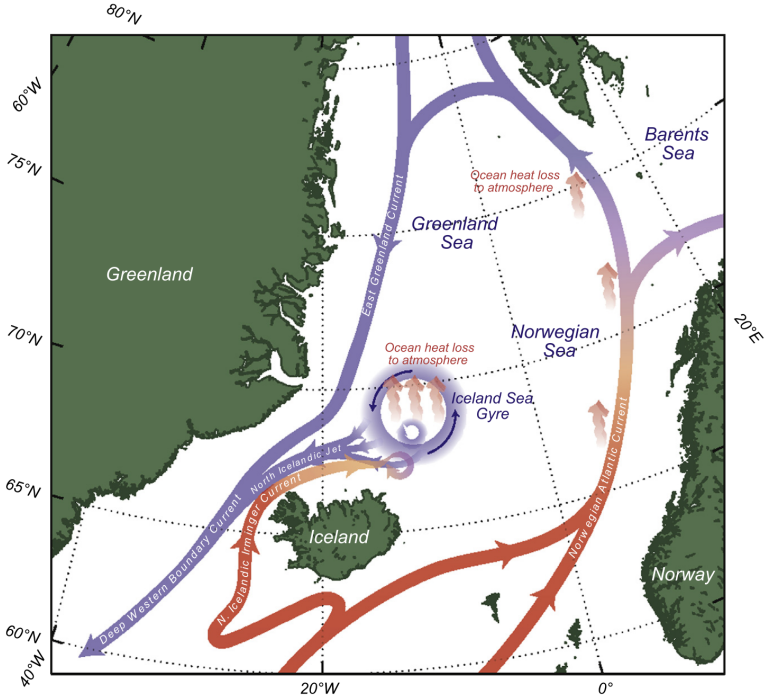
The Two Branches of the Recirculation of Atlantic Water in Fram Strait

Wilken-Jon von Appen (AWI)
Tore Hattermann (AVKVAPLAN, AWI)
Pål Erik Isachsen (NMI, UiO)
Jon Albretsen (IMR)
Arild Sundfjord (NPI)
Ursula Schauer (AWI)

ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

Ocean Sciences Session HE011
February 26th, 2016

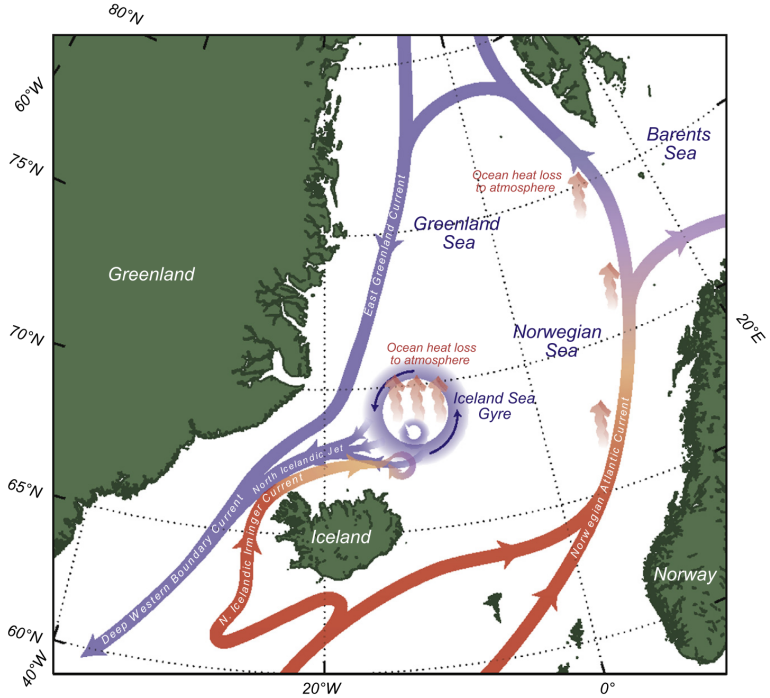
Pathways of Atlantic Water



Våge et al. (2013)

- Boundary current loop (Mauritzen, 1996)
- Flow follows f/H contours (Isachsen et al., 2003)

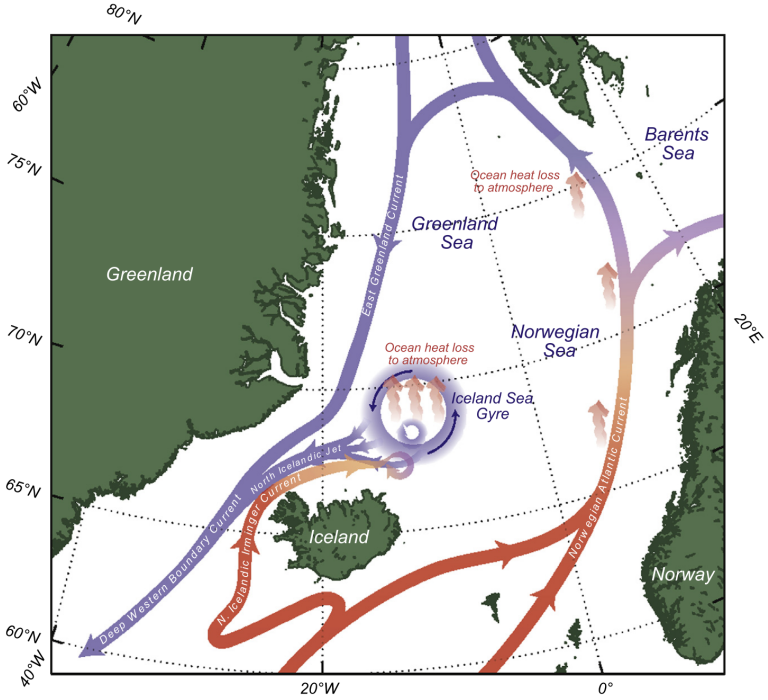
Pathways of Atlantic Water



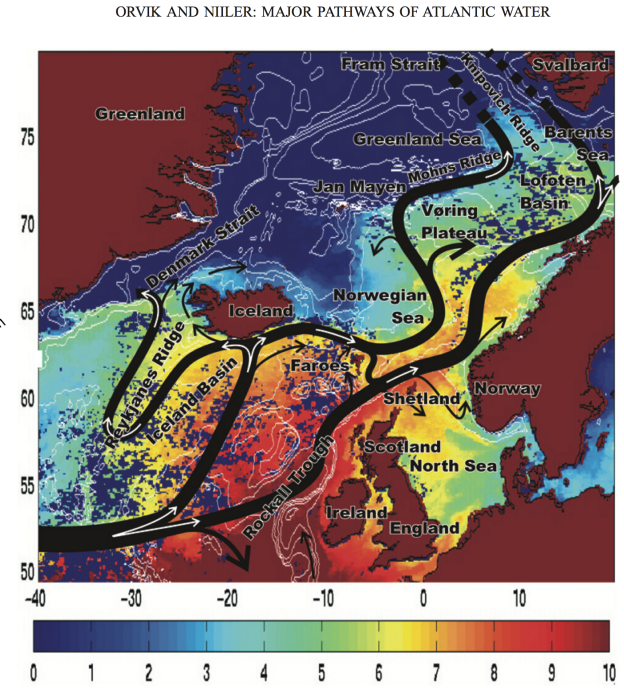
Våge et al. (2013)

- Boundary current loop (Mauritzen, 1996)
- Flow follows f/H contours (Isachsen et al., 2003)
- Bifurcation in Fram Strait:
  - to Arctic Ocean: sea ice melting, halocline formation, nutrient supply
  - to Denmark Strait: overflow water, MOC

Pathways of Atlantic Water



Våge et al. (2013)

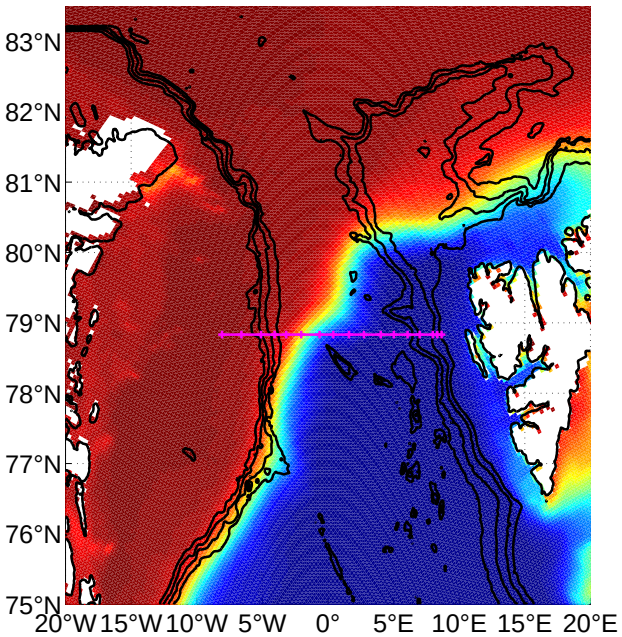


Orvik and Niiler (2002)

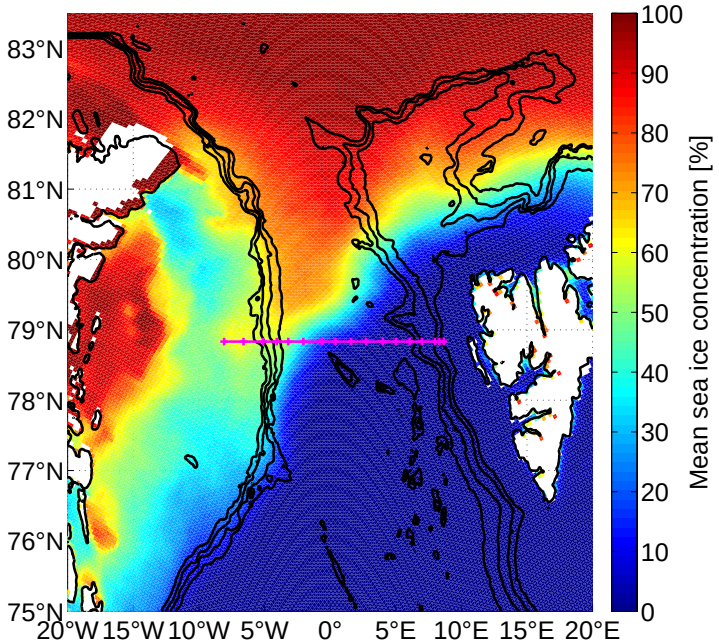
- Boundary current loop (Mauritzen, 1996)
- Flow follows f/H contours (Isachsen et al., 2003)
- Bifurcation in Fram Strait:
  - to Arctic Ocean: sea ice melting, halocline formation, nutrient supply
  - to Denmark Strait: overflow water, MOC
- Two branches of Norwegian Atlantic Current

Sea ice concentration in Fram Strait

Jan/Feb/Mar:



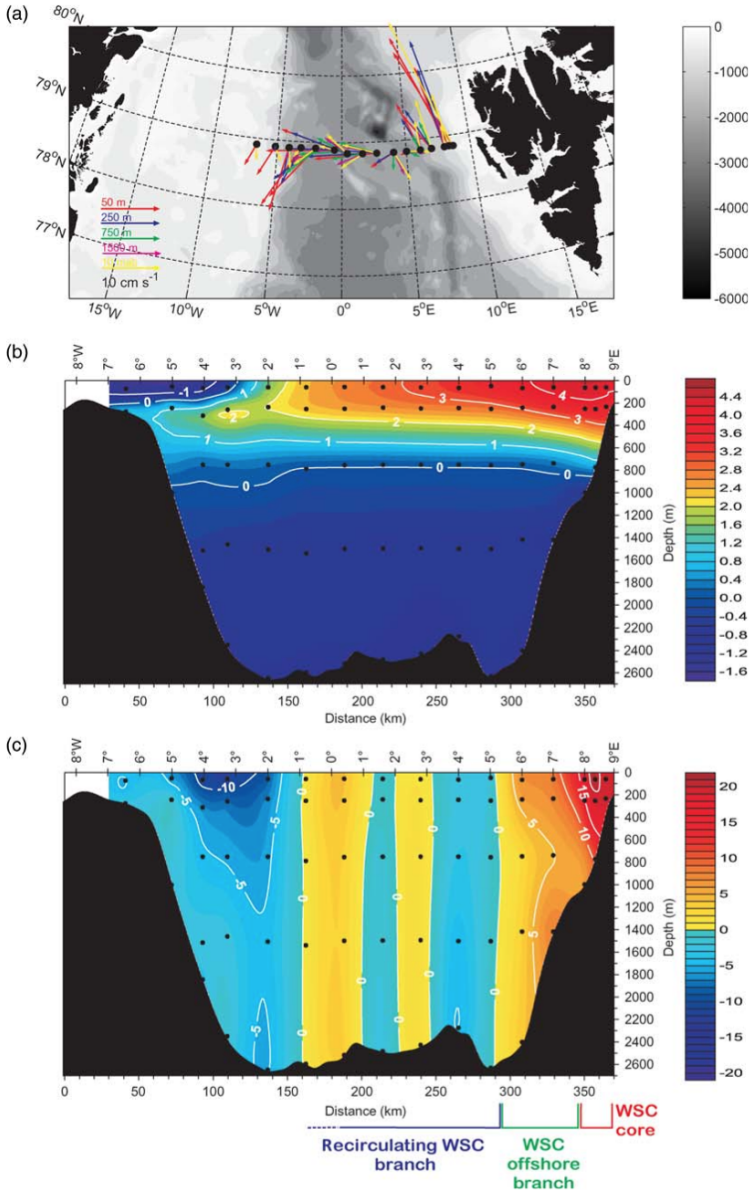
Jul/Aug/Sep:



AMSR-E 2004 to 2013

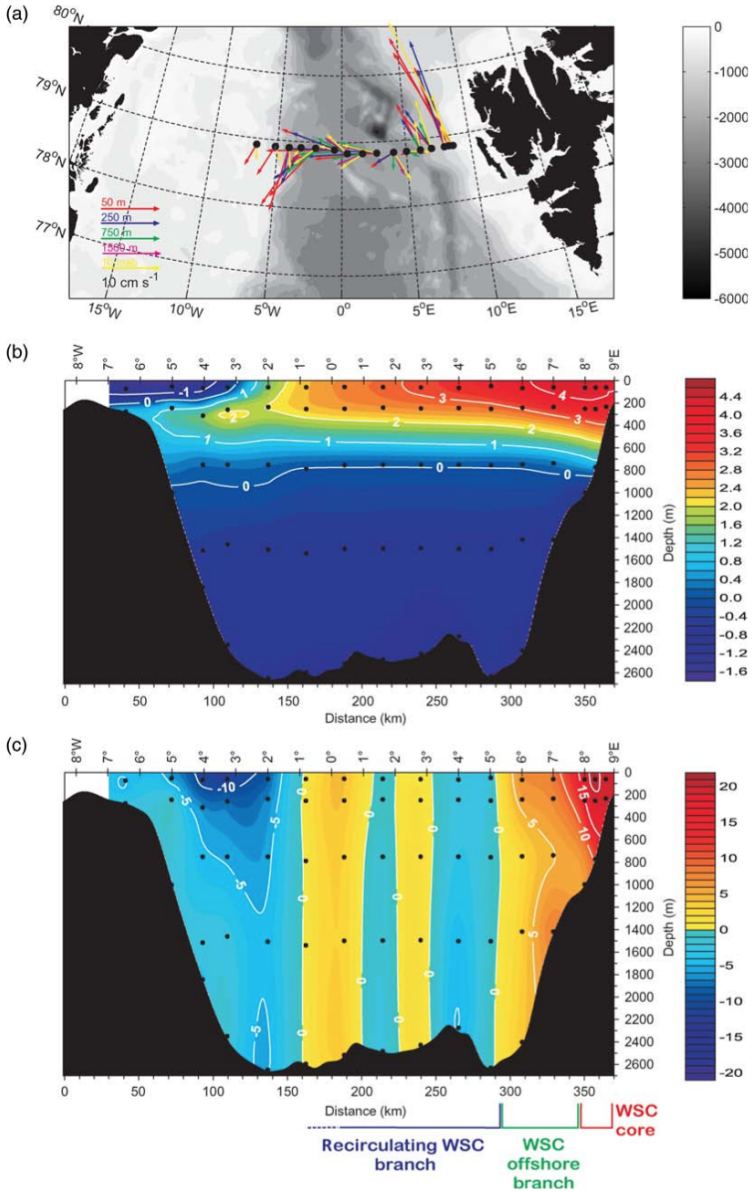
- Sea ice edge semi-permanent
- MIZ comparatively small

Mooring observations at 78°50'N



Beszczynska-Möller et al. (2012)

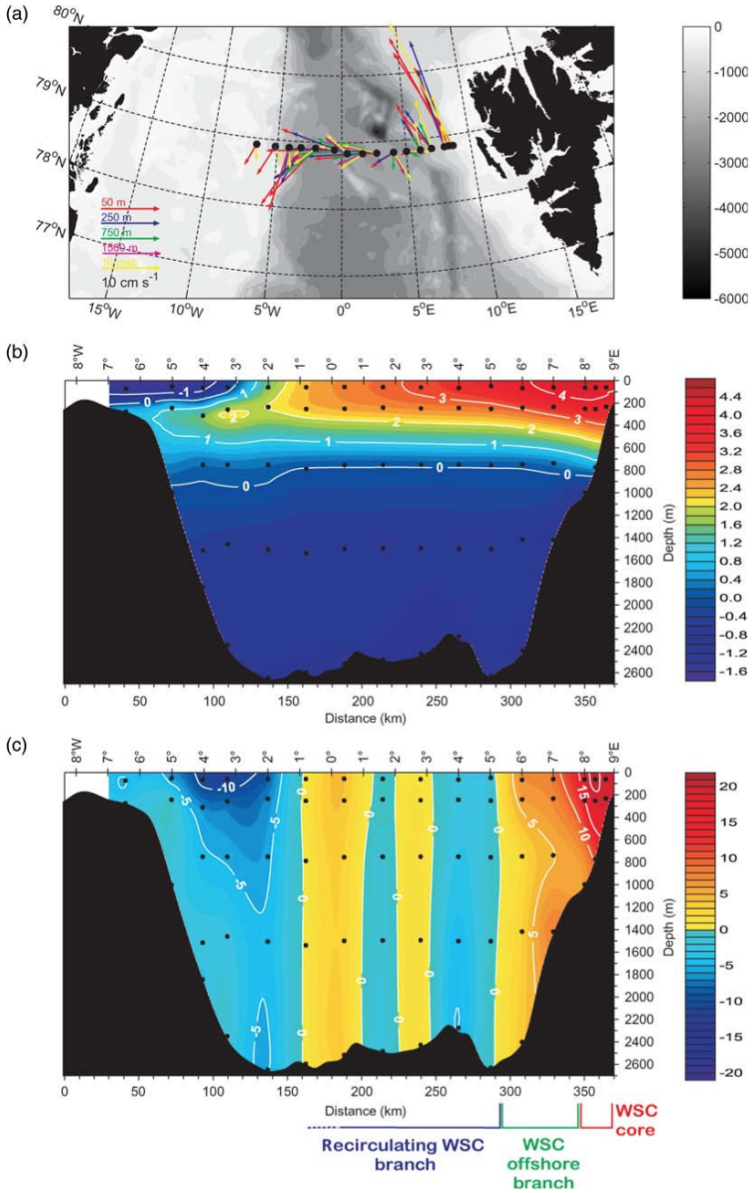
Mooring observations at 78°50'N



6.6 Sv northward transport
3.0 Sv Atlantic Water (>2°C)
But how much enters Arctic Ocean?

Beszczynska-Möller et al. (2012)

Mooring observations at 78°50'N



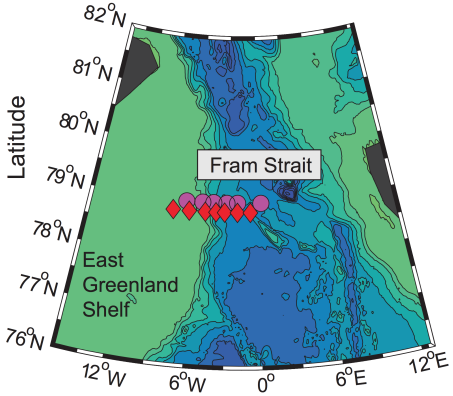
6.6 Sv northward transport
3.0 Sv Atlantic Water (>2°C)
But how much enters Arctic Ocean?

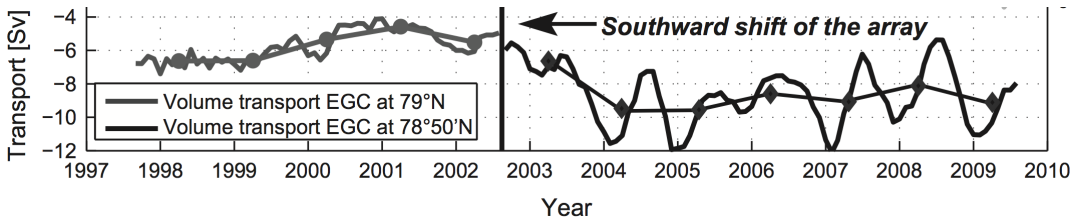
Rossby radius:
≈3 km in winter
≈6 km in summer

WSC is baroclinically unstable forming eddies, particularly in winter (von Appen et al., 2016)

Beszczynska-Möller et al. (2012)

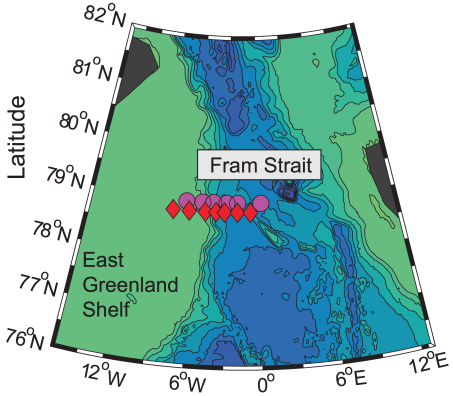
Previous estimates of the recirculation

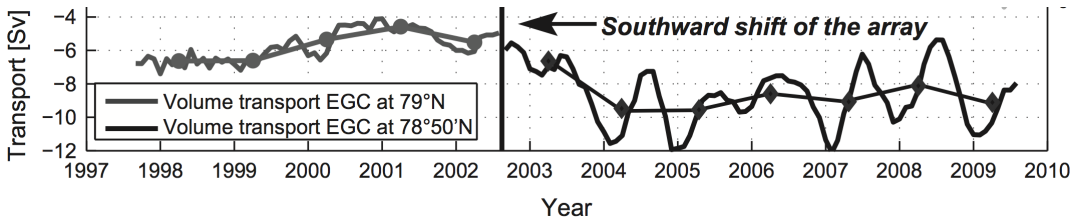




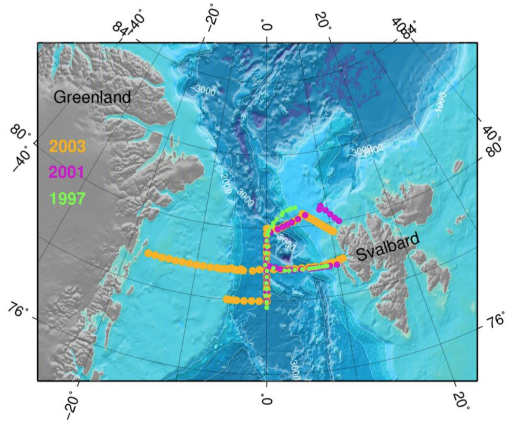
Southward transport in EGC increased by 3 Sv from 79°N to 78°50'N (de Steur et al., 2014)

Previous estimates of the recirculation





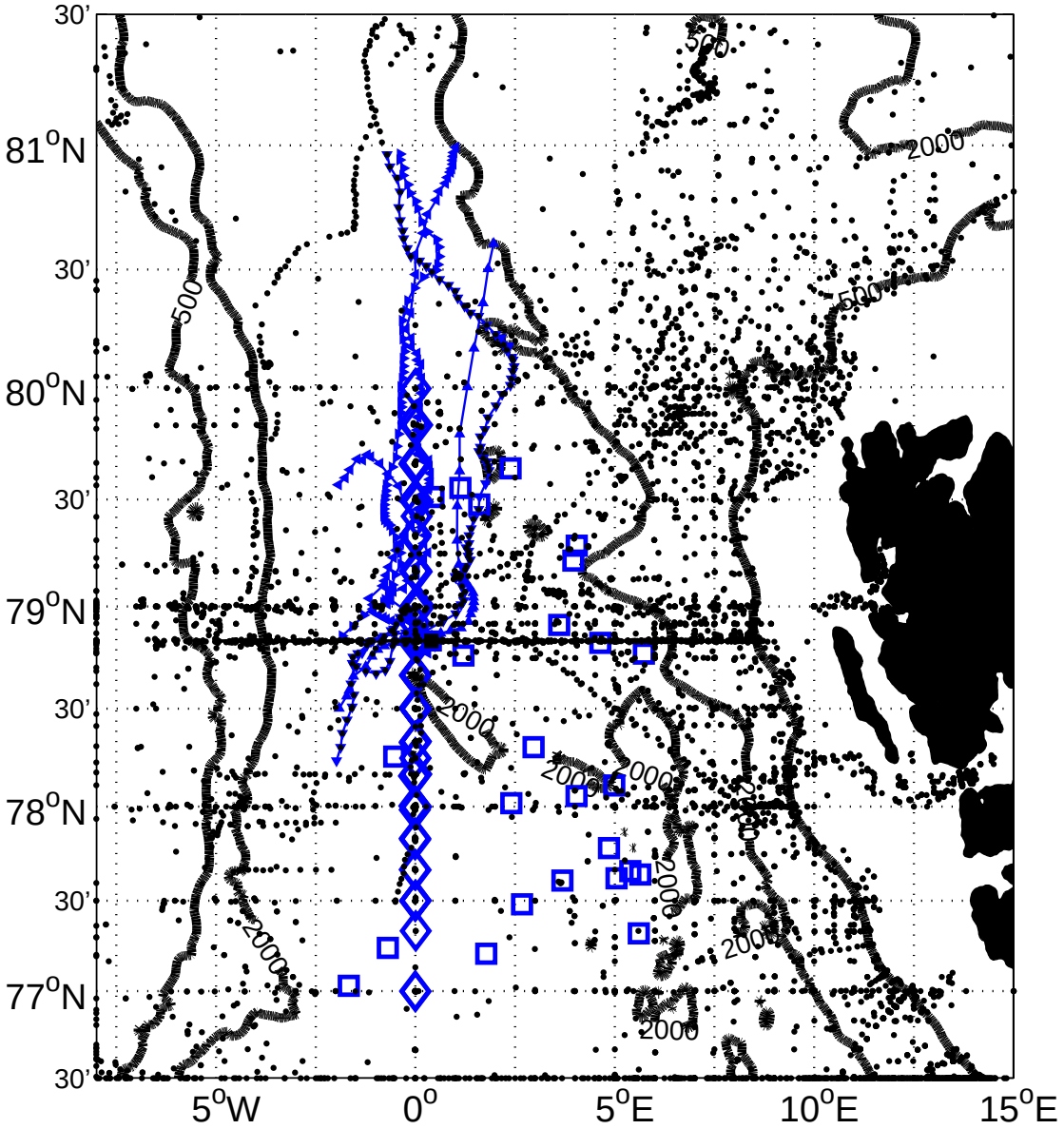
Southward transport in EGC increased by 3 Sv from 79°N to 78°50'N (de Steur et al., 2014)



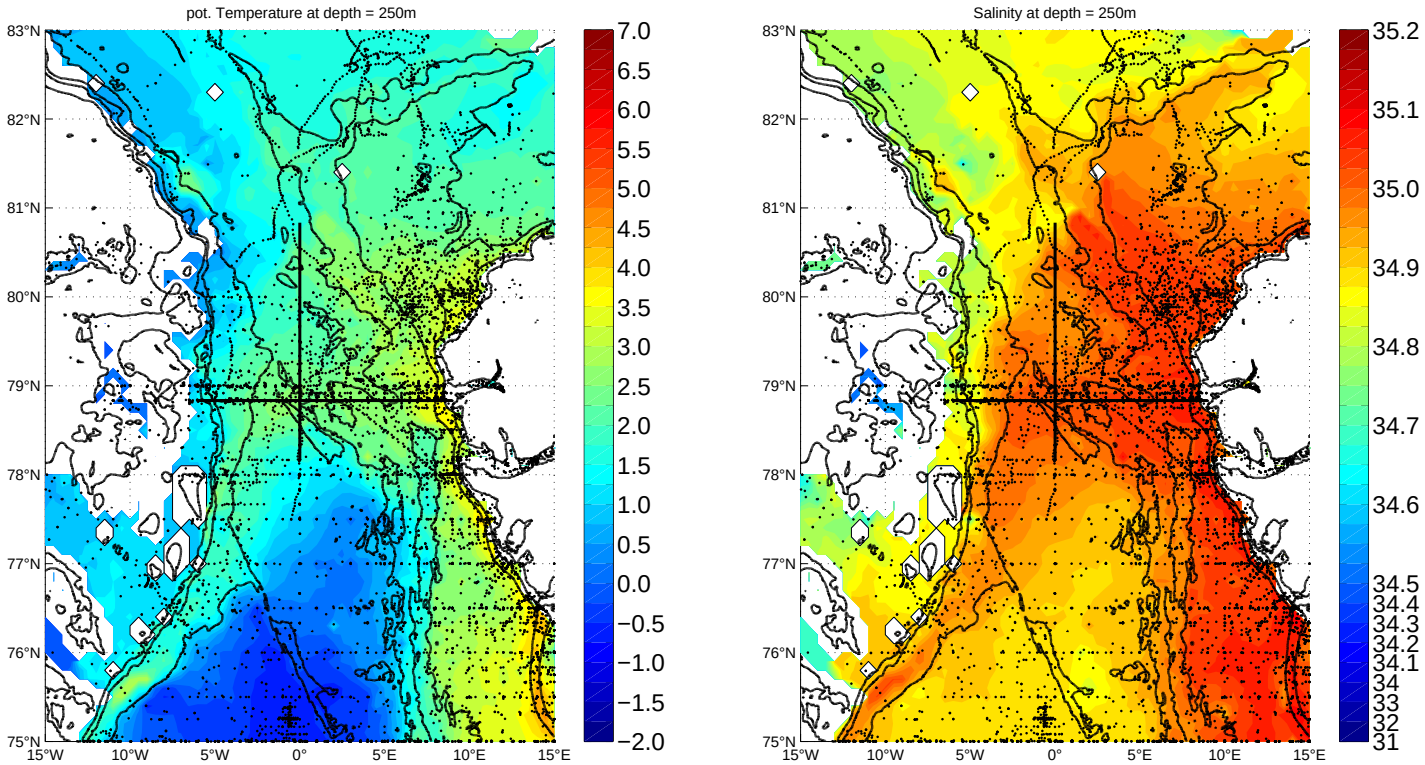
Summer time hydrographic sections:

Recirculation mainly confined to south of 80°N; half of northward AW transport recirculates in Fram Strait (Marnela et al., 2013)

How do observations constrain the recirculation?



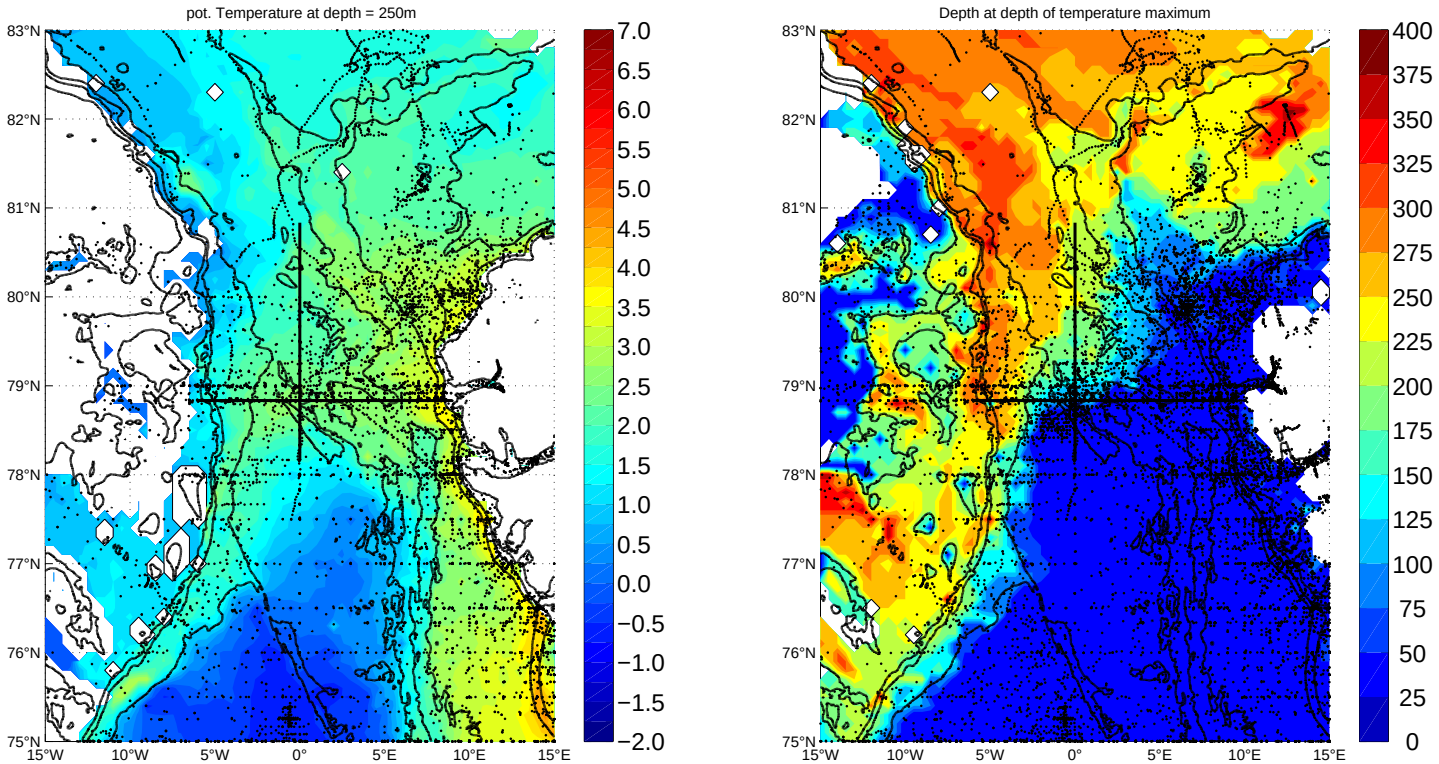
Compilation of hydrographic observations in Jul/Aug/Sep



Potential temperature and salinity at 250 m:

- Connectivity near 79°N
- Tmax/Smax protrusion near 80.5°N

Compilation of hydrographic observations in Jul/Aug/Sep



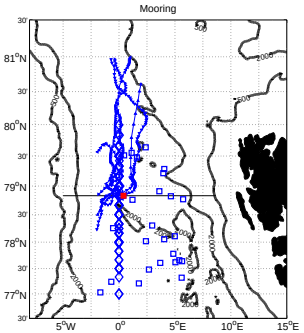
Potential temperature and salinity at 250 m:

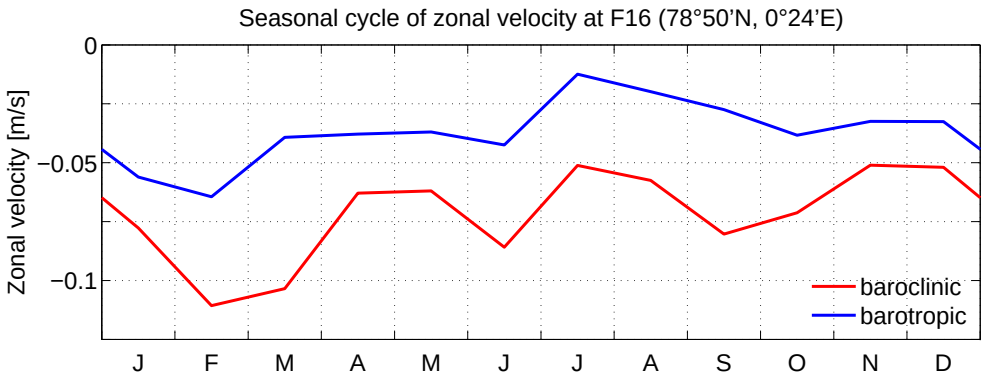
- Connectivity near 79°N
- Tmax/Smax protrusion near 80.5°N

Depth of temperature maximum:

- Subduction of AW below PW

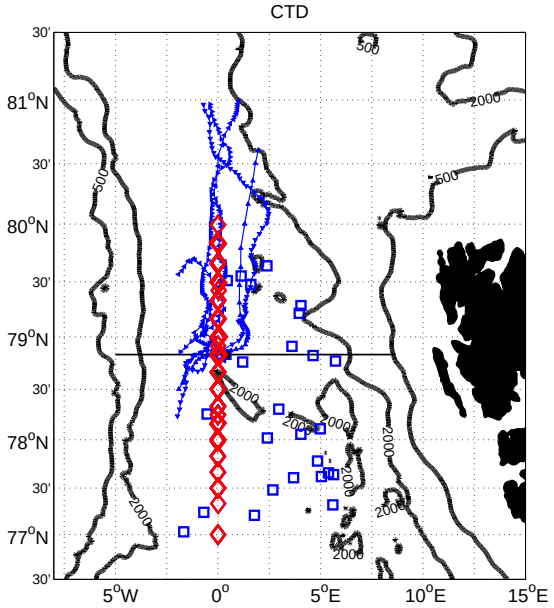
Mooring observations in southern recirculation



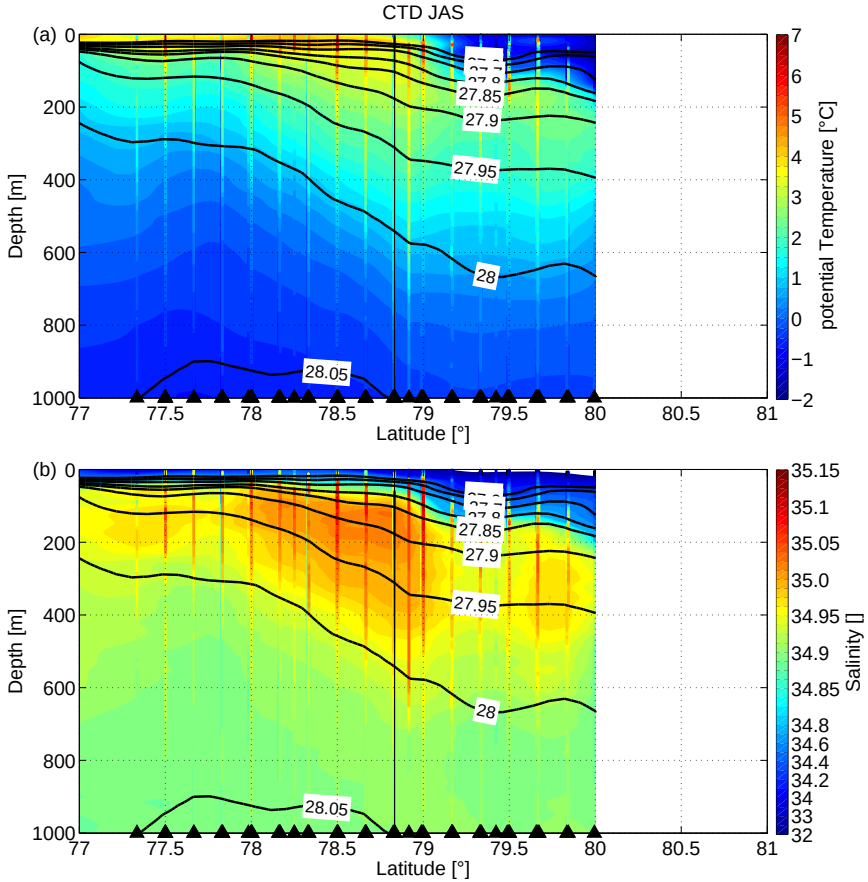


Baroclinic velocities of 10 cm/s (winter), 5 cm/s (summer)

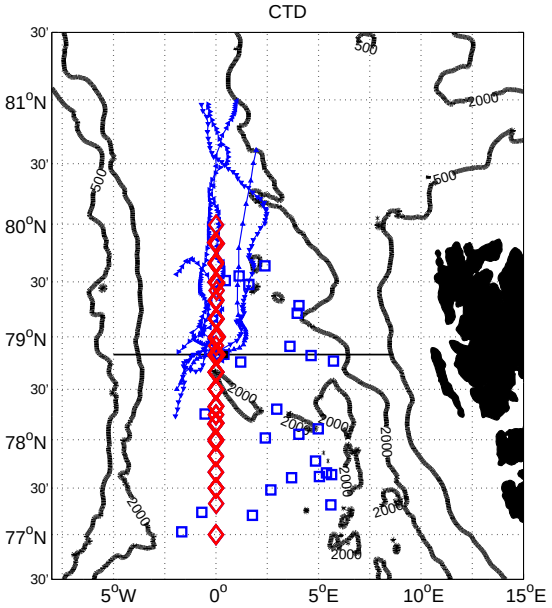
CTD sections along 0°EW in summer



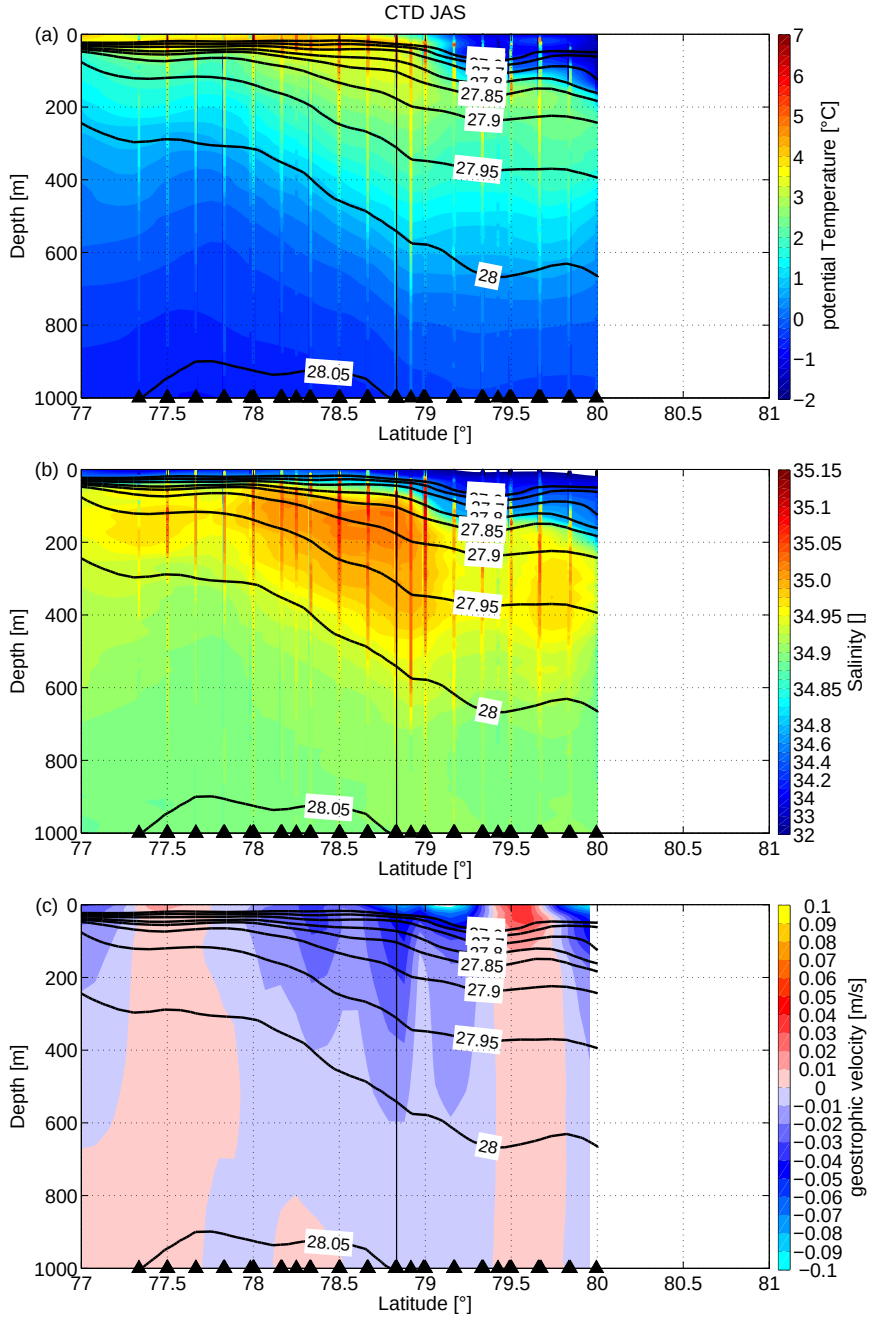
- Sloping isopycnals
- AW reaches deeper in the north



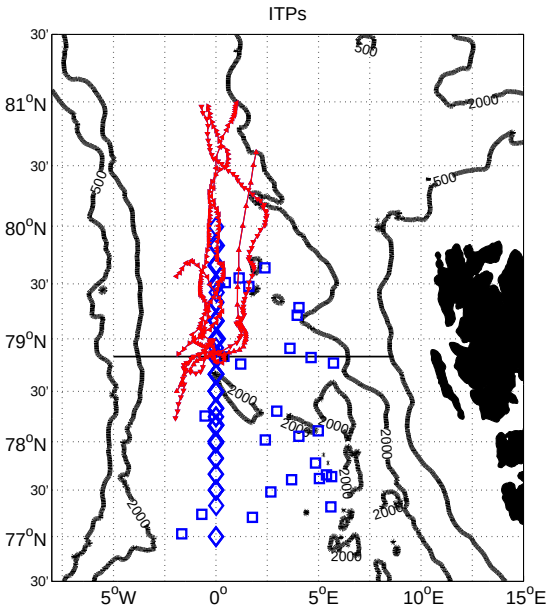
CTD sections along 0°EW in summer



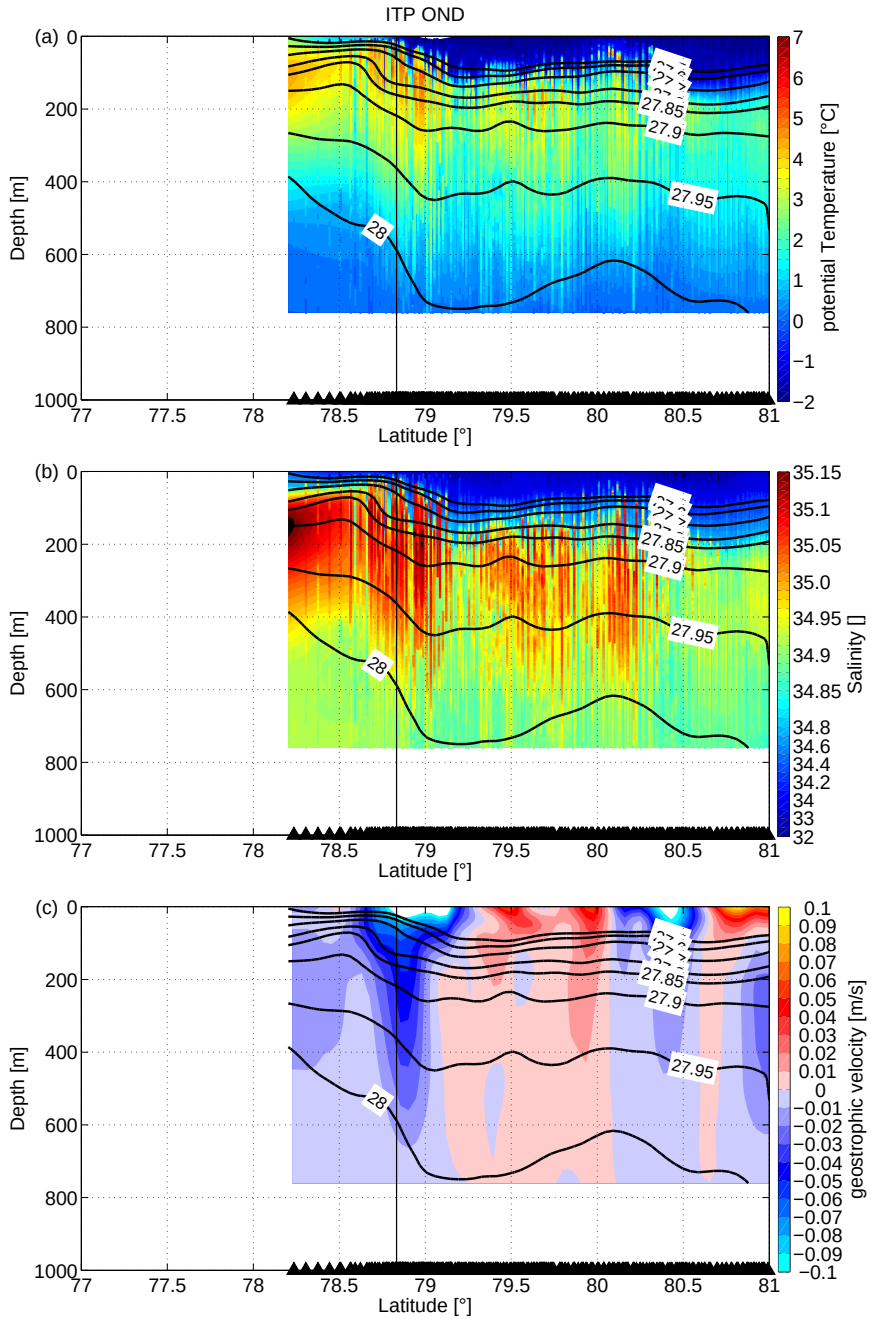
- Sloping isopycnals
- AW reaches deeper in the north
- Baroclinic velocities of 10 cm/s



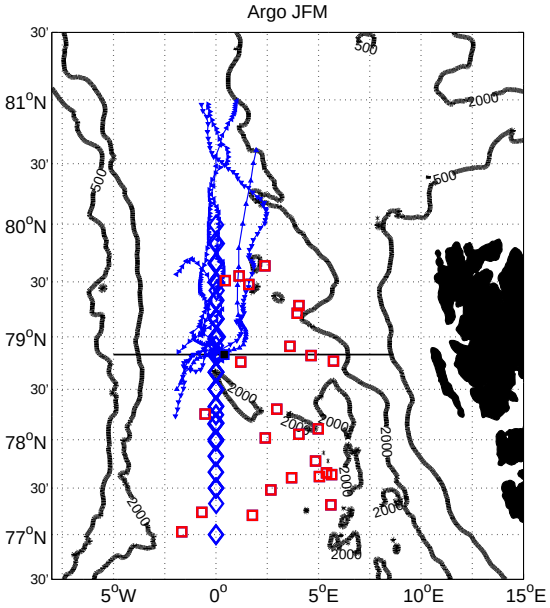
ITP sections along 0°EW in autumn



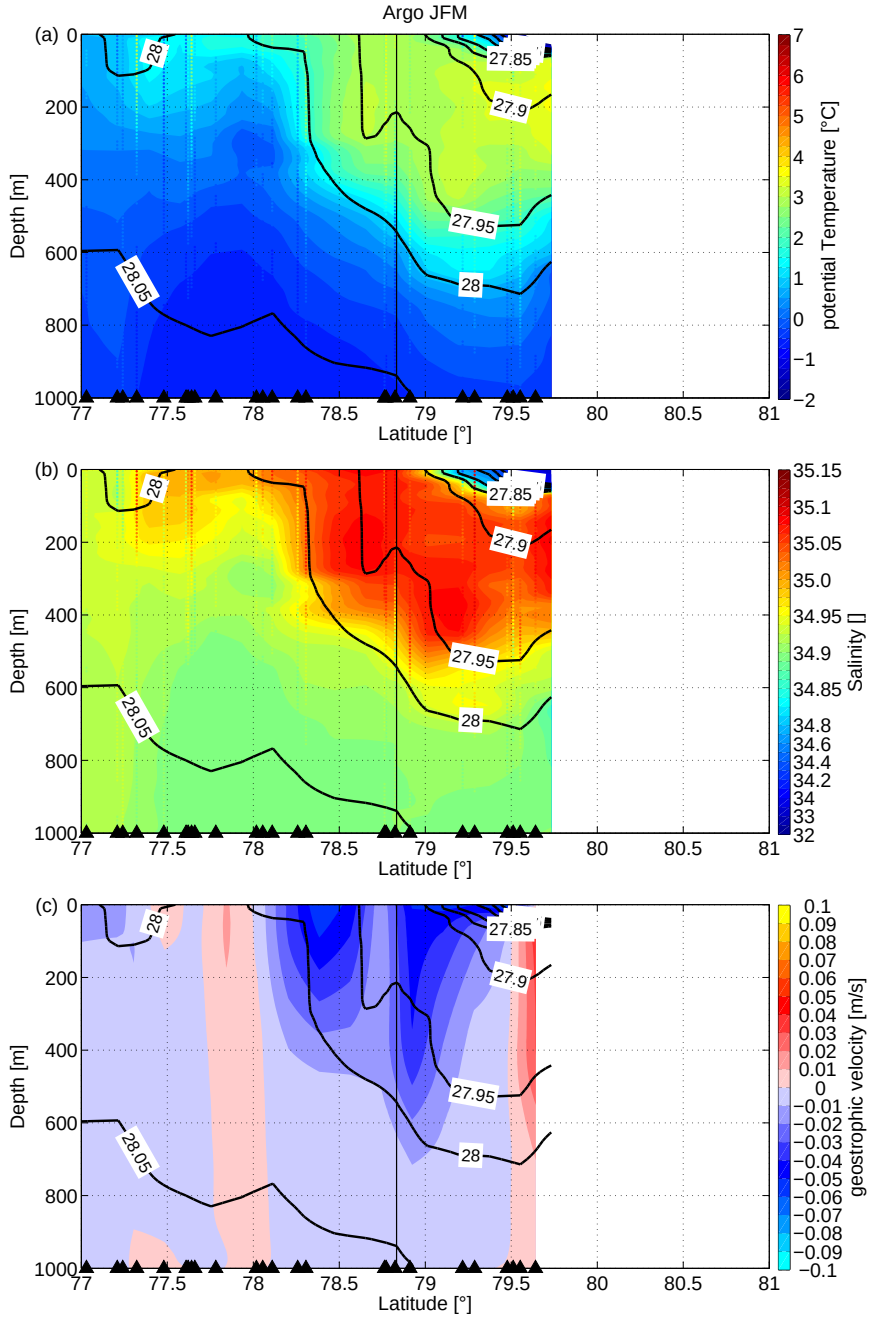
- Sloping isopycnals and westward flow near 80.5°N
- Warm salty water extends in NR



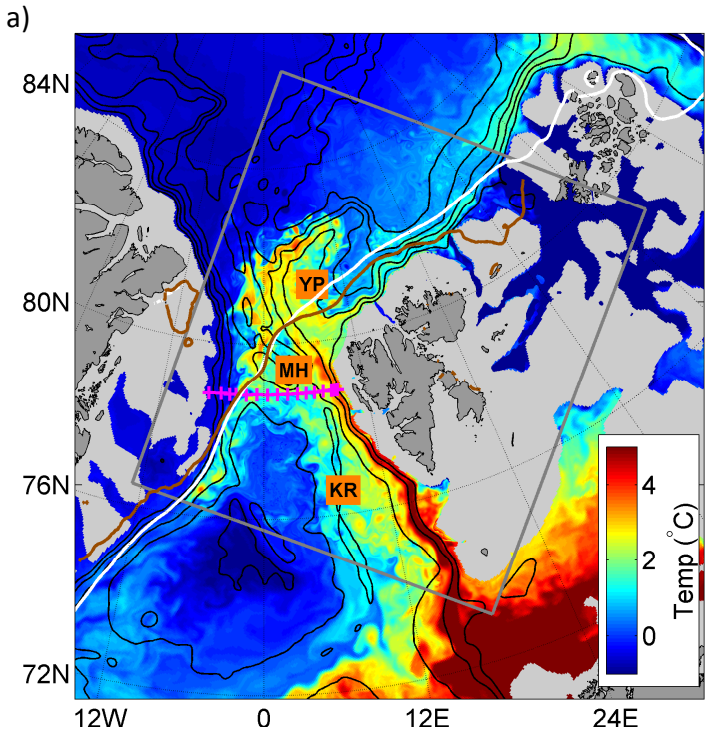
Argo sections along 0°EW in winter



- Outcropping isopycnals in Greenland Sea
- Increased density gradient and baroclinic flow



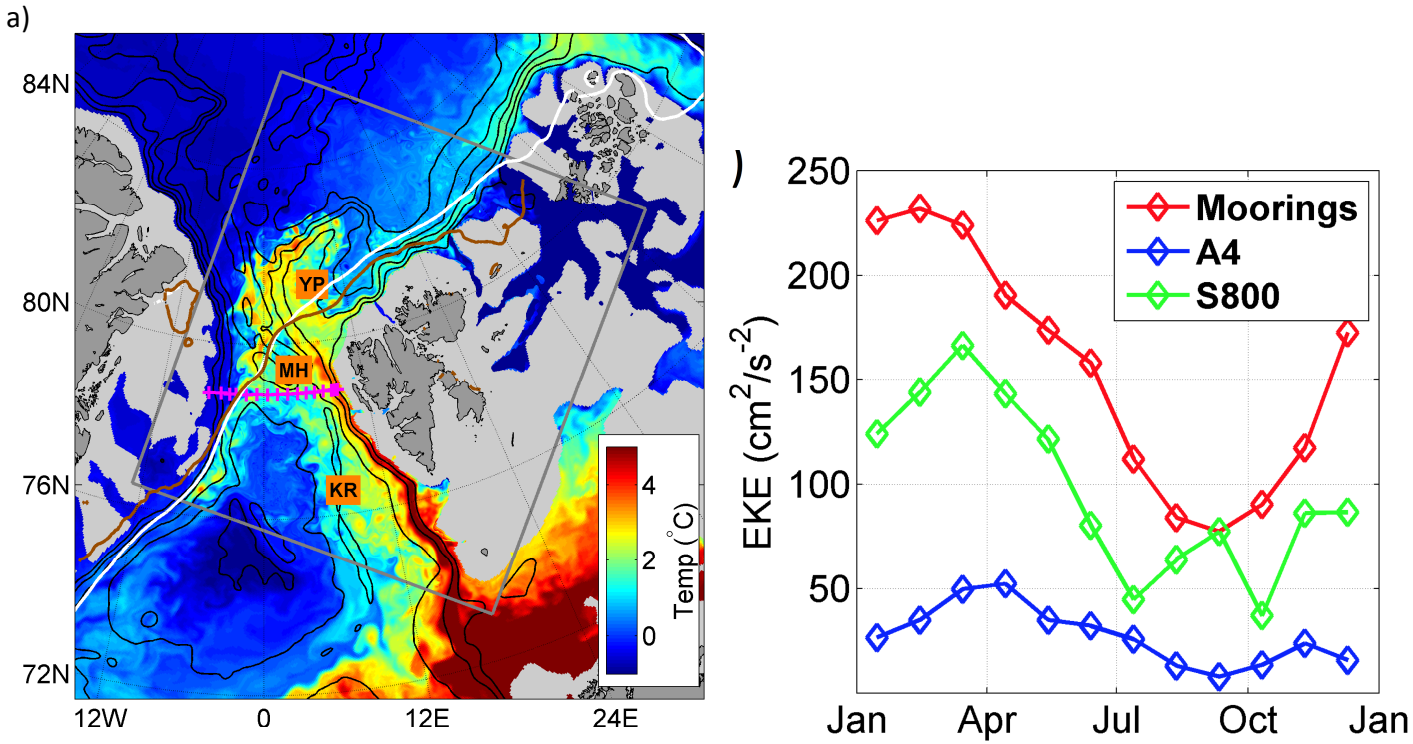
Model: Snapshot of temperature at 250 m depth



Hattermann et al. (2016)

800 m horizontal resolution model nested into 4 km Arctic wide model

Model: Snapshot of temperature at 250 m depth



Hattermann et al. (2016)

800 m horizontal resolution model nested into 4 km Arctic wide model

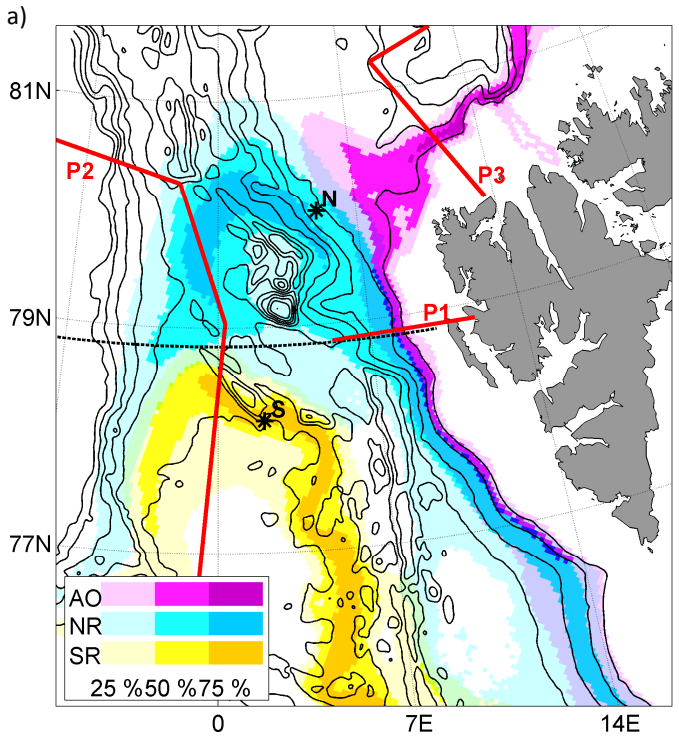
Mooring-model comparison with respect to

- Velocity direction and amplitude
- EKE amplitude and seasonal cycle

Recirculation pathways from tracking of numerical particles

Three pathway groups:

- Arctic Ocean
- Northern Recirculation
- Southern Recirculation

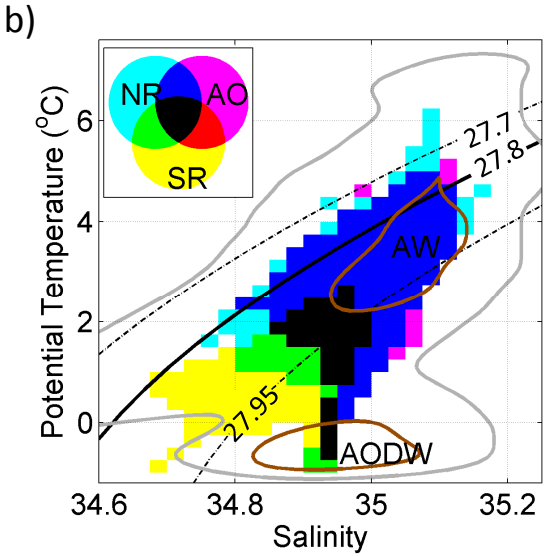


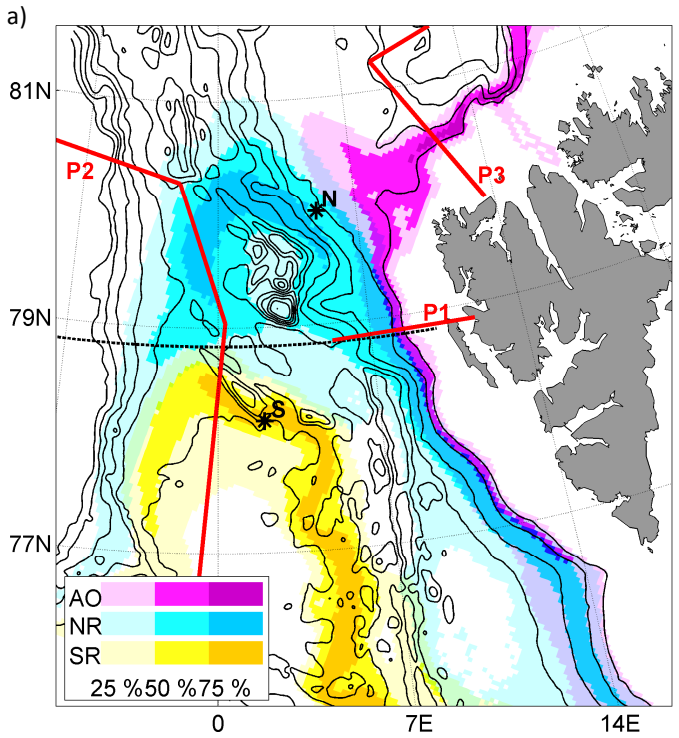
Hattermann et al. (2016)

Recirculation pathways from tracking of numerical particles

Three pathway groups:

- Arctic Ocean
- Northern Recirculation
- Southern Recirculation



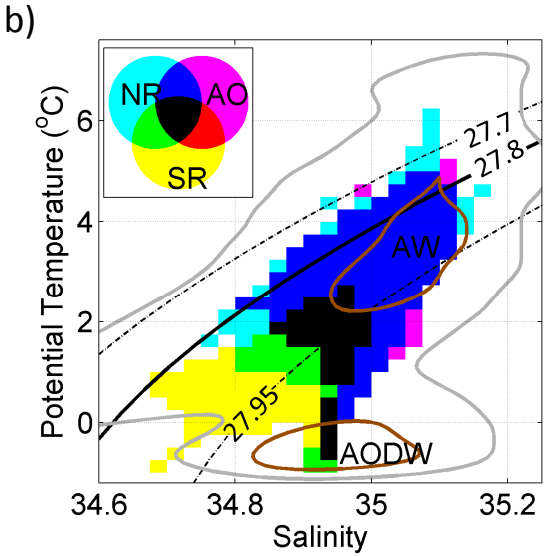


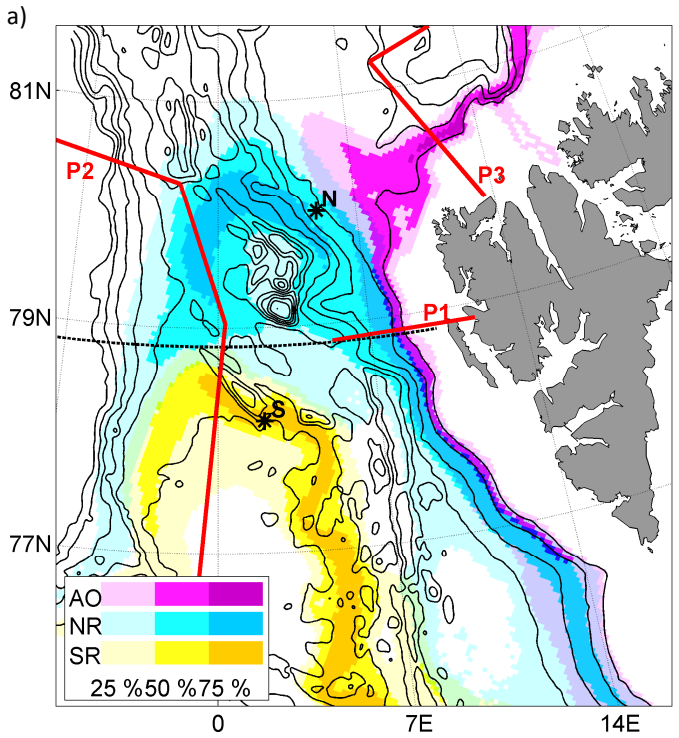
Hattermann et al. (2016)

Recirculation pathways from tracking of numerical particles

Three pathway groups:

- Arctic Ocean
- Northern Recirculation
- Southern Recirculation





Hattermann et al. (2016)

In winter, 60% of water crossing P1 recirculates

In summer, only 30%

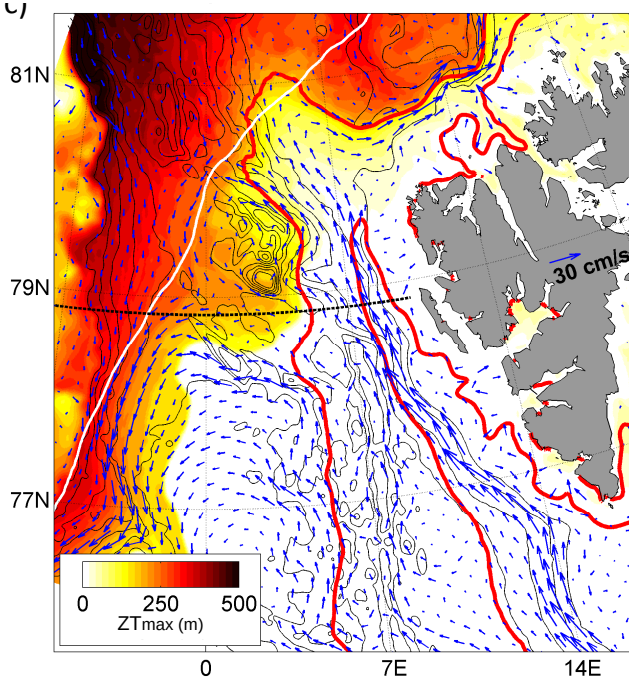
Dynamics of the northern recirculation

- EKE $>$ MKE
- EKE stronger in winter

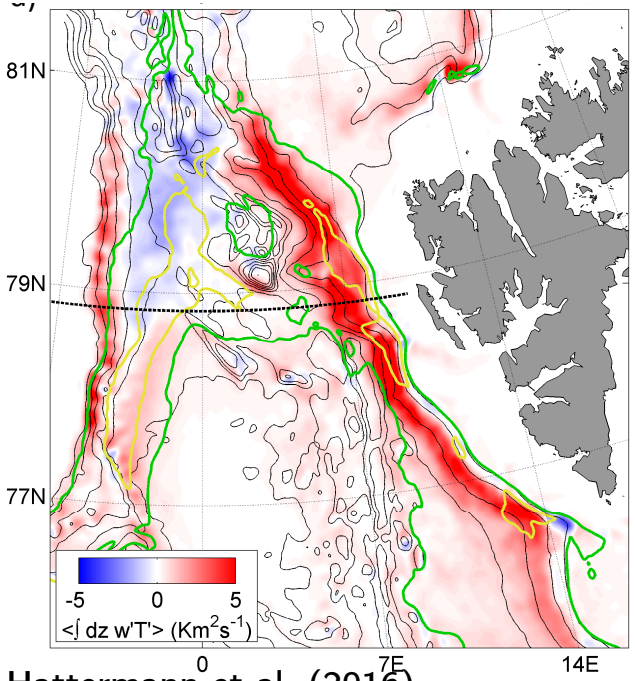
Dynamics of the northern recirculation

- EKE > MKE
- EKE stronger in winter

Depth of temperature maximum:



Depth integrated vertical eddy temperature flux:



Hattermann et al. (2016)

- Temperature maximum subducts along streamlines
- Baroclinic instability of AW/PW front
- Advective-diffusive interplay of flow along/across f/H contours

Summary

- Southern recirculation
  - Mean flow driven following f/H contours
  - Observations show baroclinic flow of ≈1.5 Sv
  - Originates from offshore branch of WSC/NwAC

Summary

- Southern recirculation
  - Mean flow driven following f/H contours
  - Observations show baroclinic flow of ≈1.5 Sv
  - Originates from offshore branch of WSC/NwAC
- Northern recirculation
  - Eddy driven flow crossing f/H contours
  - Baroclinic instability instrumental in subduction of AW
  - Only sparse observations
  - Baroclinic flow of 0.5–1.0 Sv
  - Originates from shelfbreak branch of WSC/NwAC

Summary

- Southern recirculation
  - Mean flow driven following f/H contours
  - Observations show baroclinic flow of ≈1.5 Sv
  - Originates from offshore branch of WSC/NwAC
- Northern recirculation
  - Eddy driven flow crossing f/H contours
  - Baroclinic instability instrumental in subduction of AW
  - Only sparse observations
  - Baroclinic flow of 0.5–1.0 Sv
  - Originates from shelfbreak branch of WSC/NwAC

Thank you!

References

Beszczynska-Möller, A., E. Fahrbach, U. Schauer, and E. Hansen, 2012: Variability in Atlantic water temperature and transport at the entrance to the Arctic Ocean, 1997–2010. *ICES Journal of Marine Science: Journal du Conseil*, **69 (5)**, 852–863, doi:10.1093/icesjms/fss056.

de Steur, L., E. Hansen, C. Mauritzen, A. Beszczynska-Möller, and E. Fahrbach, 2014: Impact of recirculation on the East Greenland Current in Fram Strait: Results from moored current meter measurements between 1997 and 2009. *Deep Sea Research*, **92**, 26–40.

Hattermann, T., P. E. Isachsen, W.-J. von Appen, J. Albretsen, and A. Sundfjord, 2016: Where eddies drive recirculation of Atlantic Water in Fram Strait. *Geophysical Research Letters*, **submitted**.

Isachsen, P. E., J. LaCasce, C. Mauritzen, and S. Häkkinen, 2003: Wind-driven variability of the large-scale recirculating flow in the Nordic Seas and Arctic Ocean. *Journal of Physical Oceanography*, **33 (12)**, 2534–2550.

Kawasaki, T. and H. Hasumi, 2016: The inflow of Atlantic water at the Fram Strait and its interannual variability. *Journal of Geophysical Research: Oceans*.

Marnela, M., B. Rudels, M.-N. Houssais, A. Beszczynska-Möller, and P. Eriksson, 2013: Recirculation in the Fram Strait and transports of water in and north of the Fram Strait derived from CTD data. *Ocean Science*, **9**, 499–519.

Mauritzen, C., 1996: Production of Dense Overflow Waters Feeding the North Atlantic across the Greenland-Scotland Ridge. Part 1: Evidence for a Revised Circulation Scheme. *Deep Sea Research Part I: Oceanographic Research Papers*, **43 (6)**, 769–806.

Orvik, K. A. and P. Niiler, 2002: Major pathways of atlantic water in the northern north atlantic and nordic seas toward arctic. *Geophysical Research Letters*, **29 (19)**, 1896.

Våge, K., R. Pickart, M. Spall, G. Moore, H. Valdimarsson, D. Torres, S. Erofeeva, and J. Nilsen, 2013: Revised circulation scheme north of the Denmark Strait. *Deep-Sea Research*, **79**, 20–39.

von Appen, W.-J., U. Schauer, T. Hattermann, and A. Beszczynska-Möller, 2016: Seasonal cycle of mesoscale instability of the West Spitsbergen Current. *Journal of Physical Oceanography*, **in press**, doi:10.1175/JPO-D-15-0184.1, URL `http://journals.ametsoc.org/doi/abs/10.1175/JPO-D-15-0184.1`.