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The Arctic Ocean volume, heat and freshwater transports during 2004-2010

ARCGATE: Maximizing the potential of Arctic Ocean Gateway array

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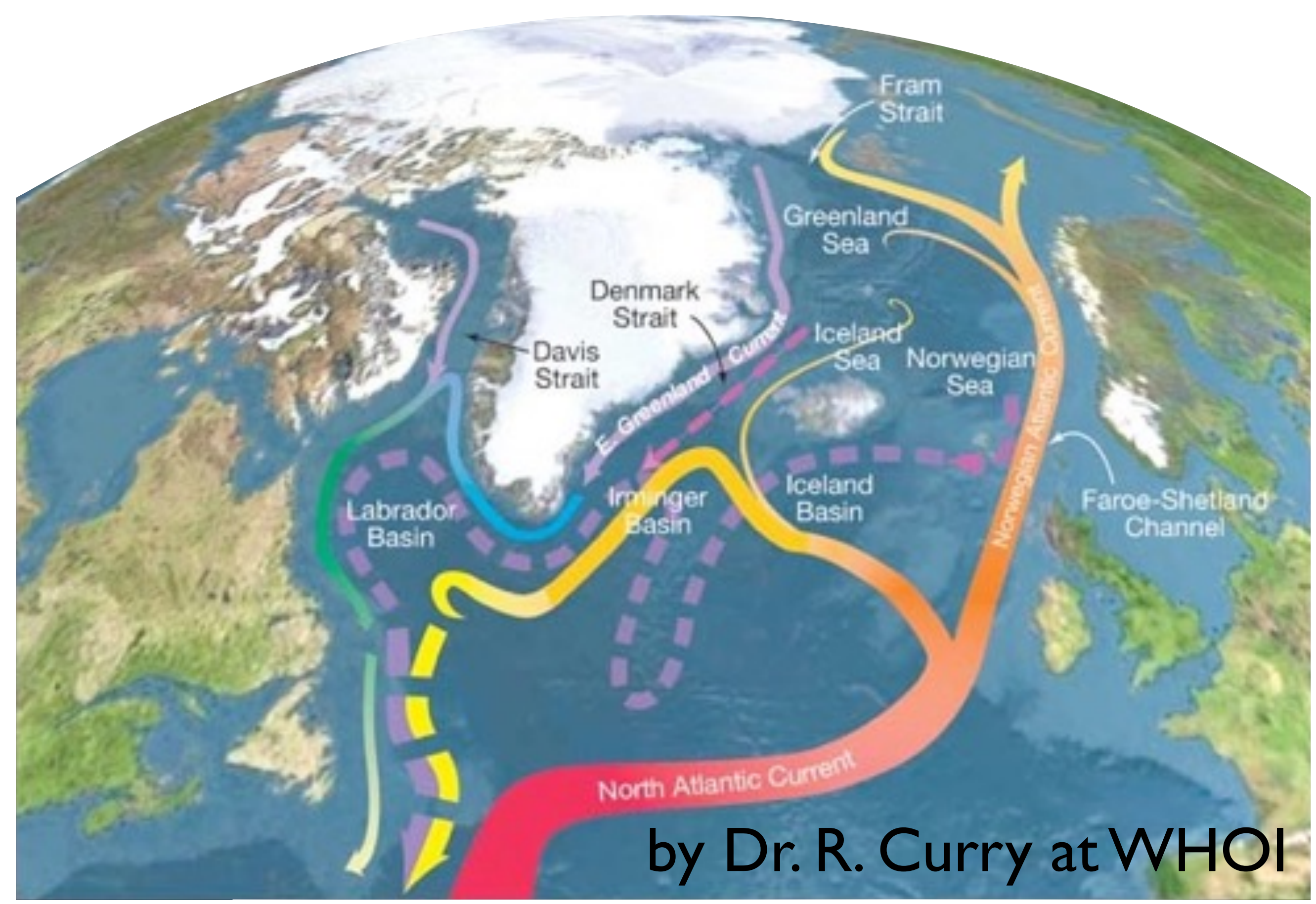


by Dr. R. Curry at WHOI

Arctic boundary observation

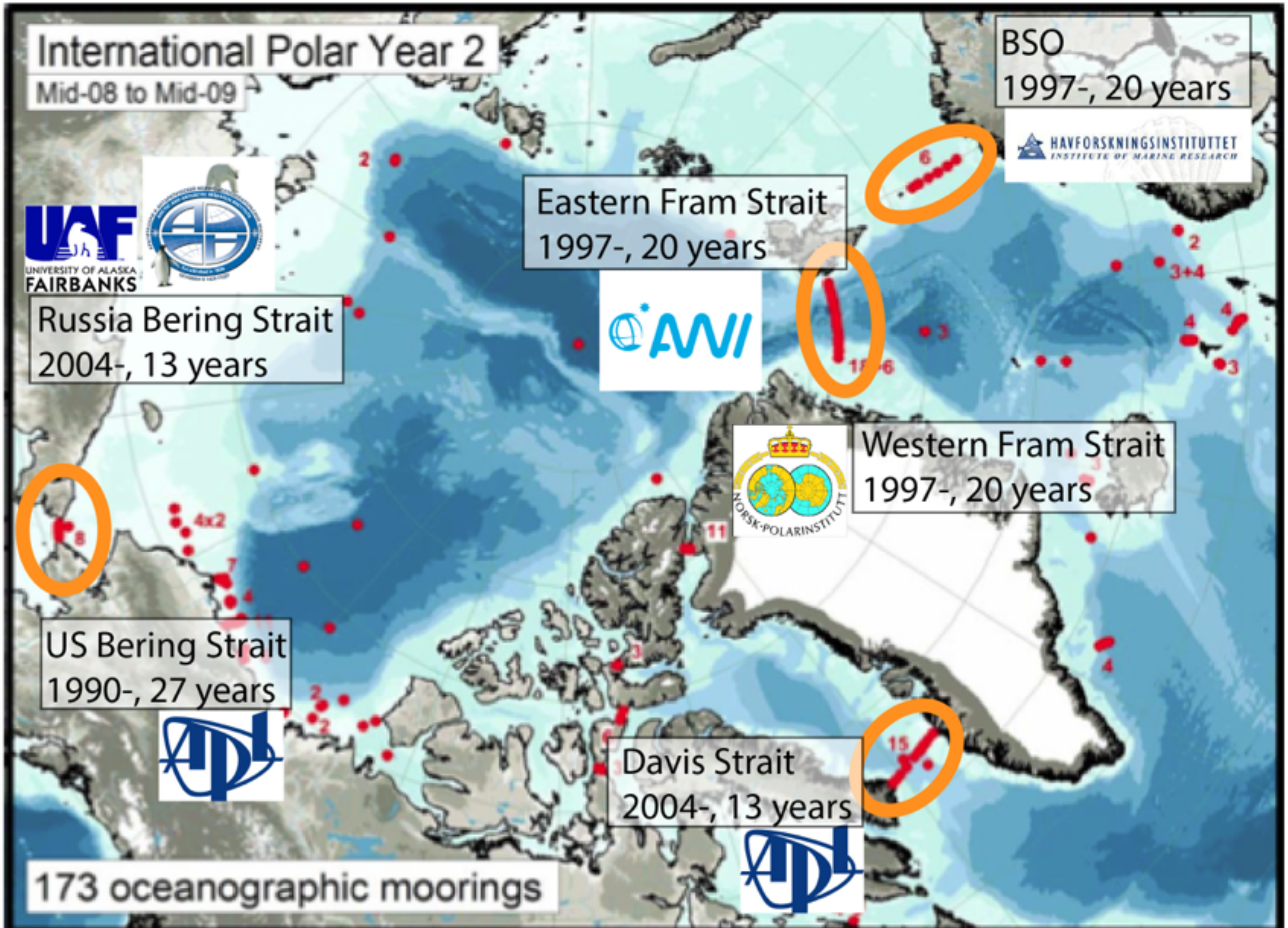
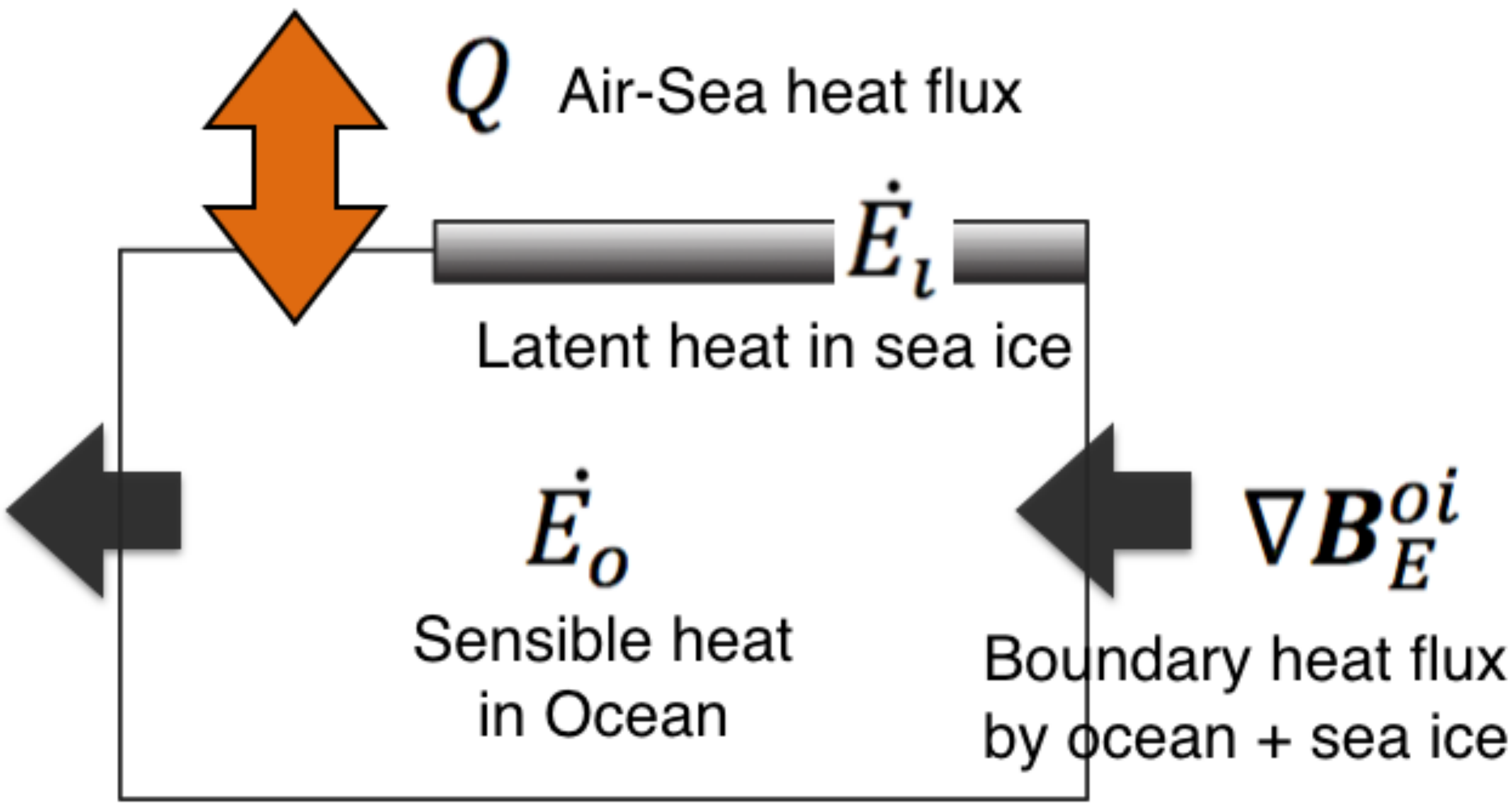


Fig. Mooring array during 2008-09, modified from Dickson et al. [2009]

The heat budget in the Arctic Ocean

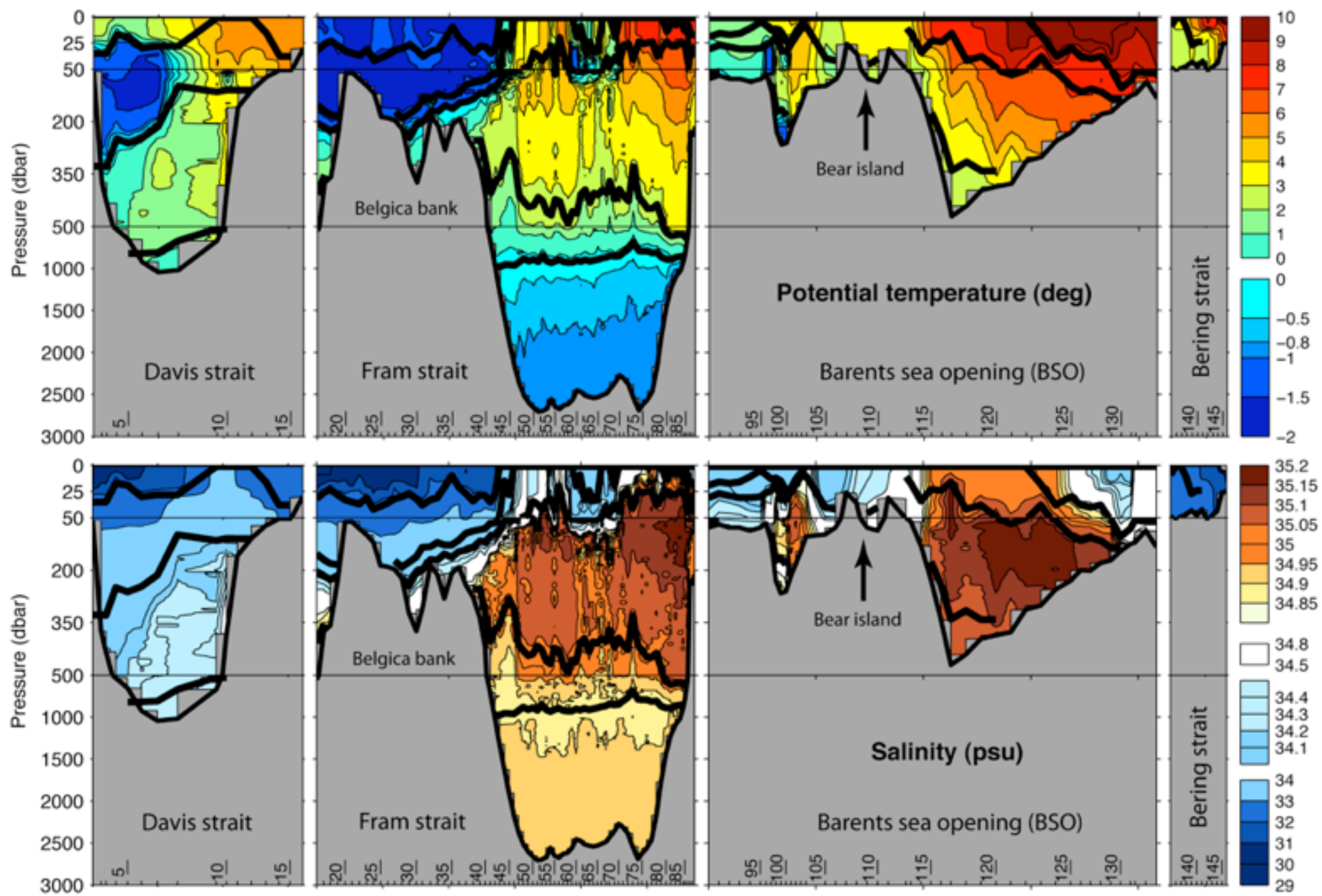
Little is known about oceanic heat temporal variability

$$\dot{E} = \dot{E}_o + \dot{E}_\iota = \nabla \boldsymbol{B}_E^{oi} + Q$$



The pan-Arctic approach: progress so far

- Quasi-synoptic estimate in summer 2005 [Tsubouchi et al., 2012].
- First seasonal cycle during 2005-06 [Tsubouchi et al. under review].



Tsubouchi et al.
[2012, JGR]

Objective of this study

Quantify "observation based" multi-year monthly volume, heat, FW transports during 2004-10.

Focus period: Oct. 2004 - May 2010 (68 months)

Data during 2004-2010

- ~1,000 moored instruments: microCAT (T, S: blue), RCM (T, (S),V: red), ADCP (V: green).
- 37 Repeat CTD sections in south of BSO.
- PIOMAS sea ice thickness & velocity data [Zhang and Rothrock, 2003]

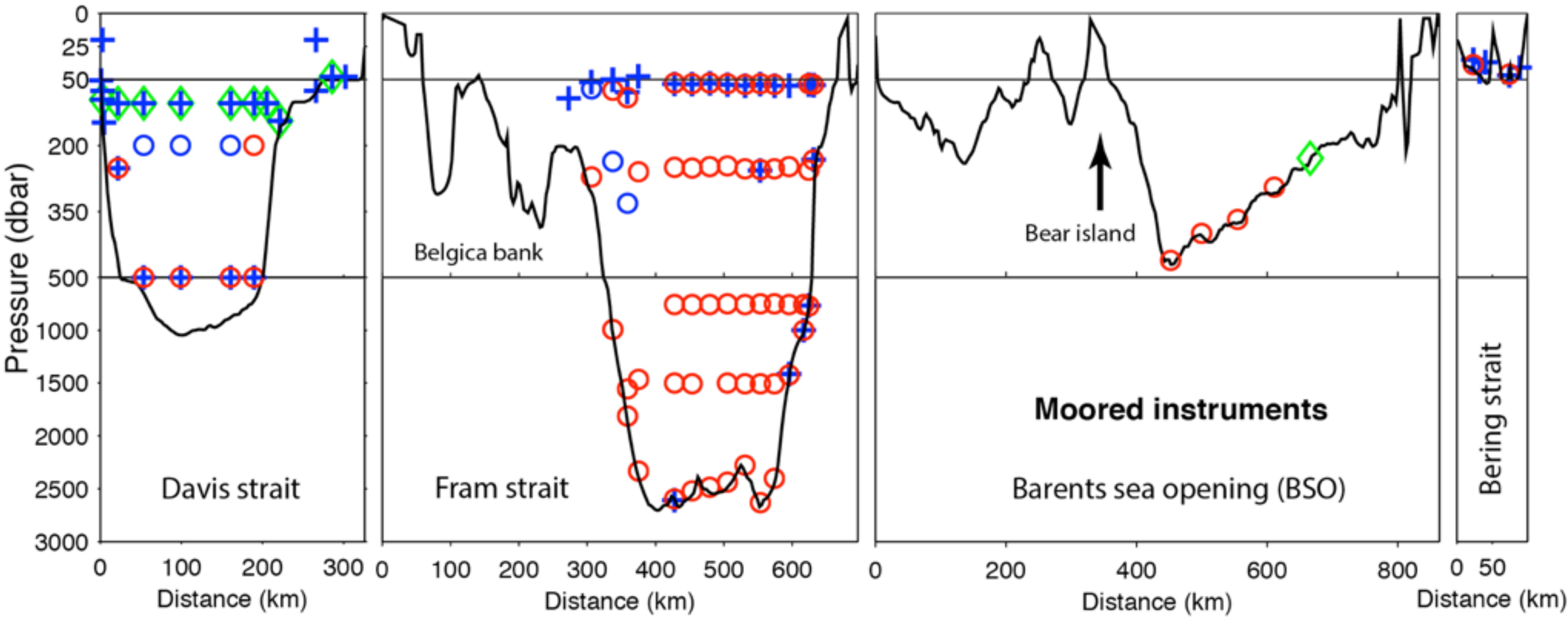
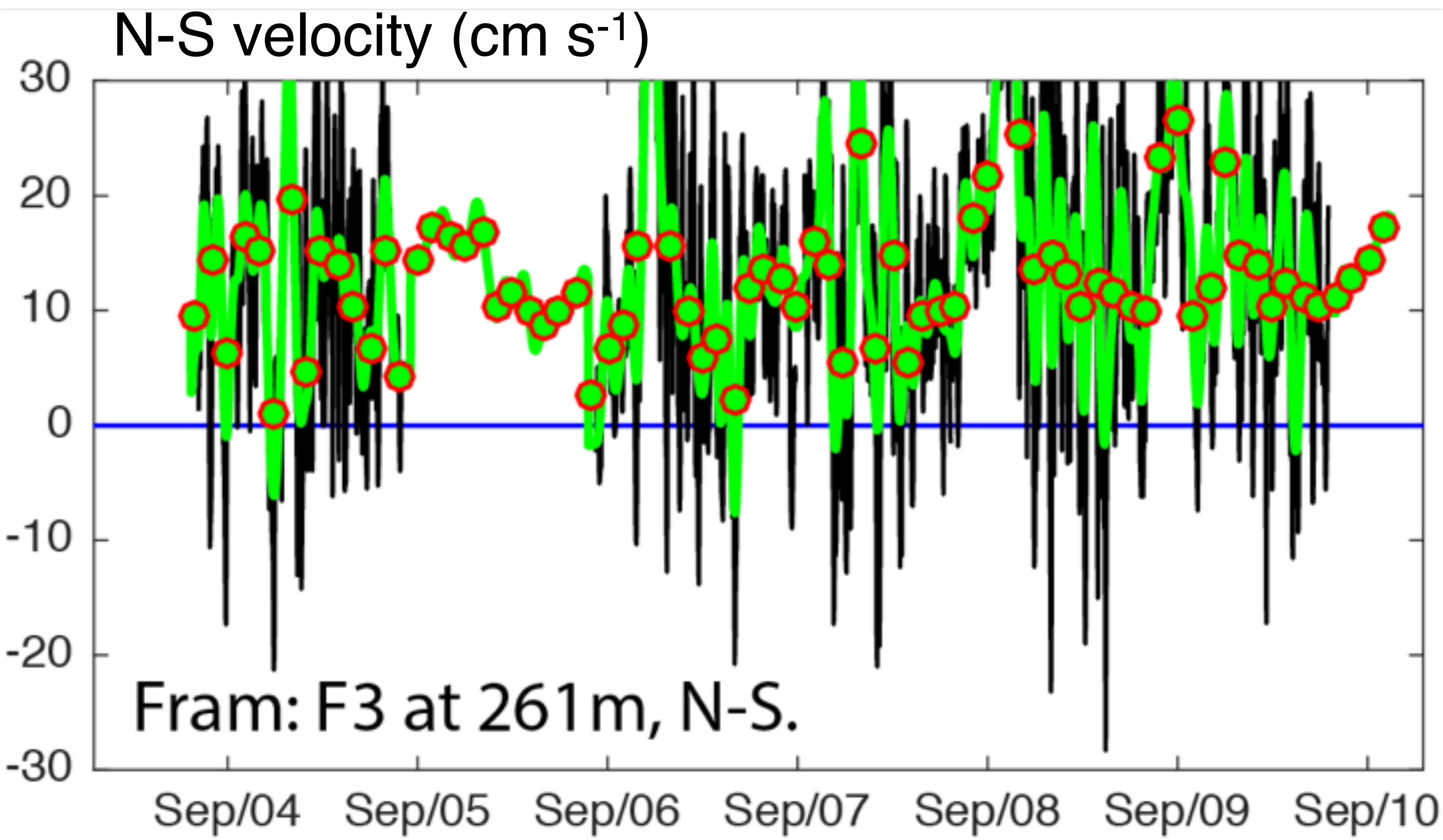


Fig. Mooring array in the Arctic four main gates

Filtering and Gridding

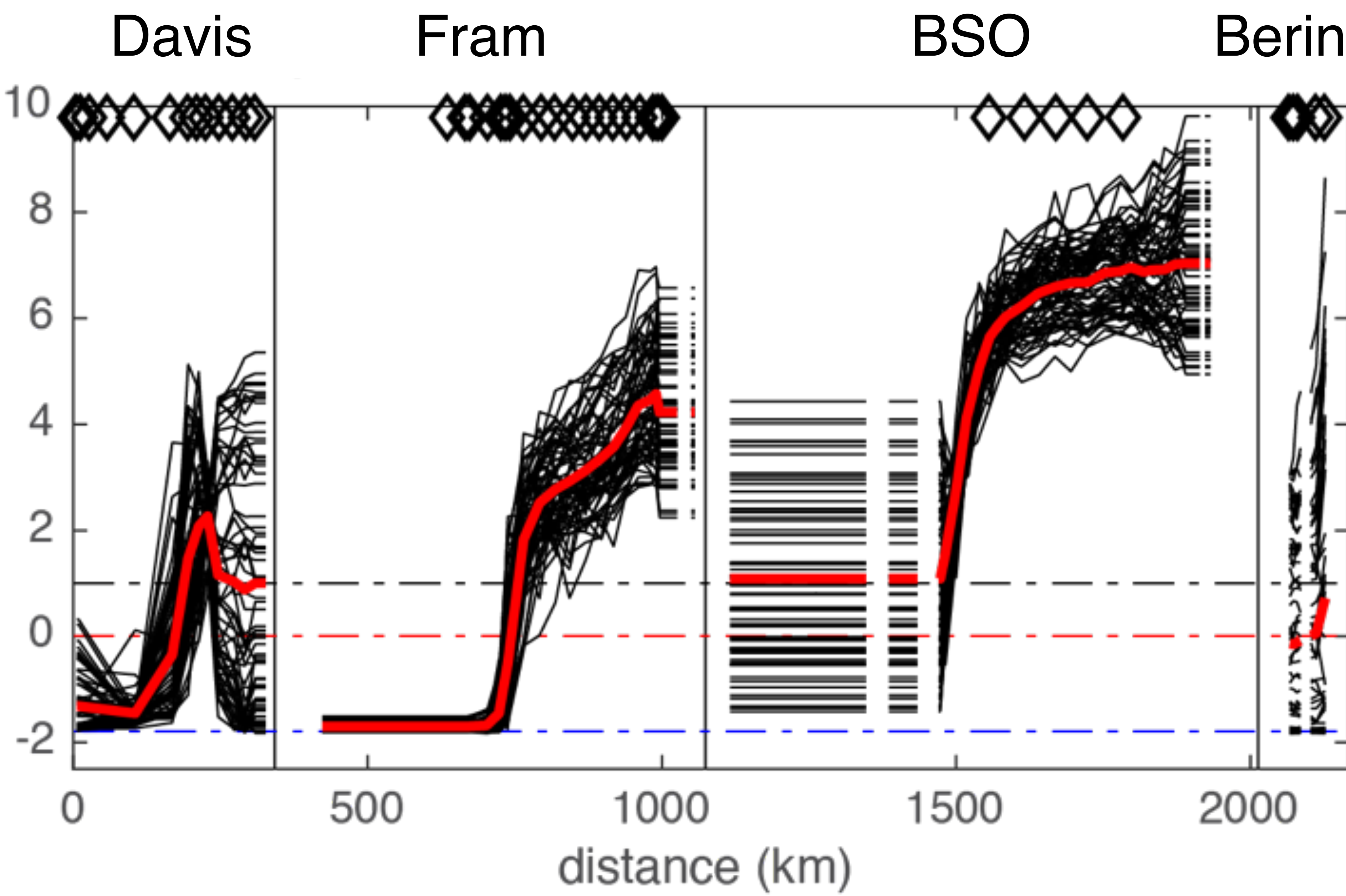
- De-tided and smoothed with Butterworth filter (27 days cutoff).
- Data gaps (> 30days) are filled by its mean annual cycle.
- Linear interpolation is applied vertically and horizontally.



Daily de-tided (black)
Daily smoothed (green)
Monthly mean (red)

Monthly Temperature fields

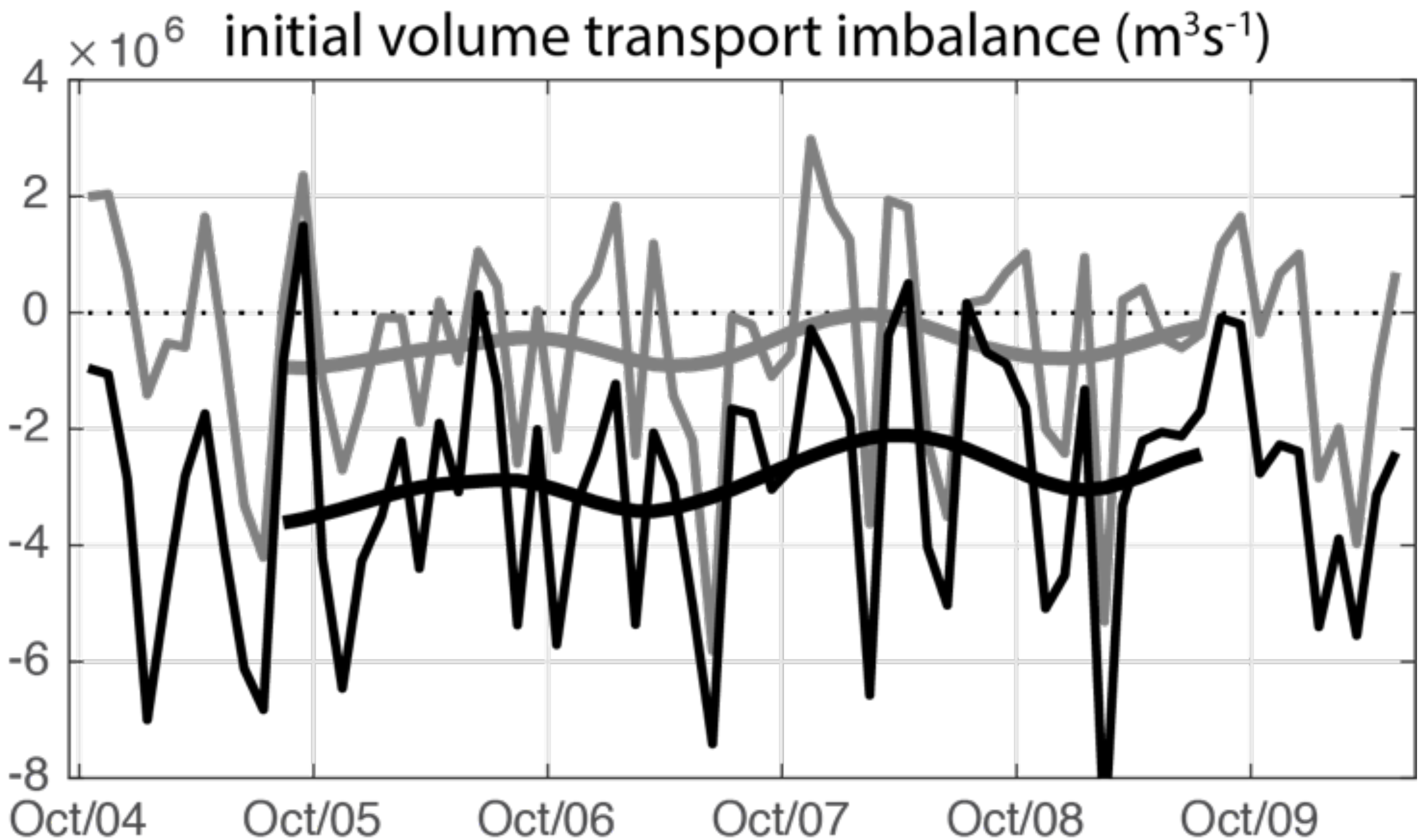
- Captures major water mass distributions & variabilities
  - AW in WSC and BSO, Polar water, large variability in Bering Strait.



Temperature at 50m.
Monthly in black,
average in red.

Monthly initial volume transport imbalance

- Initial imbalances is -3.0±2.2 Sv.
- Of which, below 1,500m accounts for -2.4±0.9 Sv.

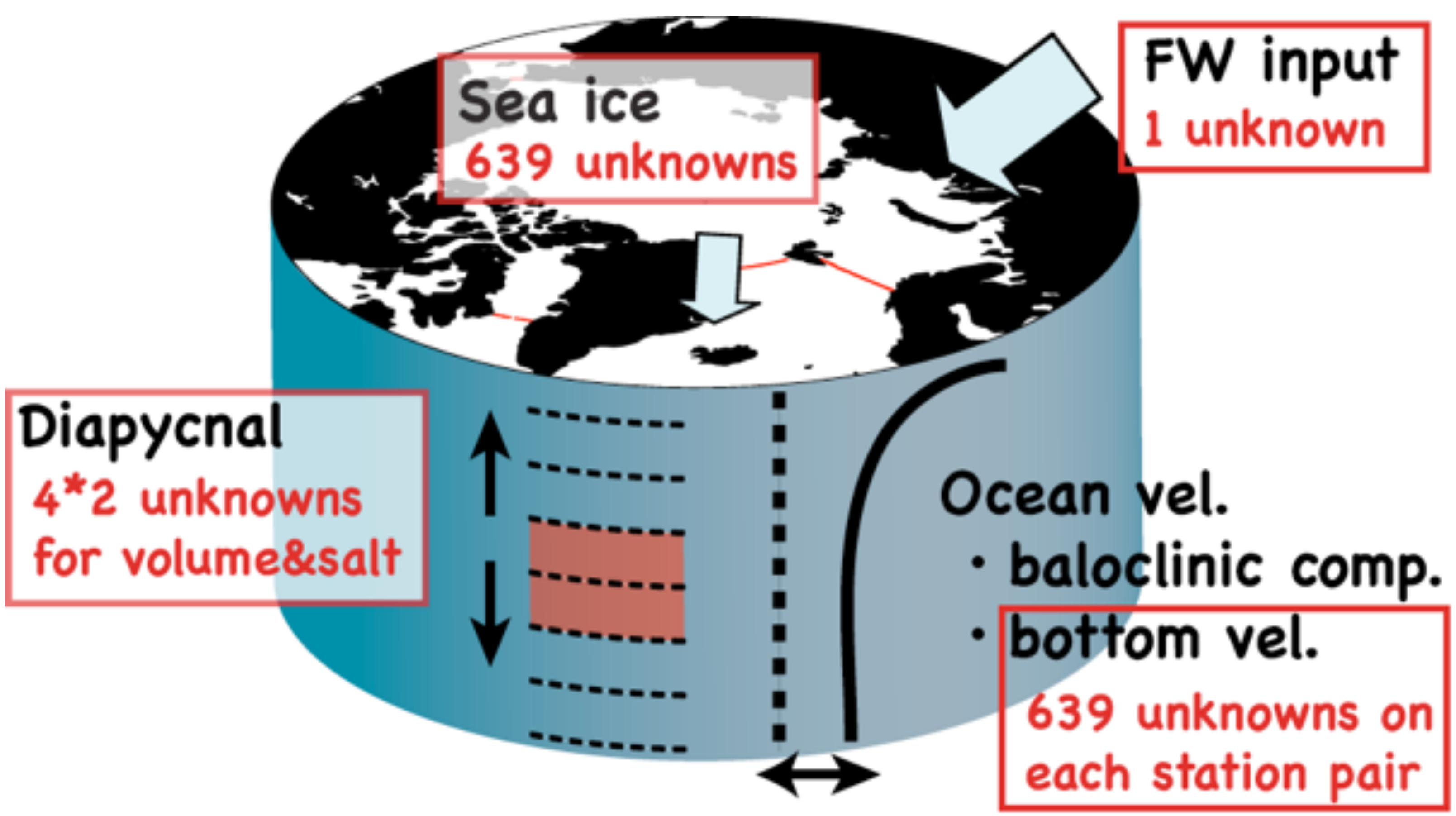


Full depth (black), above 1,500m (grey).

Inverse model: unknowns & constraints

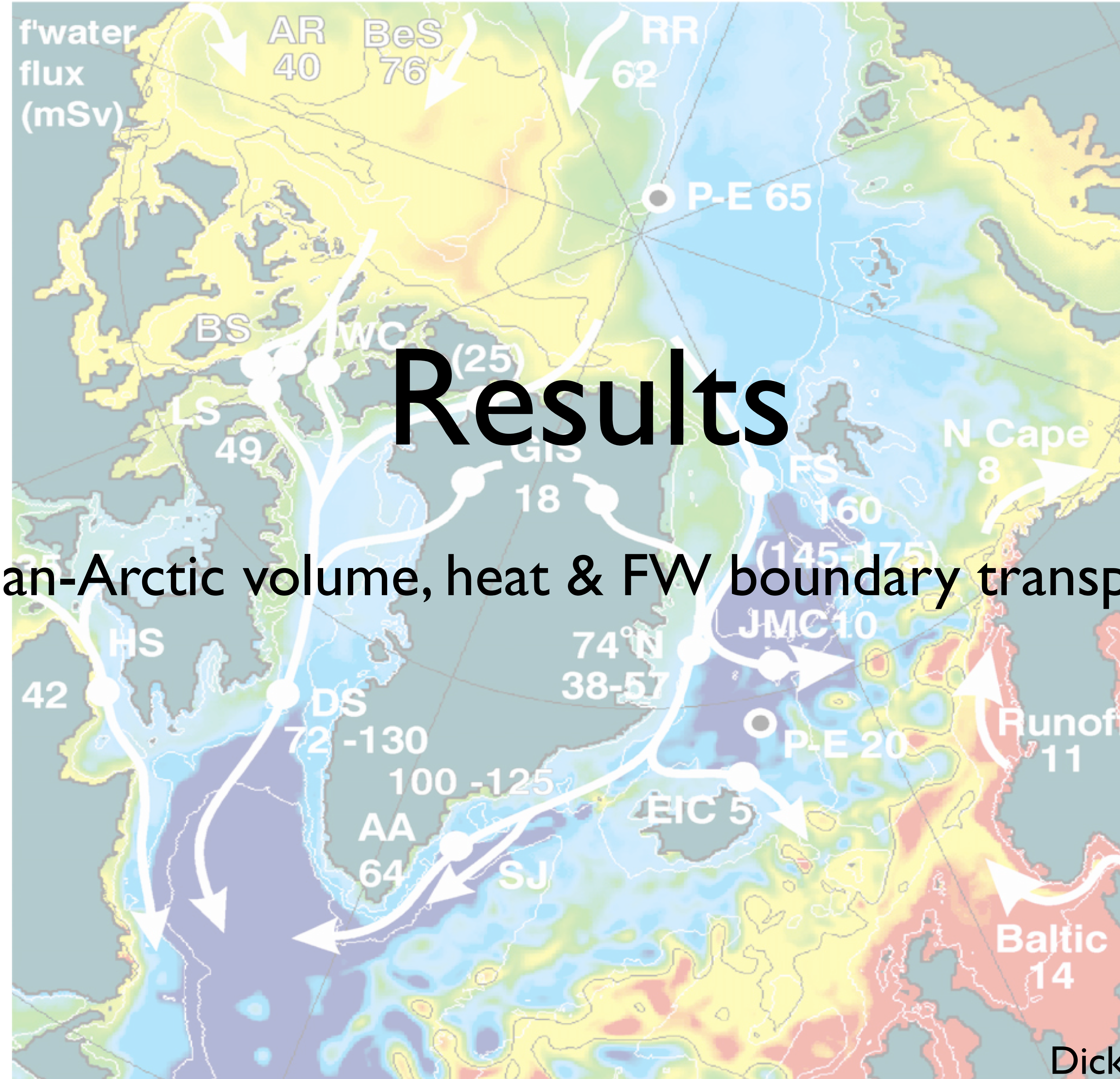
Obtain volume and salt conserved monthly velocity field for consecutive 68 months.

- 1287 unknowns are derived from 12 constraints.
  - Bottom vel (639), Sea ice (639), FW input (1), Diapycnal (8)
  - Volume & Salt: 5 layers and whole layer



Results

pan-Arctic volume, heat & FW boundary transports



Dickson et al. (2006)

Mean velocity field during 2004-2010

- Captures major current system.
    - Polar water outflow, AW inflow, PW inflow.

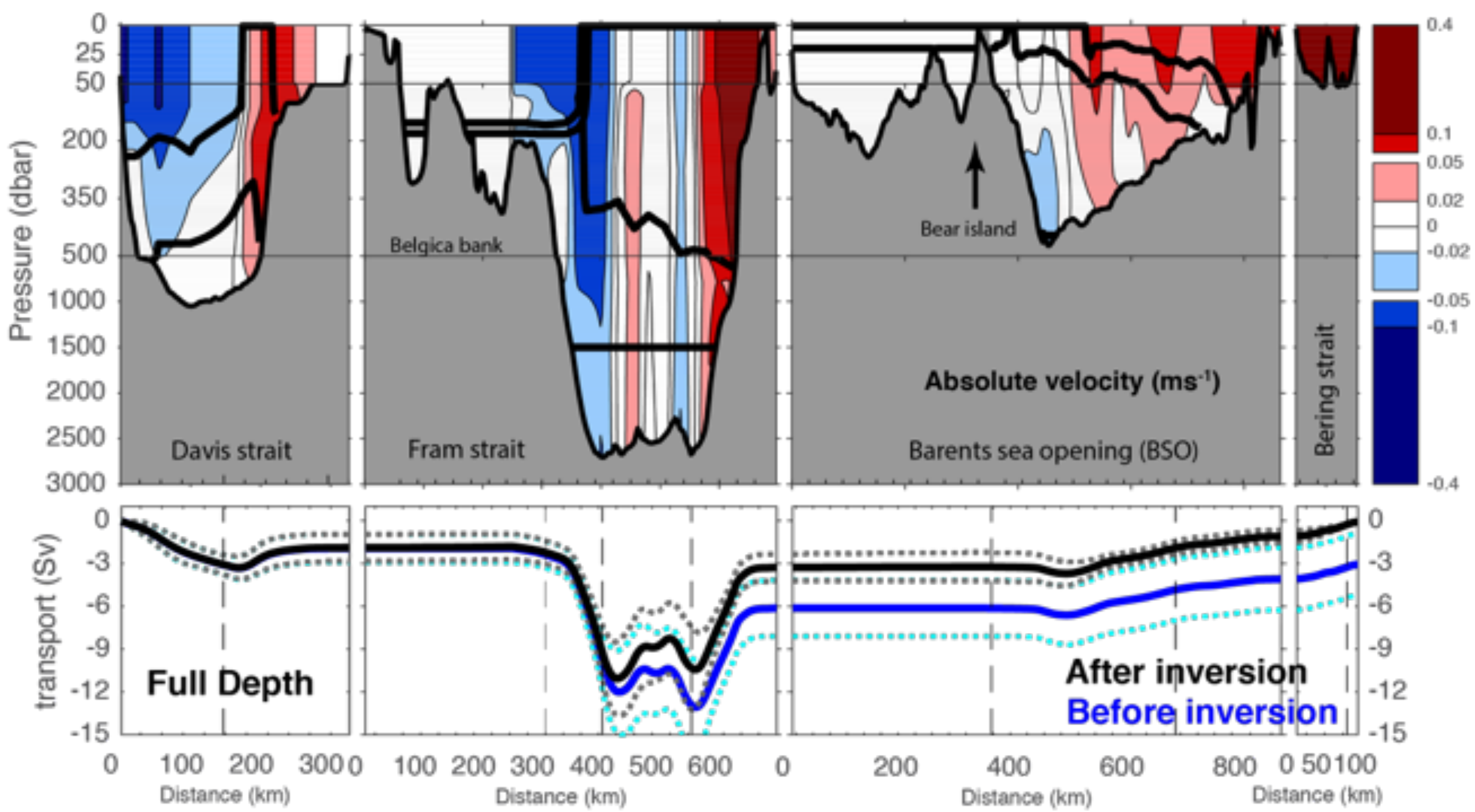


Fig. (top) mean volume & salt closed velocity field. (Bottom) cumulative full depth volume transport.

Table: volume transport comparison

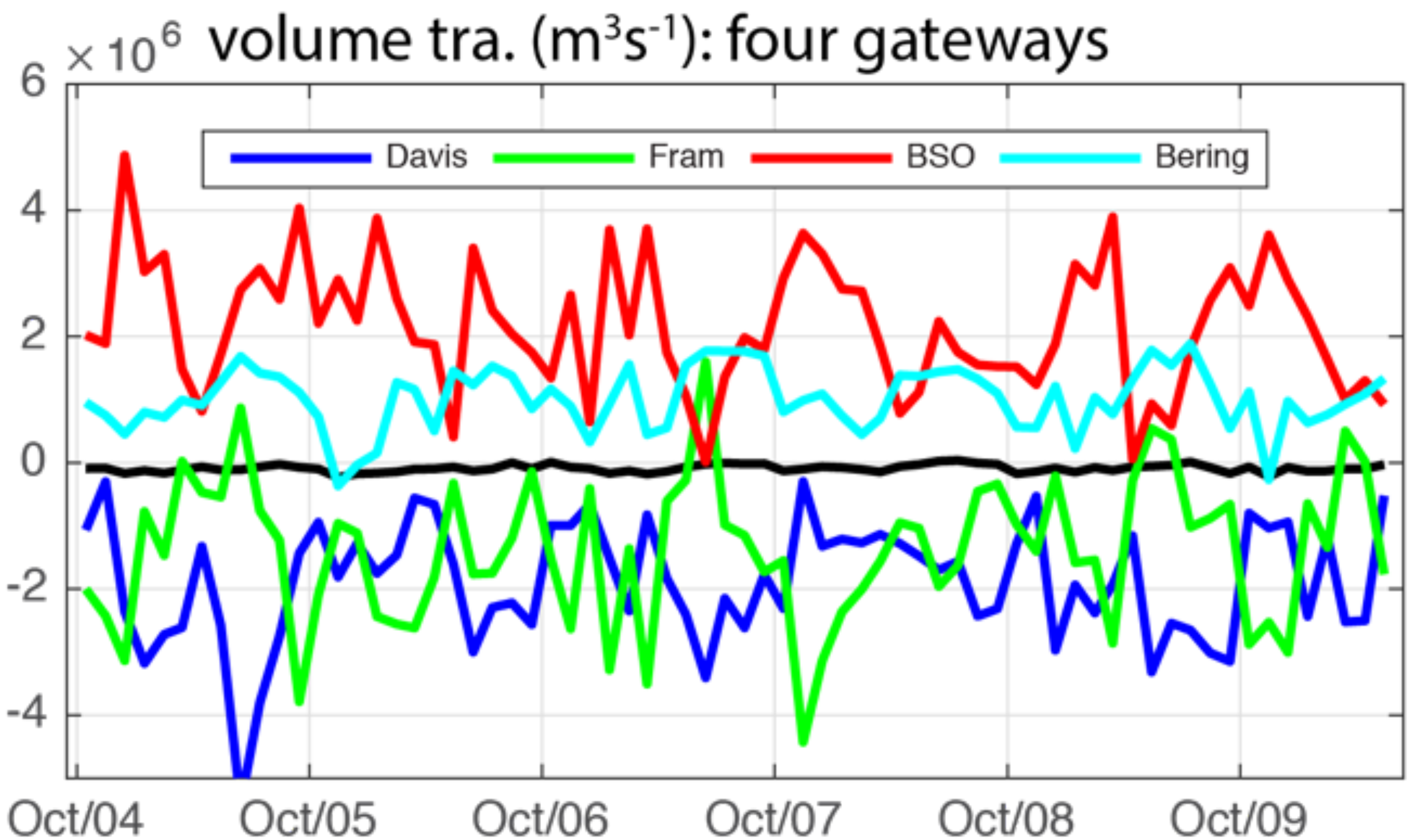
(Sv)	This study	reference
Davis	-1.9±1.0	-1.6±0.5(*1)
Fram	-1.4±1.2	-2.0±2.7 (*2)
BSO	2.2±1.0	2.0 (*3)
Bering	1.0±0.5	0.8 (*4)
Net	-0.10±0.06	-0.8

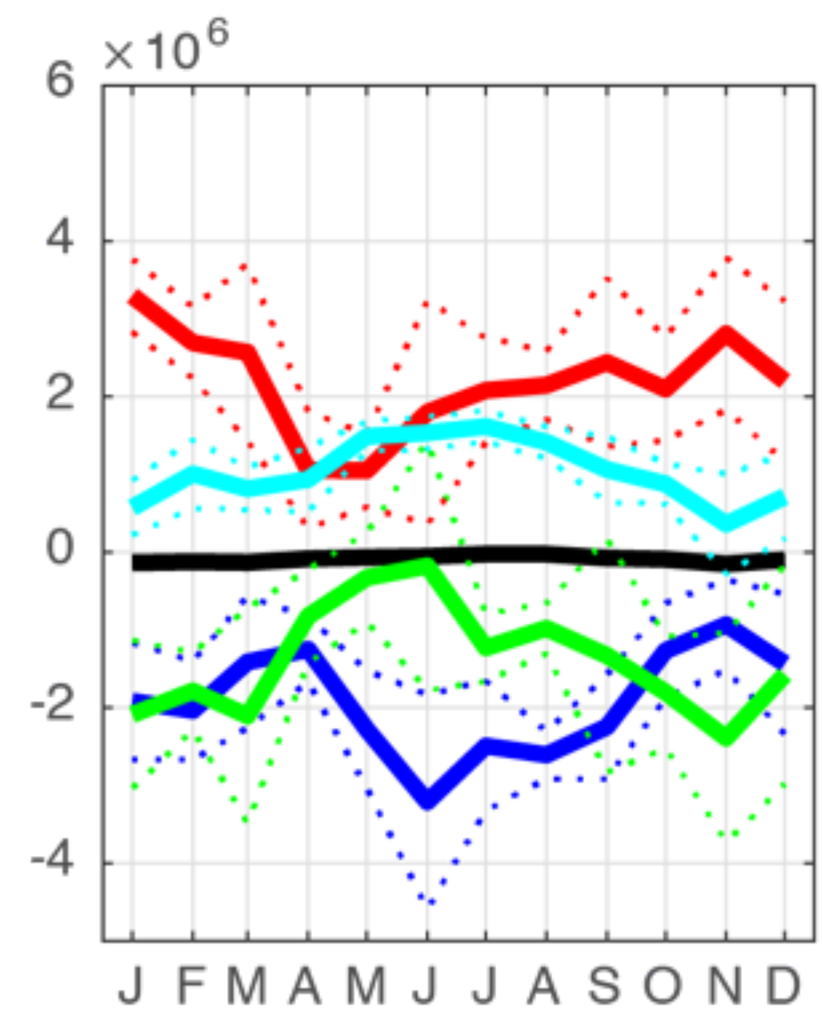
*1 Curry et al., 2014, *2 Schauer et al., 2008, *3 Smerdsrud et al., 2010, *4 Woodgate et al., 2005

Volume transports: each gateway

- Net transport is almost zero in each month.
- Seasonality.
  - Strong BSO inflow in winter.
  - Strong Bering inflow in summer.

(Sv)	long term	JFM	JAS
Davis	-1.9±1.0	-1.8	-2.4
Fram	-1.4±1.2	-2.0	-1.2
BSO	2.2±1.0	+2.9	+2.2
Bering	1.0±0.5	+0.8	+1.4

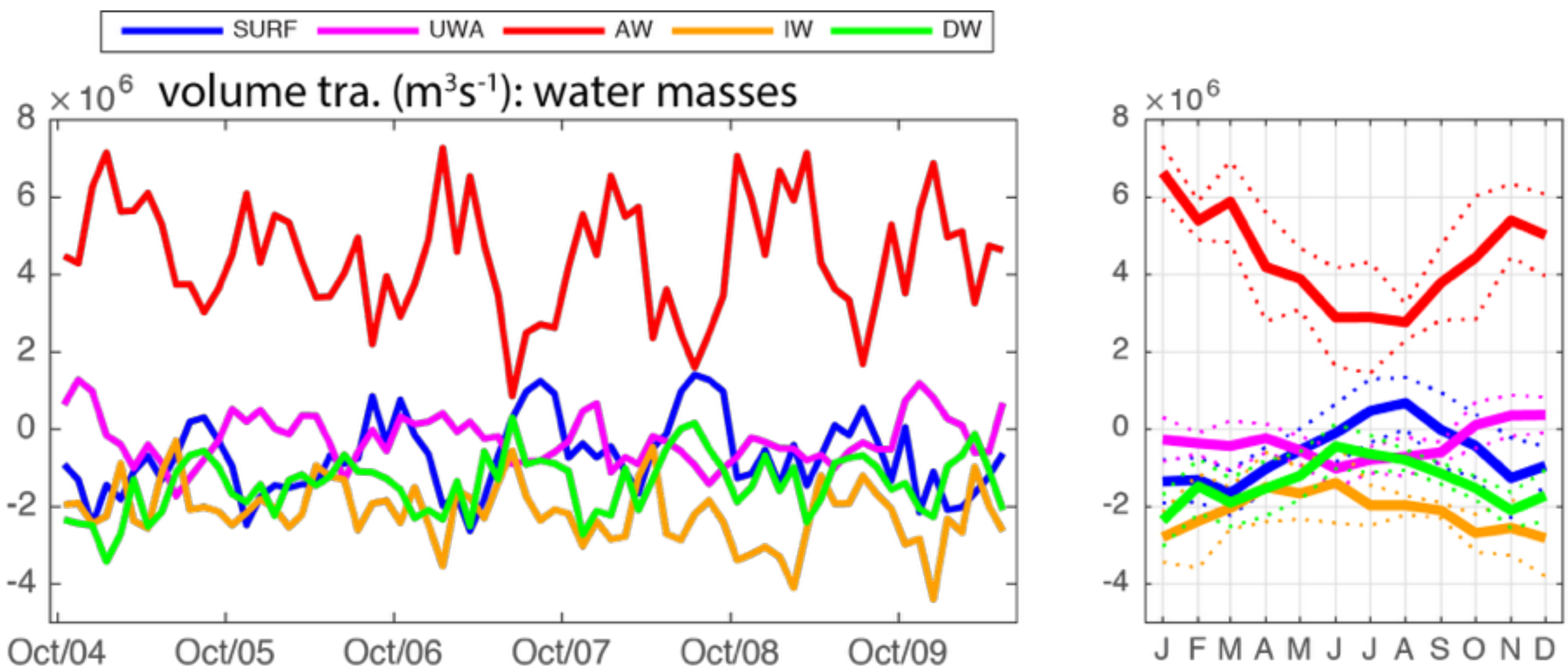




Volume transports: water mass

- Double cell overturning structure.
- AW inflow: strong in winter, weak in summer.
- DW outflow (-1.4±0.8 Sv) may be too strong.

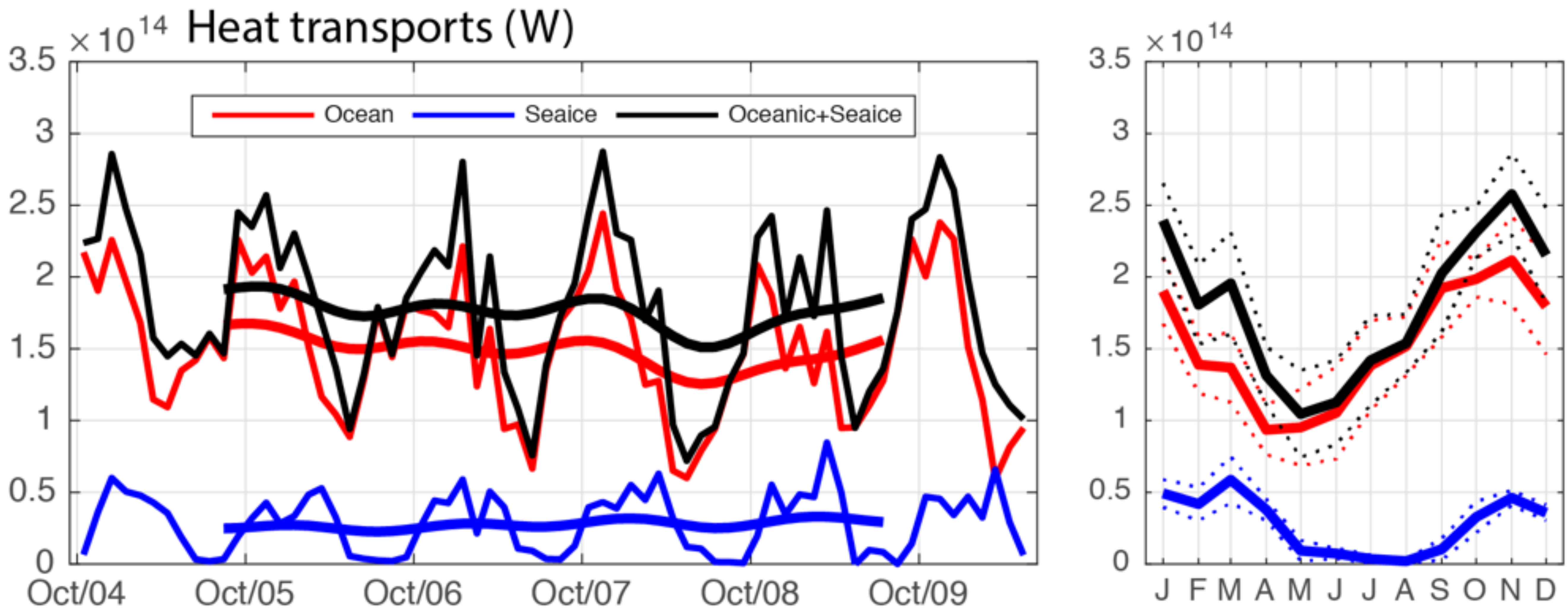
(Sv)	mean	JFM	JAS
SURF+UAW	-1.0	-1.8	-0.3
AW	+4.5	+6.0	+3.2
IW+DW	-3.5	-4.3	-2.9



The Heat transports

- The heat transport is 180±57 TW (68 monthly ave & std).
- Seasonality: ~250TW in Nov, ~100 TW in May.
- Inter-annual variability: 196±56 TW in 2004-05, 165±71 TW in 2007-08.

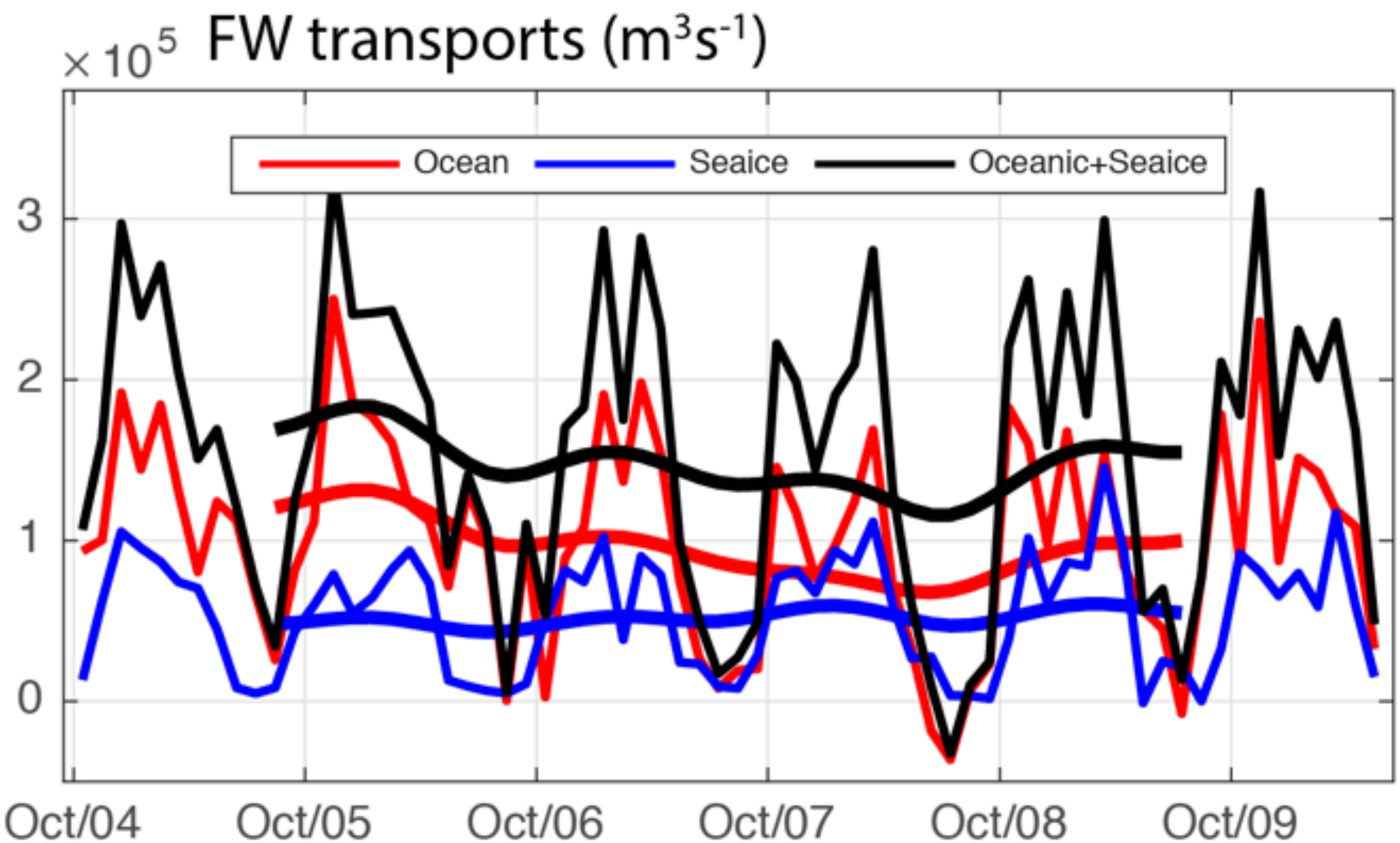
*12 monthly ave & std from Oct to following Sep.

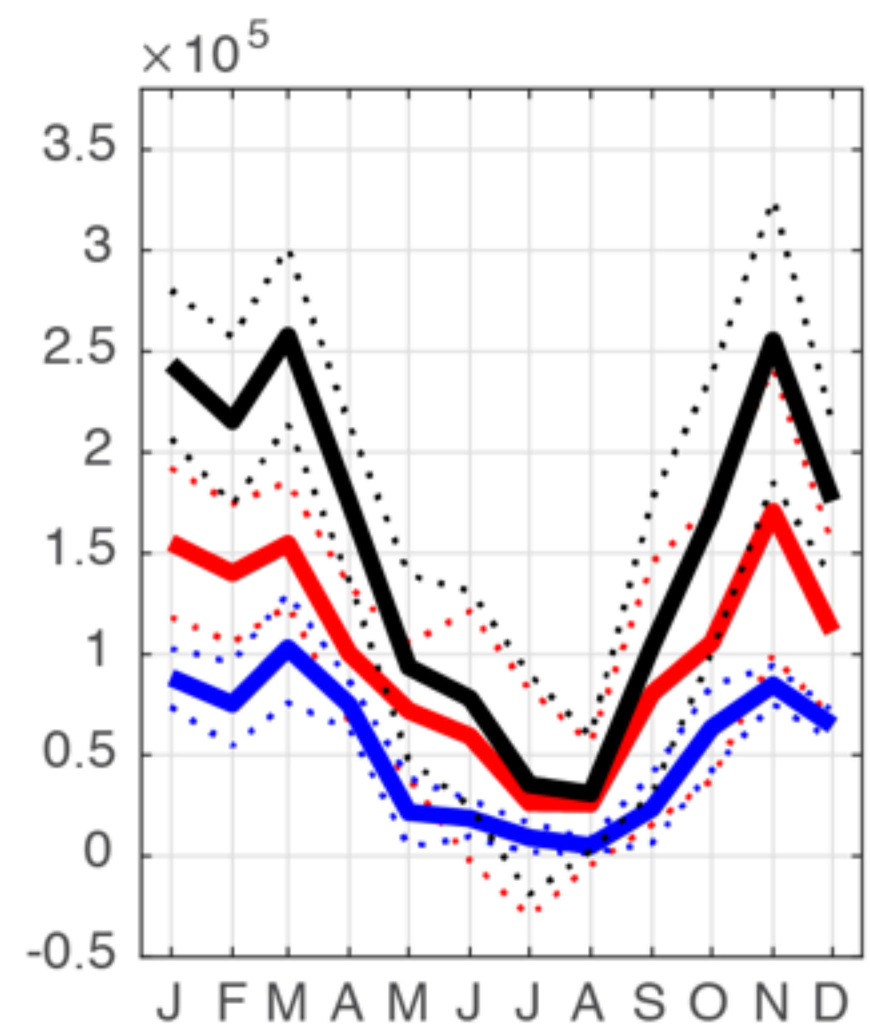


The FW transports

- The FW transport is 156±91 mSv (68 monthly ave & std).
- Seasonality: ~250 mSv in Nov-Mar, ~50 mSv in Jun-Aug.
- Inter-annual variability: 163±79 mSv in 2004-05, 121±103 mSv in 2007-08.

*12 monthly ave & std from Oct to following Sep.

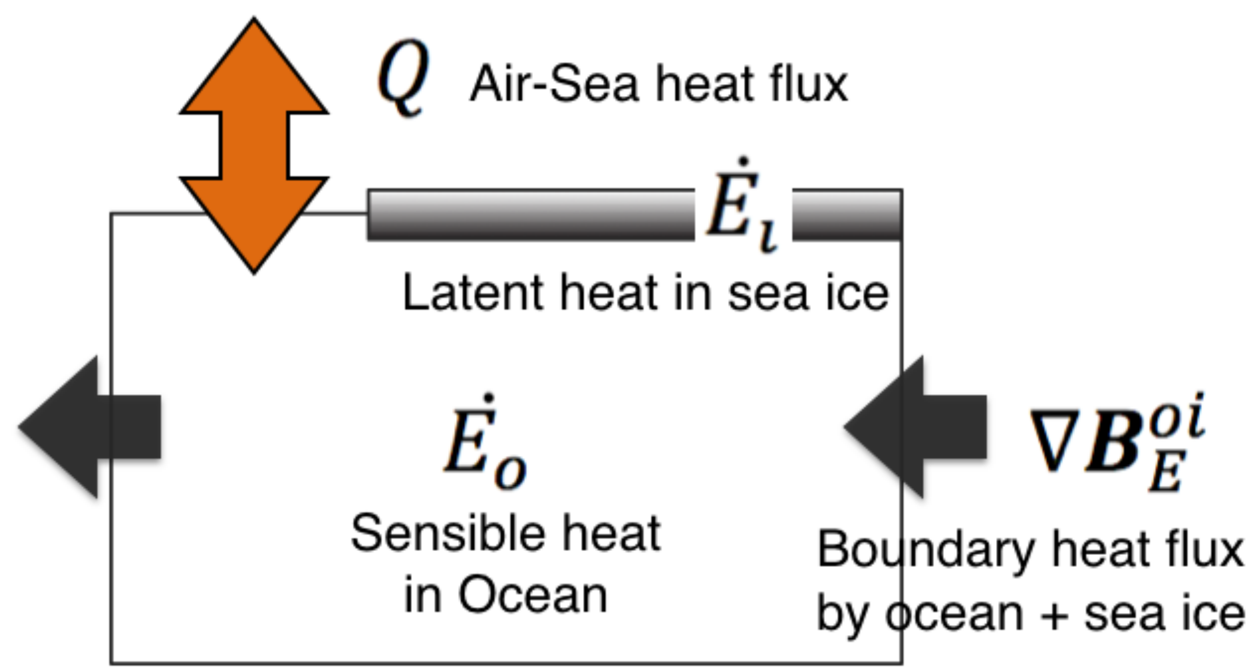




Putting into a big picture

- Heat budget
  - 180±57 TW ~ 15.9±5.0 Wm^{-2}
  - MERRA has the best agreement.

$$\dot{E} = \dot{E}_o + \dot{E}_\iota = \nabla \boldsymbol{B}_E^{oi} + Q$$



Long-term air-sea heat fluxes north of 70˚N (Wm^{-2})

NRA	ERA40	JRA25	MERRA
5	11	14	19

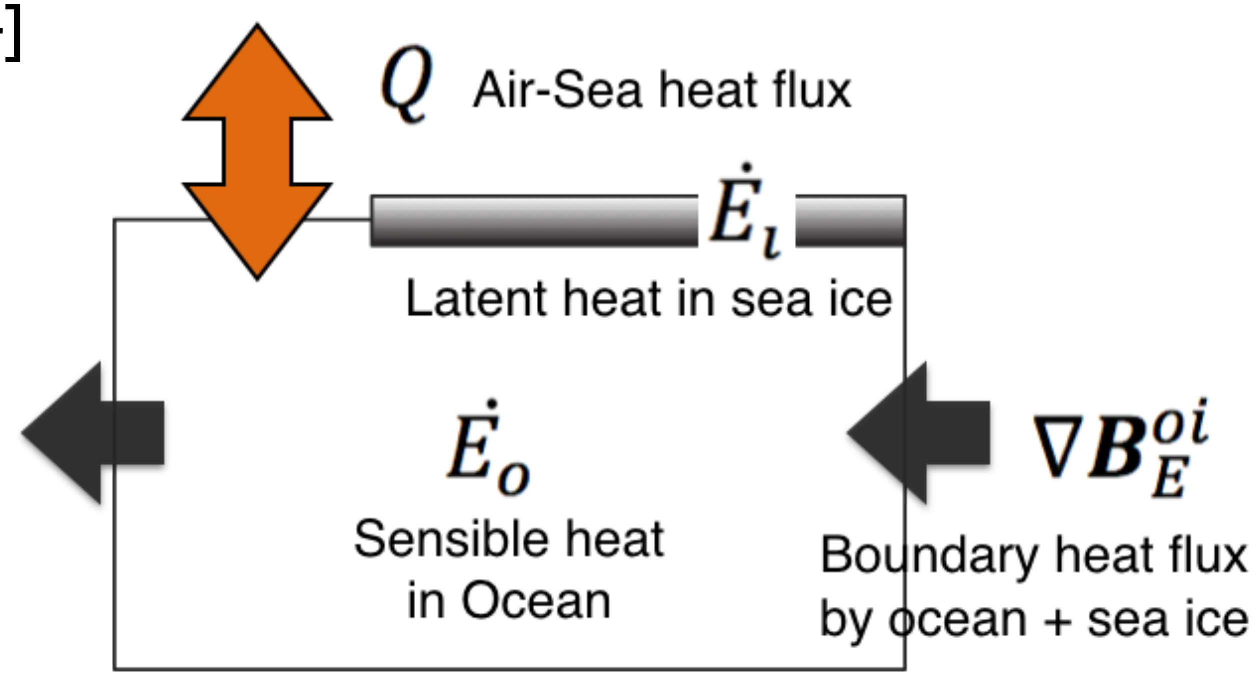
Porter et al. [2010], Cullather & Bosilovich [2012]

Note that 10W/m^2 is equivalent to 1m sea ice melt in a year.

Putting into a big picture

- FW budget
  - Boundary: 156±91 mSv
  - Surface: ~214 mSv. Haine et al. [2015]
  - FW content: ~25 mSv. Rabe et al. [2014]
  - Imbalance of ~33 mSv - significant?

$$\dot{E} = \dot{E}_o + \dot{E}_\iota = \nabla \boldsymbol{B}_E^{oi} + Q$$



What changes by changing T_{ref}?

- Total heat transport DOES NOT change.
- Temperature transport in each piece of section DOES change.
  - e.g. WSC: 33±14 TW-eq (1.01±0.18˚C), 113±34 TW-eq (-1.8˚C).

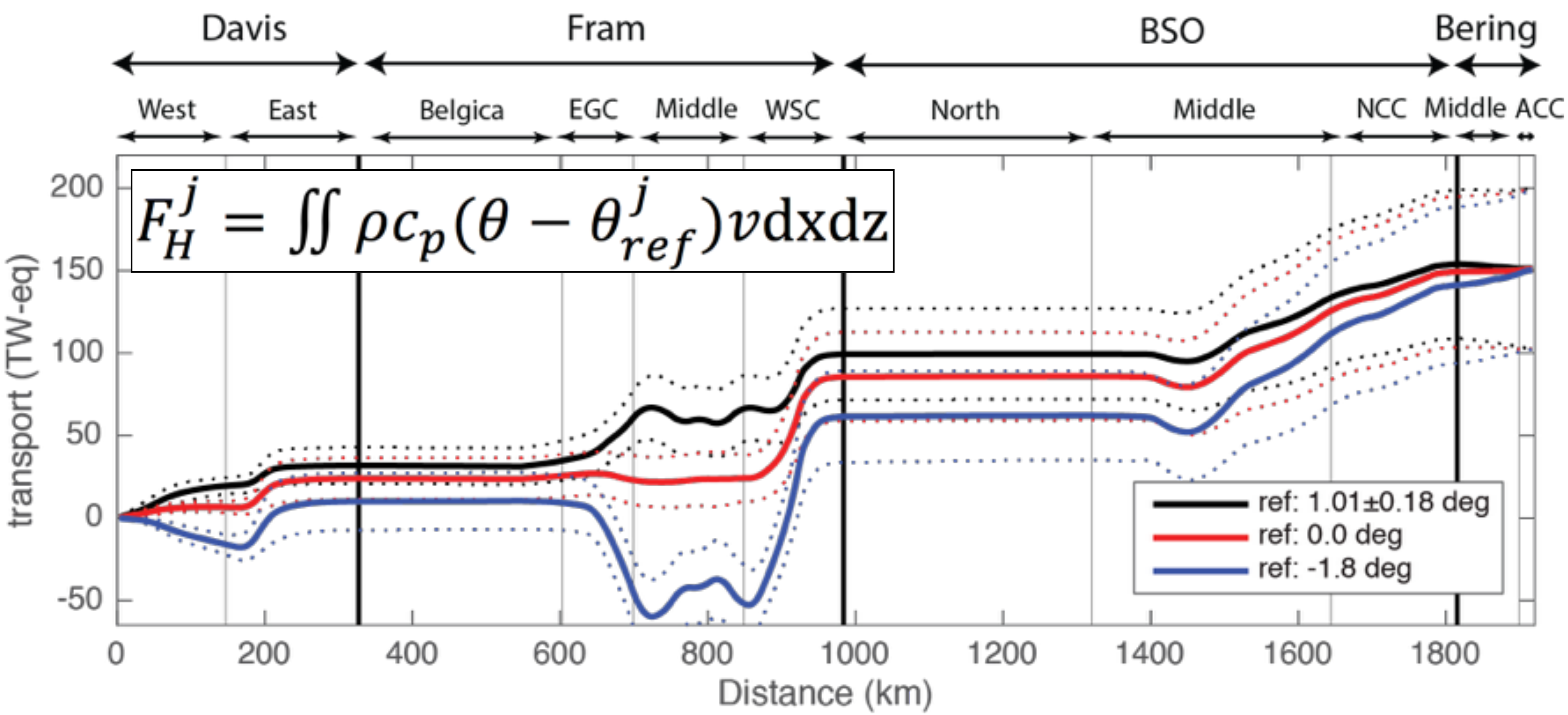


Fig. Accumulative full depth heat transport along sections.

What changes by changing S_{ref}?

- Total FW transport DOES NOT change (almost).
- FW transport in each piece of section DOES change.
    - e.g. EGC: -4±11 mSv-eq (34.70±0.02), 95±21 mSv-eq (35.2).

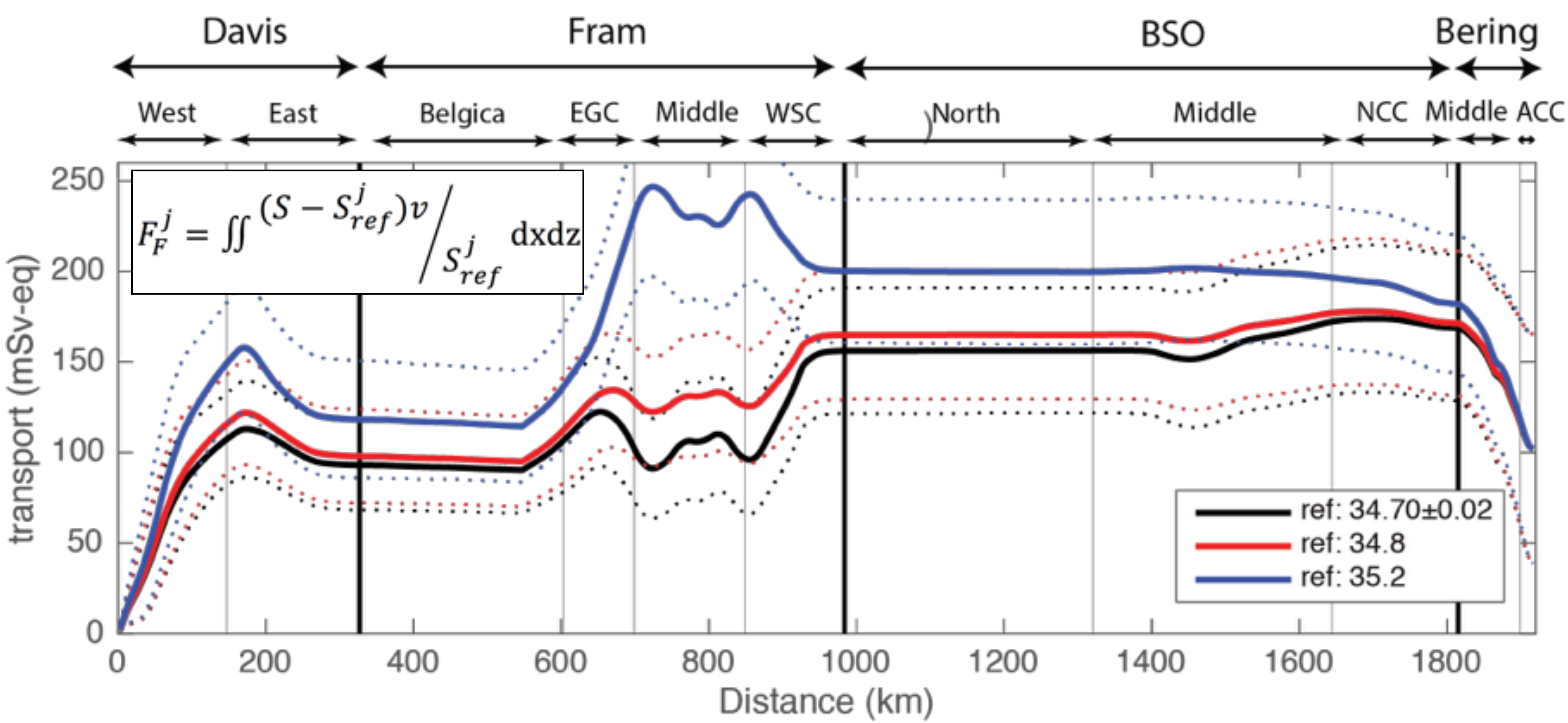


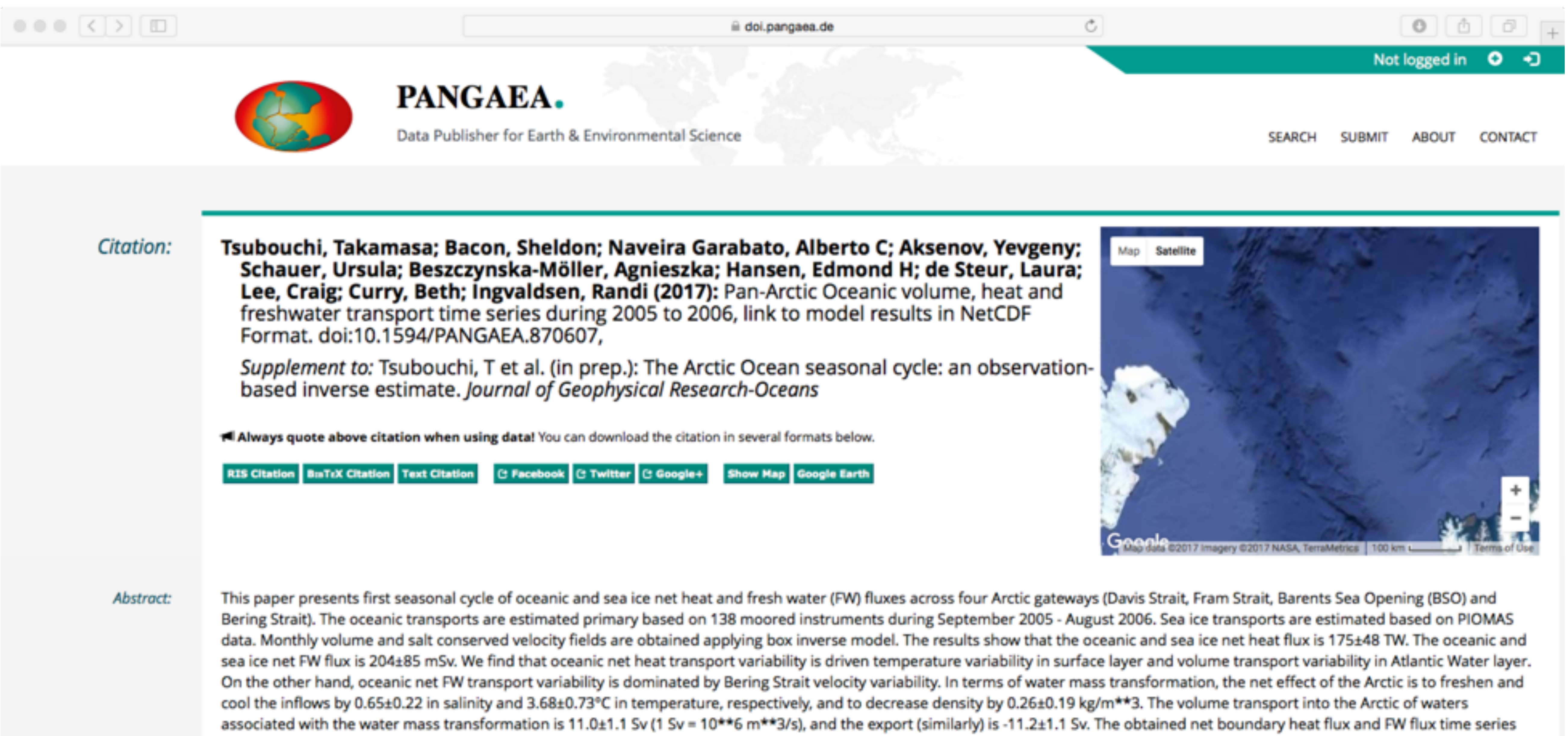
Fig. Accumulative full depth FW transport along sections.

Take home message

- Mass & salt conserved velocity field is crucial to calculate heat & FW transport.
- Choice of reference value is arbitrary.
  - For heat, any value is possible.
  - For FW, sensible values (34.7-35.2) only introduce error of ~1%.
- Recognise the impact of choice of reference values.
  - Total heat & FW DOES NOT change (For FW, almost).
  - Partial sectional values DOES change.

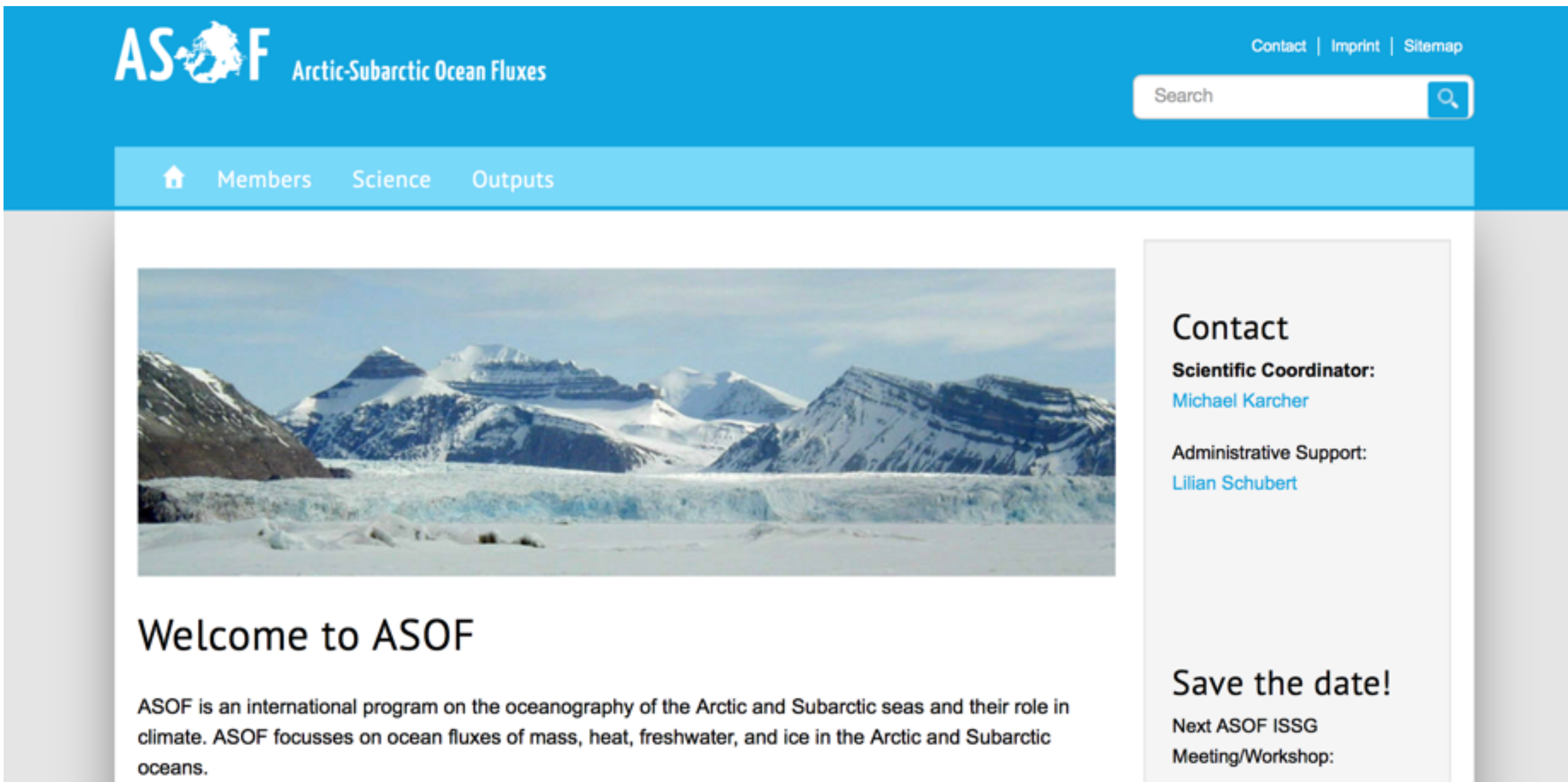
Data on PANGAEA

- One year data is available.
  - Search Tsubouchi, then you will find it.
- 68 month data will be available in this summer.



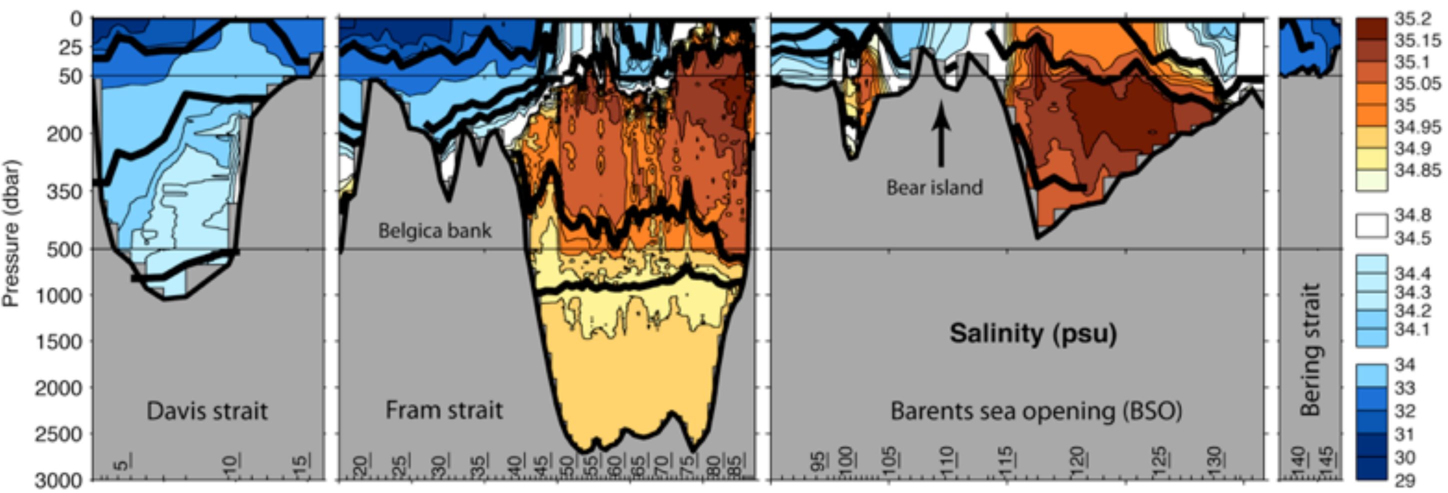
ASOF's role to promote this study

- Endorsement
- Gateway to the PANGAEA web link
- Present the time series as scientific deliverable

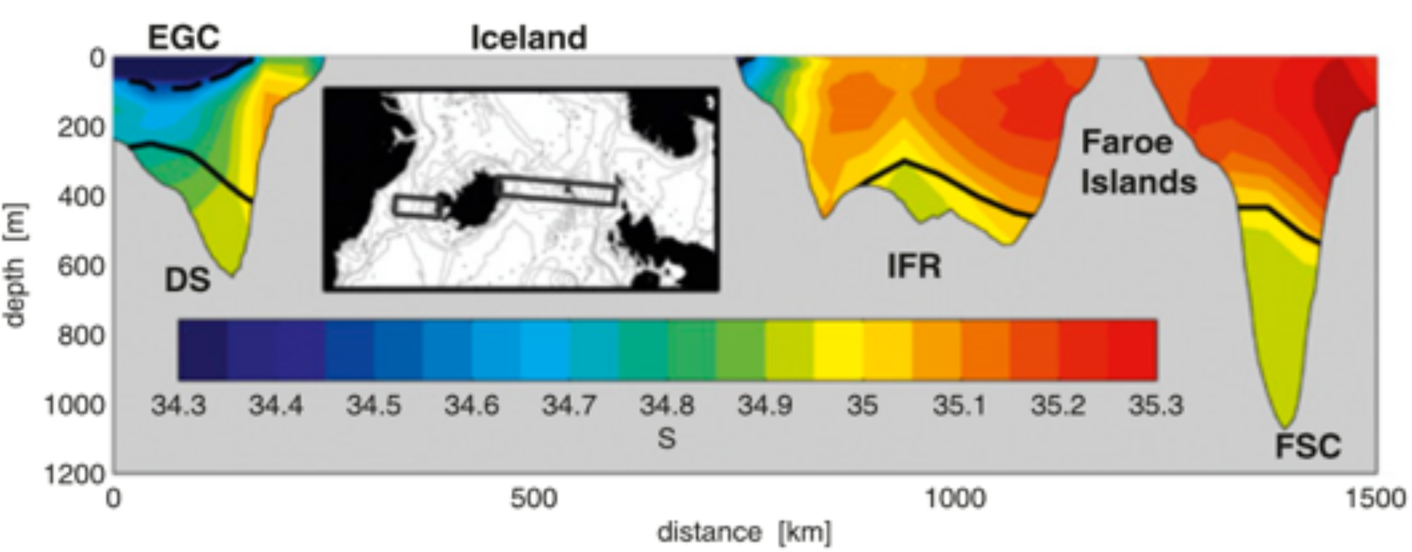


What is next break though?

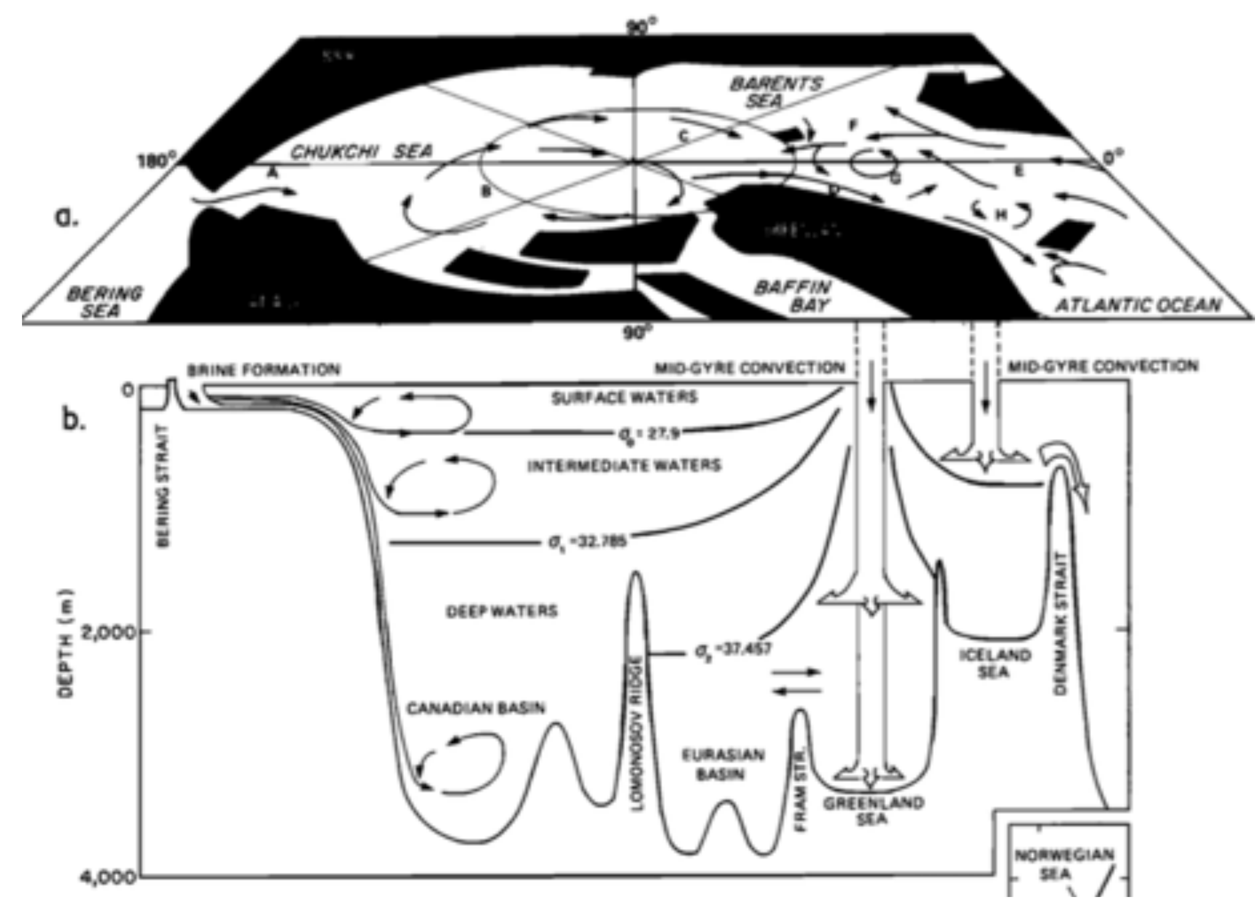
- Include Greenland-Scotland Ridge section in the box inverse model.
  - Two boxes - Arctic Ocean & Nordic Seas.
  - Initial focus period would be 2004-2010 (same as this study).



Tsubouchi et al. [2012, JGR]



Eldevik & Nilsen. [2013, JC]



AaGaard et al. [1985, JGR]

Summary

- Oceanic volume, heat & FW transports under mass and salt constraints during Oct 2004 - May 2010.
- Volume tra. has Seasonality in each gateway and water masses.
- Double cell over-turning structure and its seasonality.
- Heat transport is 180±57 TW ~ 15.9±5.0 Wm^{-2}
- FW transport is 156±91 mSv.
- The seasonal & interannual variability in the Heat & FW transports
- I am looking for a job. - ideally related work.

Acknowledgement

- The Arctic main gateways have been measured by six research institutes in the world: UW for Davis Strait and for the US side of Bering Strait; NPI and AWI for Fram Strait; IMR for BSO; UAF and AARI for the Russian side of Bering Strait.

- The pan-Arctic approach is developed under two UK NERC projects, ASBO and TEA-COSI.

- This work is supported by EU Marie Curie project, ARCGATE.