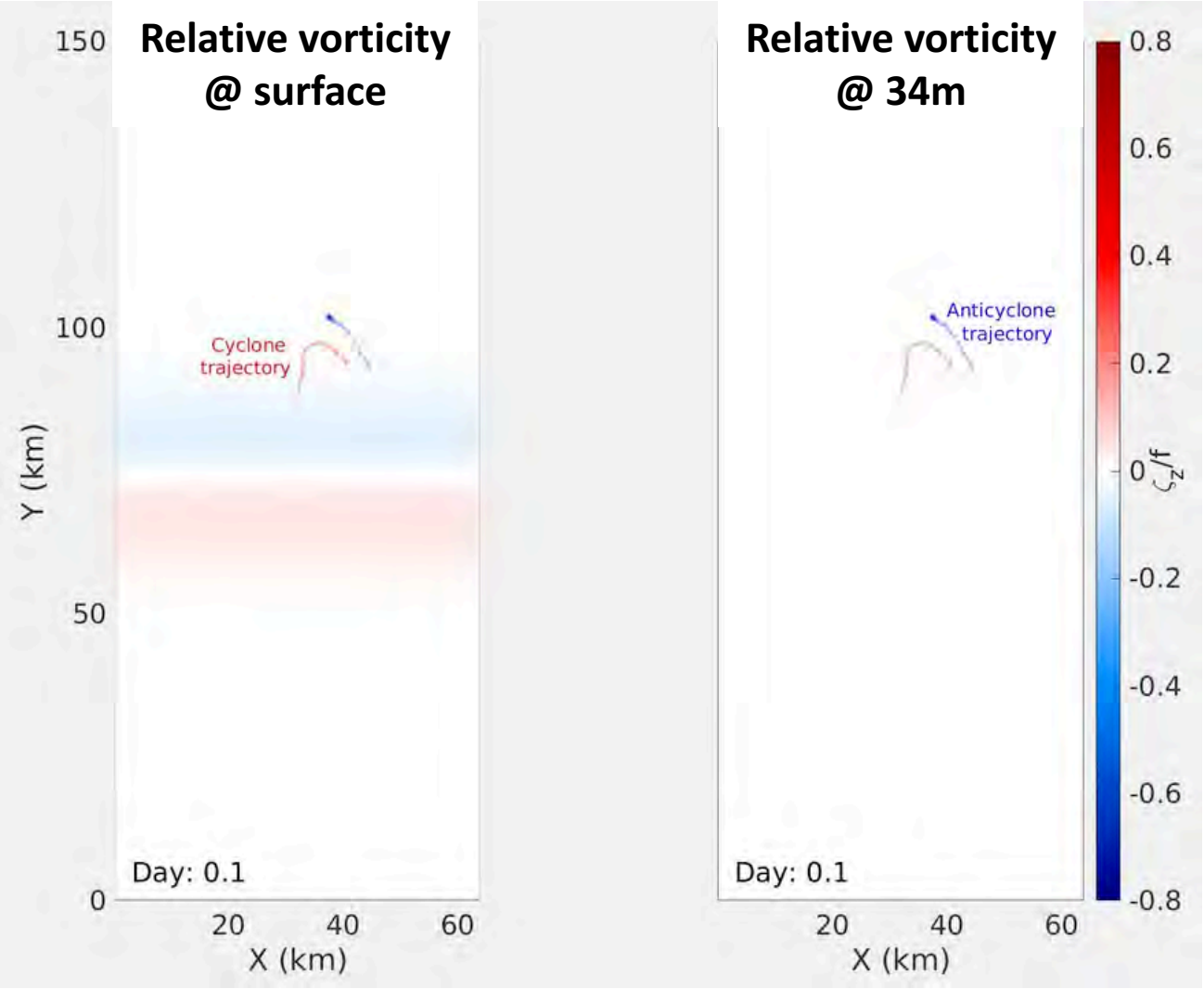
Timmermans et al. 2008, Manucharyan & Timmermans et al. 2013

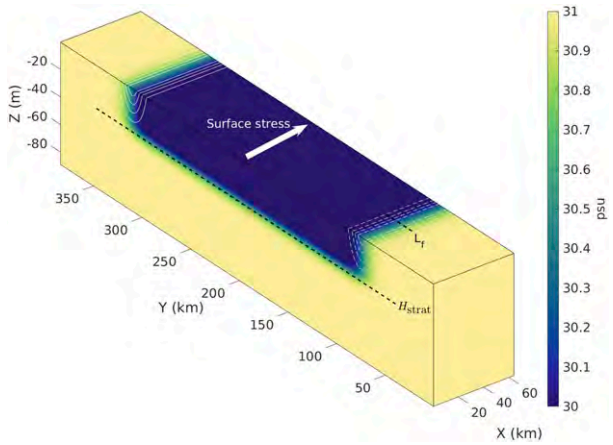
Beaufort Gyre, surface front and eddy generation

> The northern limit of the Beaufort Gyre corresponds to a surface salinity front

> where eddies (dipoles) grow out of instabilities in two layers

> Eddy detachment depends on orientation of surface stress relative to front





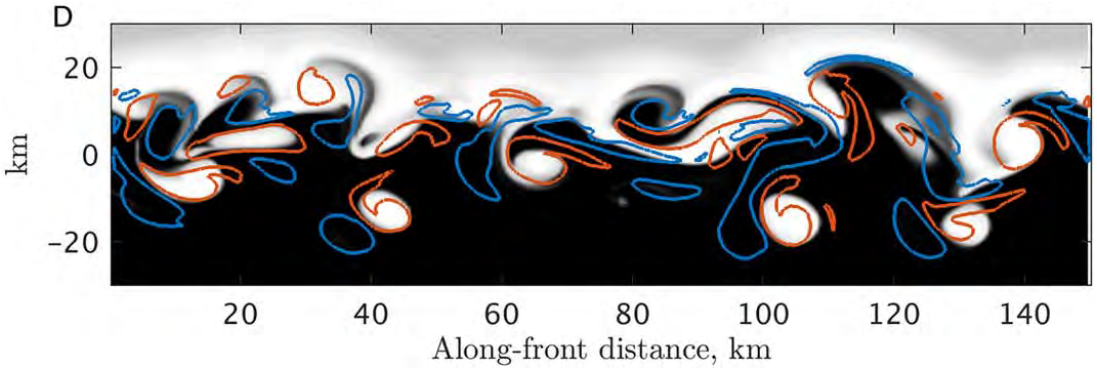
Set up

- *MITgcm*
- *Δx=500m, Δz=0.5m*
- *Initialized with a salinity front over 30m*

Brannigan et al. 2017 JPO

Surface front, eddy generation and sea ice

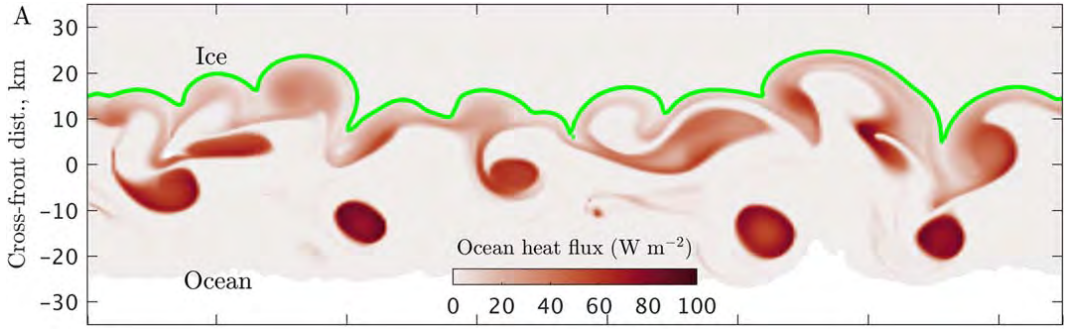
- The presence of surface salinity fronts (like the one on the northern limit of the Beaufort Gyre) is promoting the generation of mesoscale eddies
- Anticyclones are more likely to survive… Consistent with eddy census from ITPs (Zhao et al. 2014, 2016)
- Eddies further interact with sea ice:
  > sea ice exert friction on eddy (Ou & Gordon 1986)
  > eddy tends to increase sea ice melt (Manucharyan & Thompson 2017, Horvat et al. 2016).



Sea ice and mixed layer vorticity

Red > 0

Blue < 0



Associated heat flux

Manucharyan & Thompson 2017

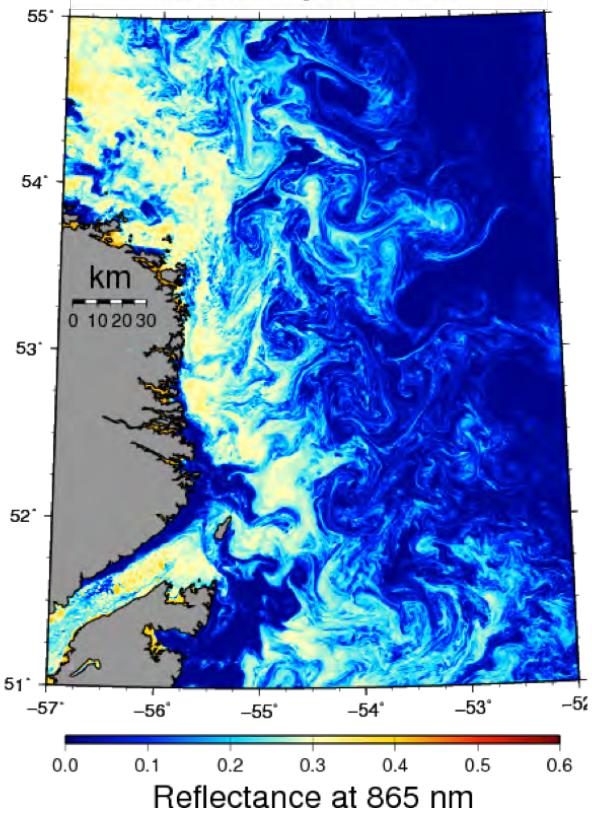
Eddy and sea ice

Imprint of (sub-)mesoscale dynamics on sea ice: *examples in the MIZ*

Aerial survey, Fram Strait, 30 June 1984

Plate 1 [*Johannessen et al.*]. Aerial photograph of the 20- to 40-km ice edge eddy E1 centered at 79°N, 2°30′W taken from the CV 580 on June 30, 1984.

MODIS-Terra, Labrador Sea, 6 April 2008



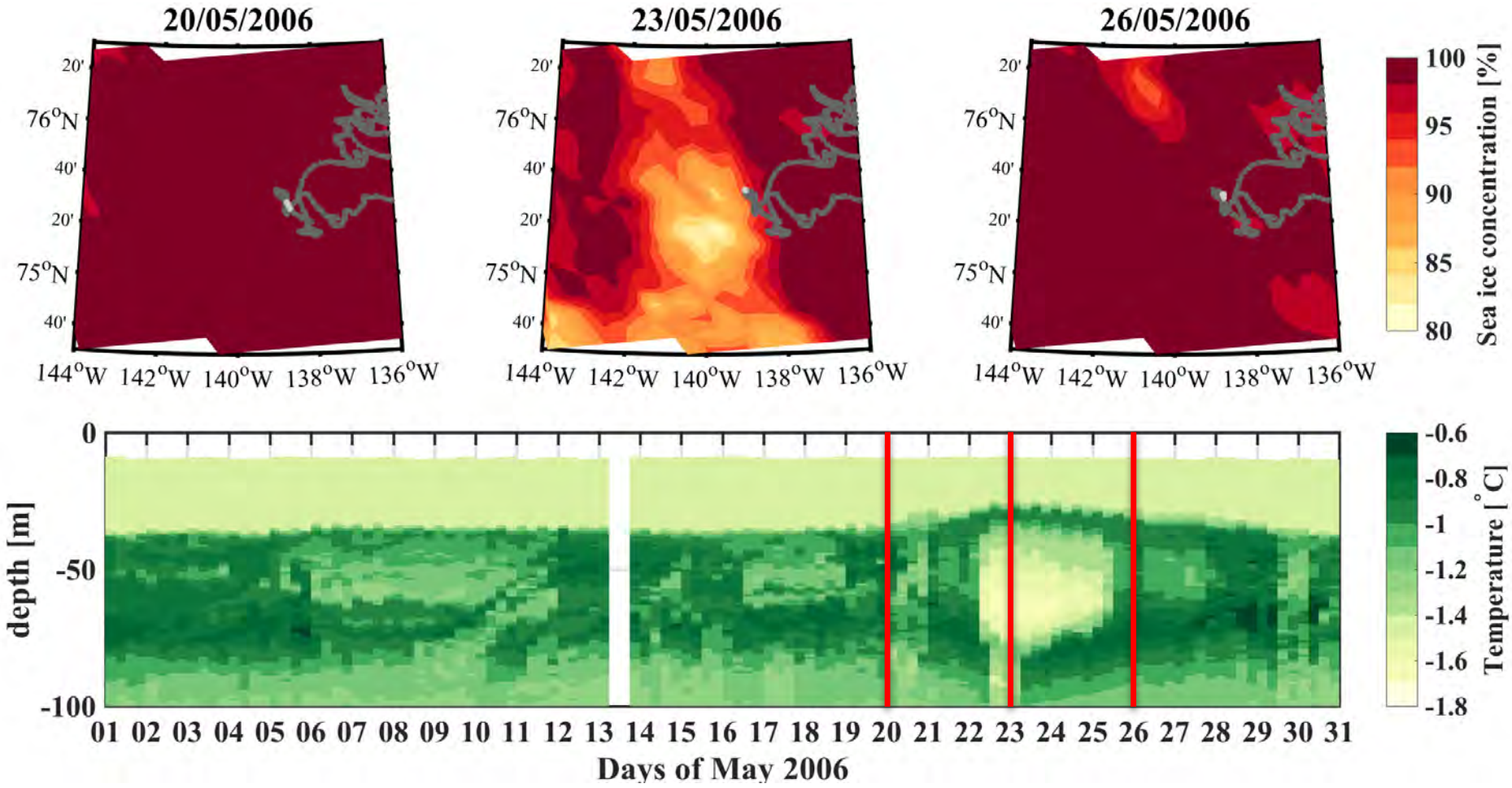
Sentinel 1A SAR, Beaufort Sea, 12 Sept. 2015

Johannessen et al. 1987, Manucharyan & Thompson 2017

Eddy and sea ice

Imprint of mesoscale dynamics on sea ice: *in the ice pack*

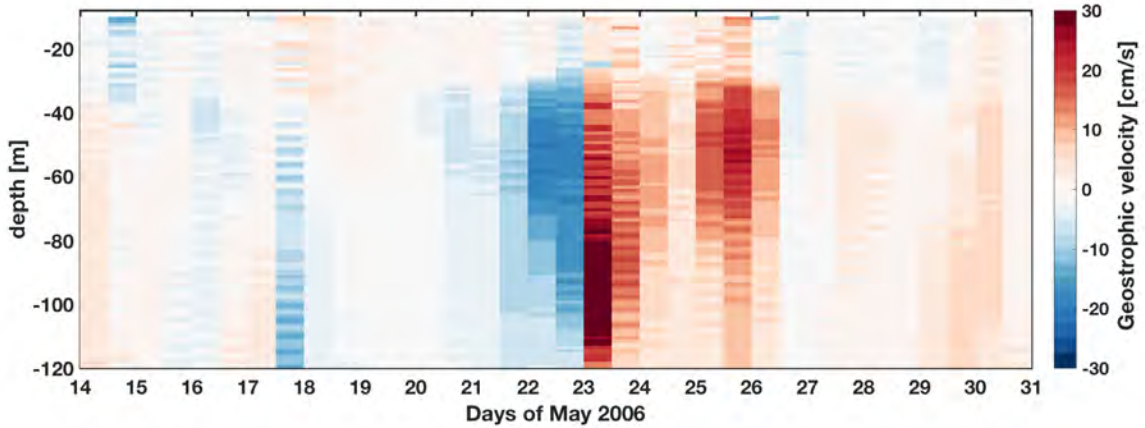
T/S profiles from ITP#3
Sea ice concentration from CERSAT



Lique & Rampal, in prep.

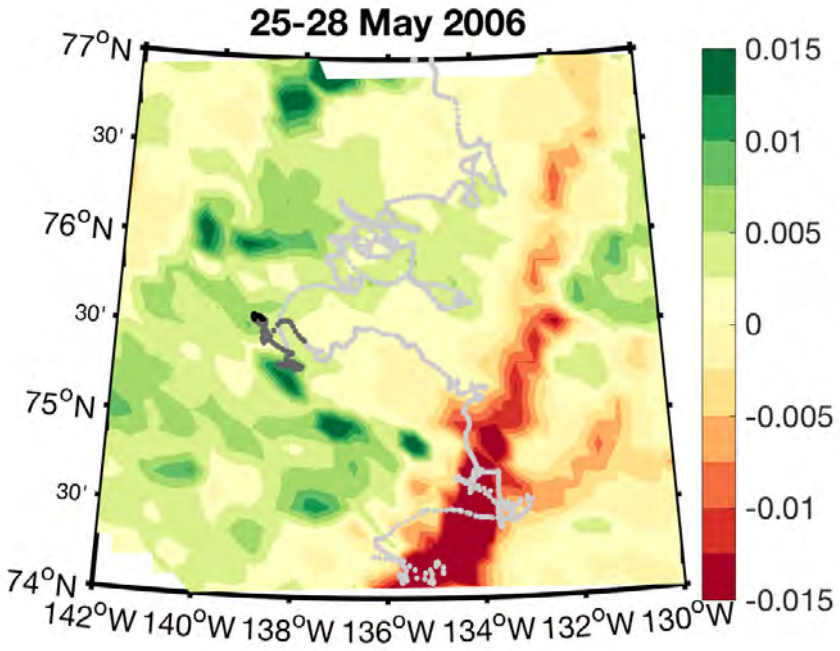
Eddy and sea ice

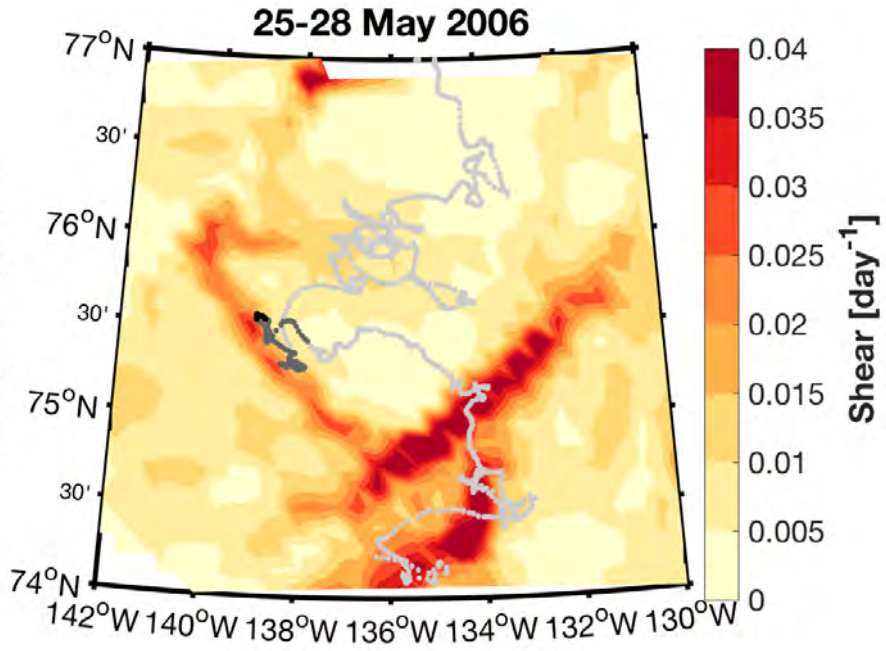
Imprint of mesoscale dynamics on sea ice: *in the ice pack, through dynamical processes*



Shear associated with eddy too small to break the sea ice cover (3m thick!)

… but likely large enough to re-open a pre-existing lead

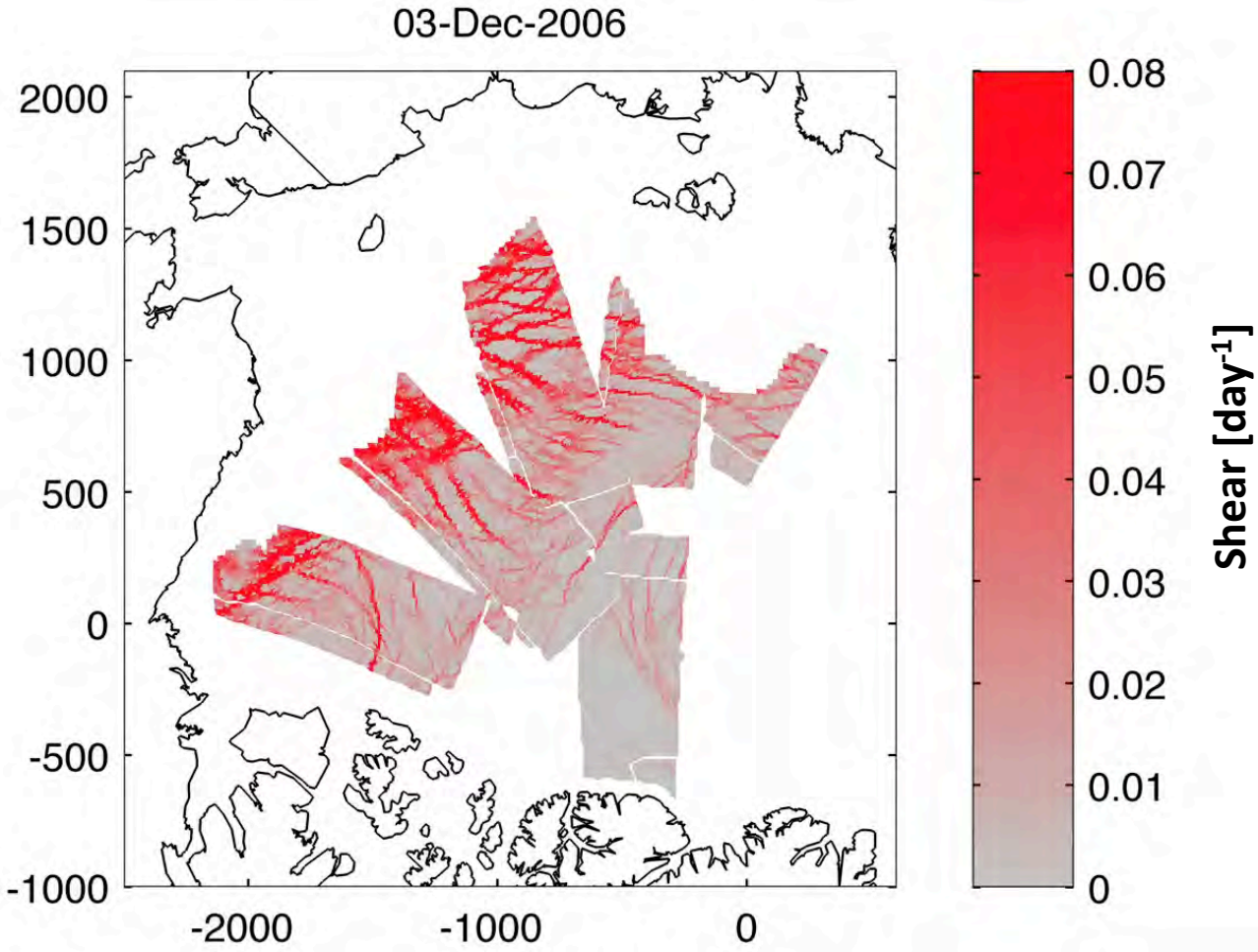




Lique & Rampal, in prep., RGPS data from JPL (Kwok 2001)

Eddy and sea ice

- LKFs are present everywhere in the sea ice pack (due to wind or eddies?)
- promotes the generation of eddies? (through their signature onto SSS)



Bouillon & Rampal, 2015

Some conclusions…

Some examples of scale interactions (arguably badly/not represented in state-of-the-art models…):

- Bathymetry does influence the large scale circulation,
  … including the surface layer… and sea ice!
  > In the Barents Sea, the PF is fixed to the 220m isobath and limits the winter expansion of sea ice
  > The variations of size and shape of the Beaufort Gyre are strongly constrained by the bathymetry

- Eddy can arise from instability of the large scale circulation or ML instabilities
  > through the interaction of the Beaufort Gyre with the shelves,
  > … or at surface front
  > Ability to survive might depend on the surface forcing (wind and sea ice)
  Running a model at eddy resolving resolution does not mean that you actually fully capture the mesoscale activity!!

- There is some interplay between mesoscale dynamics and sea ice
  > Surface fronts might themselves be the signature of sea ice dynamics
  > Eddies are imprinting their signatures on sea ice, through dynamical and thermodynamical processes