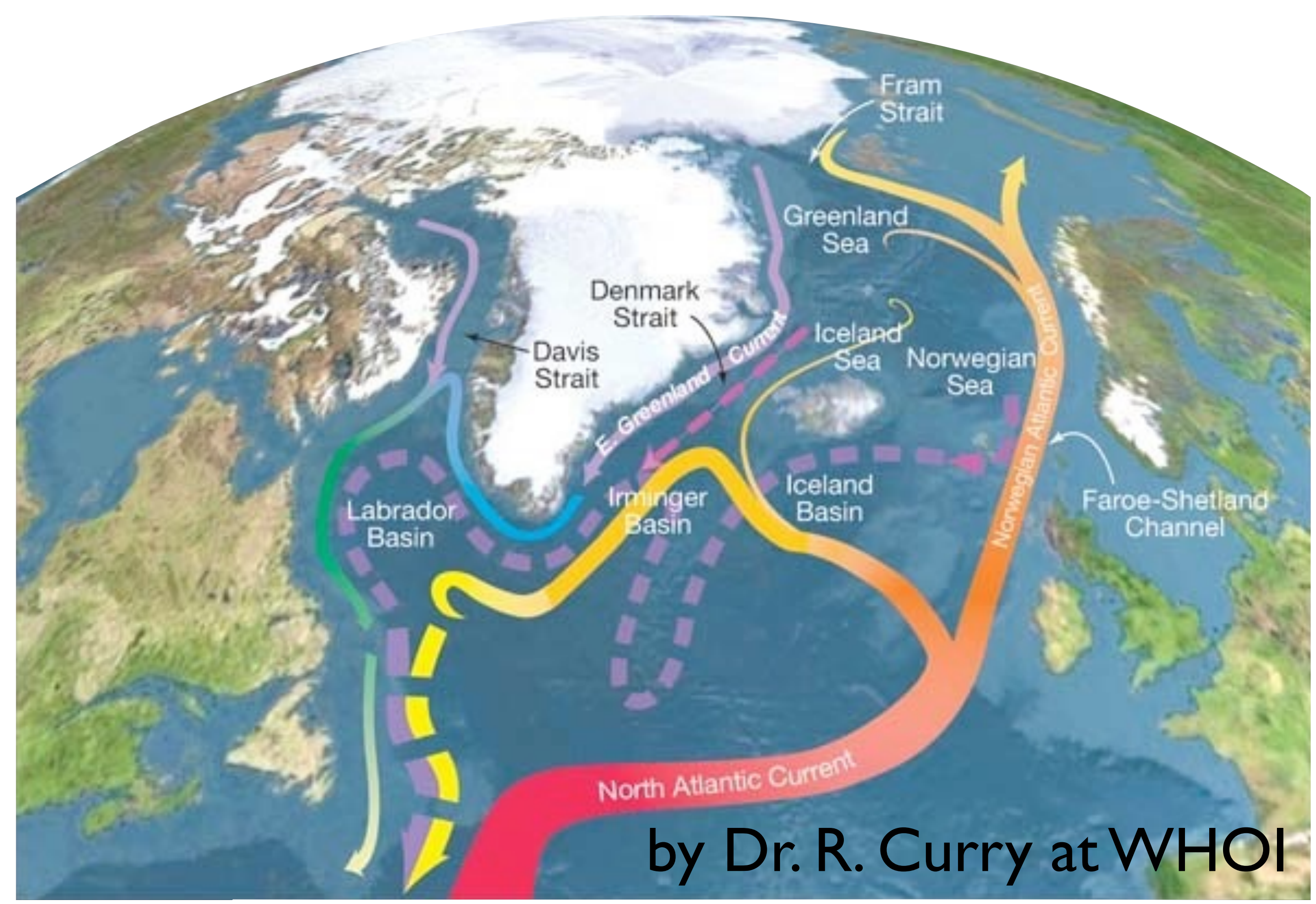
21 March 2017
ASOF meeting @ IOPAN

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

ARCGATE: Maximizing the potential of Arctic Ocean Gateway array

Takamasa Tsubouchi
Wilken-Jon von Appen
Ursula Schauer



by Dr. R. Curry at WHOI

Arctic boundary observation

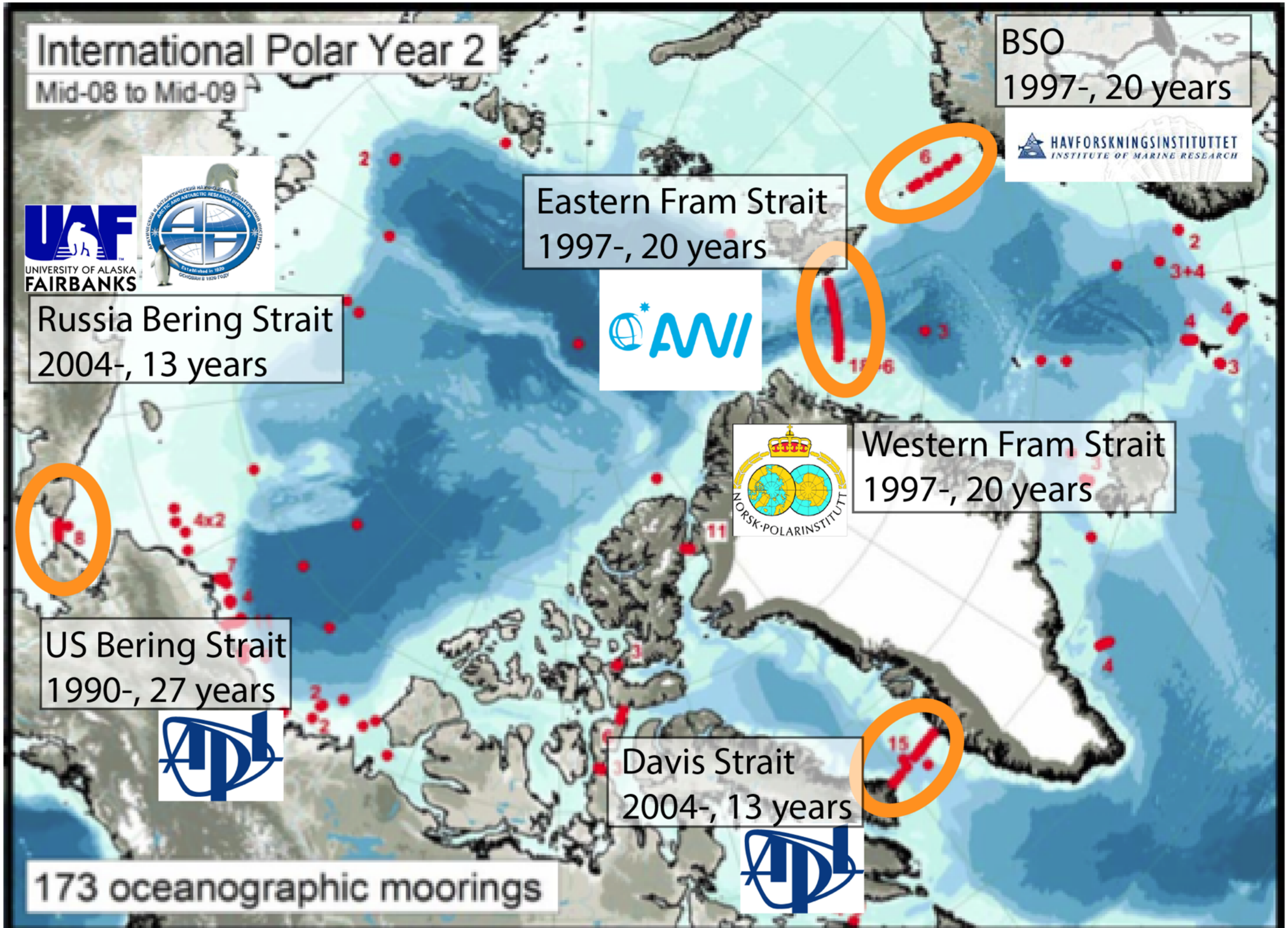
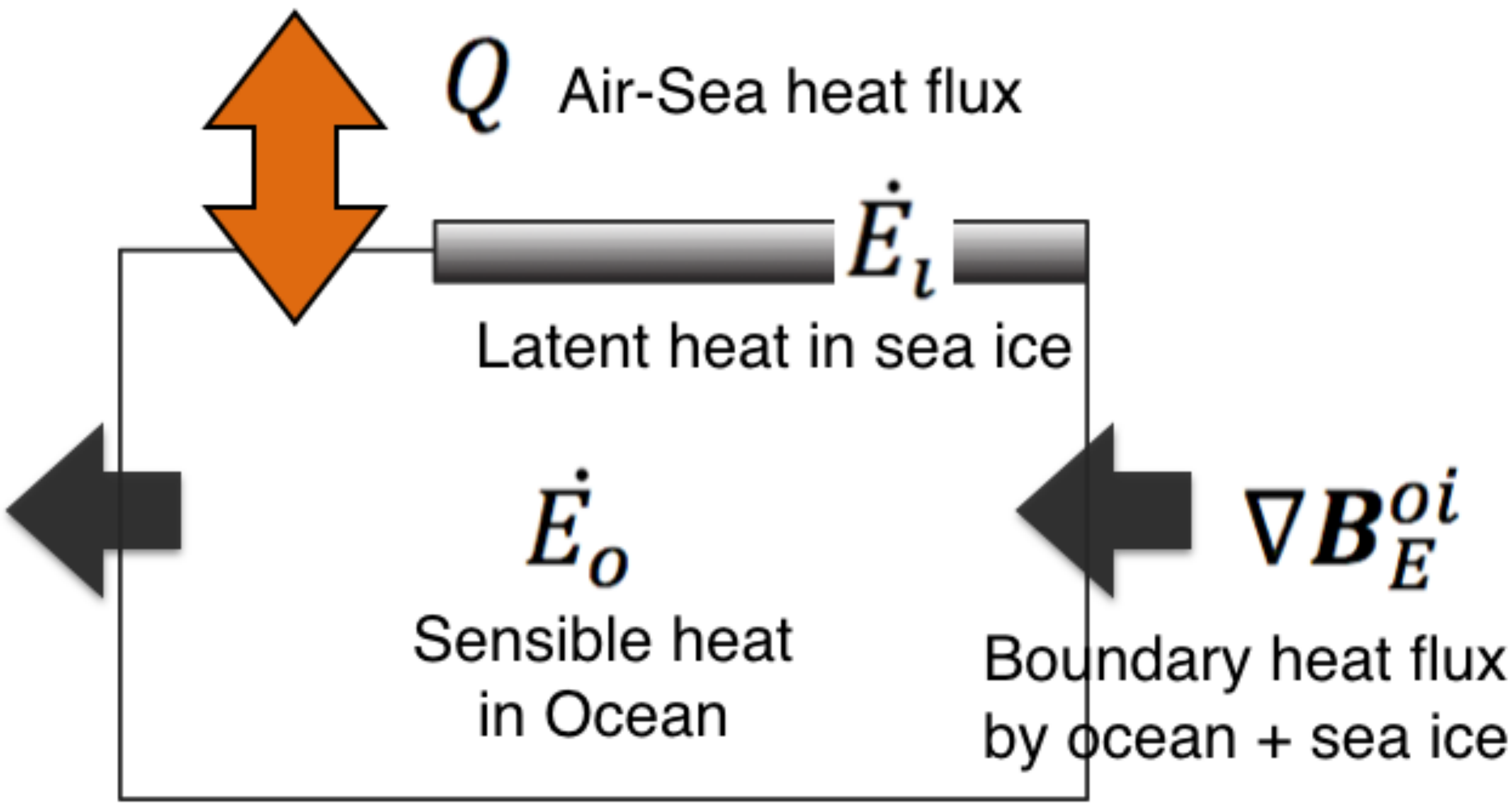


Fig. Mooring array during 2008-09, modified from Dickson et al. [2009]

The heat budget in the Arctic Ocean

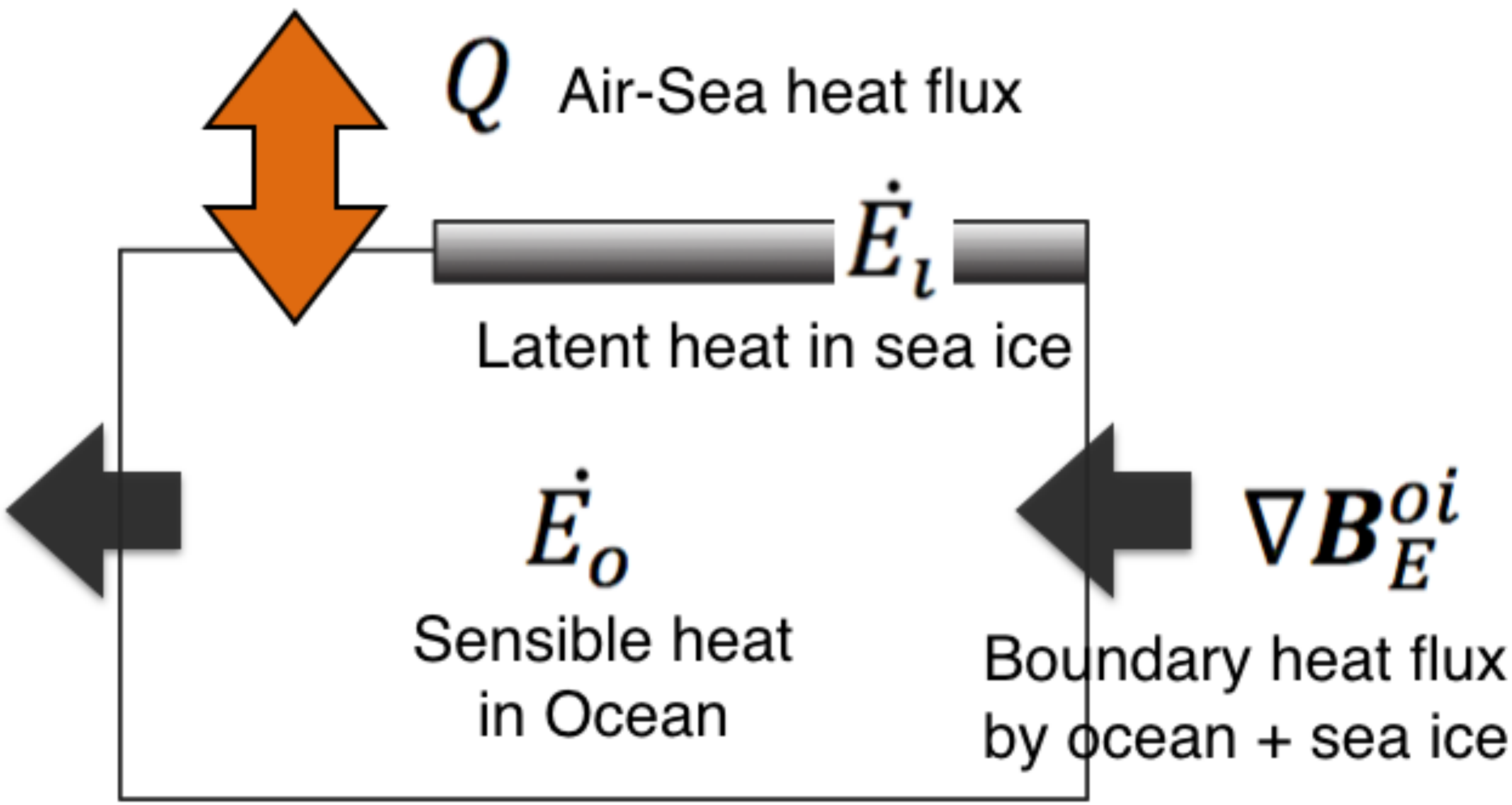
$$\dot{E} = \dot{E}_o + \dot{E}_\iota = \nabla \boldsymbol{B}_E^{oi} + Q$$



The heat budget in the Arctic Ocean

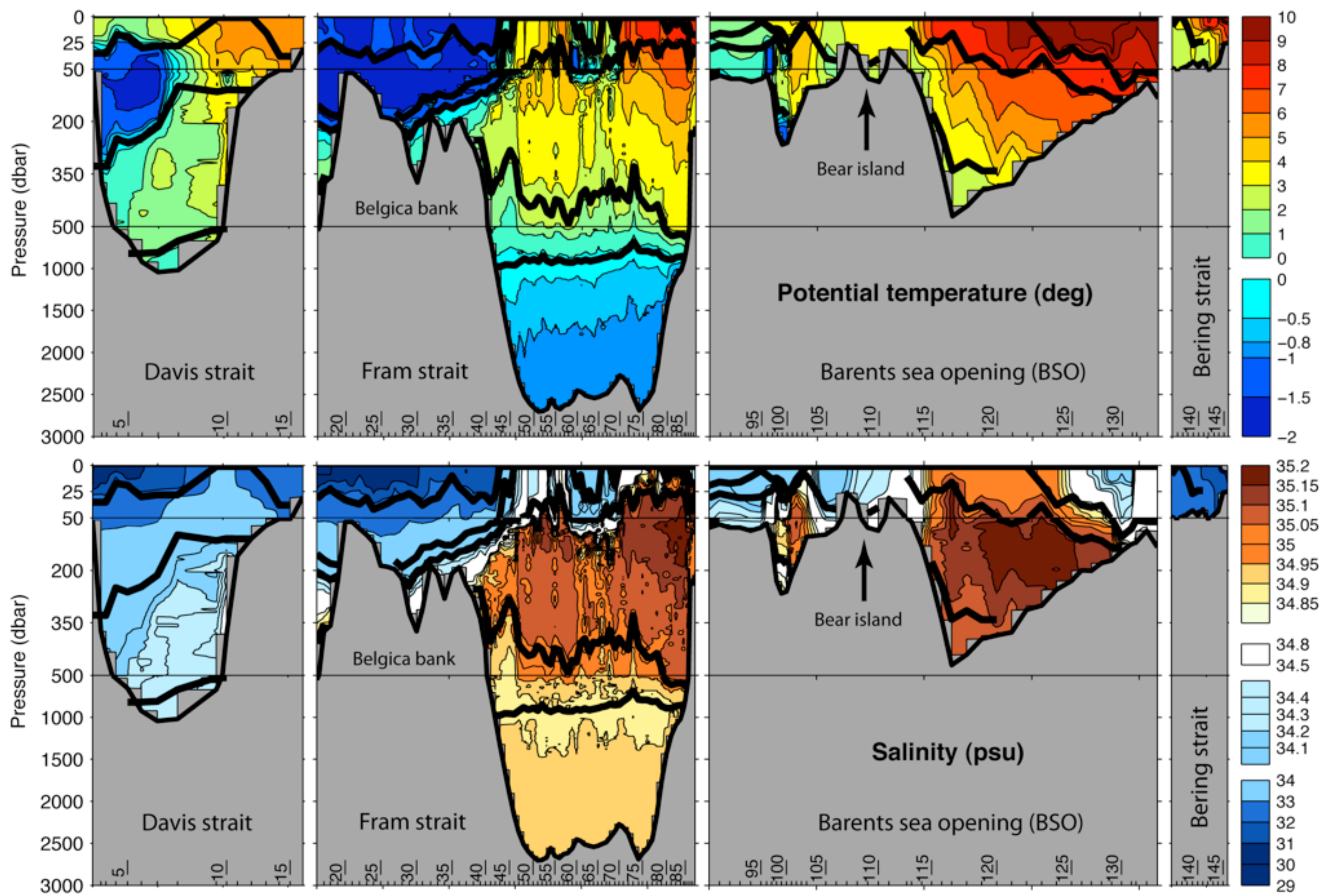
Little is known about oceanic heat temporal variability

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



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]

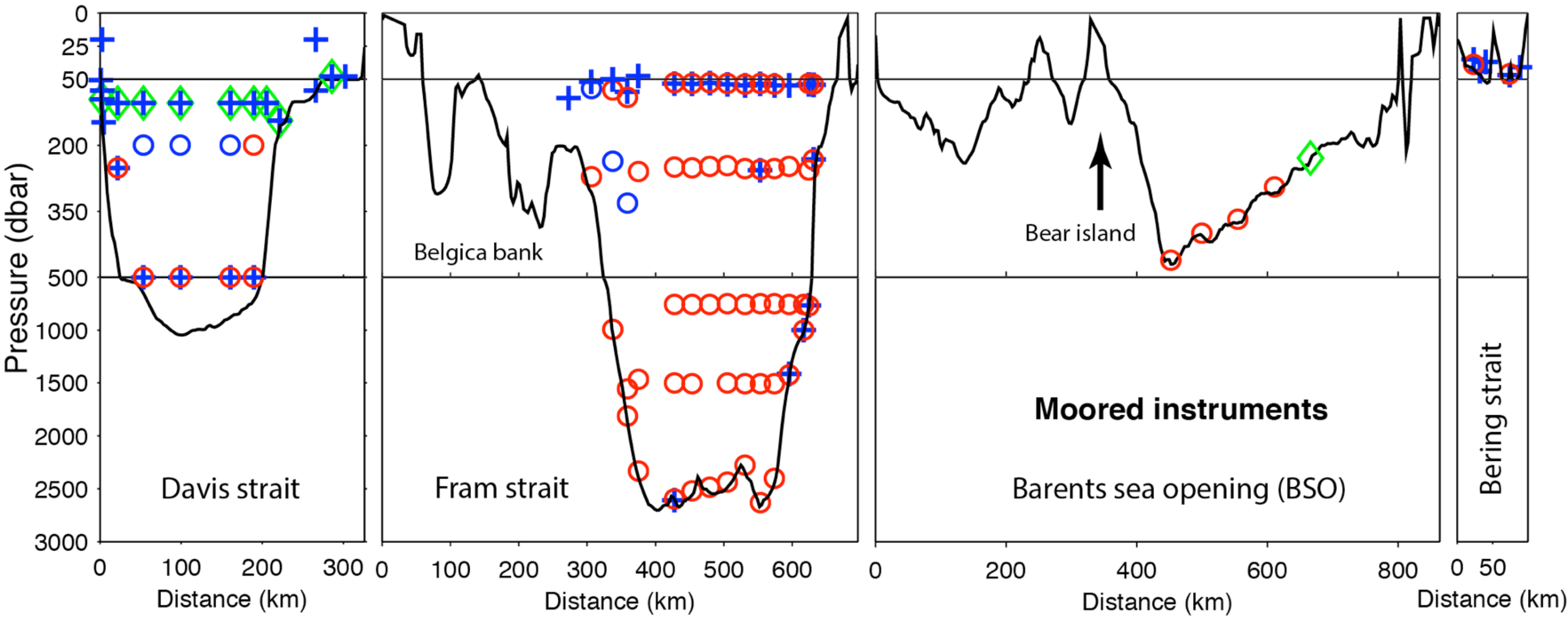
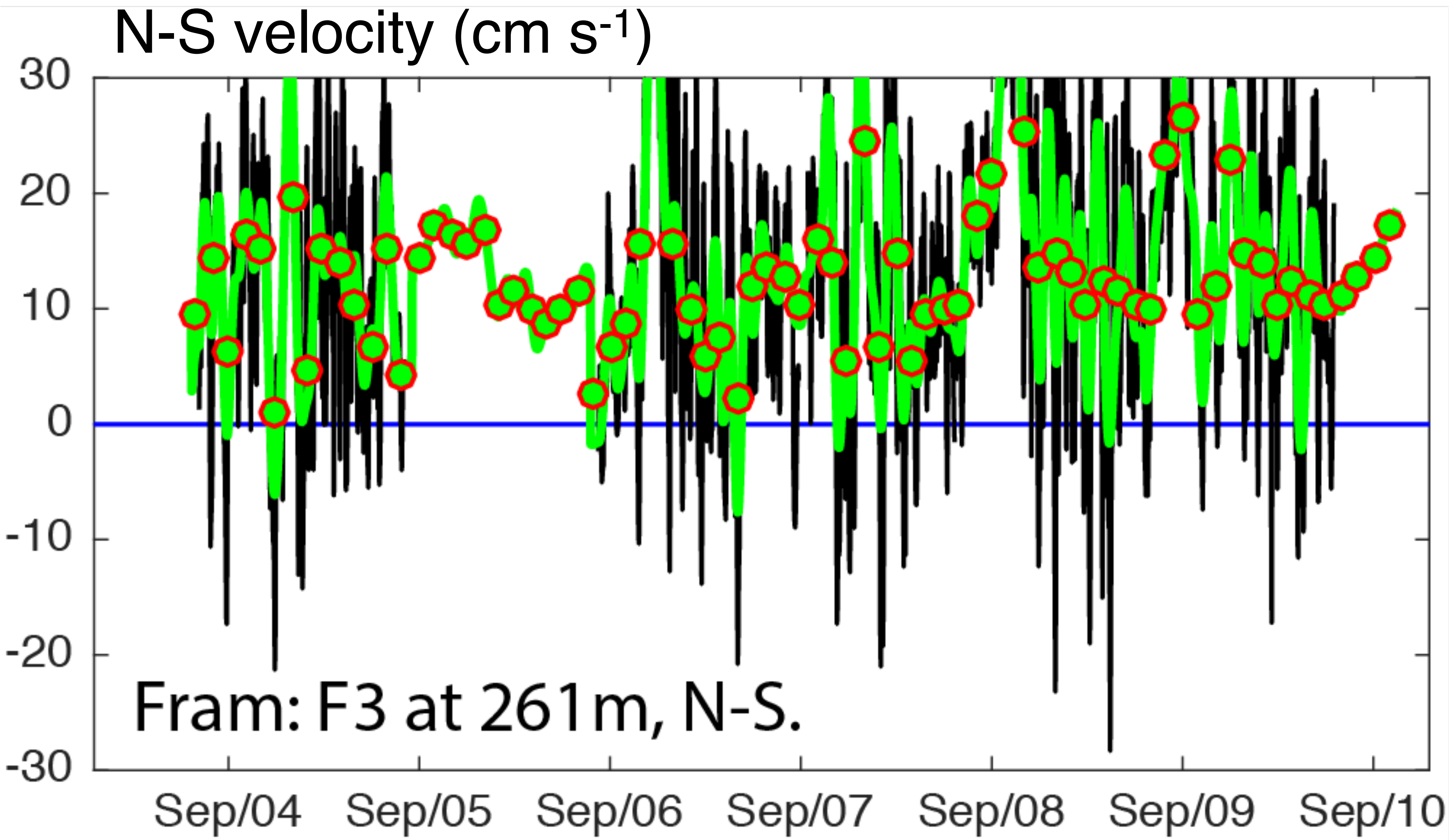


Fig. Mooring array in the Arctic four main gates

Filtering and Gridding

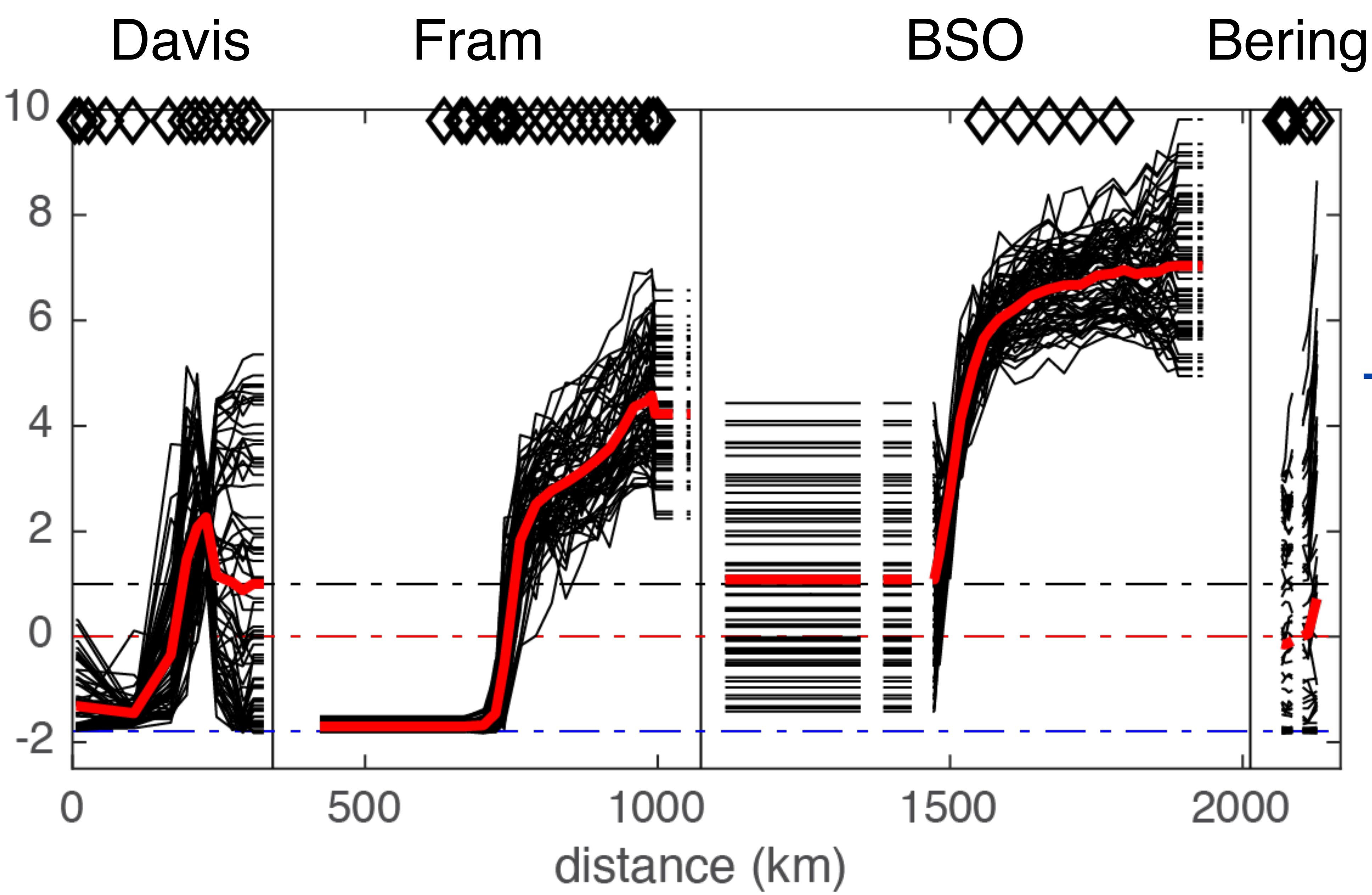
- De-tided and smoothed with Butterworth filter (27 days cutoff).
- Data gaps (> 30days) are filled by its mean annual cycle.
- Linear interpolation is applied vertically and horizontally.



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

Monthly Temperature fields

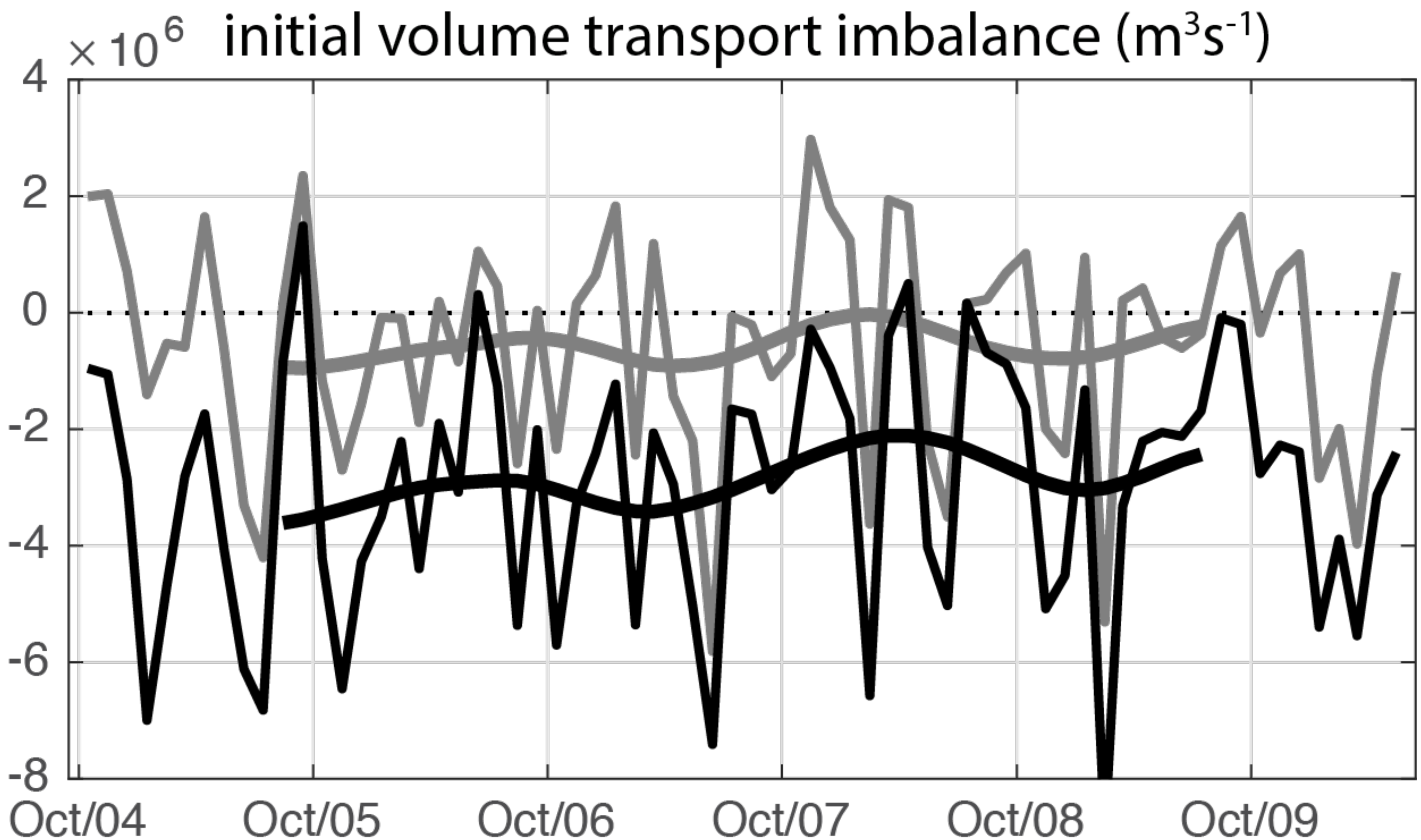
- Captures major water mass distributions & variabilities
  - AW in WSC and BSO, Polar water, large variability in Bering Strait.



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.

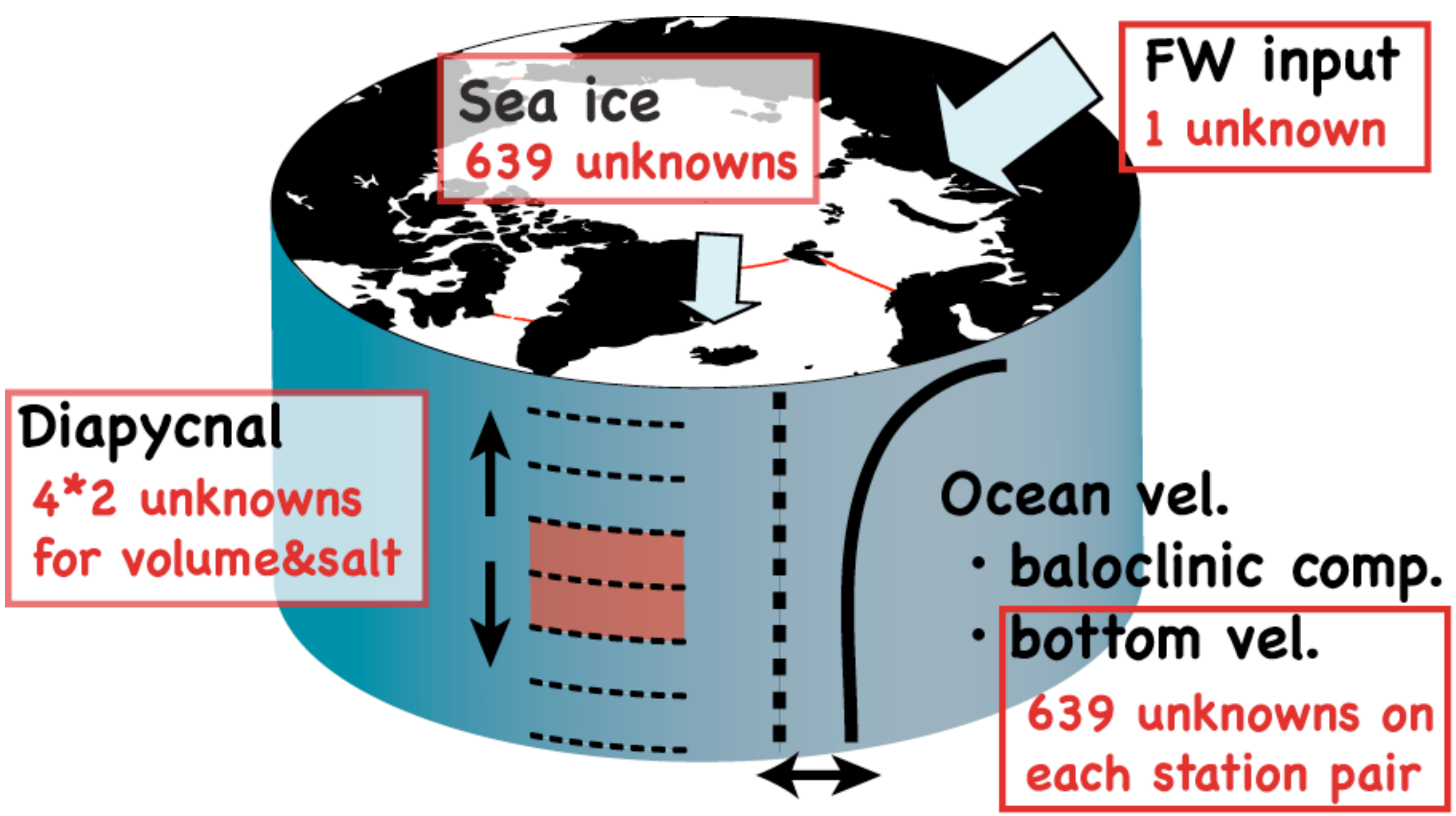


Full depth (black), above 1,500m (grey).

Inverse model: unknowns & constraints

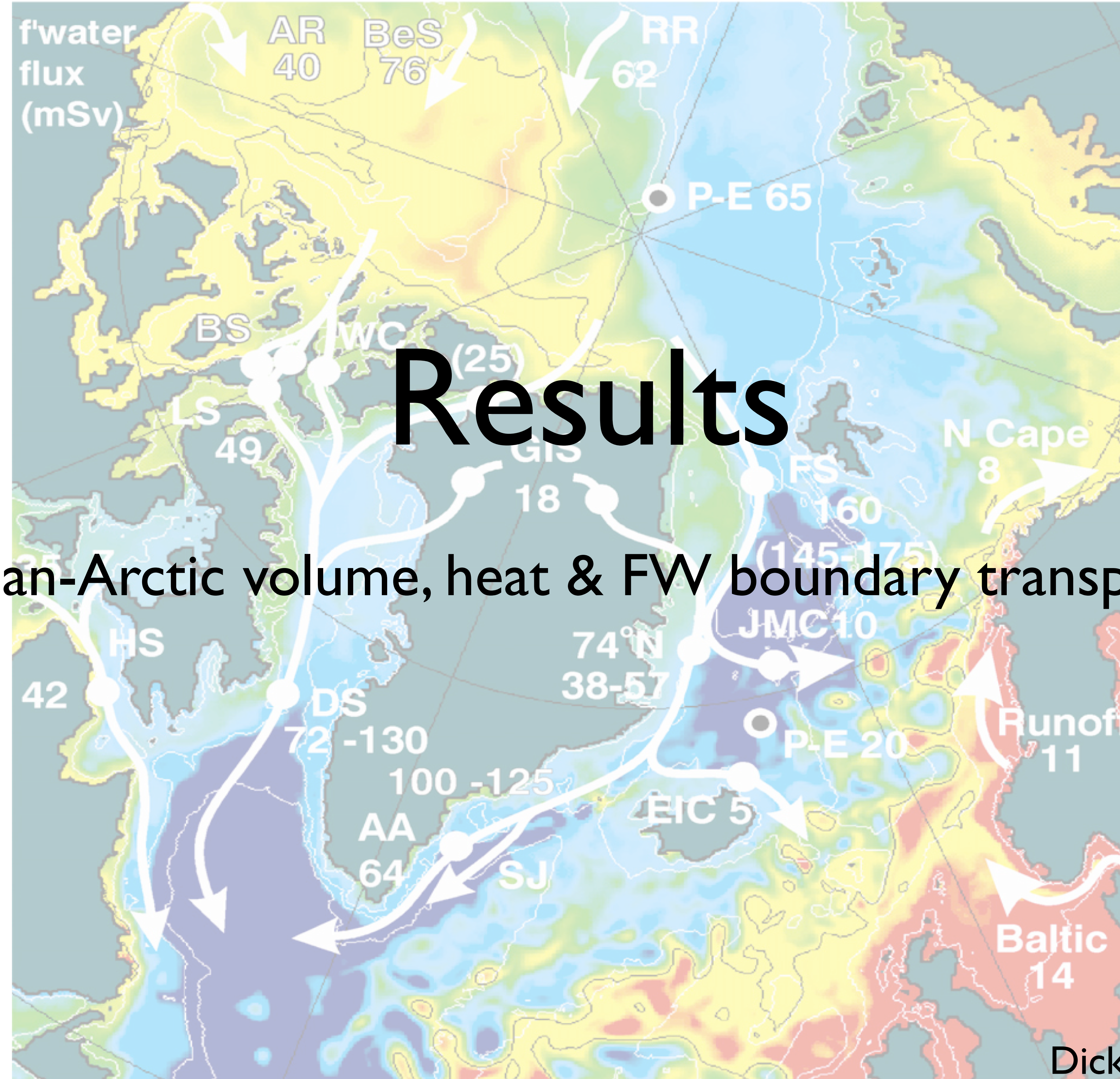
Obtain volume and salt conserved monthly velocity field for consecutive 68 months.

- 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.

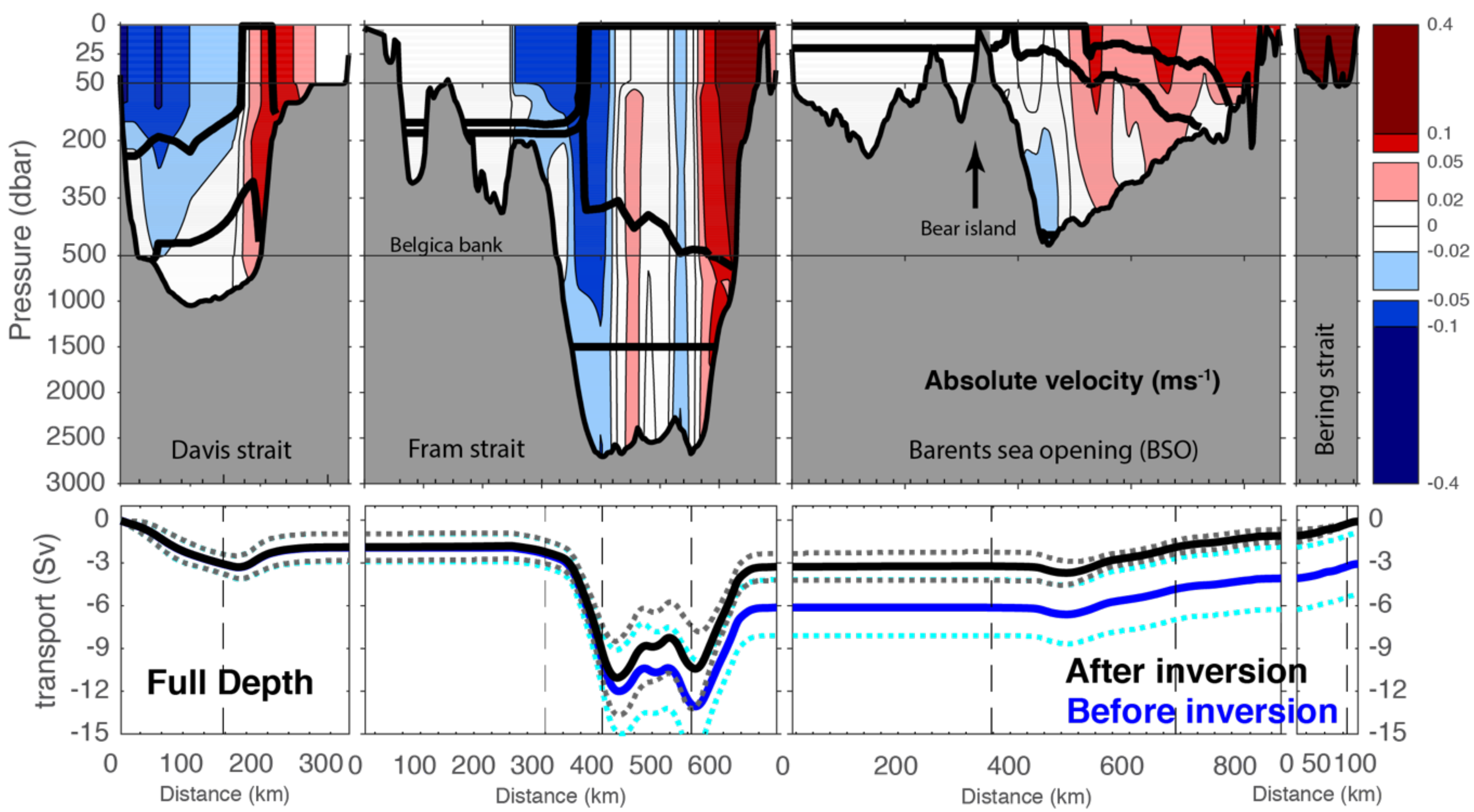


Fig. (top) mean volume & salt closed velocity field. (Bottom) cumulative full depth volume transport.

Table: volume transport comparison

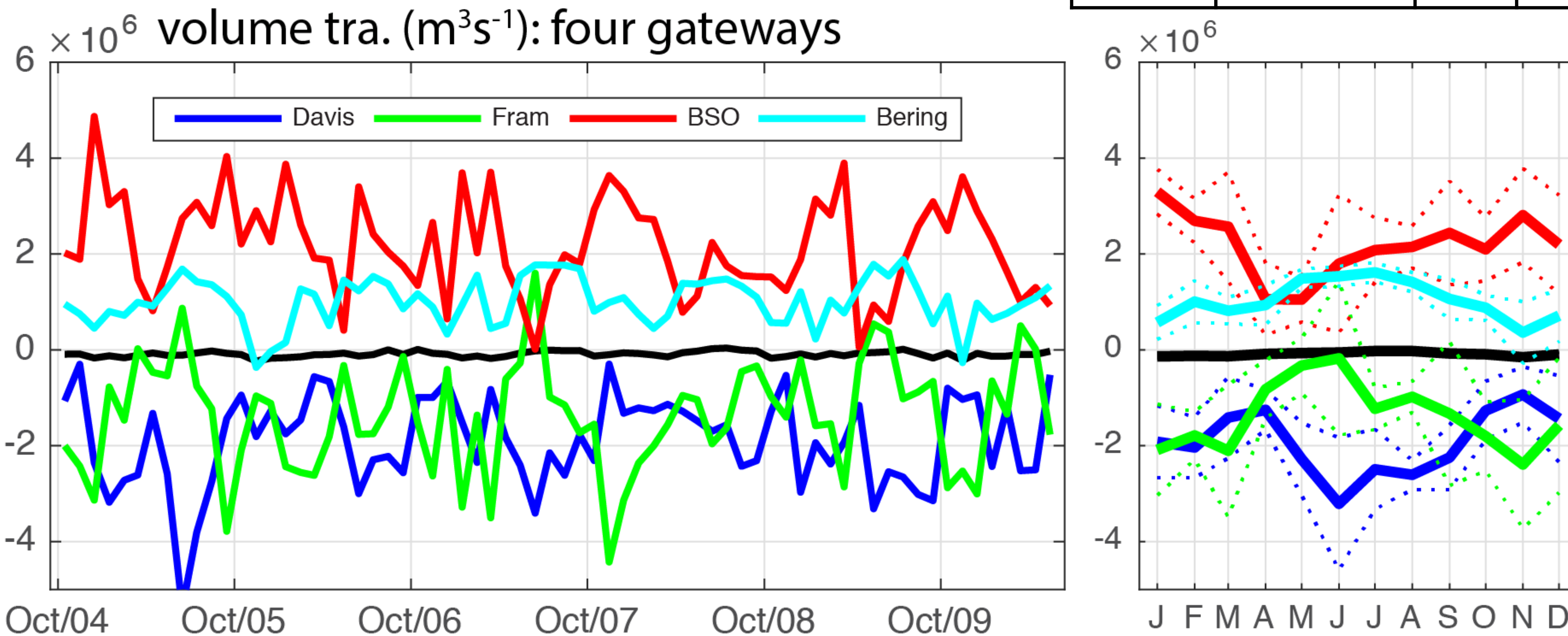
(Sv)	This study	reference
Davis	-1.9±1.0	-1.6±0.5(*1)
Fram	-1.4±1.2	-2.0±2.7 (*2)
BSO	2.2±1.0	2.0 (*3)
Bering	1.0±0.5	0.8 (*4)
Net	-0.10±0.06	-0.8

*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.

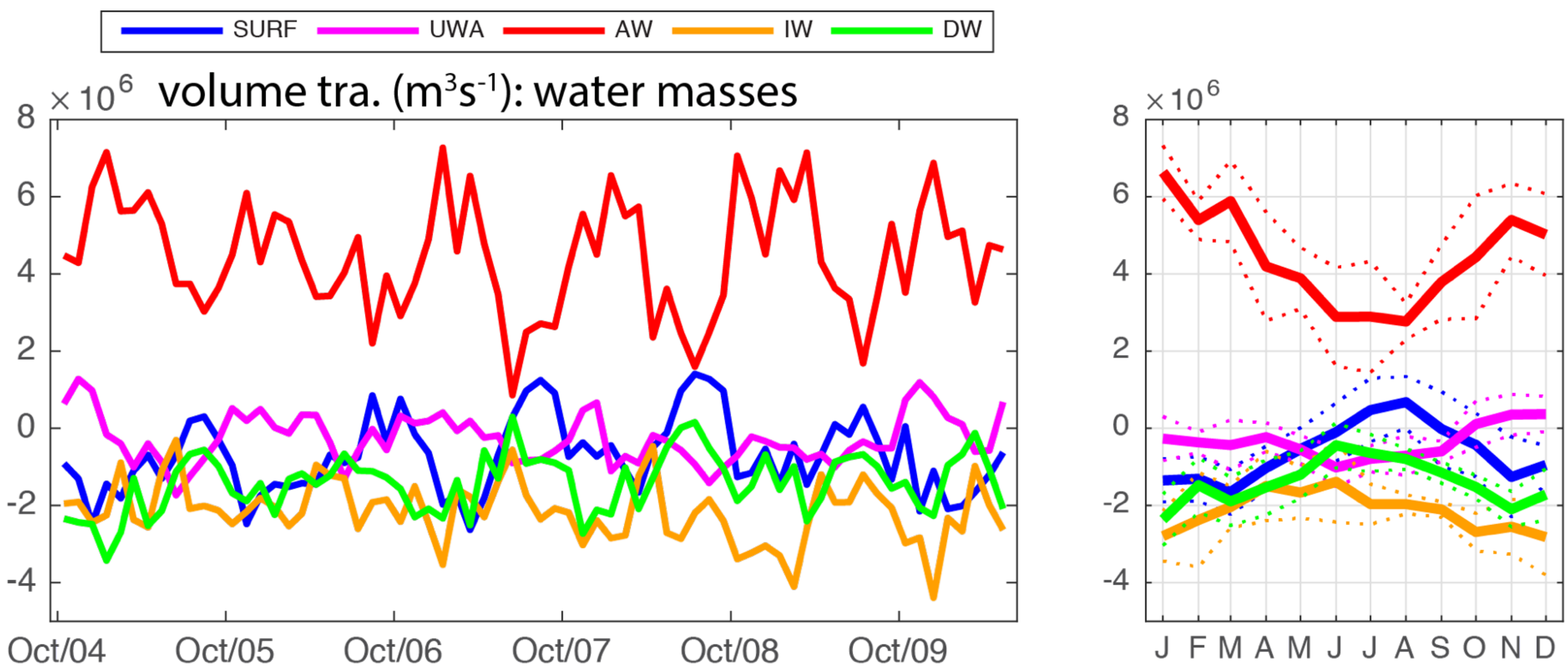
(Sv)	long term	JFM	JAS
Davis	-1.9±1.0	-1.8	-2.4
Fram	-1.4±1.2	-2.0	-1.2
BSO	2.2±1.0	+2.9	+2.2
Bering	1.0±0.5	+0.8	+1.4



Volume transports: water mass

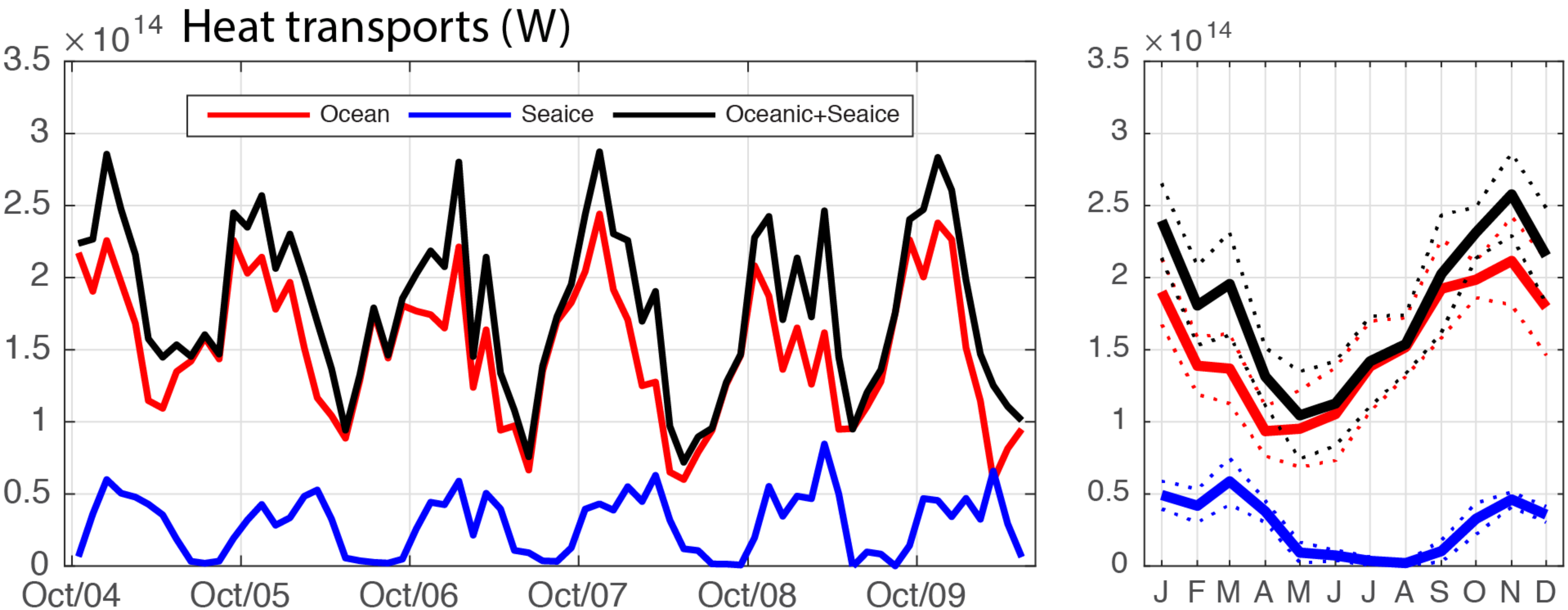
- Double cell overturning structure.
- AW inflow: strong in winter, weak in summer.
- DW outflow (-1.4±0.8 Sv) may be too strong.

(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

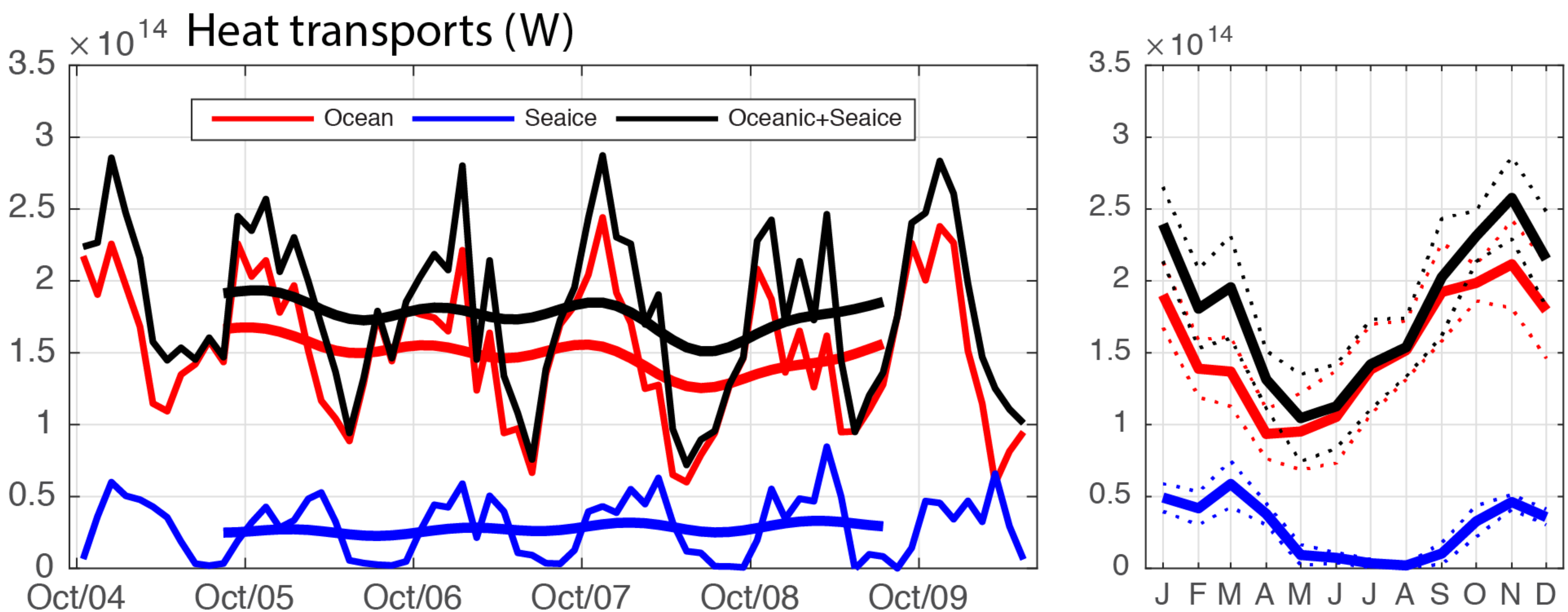
- The heat transport is 180±57 TW (68 monthly ave & std).
- Seasonality: ~250TW in Nov, ~100 TW in May.



The Heat transports

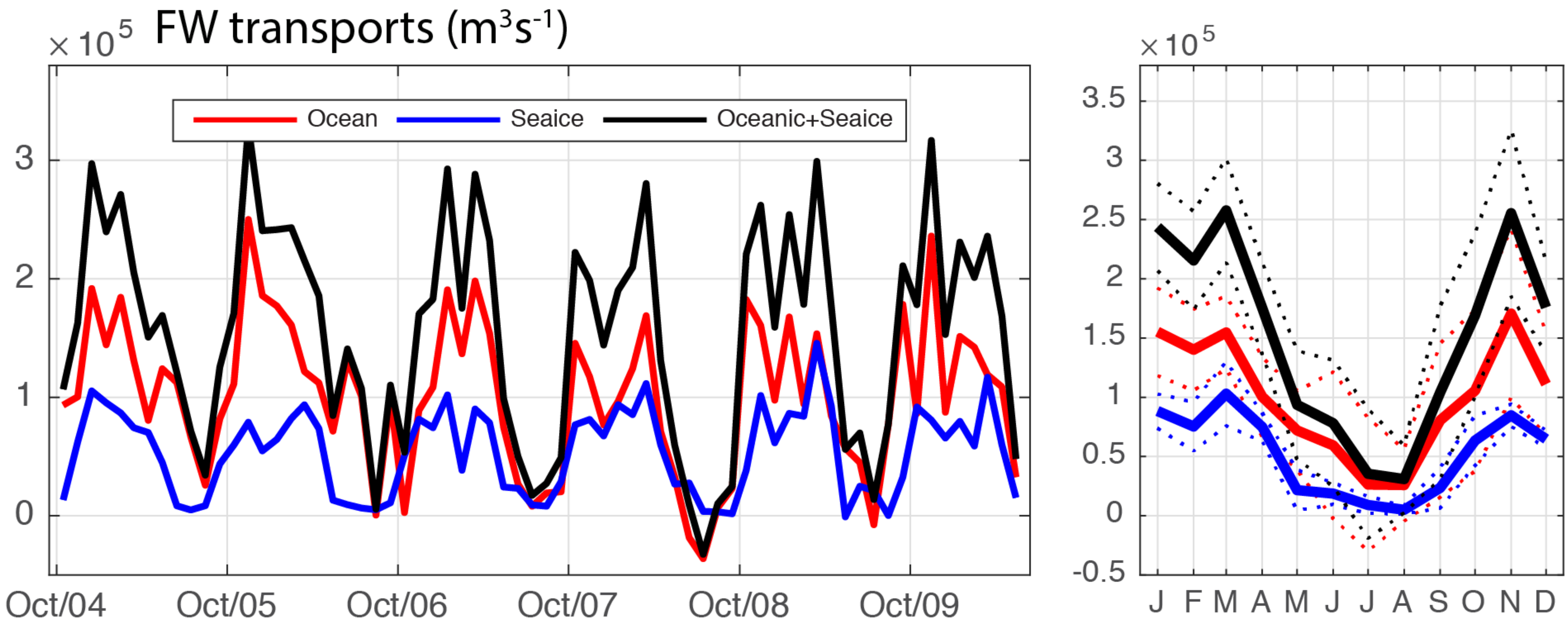
- The heat transport is 180±57 TW (68 monthly ave & std).
- Seasonality: ~250TW in Nov, ~100 TW in May.
- Inter-annual variability: 196±56 TW in 2004-05, 165±71 TW in 2007-08.

*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.

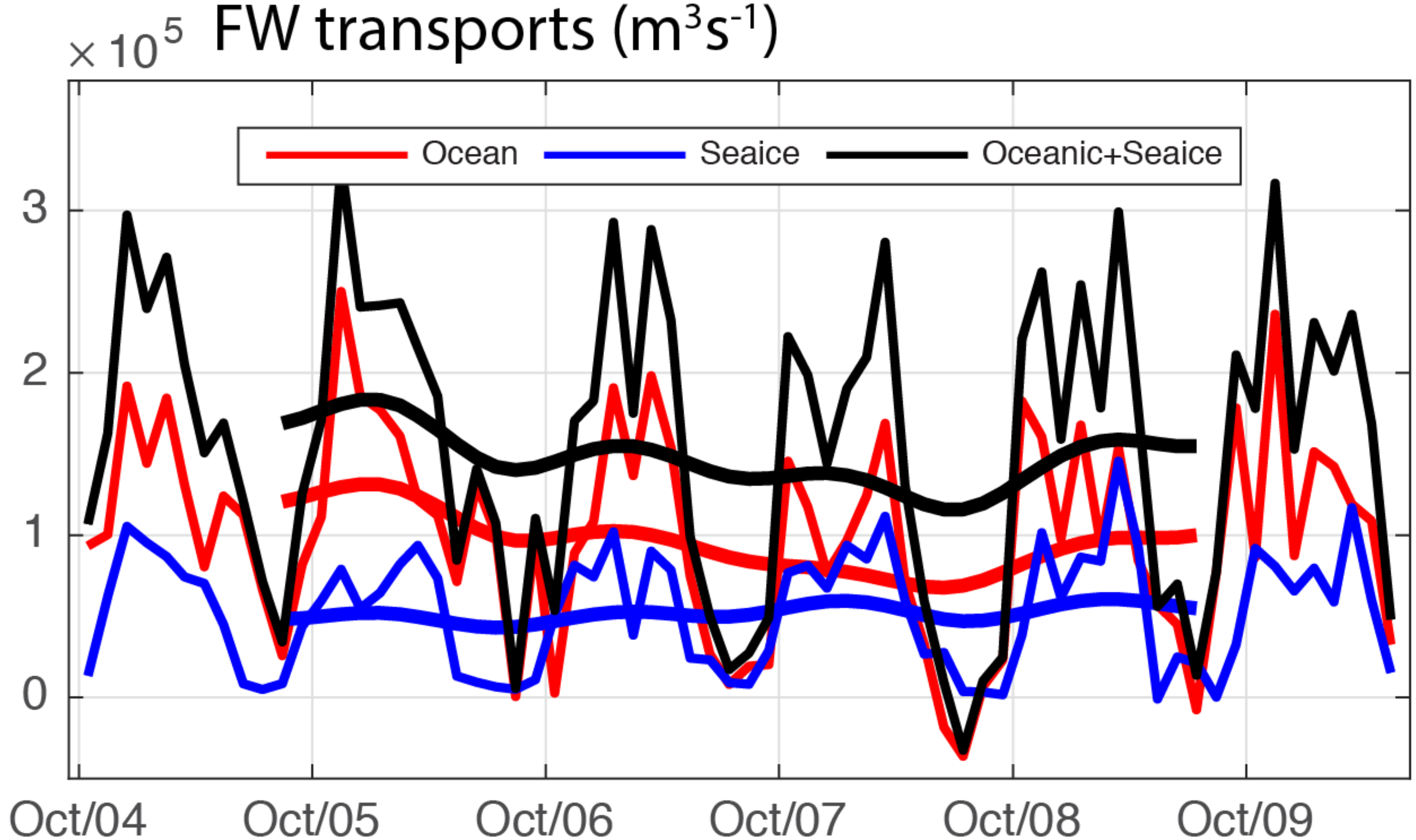


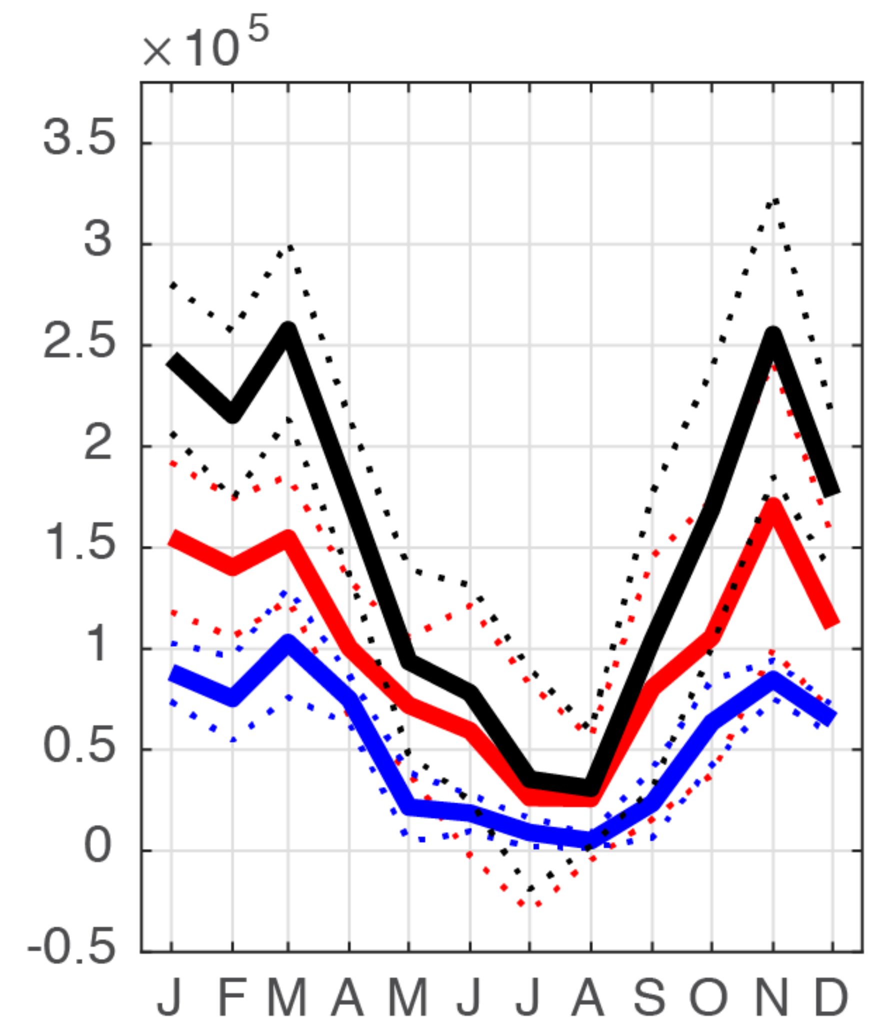
The FW transports

- 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.

FW transports (m^3s^{-1})





Putting into a big picture

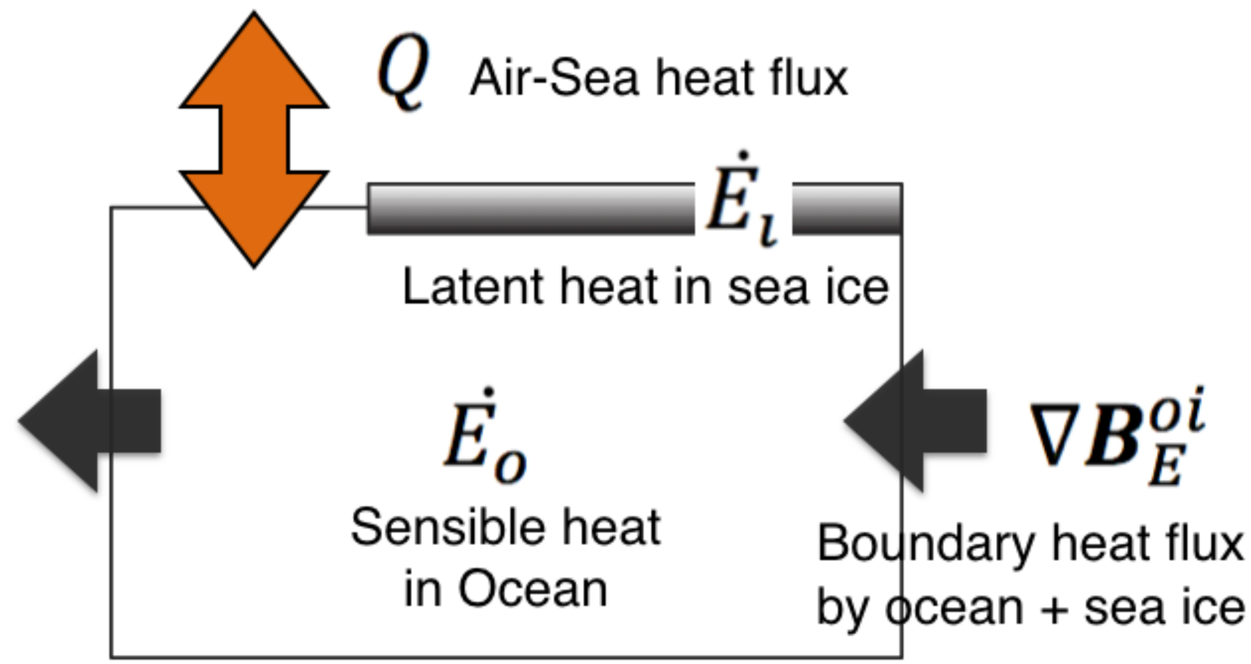
- Heat budget
  - 180±57 TW ~ 15.9±5.0 Wm^{-2}
  - MERRA has the best agreement.

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

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]

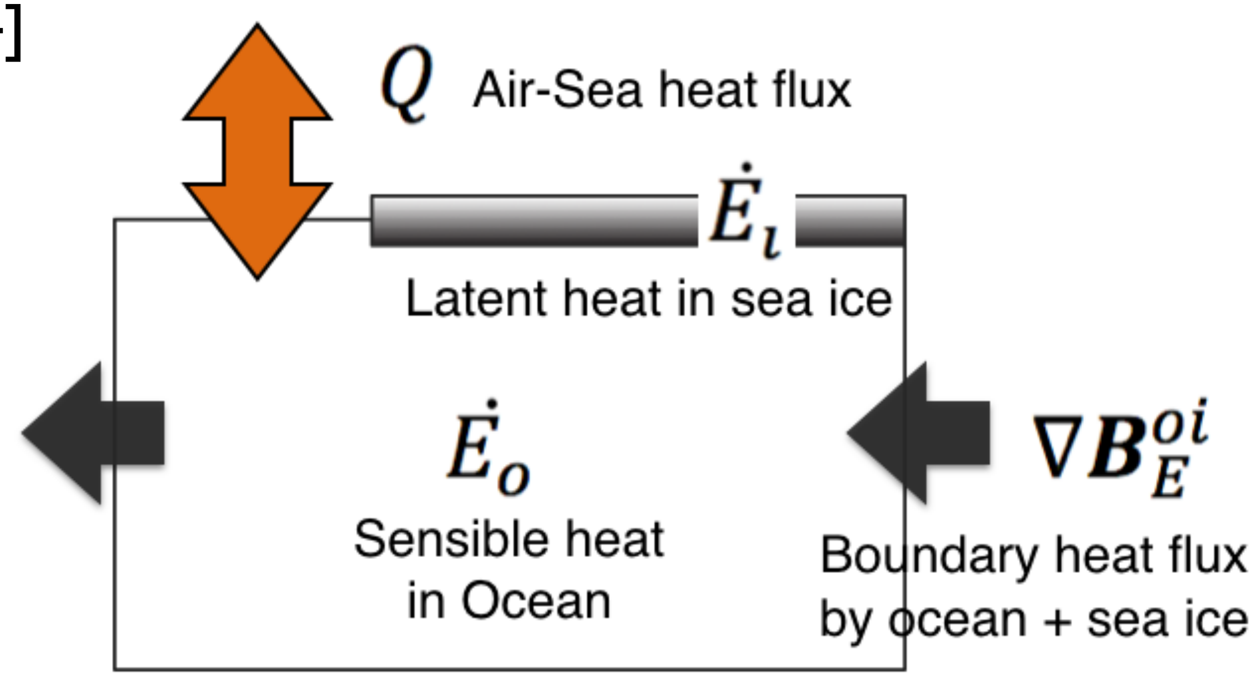


Note that 10W/m^2 is equivalent to 1m sea ice melt in a year.

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).

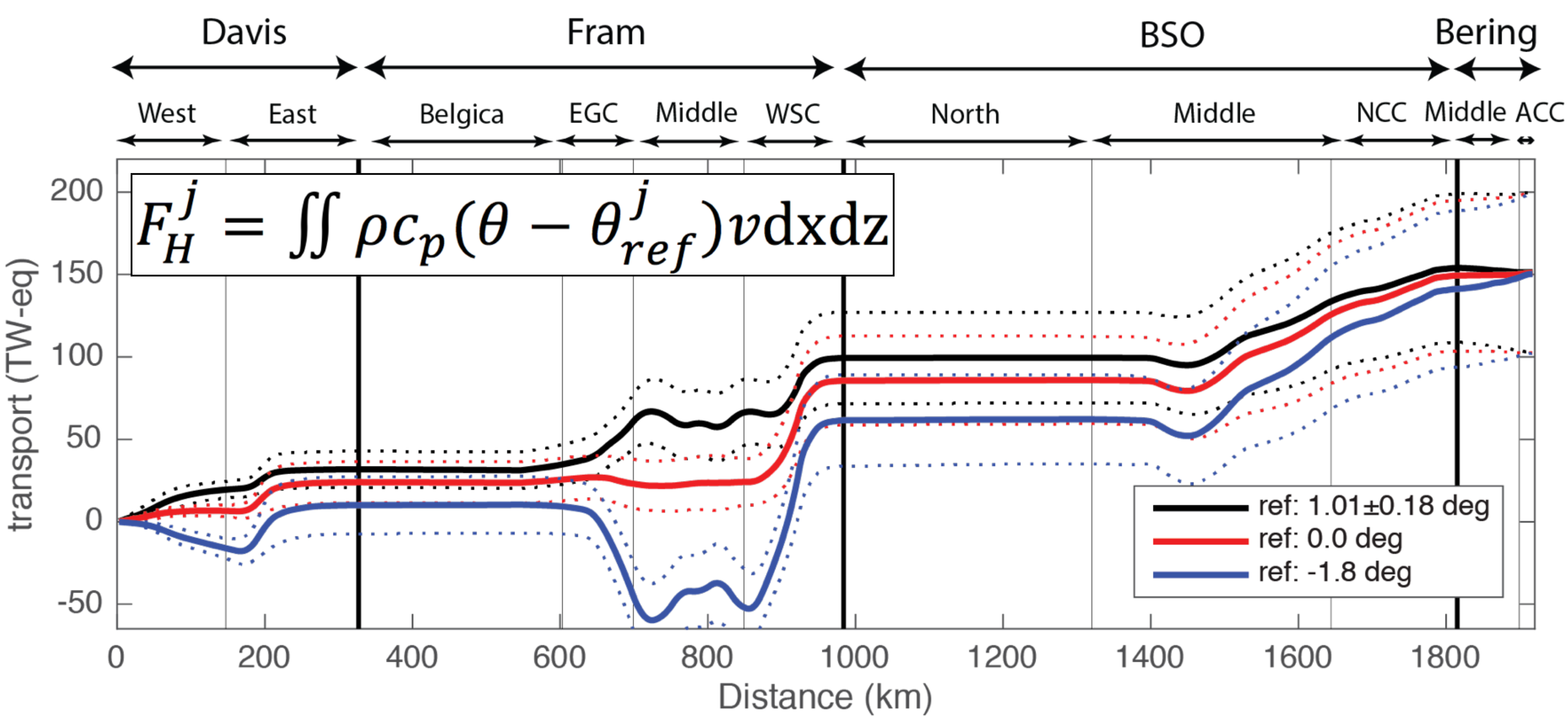


Fig. Accumulative full depth heat transport along sections.

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).

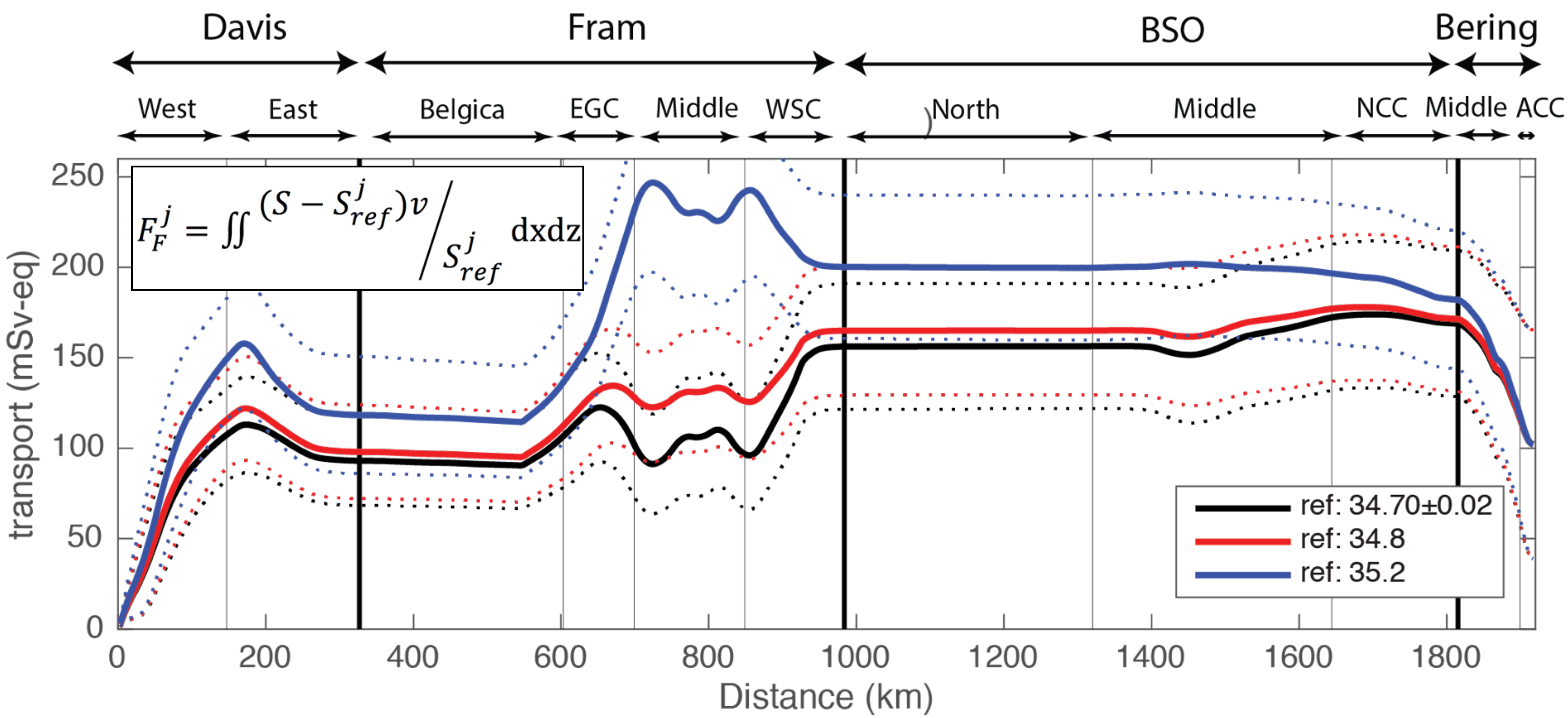


Fig. Accumulative full depth FW transport along sections.

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.

doi.pangaea.de

Not logged in

PANGAEA.

Data Publisher for Earth & Environmental Science

SEARCH SUBMIT ABOUT CONTACT

Citation: **Tsubouchi, Takamasa; Bacon, Sheldon; Naveira Garabato, Alberto C; Aksenov, Yevgeny; Schauer, Ursula; Beszczynska-Möller, Agnieszka; Hansen, Edmond H; de Steur, Laura; Lee, Craig; Curry, Beth; Ingvaldsen, Randi (2017):** Pan-Arctic Oceanic volume, heat and freshwater transport time series during 2005 to 2006, link to model results in NetCDF Format. doi:10.1594/PANGAEA.870607,

Supplement to: Tsubouchi, T et al. (in prep.): The Arctic Ocean seasonal cycle: an observation-based inverse estimate. *Journal of Geophysical Research-Oceans*

Always quote above citation when using data! You can download the citation in several formats below.

RIS Citation | BibTeX Citation | Text Citation | Facebook | Twitter | Google+ | Show Map | Google Earth

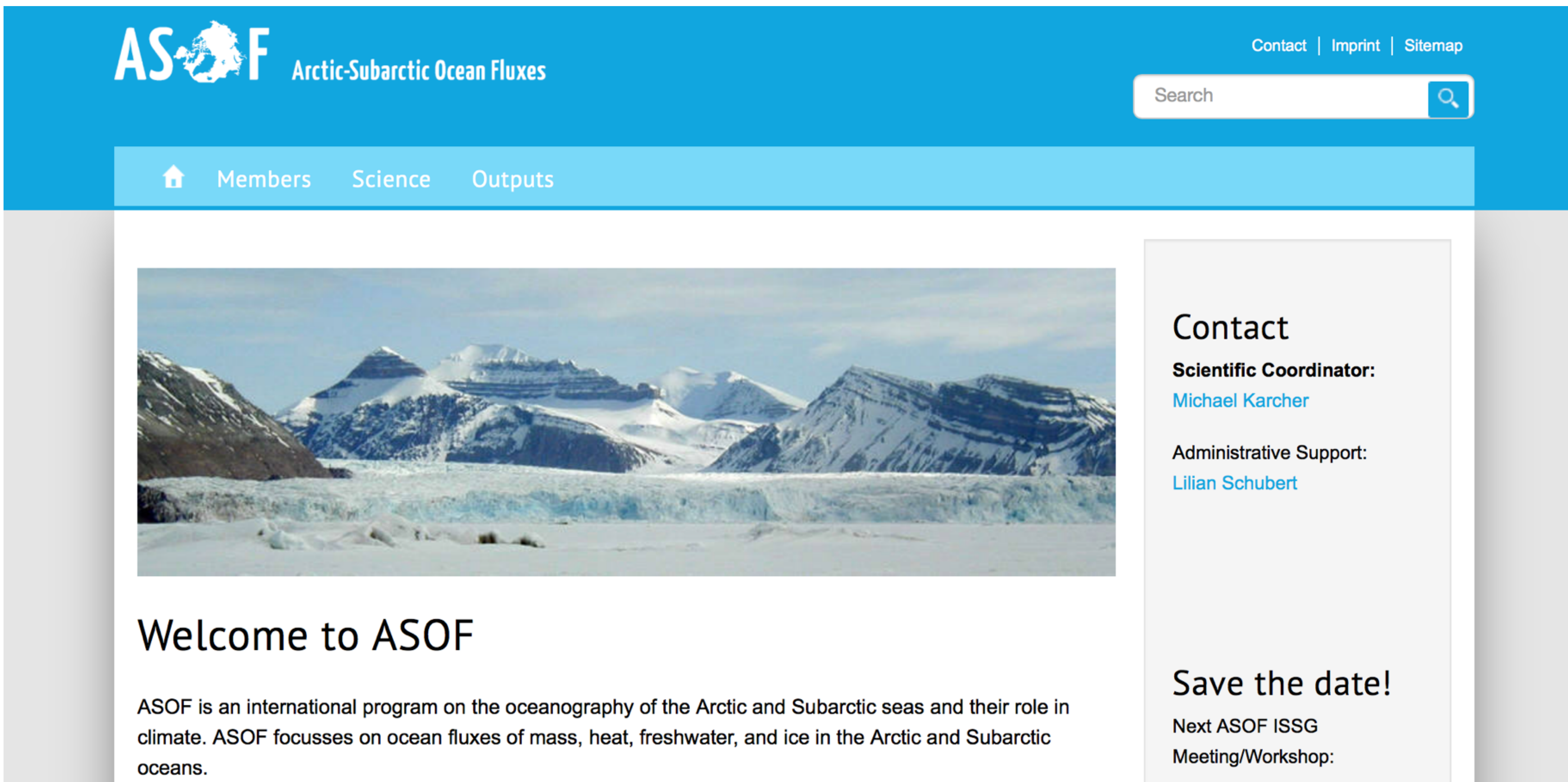
Abstract: This paper presents first seasonal cycle of oceanic and sea ice net heat and fresh water (FW) fluxes across four Arctic gateways (Davis Strait, Fram Strait, Barents Sea Opening (BSO) and Bering Strait). The oceanic transports are estimated primary based on 138 moored instruments during September 2005 - August 2006. Sea ice transports are estimated based on PIOMAS data. Monthly volume and salt conserved velocity fields are obtained applying box inverse model. The results show that the oceanic and sea ice net heat flux is 175±48 TW. The oceanic and sea ice net FW flux is 204±85 mSv. We find that oceanic net heat transport variability is driven temperature variability in surface layer and volume transport variability in Atlantic Water layer. On the other hand, oceanic net FW transport variability is dominated by Bering Strait velocity variability. In terms of water mass transformation, the net effect of the Arctic is to freshen and cool the inflows by 0.65±0.22 in salinity and 3.68±0.73°C in temperature, respectively, and to decrease density by 0.26±0.19 kg/m**3. The volume transport into the Arctic of waters associated with the water mass transformation is 11.0±1.1 Sv (1 Sv = 10**6 m**3/s), and the export (similarly) is -11.2±1.1 Sv. The obtained net boundary heat flux and FW flux time series

ASOF's role to promote this study

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

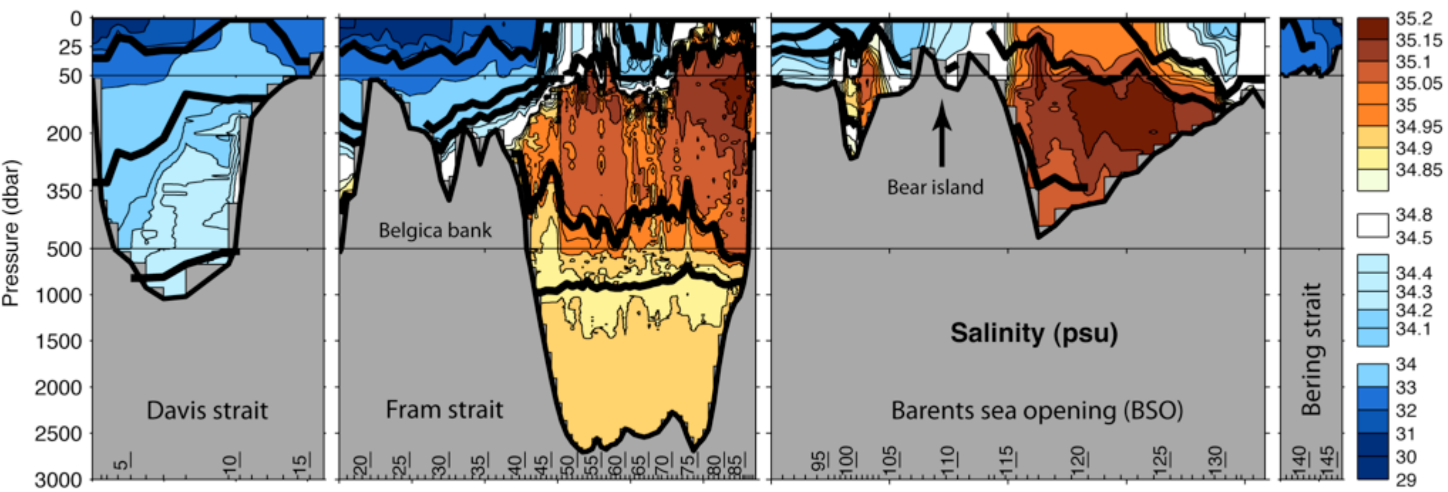
ASOF's role to promote this study

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

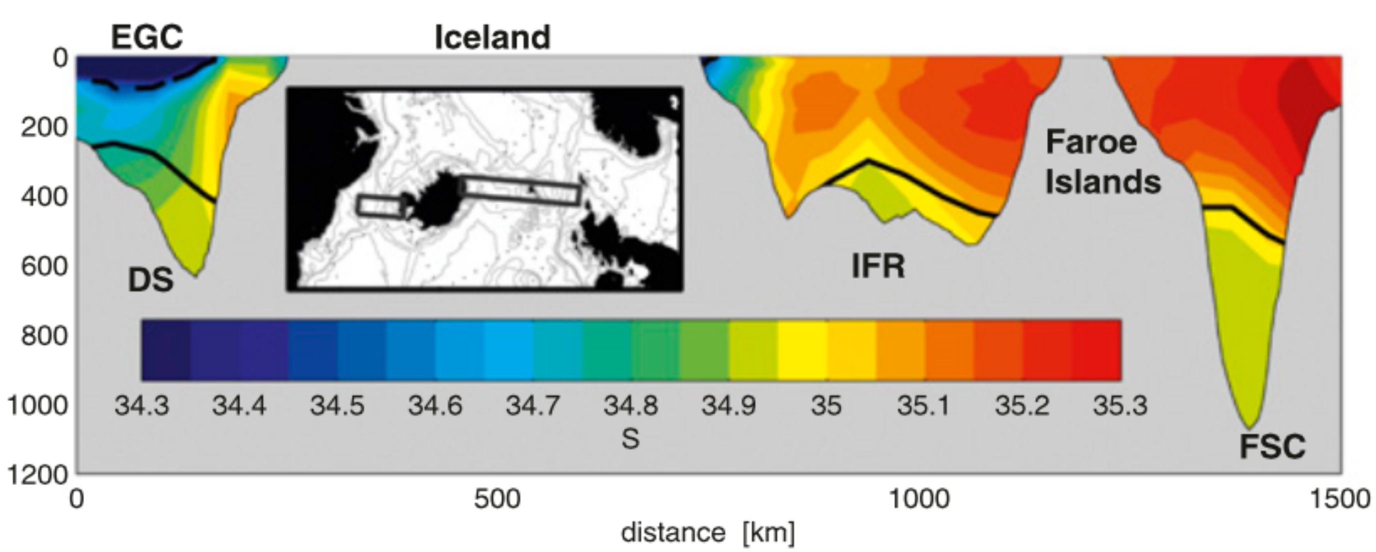


What is next break though?

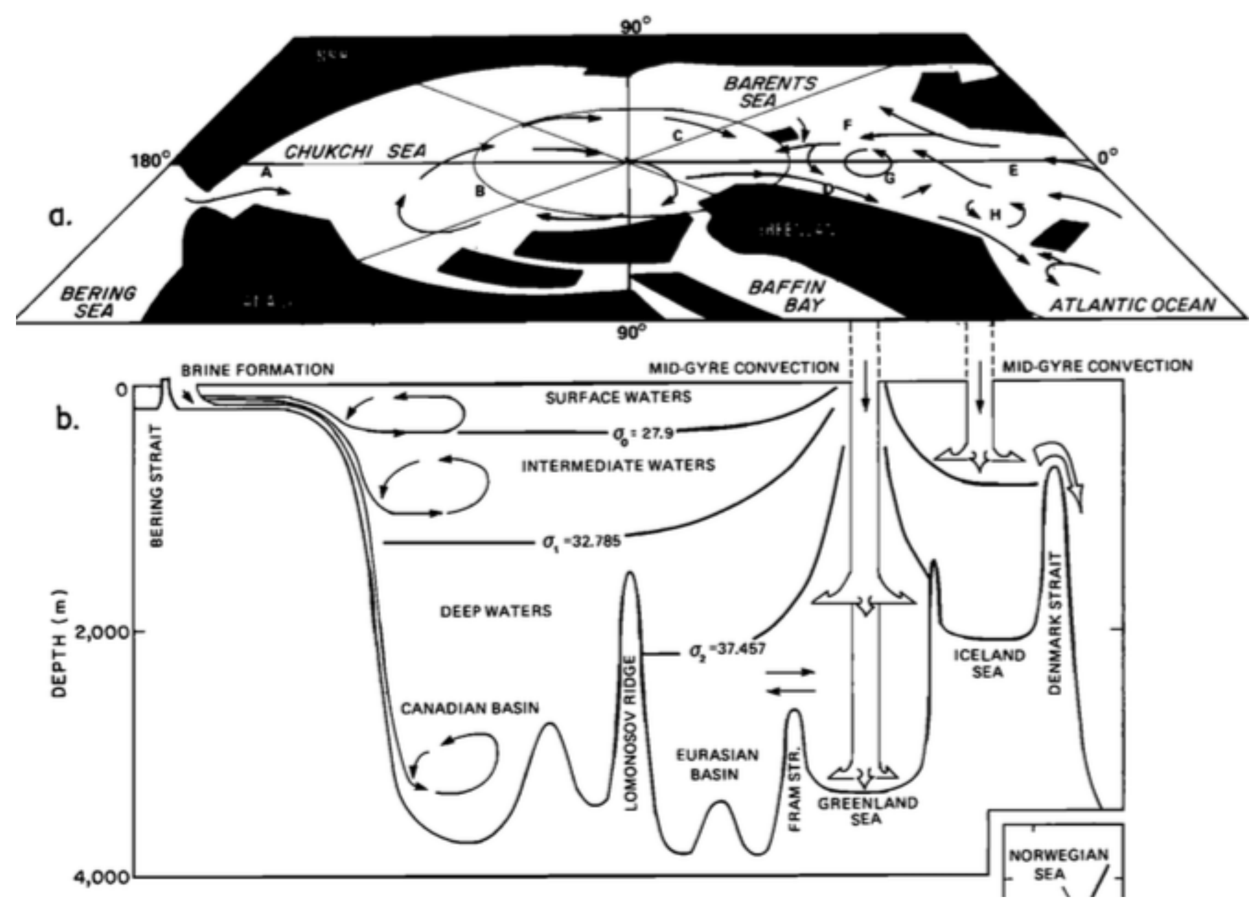
- Include Greenland-Scotland Ridge section in the box inverse model.
  - Two boxes - Arctic Ocean & Nordic Seas.
  - Initial focus period would be 2004-2010 (same as this study).



Tsubouchi et al. [2012, JGR]



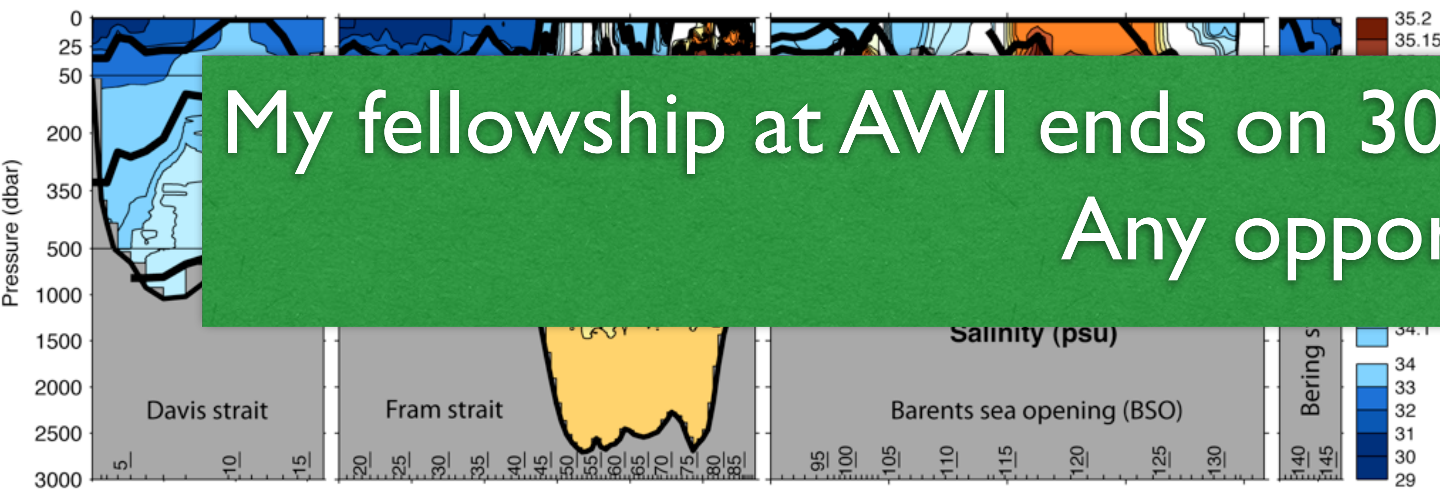
Eldevik & Nilsen. [2013, JC]



AaGaard et al. [1985, JGR]

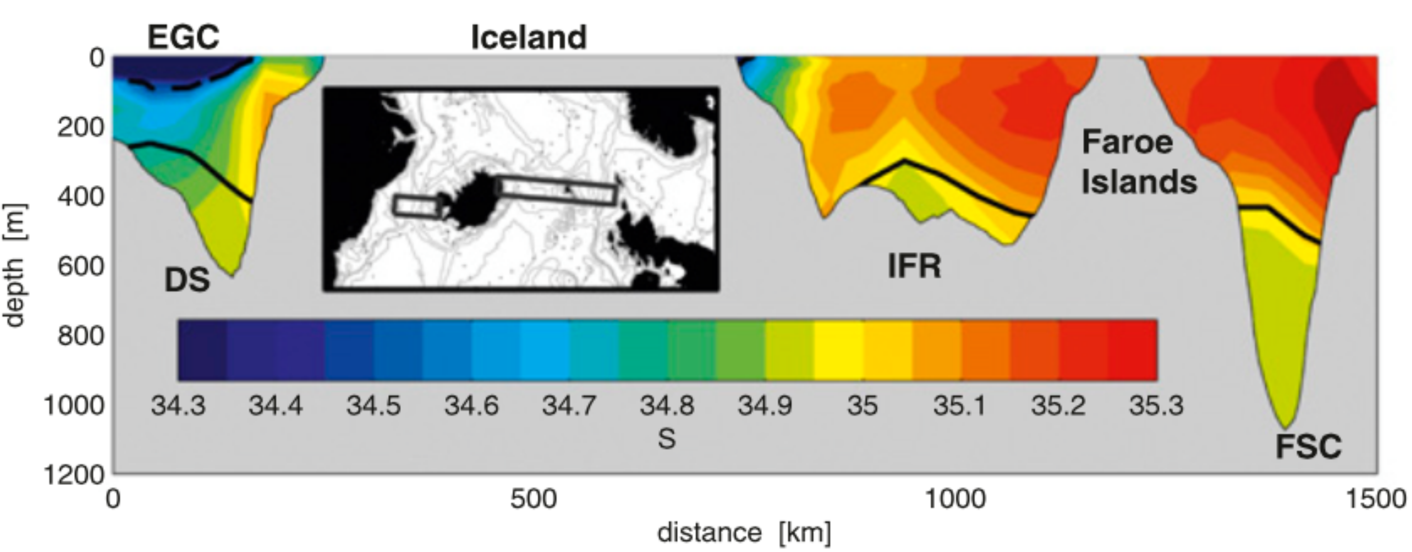
What is next break though?

- 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).

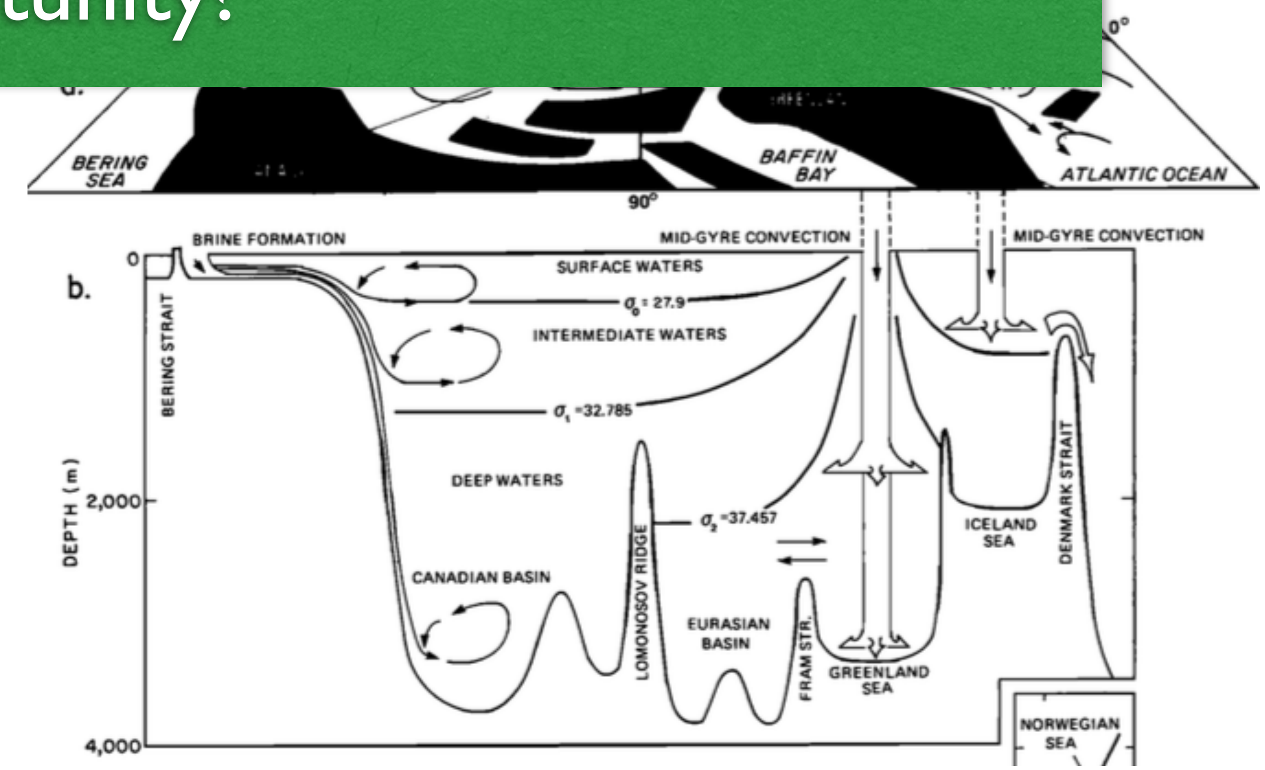


My fellowship at AWI ends on 30 June 2017 (within 3 months). Any opportunity?

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.

Appendix

What changes by changing T_{ref}?

- Not only mean value, but also variance and shape of variability.

Table 4: Oceanic temperature transports with different reference temperature (TW-eq). Correlation coefficients of a pair of two time series with different reference temperatures are also shown.

	Tref 1.01±0.18˚C	Tref 0.0˚C	Tref -1.8˚C	R12	R13	R23
Four main gateways						
Davis	32±11	24±12	10±17	0.94	0.79	0.94
Fram	68±22	62±21	51±22	0.97	0.80	0.92
Barents	55±23	64±28	80±35	1.00	0.99	1.00
Bering	-3±9	2±10	9±12	0.97	0.86	0.95
Fram components						
EGC	26±8	-3±4	-54±13	0.45	-0.56	0.23
WSC	33±14	62±19	113±34	0.88	0.57	0.87
Total oceanic transports	151±48	151±48	151±48	1.00	1.00	1.00

What changes by changing S_{ref}?

- Not only mean value, but also variance and shape of variability.

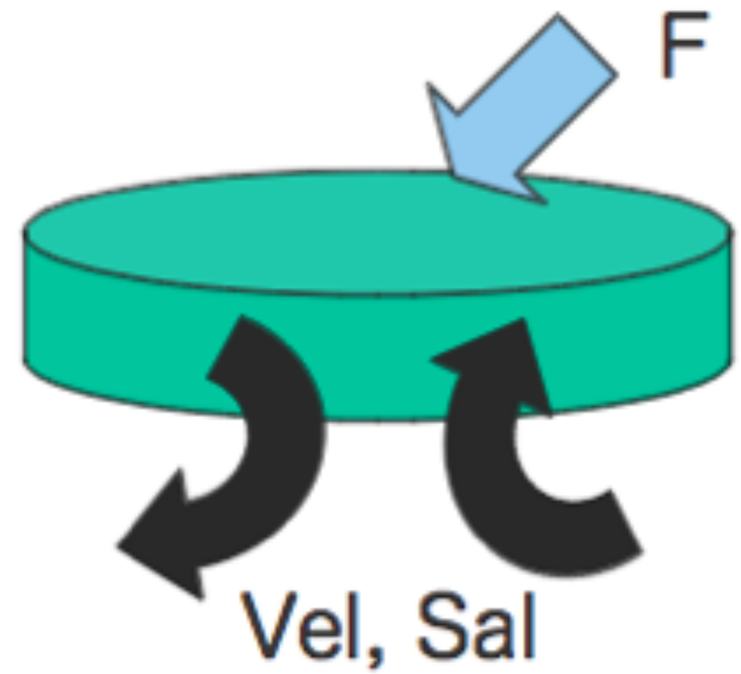
Table 5: Oceanic FW transports with different reference saliinty (mSv-eq). Correlation coefficients of a pair of two time series with different reference salinities are also shown.

	Sref 34.70±0.02	Sref 34.8	Sref 35.2	R12	R13	R23
Four main gateways						
Davis	93±25	98±26	118±32	1.00	0.93	0.96
Fram	63±22	67±23	82±30	0.99	0.84	0.91
Barents	13±13	6±10	-18±7	0.98	-0.05	0.12
Bering	-67±35	-69±36	-80±41	1.00	1.00	1.00
Fram components						
EGC	-4±11	16±10	95±21	0.78	-0.28	0.32
WSC	59±21	39±13	-41±18	0.98	-0.86	-0.82
Total oceanic transports	102±63	102±63	102±63	1.00	1.00	1.00

Surface FW flux equation (1/2)

$$Volume: F + \oint V dx dz = 0$$

$$Salt: \oint SV\, dx\, dz = \frac{\partial}{\partial t}\oint S d(vol)$$



$$F + \oint \left(\bar{V} + V'\right) dA = 0 \qquad (1)$$

$$\oint \left(\bar{S} + S'\right)\left(\bar{V} + V'\right) dA = \frac{\partial}{\partial t}\oint S d(vol) \qquad (2)$$

$$F + \bar{V}A + \cancel{\oint V' dA} = 0 \rightarrow F = -\bar{V}A \qquad (3)$$

$$\oint \overline{VS}\, dA + \cancel{\oint \bar{V}S' dA} + \cancel{\oint V'\bar{S} dA} + \oint V'S'\, dA = \frac{\partial}{\partial t}\oint S d(vol)$$

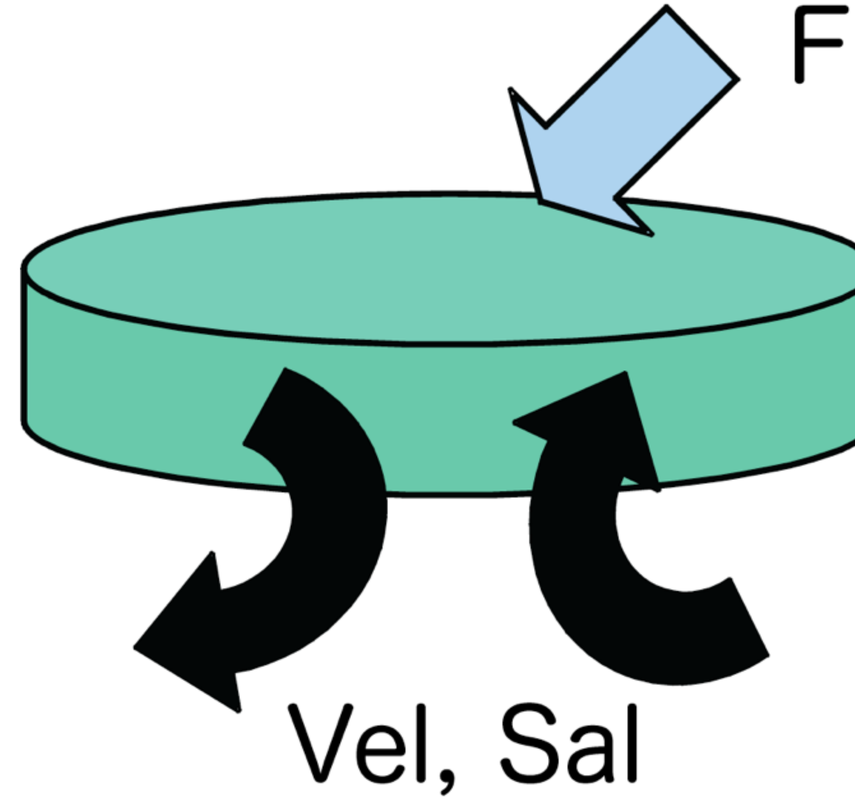
$$\overline{VS}A + \oint V'S' dA = \frac{\partial}{\partial t}\oint S d(vol)$$

$$F\bar{S} = \oint V'S' dA - \frac{\partial}{\partial t}\oint S d(vol)$$

$$\boxed{F = \frac{\oint V'S' dA}{\bar{S}} - \frac{\frac{\partial}{\partial t}\oint S d(vol)}{\bar{S}}}$$

Surface FW flux equation (2/2)

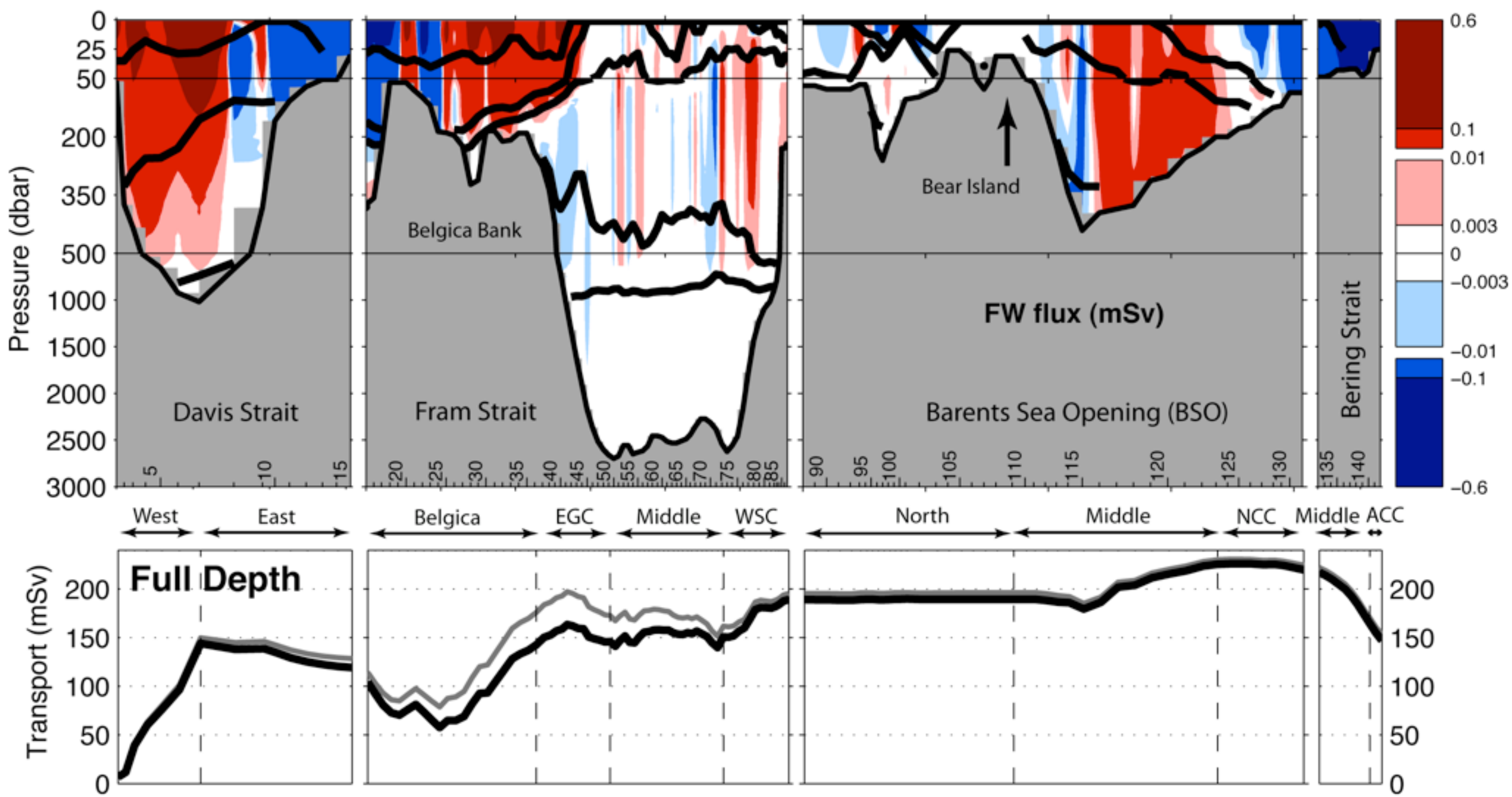
$$F = \frac{\oint V'S'dA}{\bar{S}} - \frac{\frac{\partial}{\partial t}\oint Sd(vol)}{\bar{S}}$$



- $\bar{S}$ is mean salinity across boundary.
  - including Sea ice (6 psu), this is 34.662.
  - Not 34.8, 35.0.
- F is balanced by (V'S').
  - Positive V'S': S'>0 inflow or S'<0 outflow.
  - Negative V'S': S'<0 inflow or S'>0 outflow.

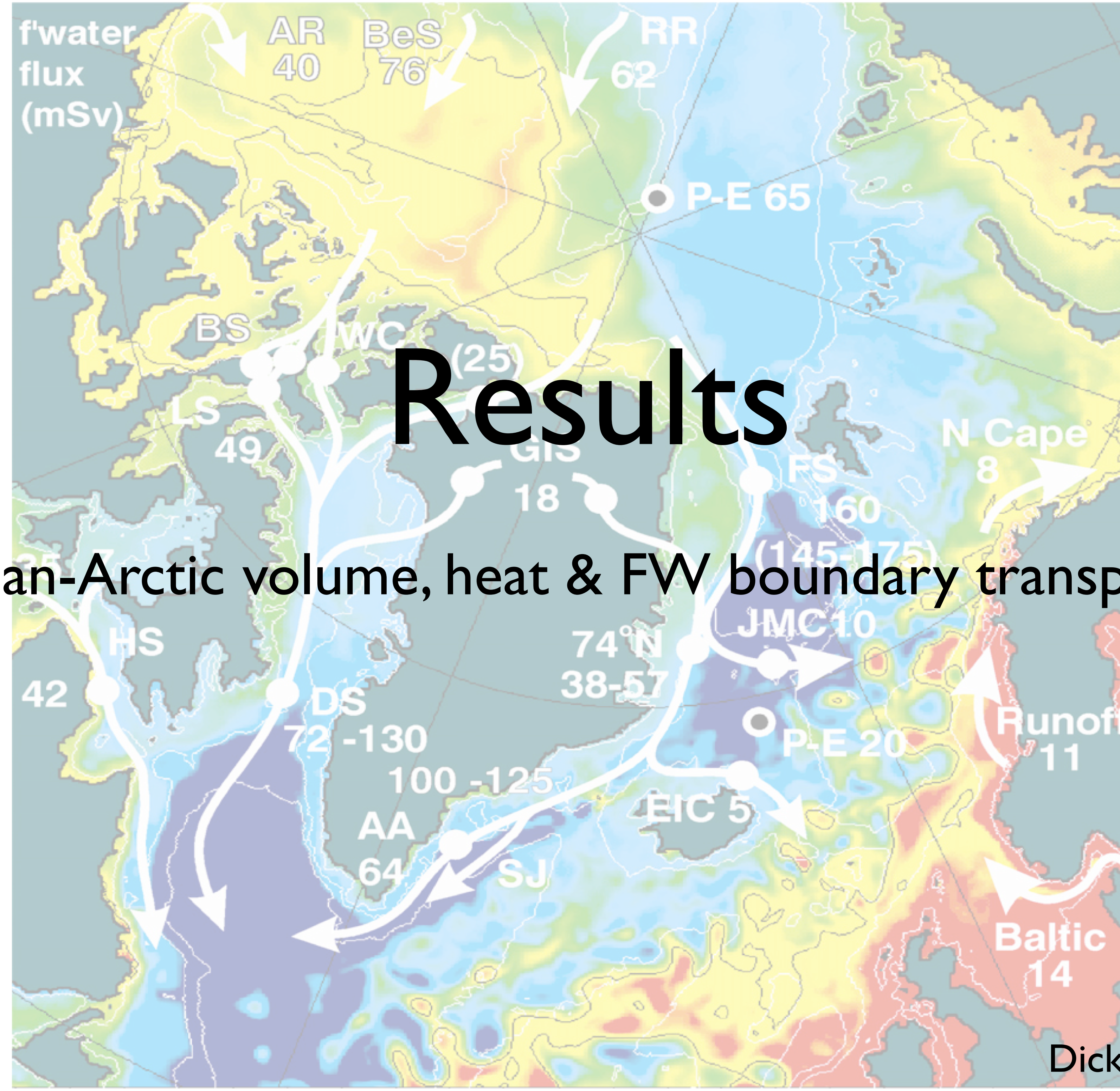
$$\frac{\oint V'S'dA}{\bar{S}} : S_{ref}=34.662$$

- Positive S'v': Davis middle (S'<0.,V'<0.), Belgica east (S'<0,V'<0), BSO AW (S'>0.,V'>0.)
- Negative S'v': Davis east (S'<0.,V'>0.), Belgica west (S'<0,V'>0), NCC (S'<0.,V'>0.), Bering (S'<0.,V'>0.)



Results

pan-Arctic volume, heat & FW boundary transports

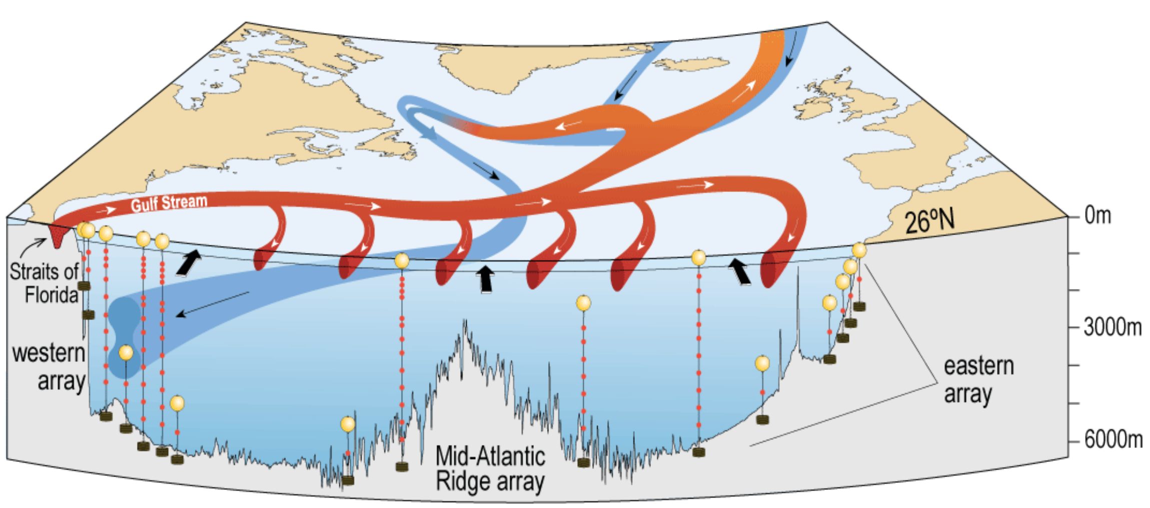


Dickson et al. (2006)

Be Strict: Temperature transport, heat transport.

- We refer temperature transport (W-eq) and interim FW transport (mSv-eq) when mass is not closed, followed by Talley [2003, 2008].
- We only refer heat transport (W) and FW transport (mSv) when mass is closed.
- See detail for Hall and Bryden 1982, Wijffels et al. 1992, Wijffels 2001, Ganachaud and Wunsch 2003, Schauer and Beszczynska-Möller 2009

Only when the mass fluxes of these components balance and they are summed together do these temperature transports yield a meaningful heat transport value. [Johns et al 2011]



RAPID array at 26.5°N

TABLE 1. Mean values and standard deviations of temperature transport components that are combined to estimate the total, basinwide meridional heat transport. Units of PW (10^{15} watts).

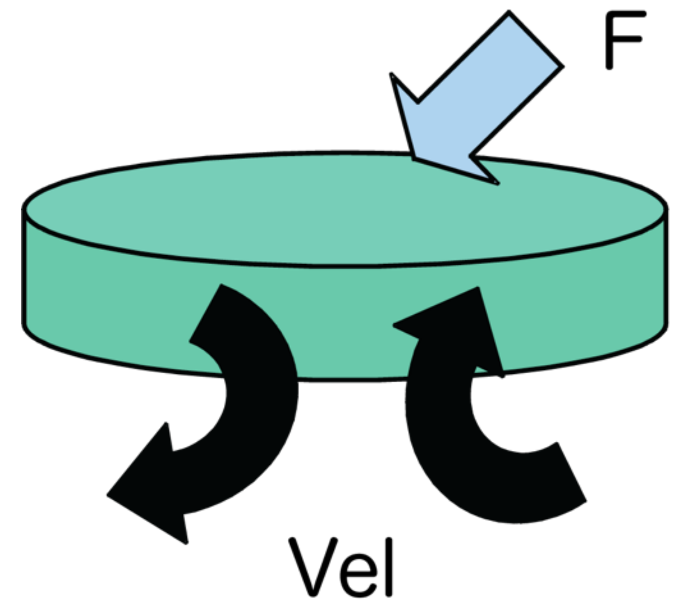
Meridional heat transport component	Temperature transport (relative to 0°C)	Temperature transport (relative to $\theta_{midocean}$)
Florida Current	2.53 ± 0.24	1.84 ± 0.18
Ekman	0.35 ± 0.34	0.27 ± 0.27
Midocean	−1.77 ± 0.25	−0.97 ± 0.20
WB-Abaco	0.13 ± 0.16	0.10 ± 0.11
Eddy*	0.11 ± 0.04	0.11 ± 0.04
Total*	1.35 ± 0.40	1.35 ± 0.40

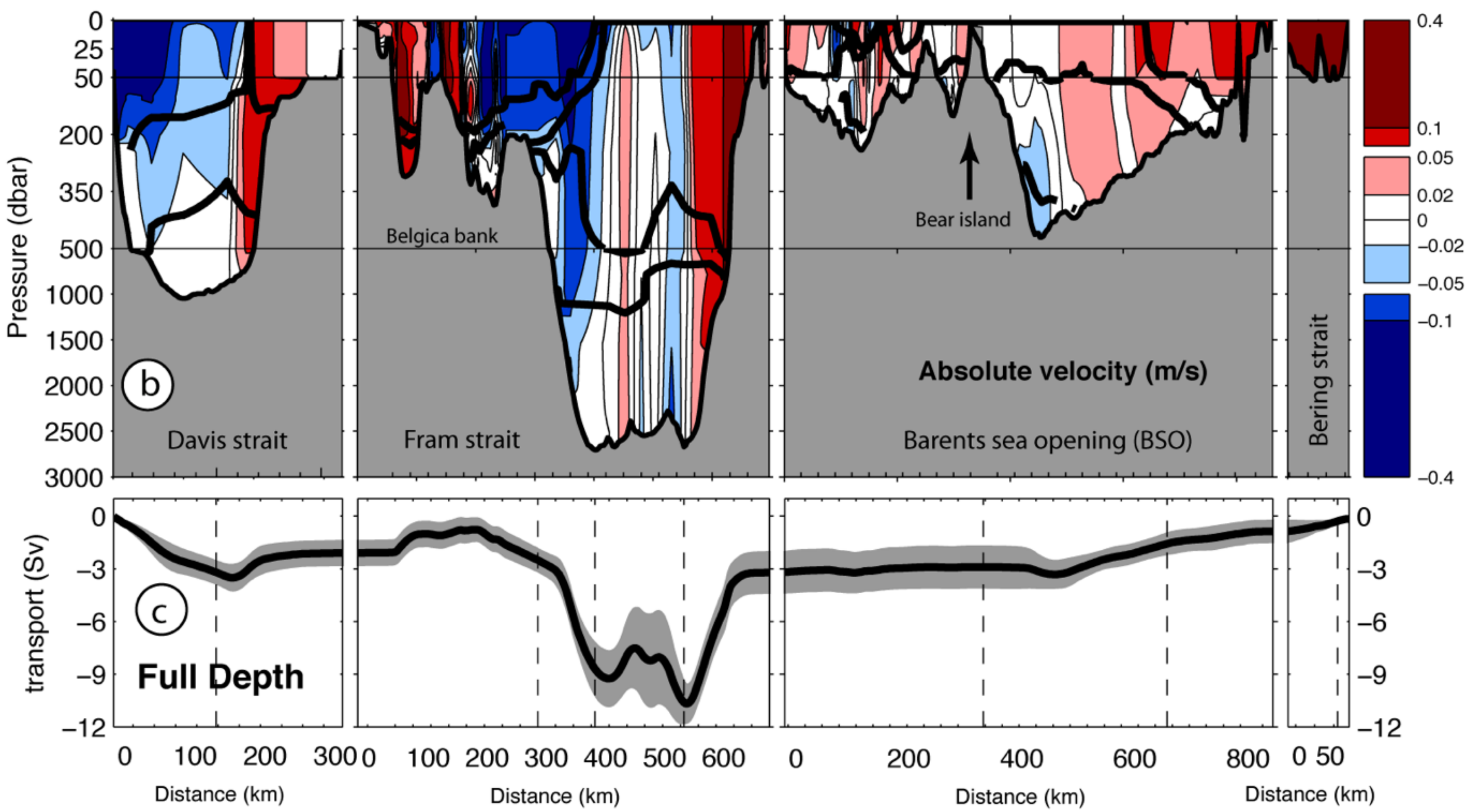
* Independent of temperature reference

Johns et al [2011, JC]

pan-Arctic volume transports

$$\frac{\partial}{\partial t}\iiint dV = \boxed{\iint_{bot}^{0} v dx dz} + \int h_i v_i dx + F$$





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

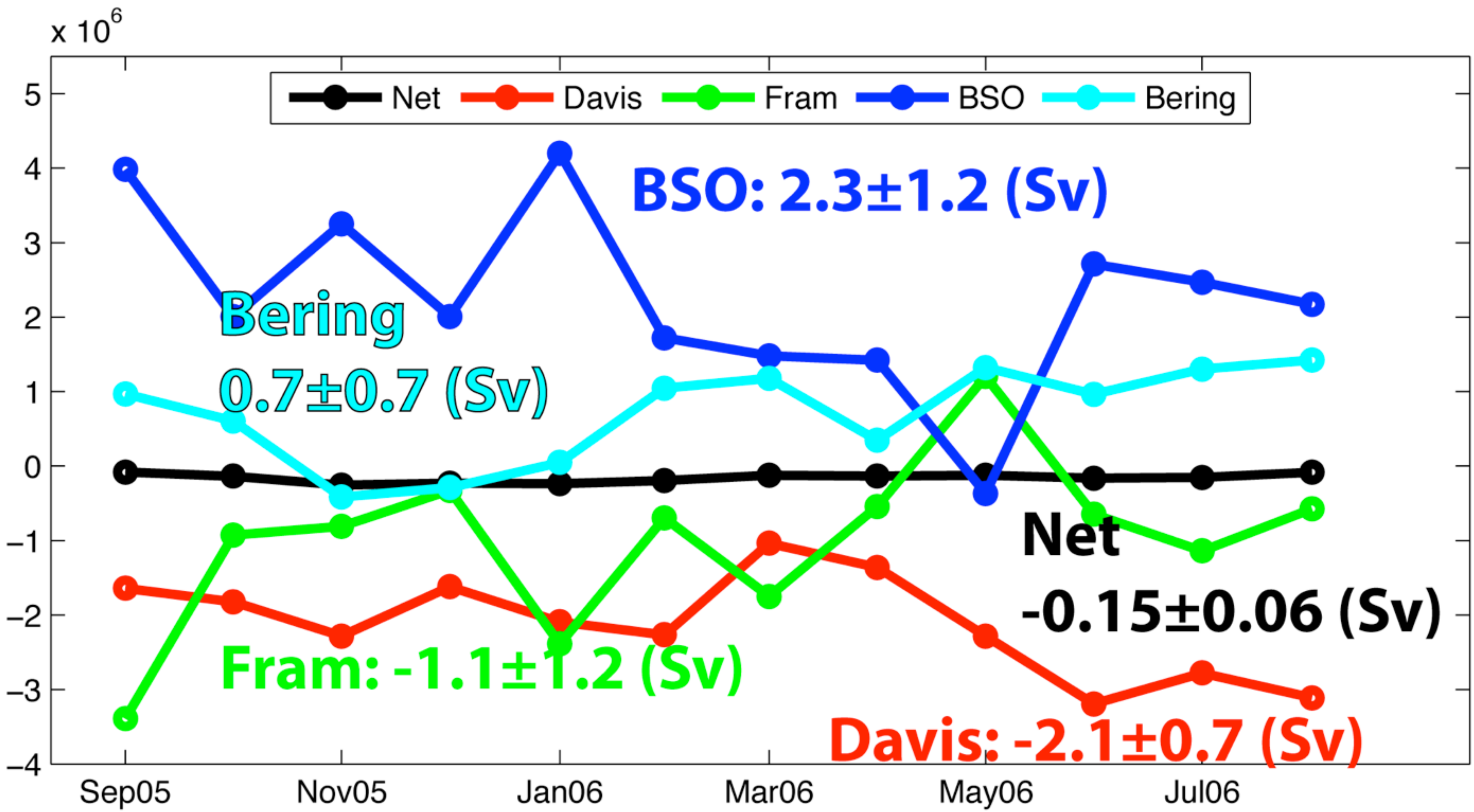
Table: pan-Arctic volume transport compared with previous estimates

(Sv)	This study	reference
Davis	-2.1±0.7	-1.6±0.5(*1)
Fram	-1.1±1.2	-2.0±2.7 (*2)
BSO	2.3±1.2	2.0 (*3)
Bering	0.7±0.7	0.8 (*4)
Net	-0.15±0.06	-0,8

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

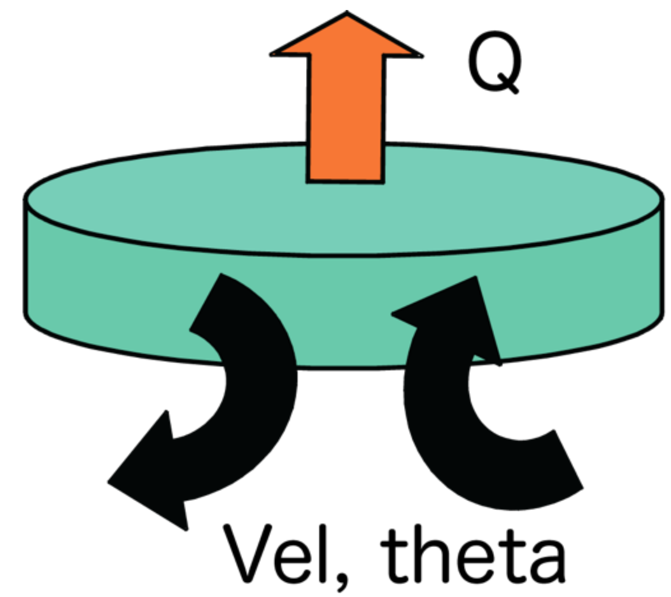
pan-Arctic Volume transport time series

- Reasonable mean and standard deviation values.
- Net transport is almost zero in each month.



Oceanic temperature transports

$$\frac{\partial E}{\partial t} = \boxed{\iint_{bot}^{h_i} \rho c_p \theta v dxdz} + \int_{h_i}^{0} \rho_i h_i v_i (c_f + c_p^i \theta_i) dxdz + Q$$



Reference theta = 1.00±0.16˚C

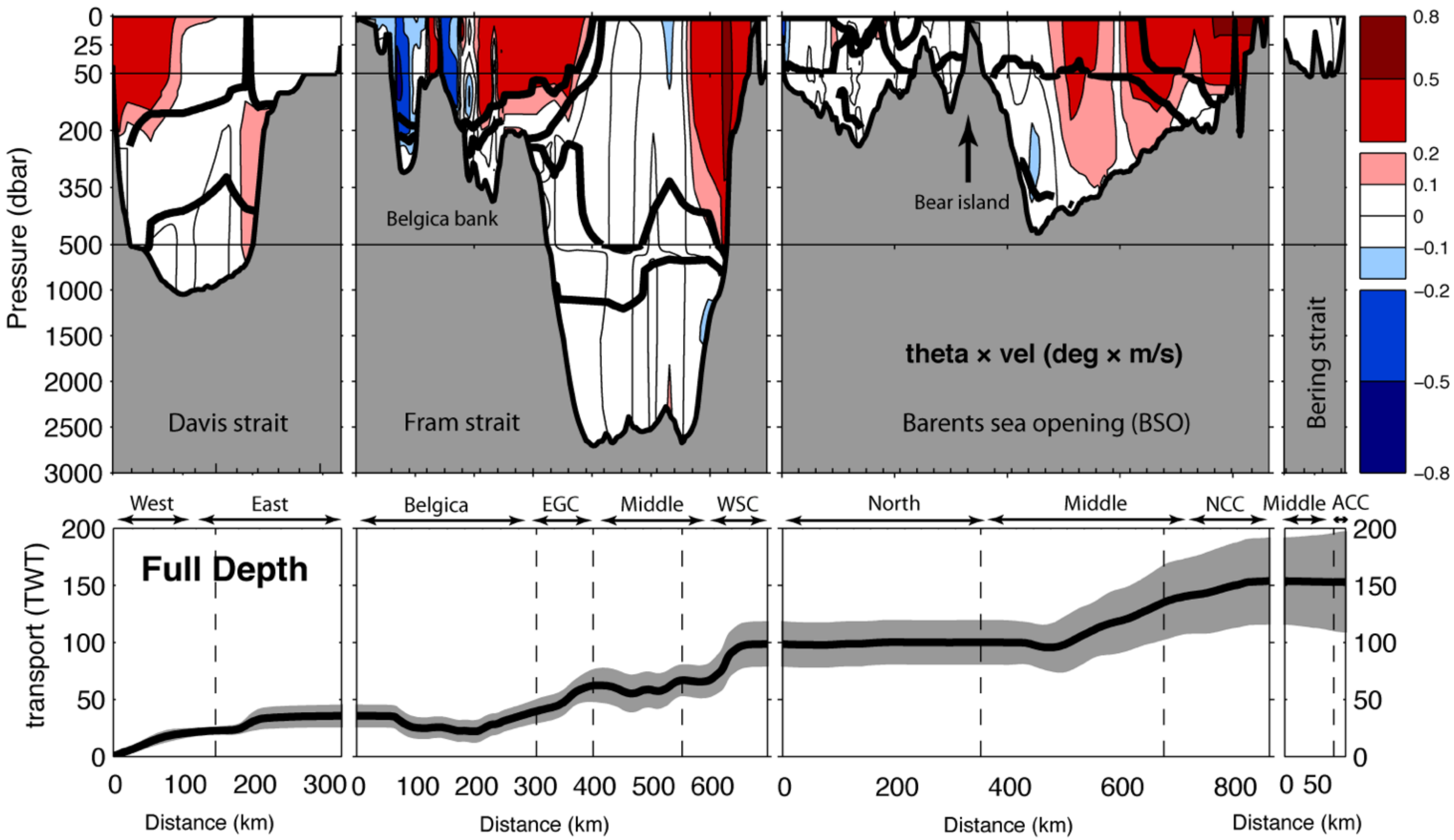


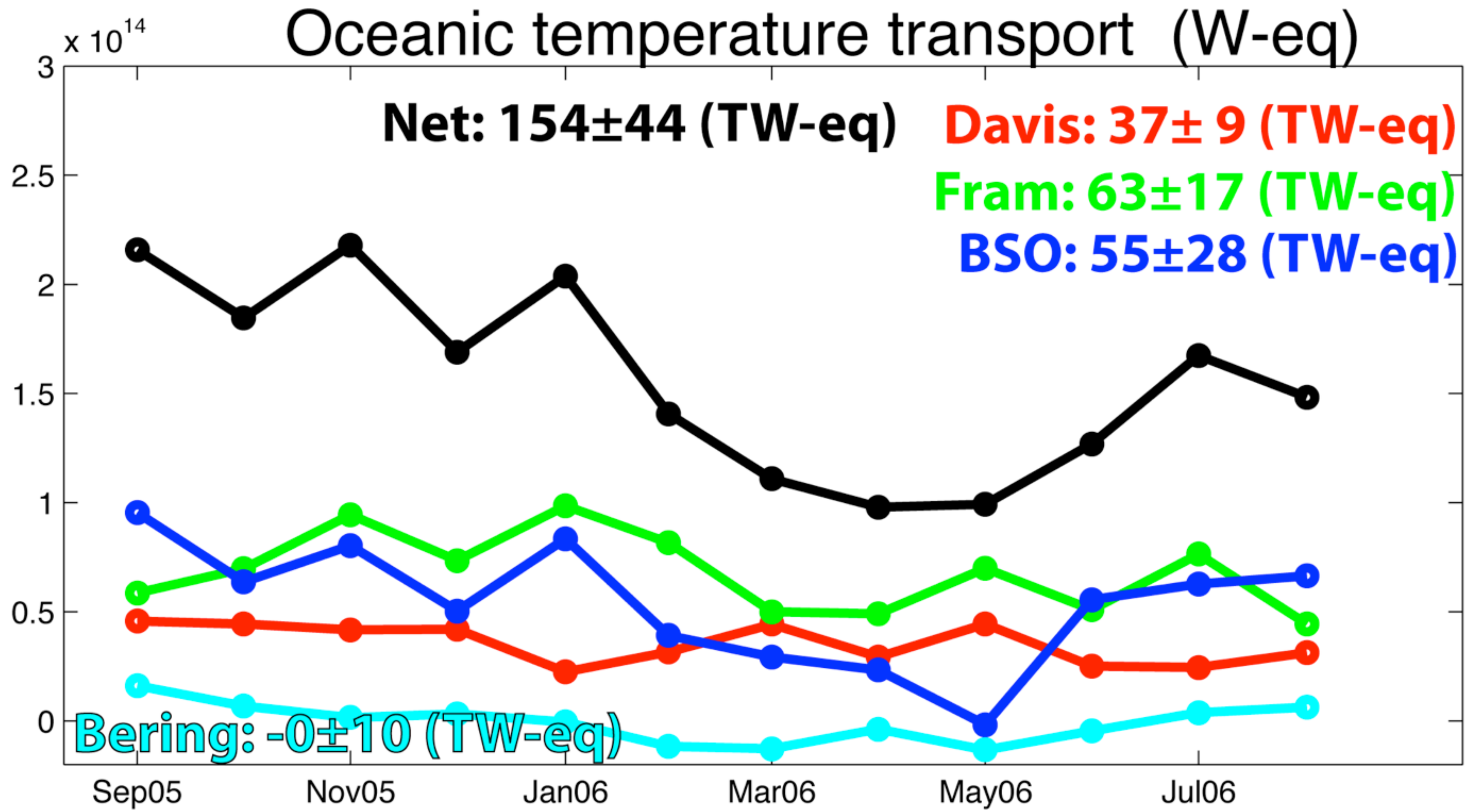
Table: Oceanic heat transport compared with previous estimates

(TW-eq)	This study	ref
Davis	37±9	28
Fram	63±17	43
BSO	55±28	86
Bering	-0±10	13
Net	154±44	189

Reference: Tsubouchi et al. [2012]

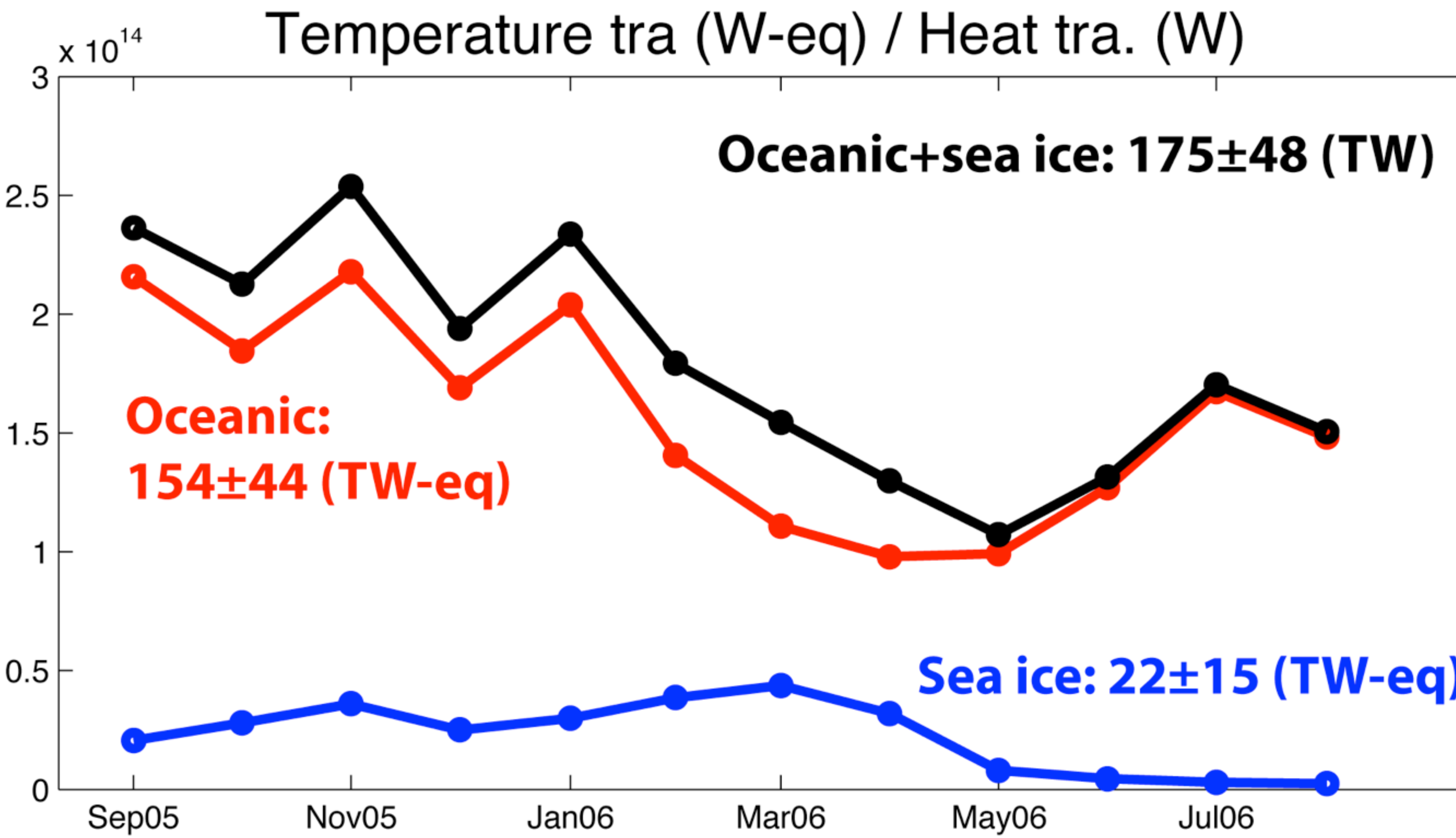
Oceanic temperature transports

- Net temperature transports has maxima in Sep.-Dec. and minima in Mar.-May
- Net temperature transport variation is largely dominated by BSO and Fram Strait.



Oceanic & sea ice Heat transports

$$\frac{\partial E}{\partial t} = \boxed{\iint_{bot}^{h_i} \rho c_p \theta v \, dx dz} + \boxed{\int_{h_i}^{0} \rho_i h_i v_i \left(c_f + c_p^i \theta_i\right) dx dz} + Q$$



Driving factors of oceanic temperature transport

- AW layer velocity driven component & SURF layer temperature driven component are both equally important.

$$\iint_{bot}^{h_i} \rho c_p \theta v dx dz = \Theta V = <\Theta><V> + <\Theta>V' + \Theta'<V> + \Theta'V'$$

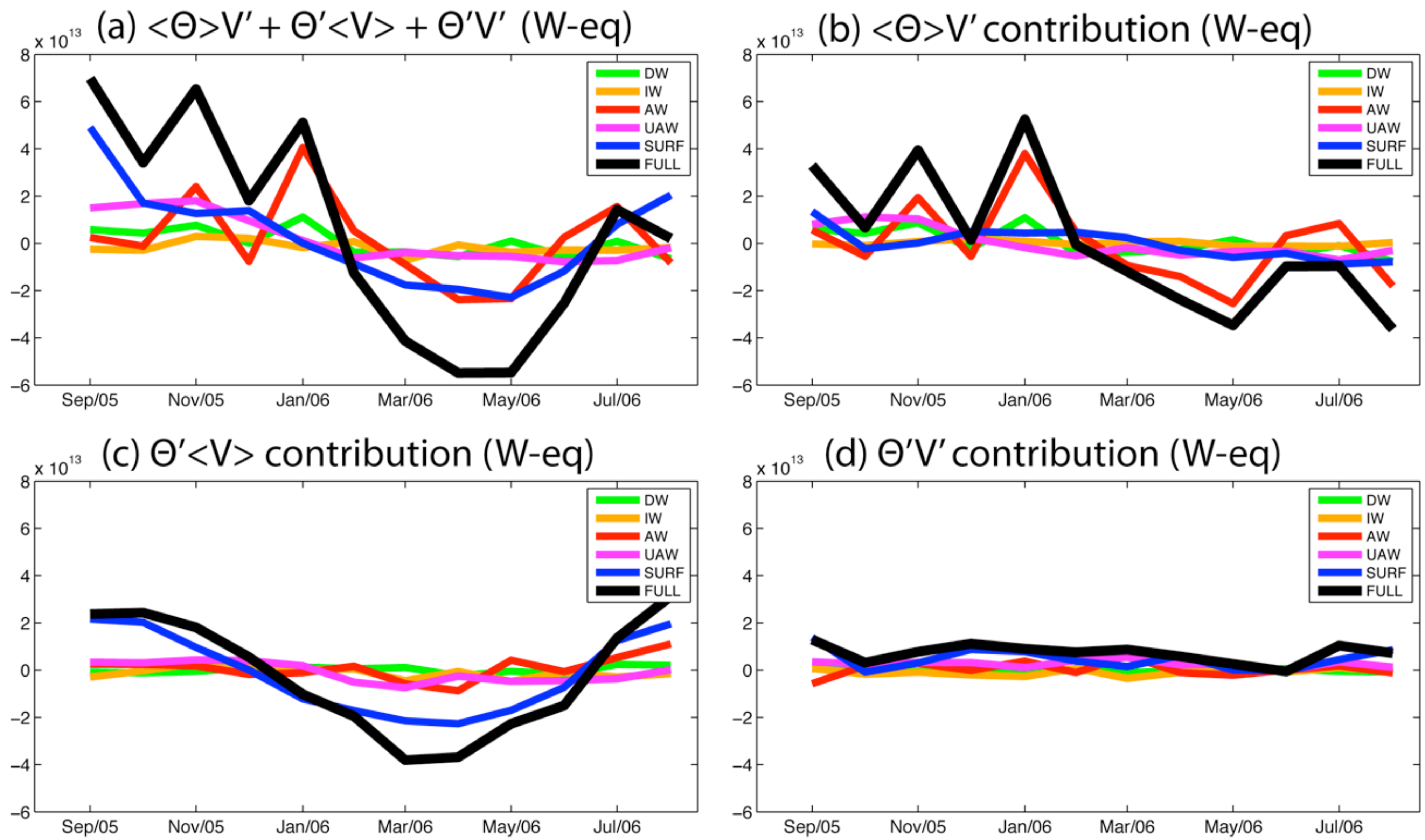
Temperature transport

Steady state component

Velocity driven component

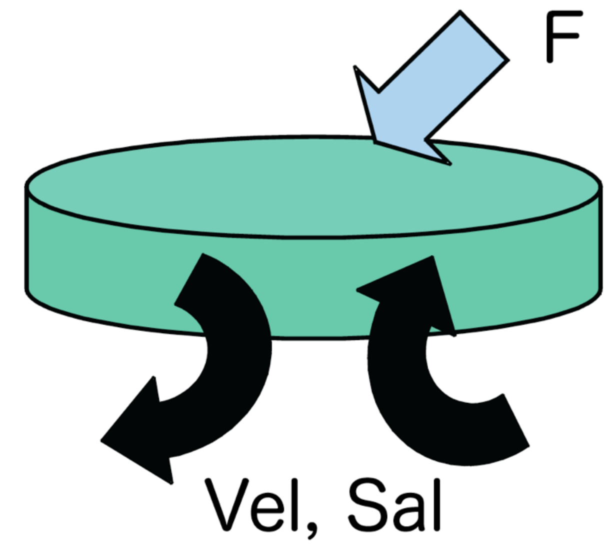
Temperature driven component

Eddy driven component



Oceanic interim FW transports

$$\frac{\partial M}{\partial t} = \boxed{\frac{\iint_{bot}^{0} S' v' dxdz}{\bar{S}}} + \frac{\int S_i' h_i v_i dx}{\bar{S}} + F$$



Reference salinity = 34.67±0.02

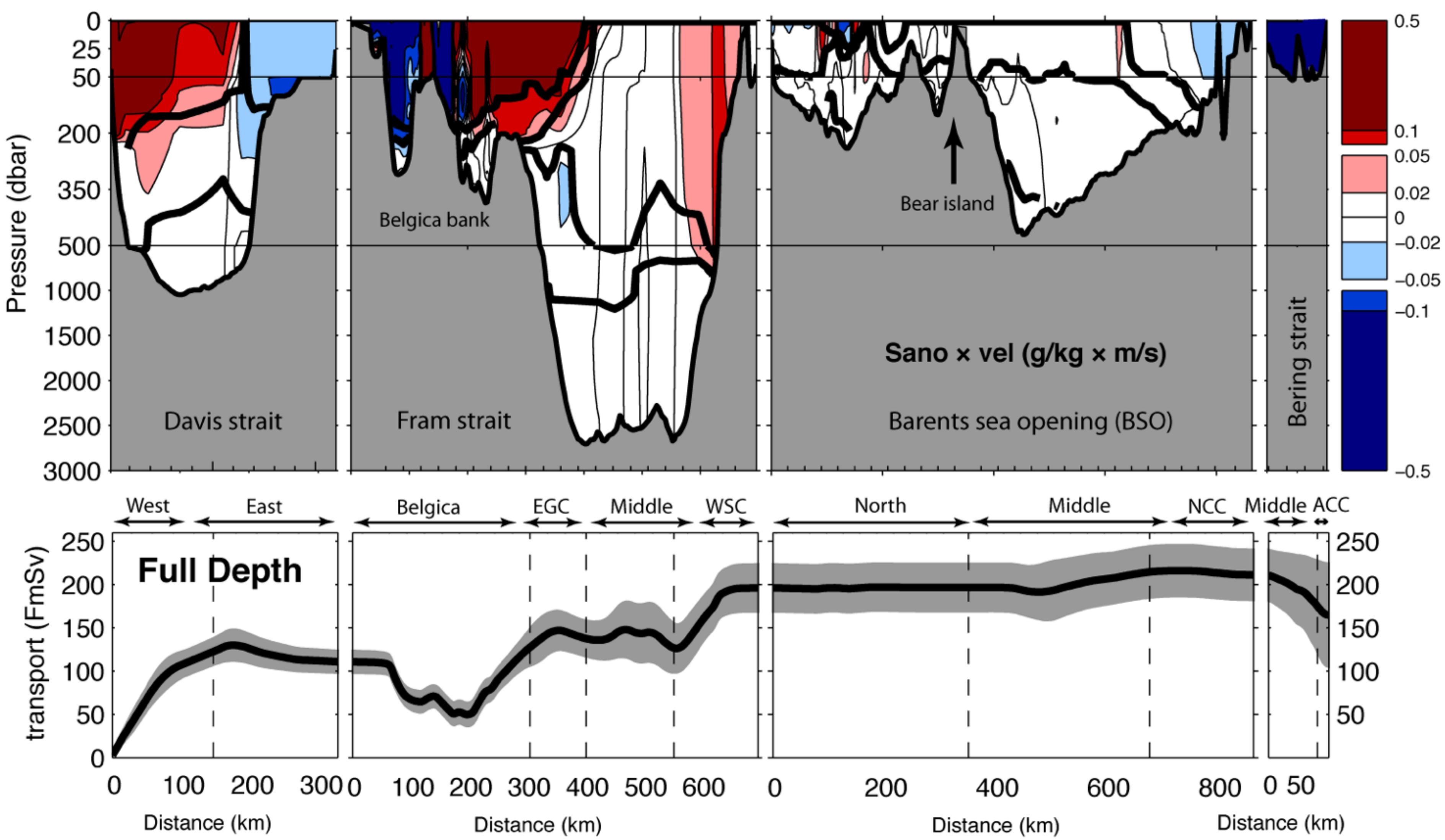


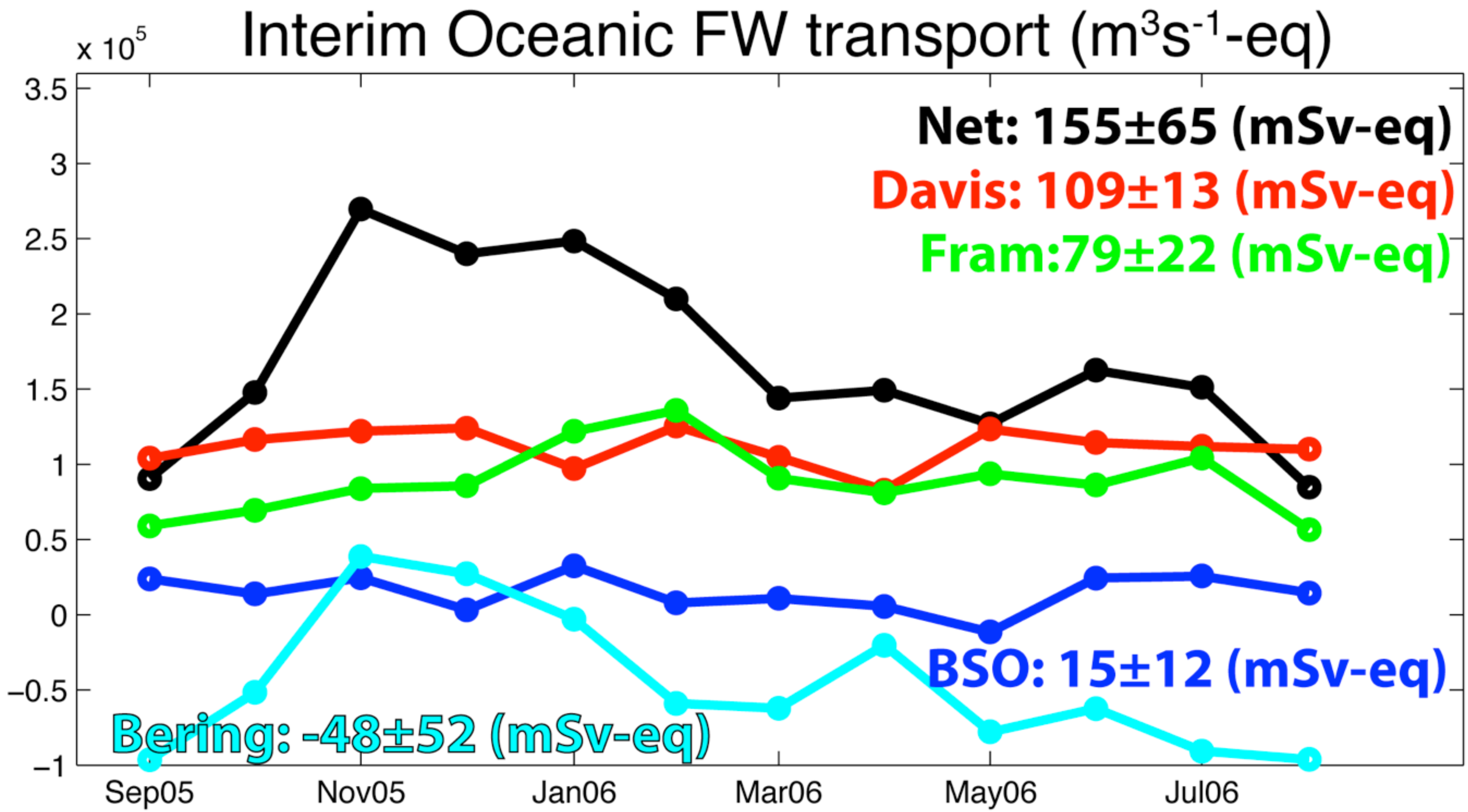
Table: Oceanic FW transport compared with previous estimates

(mSv-eq)	This study	ref
Davis	109±13	119
Fram	79±22	70
BSO	15±12	31
Bering	-48±52	-72
Net	155±65	147

Reference: Tsubouchi et al. [2012]

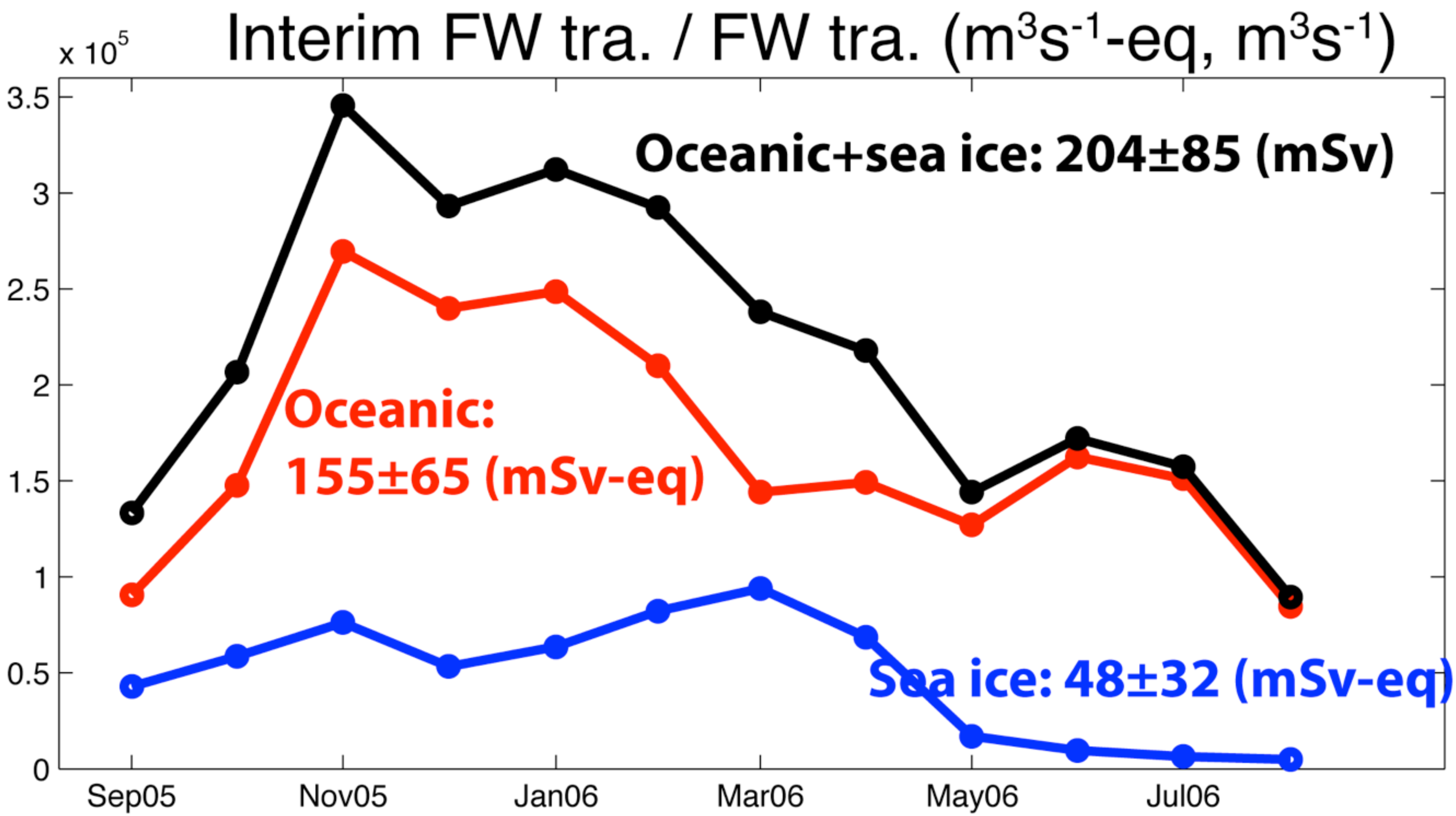
Oceanic interim FW transports

- Net interim FW transport has maxima in Nov.-Feb. and minima in Aug.-Sep.
- Net interim FW transport variation is largely dominated by Bering Strait.



Oceanic & sea ice FW transports

$$\frac{\partial M}{\partial t} = \boxed{\frac{\iint_{bot}^{0} S'v'dxdz}{\bar{S}}} + \boxed{\frac{\int S_i'h_iv_idx}{\bar{S}}} + F$$



Driving factor of oceanic interim FW transport

- SURF layer velocity driven component dominates the variability.

$$\frac{\iint_{bot}^{0} S'v'dxdz}{\bar{S}} = \Sigma V = \langle\Sigma\rangle\langle V\rangle + \langle\Sigma\rangle V' + \Sigma'\langle V\rangle + \Sigma' V'$$

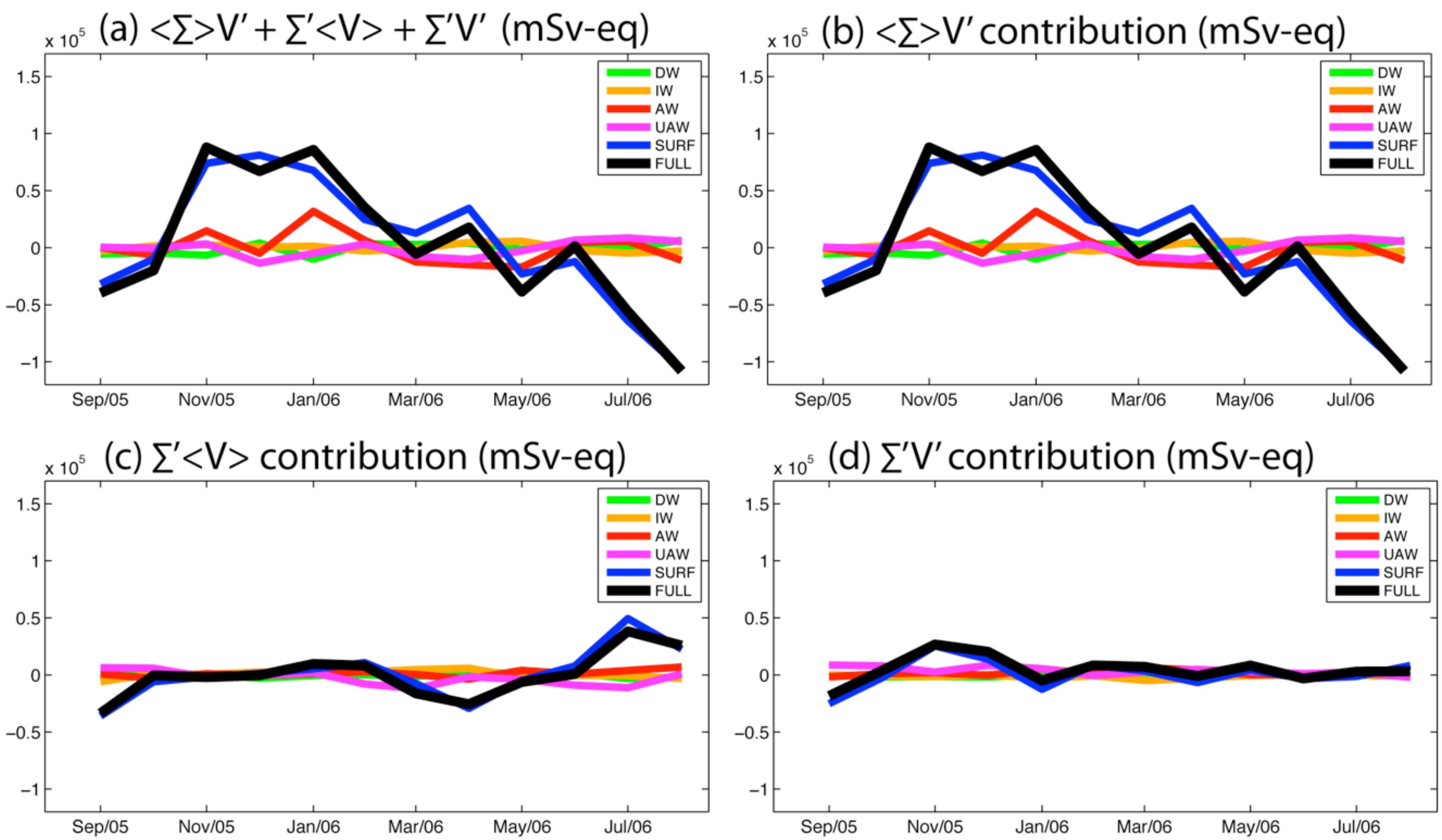
FW transport

Steady state component

Velocity driven component

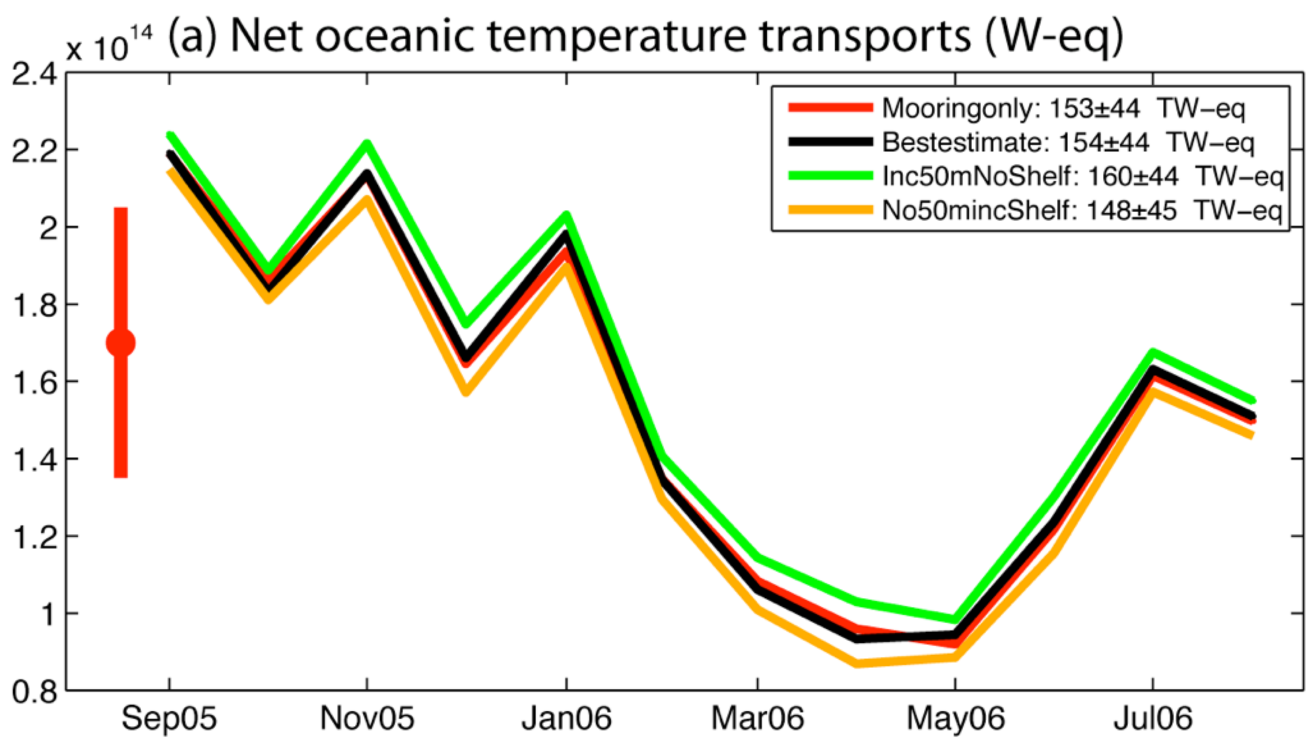
Salinity driven component

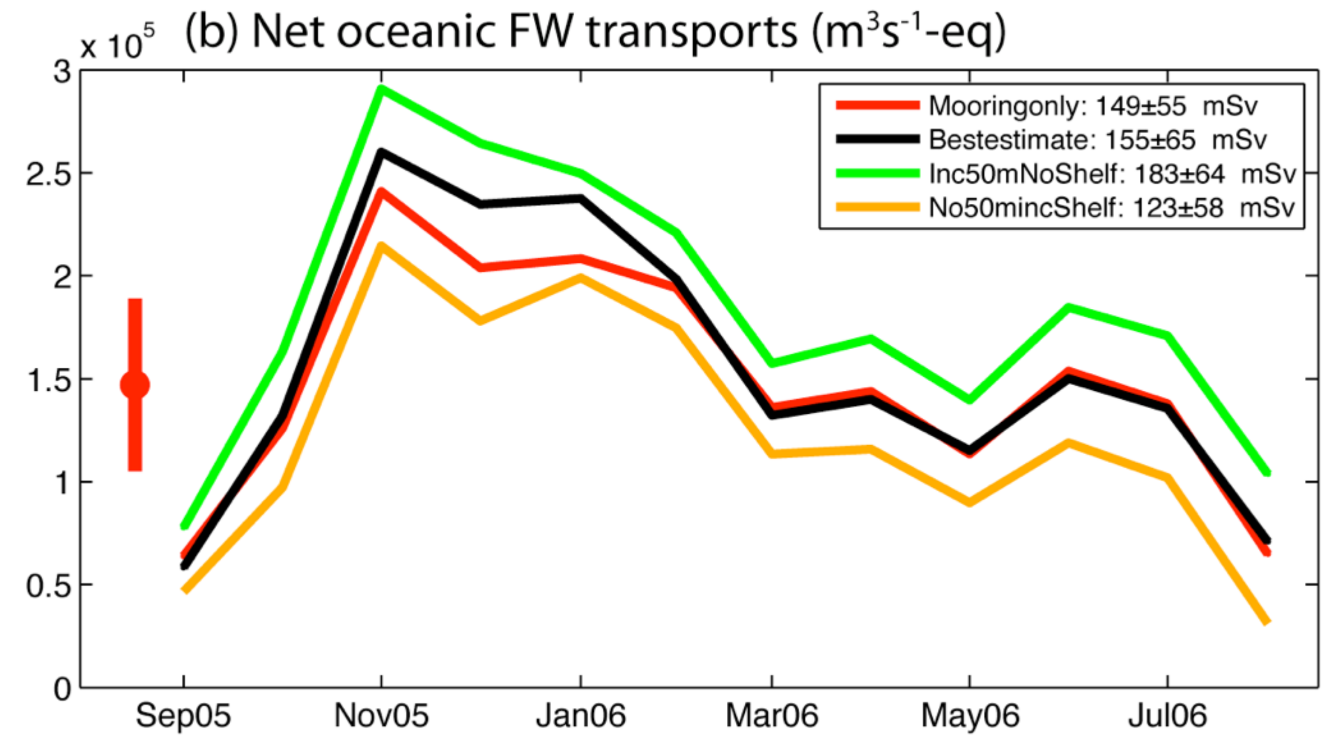
Eddy driven component



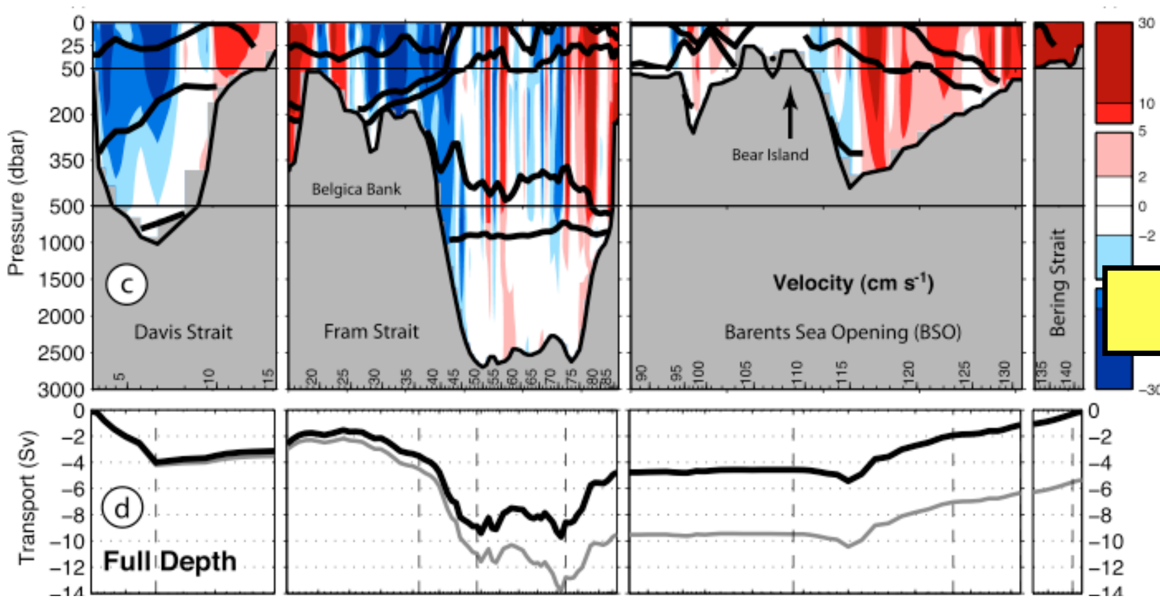
Robustness of the oceanic transports

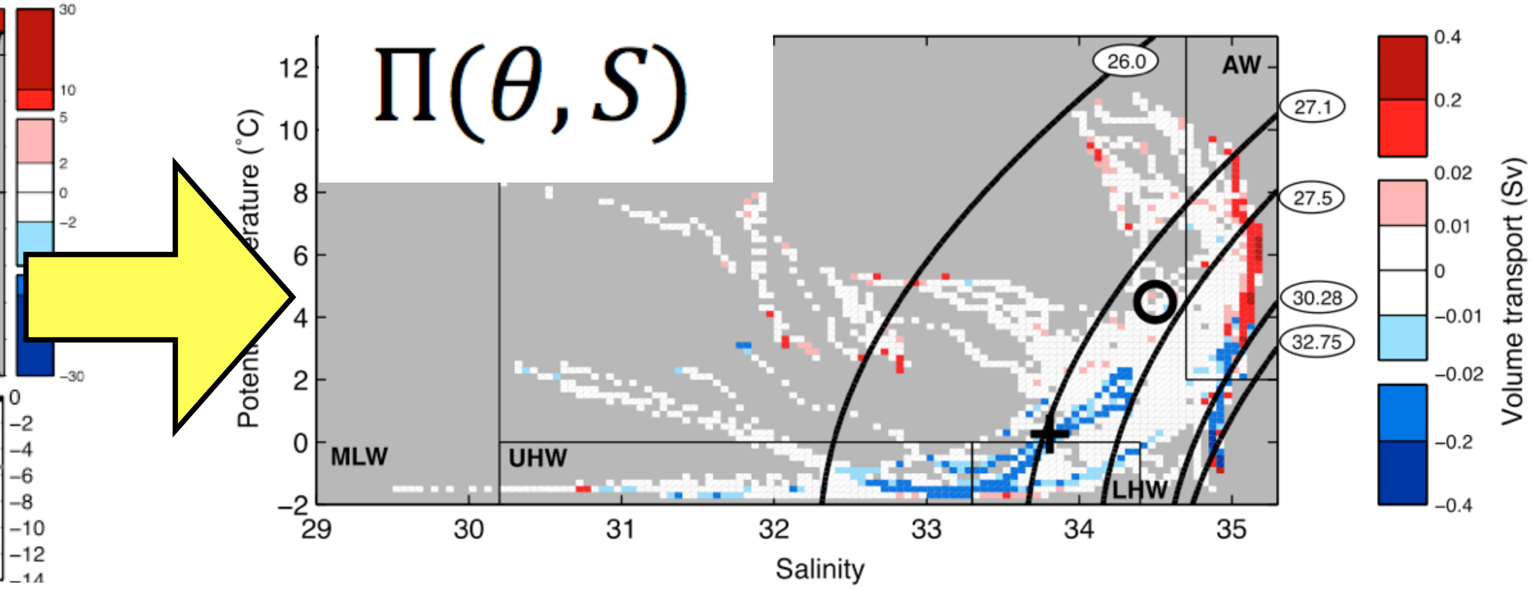
- Apply different set of TSV sections
  - Mooring only, Best estimate, Inc50mNoshelf, No50mIncshelf
- Net temperature transports are all similar within ±5 TW-eq.
- Net interim FW transports differs with ± 30 mSv-eq.





Water mass transformation on T-S space





Tsubouchi et al [2012]

Inflow

$$V_{in} = \iint \delta_{in}(\theta, S)\Pi(\theta, S) dS d\theta$$

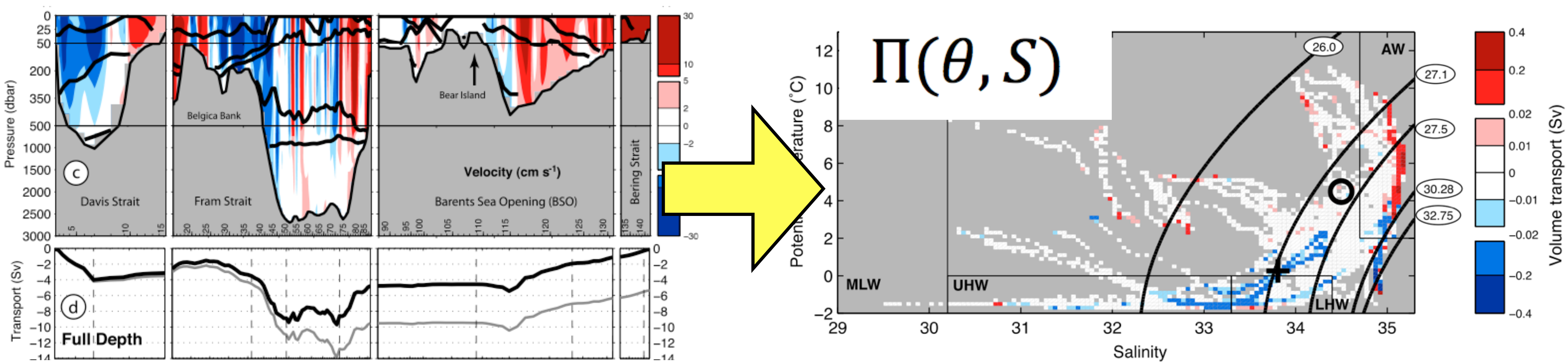
$$\delta_{in}(\theta, S) = 1 \text{ when } \Pi(\theta, S) > 0.$$

$$\delta_{in}(\theta, S) = 0 \text{ when } \Pi(\theta, S) < 0.$$

$$T_{in} = \iint \delta_{in}(\theta, S)\Pi(\theta, S)\theta dS d\theta / V_{in}$$

$$S_{in} = \iint \delta_{in}(\theta, S)\Pi(\theta, S) S dS d\theta / V_{in}$$

Water mass transformation on T-S space



Tsubouchi et al [2012]

Outflow

$$V_{out}^{o} = \iint \delta_{out}(\theta,S)\Pi(\theta,S)dSd\theta$$

$$V_{out}^{i} = \iint_{h_i}^{0} v_i dxdz$$

$$V_{out}^{oi} = V_{out}^{o} + V_{out}^{i}$$

$$\delta_{out}(\theta,S) = 1 \text{ when } \Pi(\theta,S) < 0.$$

$$\delta_{out}(\theta,S) = 0 \text{ when } \Pi(\theta,S) > 0.$$

$$T_{out}^{o} = \iint \delta_{out}(\theta,S)\Pi(\theta,S)\theta dSd\theta / V_{out}^{o}$$

$$T_{out}^{oi} = \left\{\iint \delta_{out}(\theta,S)\Pi(\theta,S)\theta dSd\theta + \frac{\rho_i}{\rho_o}\left(\frac{c_f}{c_p^i} + \theta_i\right)V_{out}^{i}\right\} / (V_{out}^{o} + V_{out}^{i})$$

$$S_{out}^{o} = \iint \delta_{out}(\theta,S)\Pi(\theta,S)SdSd\theta / V_{out}^{o}$$

$$S_{out}^{oi} = \{\iint \delta_{out}(\theta,S)\Pi(\theta,S)SdSd\theta + S_i V_{out}^{i}\} / (V_{out}^{o} + V_{out}^{i})$$

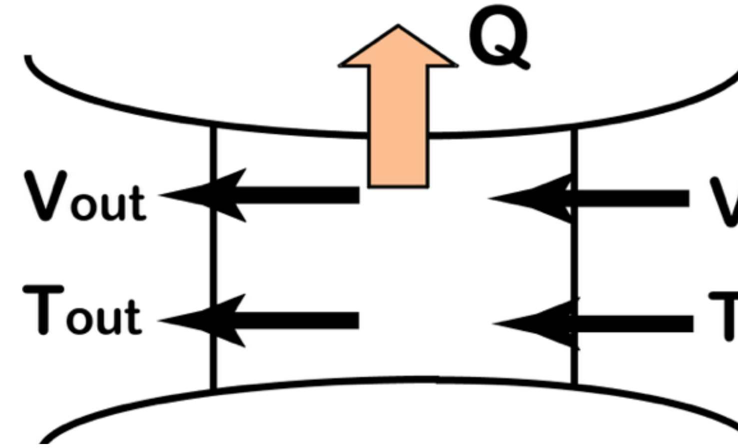
Surface heat flux (Q), FW flux (F)

Volume, heat & salt conservations

$$V_{in} + \mathrm{F} = V_{out}^{oi}$$

$$\rho c_p V_{in} T_{in} + \rho_F c_p^F \mathrm{F} T_F = \rho c_p V_{out}^{oi} T_{out}^{oi} + Q$$

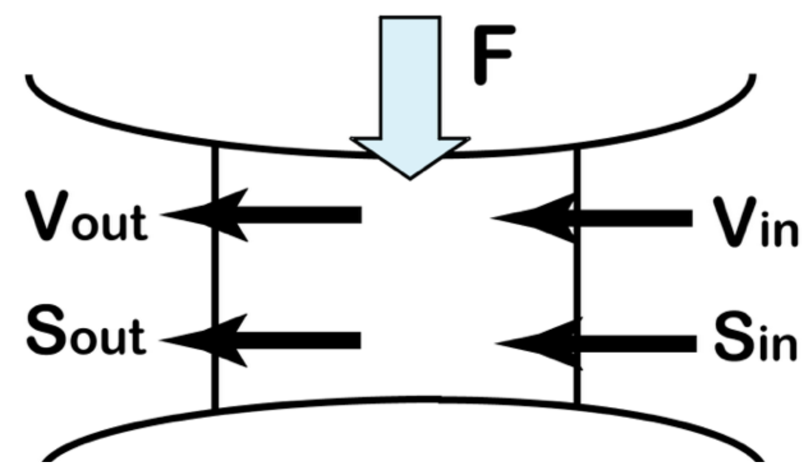
$$V_{in} S_{in} = V_{out}^{oi} S_{out}^{oi}$$



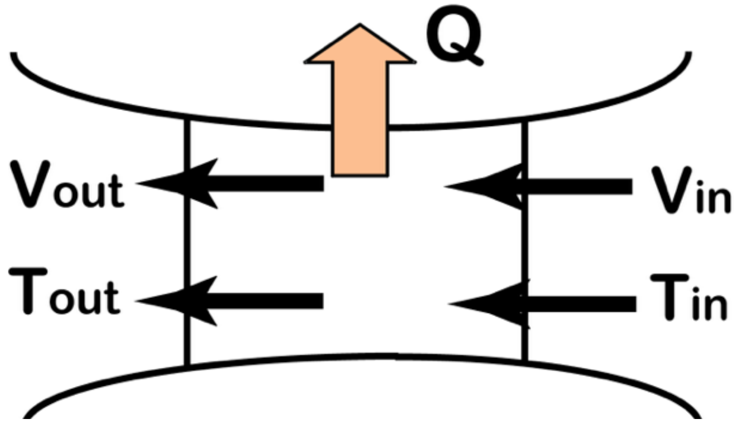
Surface heat flux (Q), FW flux (F)

$$Q = \rho c_p (T_{in} - T_{out}^{oi}) V_{in}$$

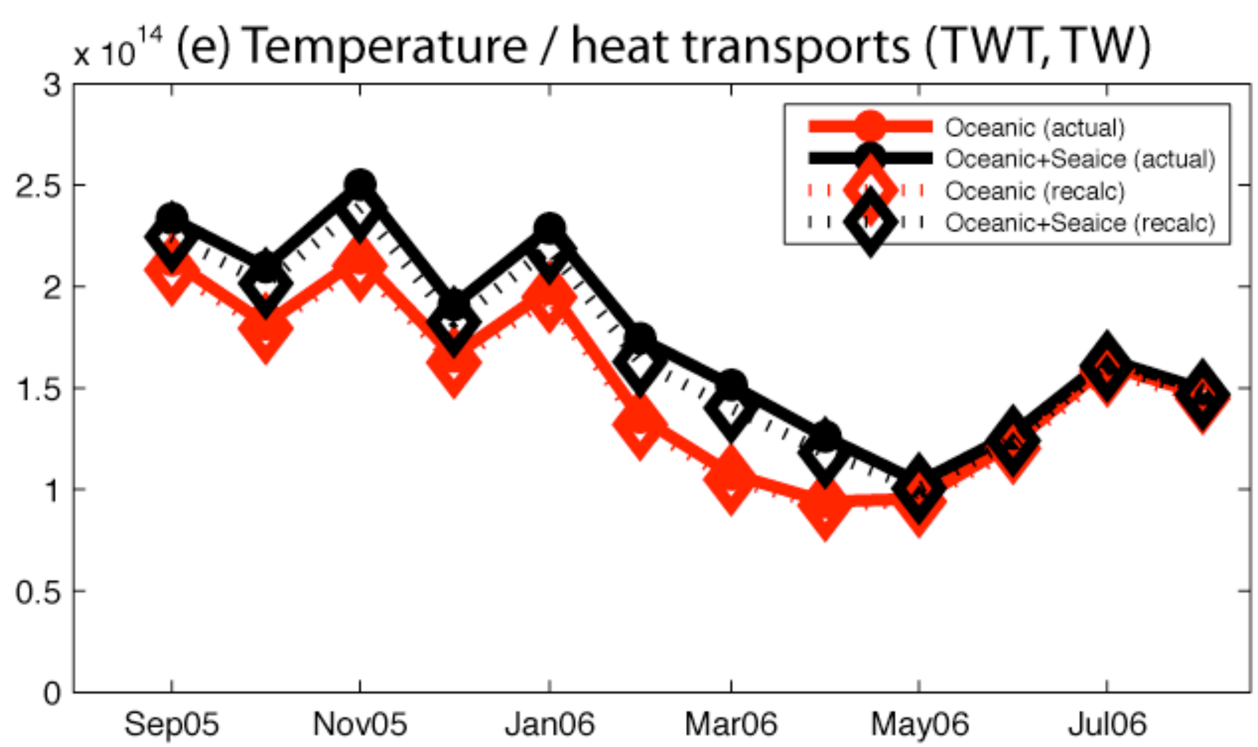
$$F = (S_{in}^{oi} - S_{out}^{oi}) V_{in} / S_{out}^{oi}$$



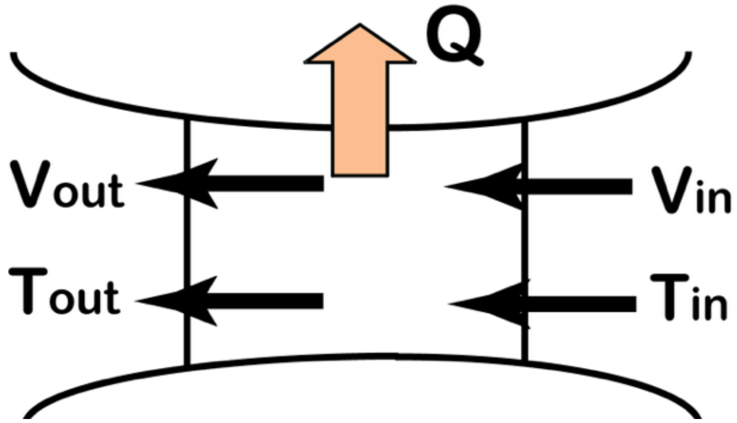
$$Q = \rho c_p (T_{in} - T^{oi}_{out}) V_{in}$$



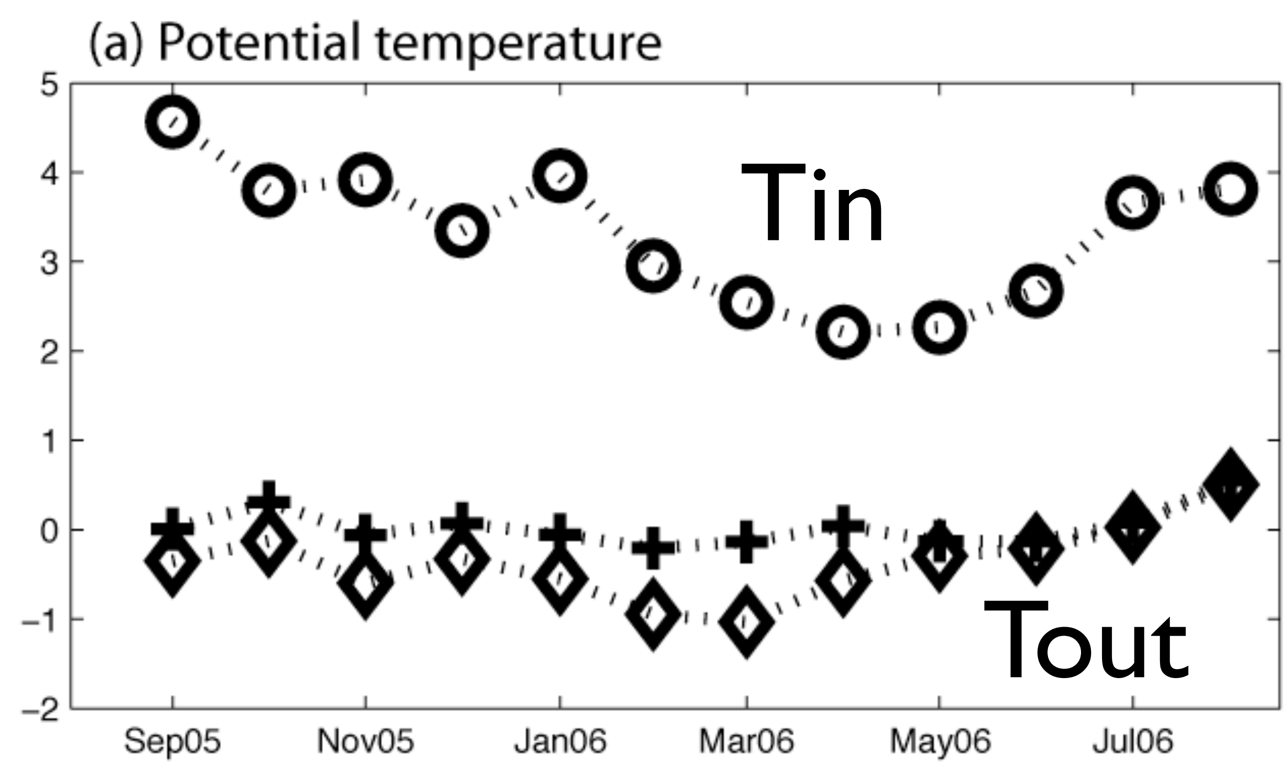
ΔT 5.0 (deg) &12(Sv) ~ 240 (TWT)
ΔT 2.5 (deg) & 9 (Sv) ~ 90 (TWT)

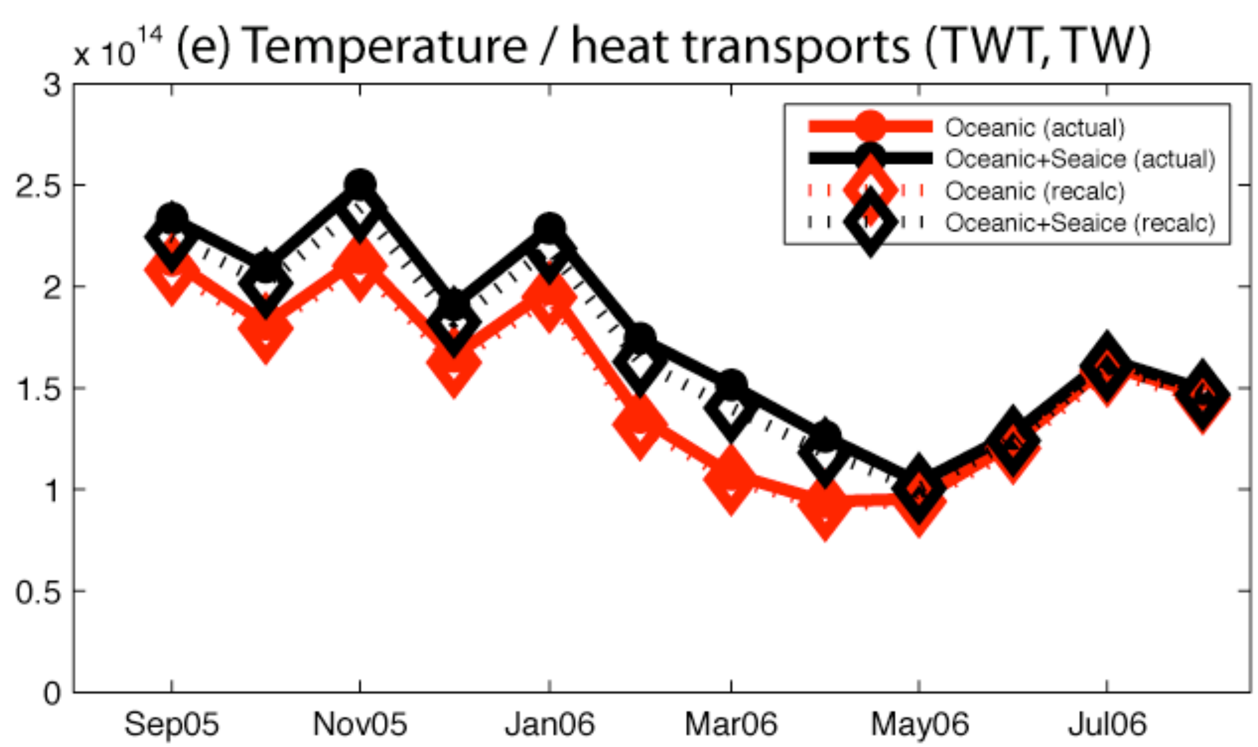


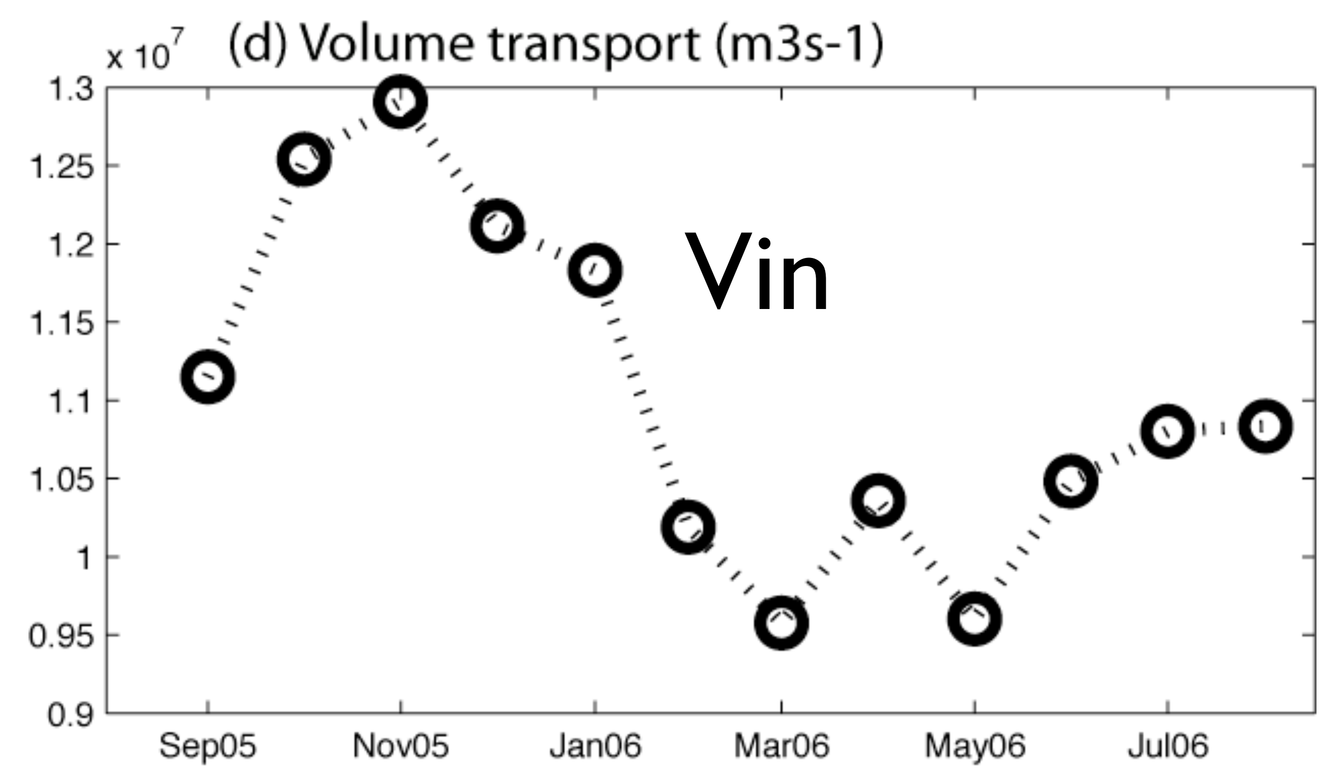
$$Q = \rho c_p (T_{in} - T_{out}^{oi}) V_{in}$$



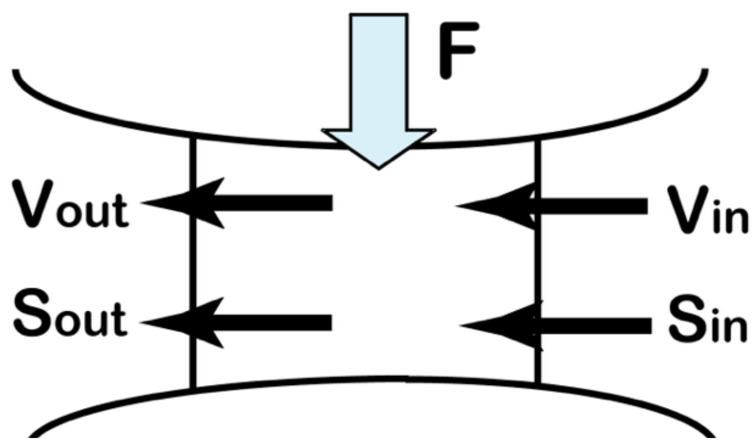
ΔT 5.0 (deg) &12(Sv) ~ 240 (TWT)
ΔT 2.5 (deg) & 9 (Sv) ~ 90 (TWT)



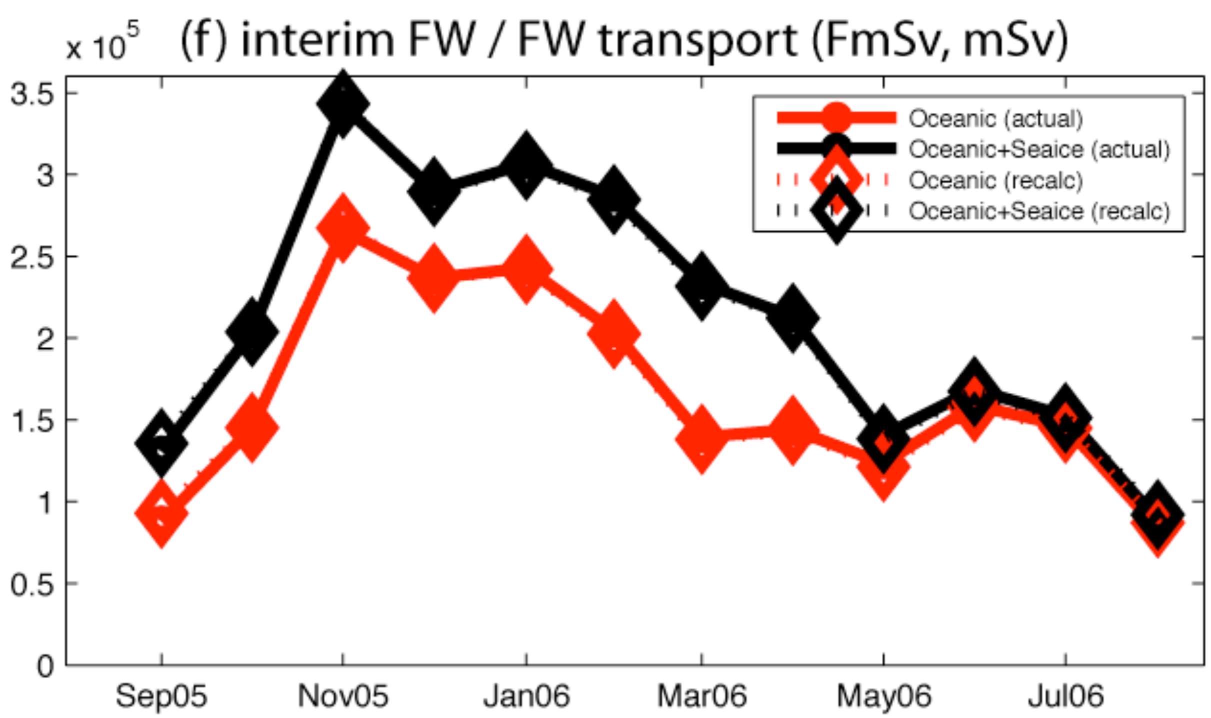




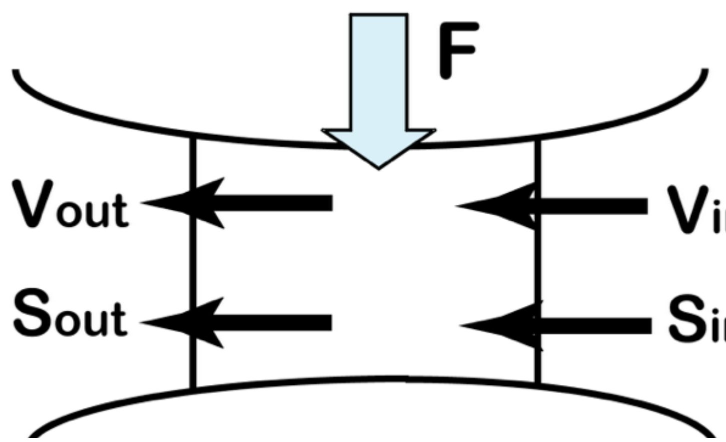
$$F = (S_{in}^{oi} - S_{out}^{oi})V_{in}/S_{out}^{oi}$$



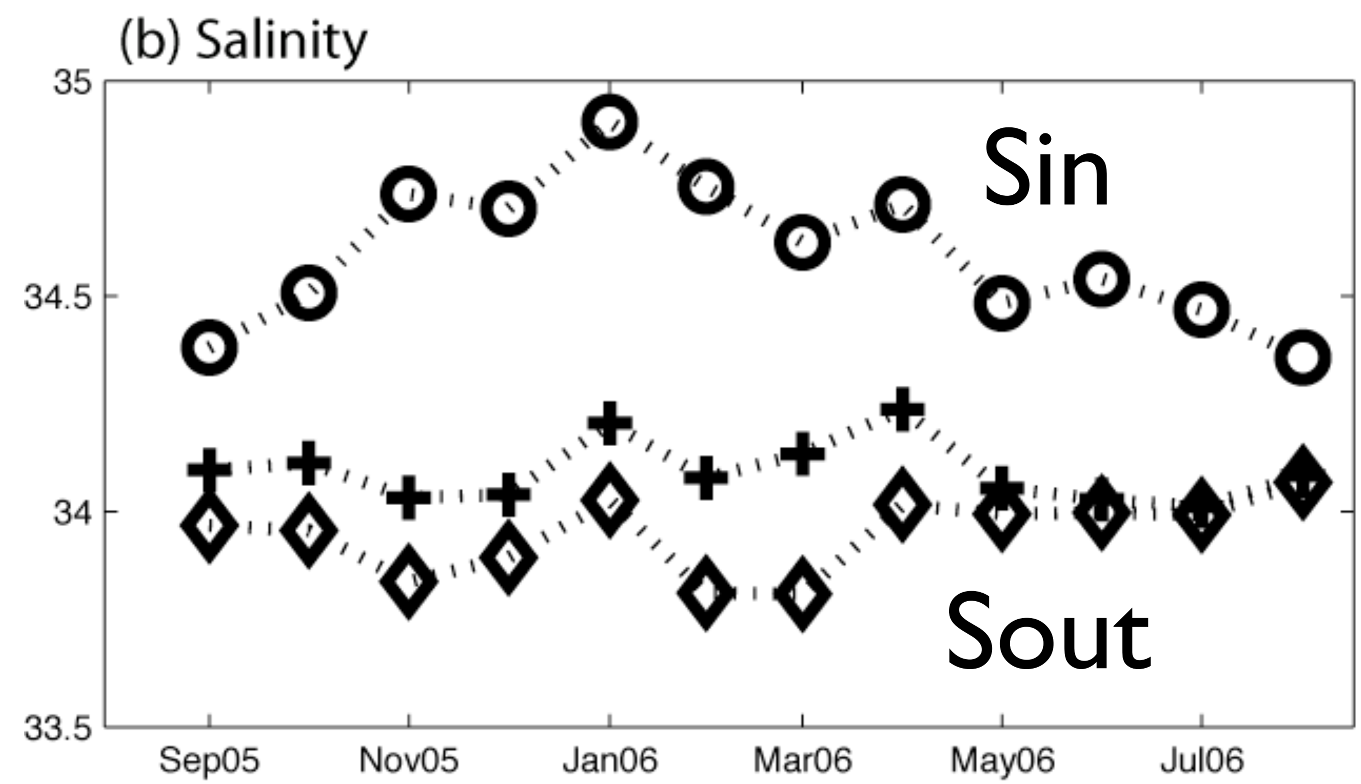
ΔS 1.0 &12(Sv) ~ 352 (FmSv)
ΔS 0.3 & 9 (Sv) ~ 79 (FmSv)

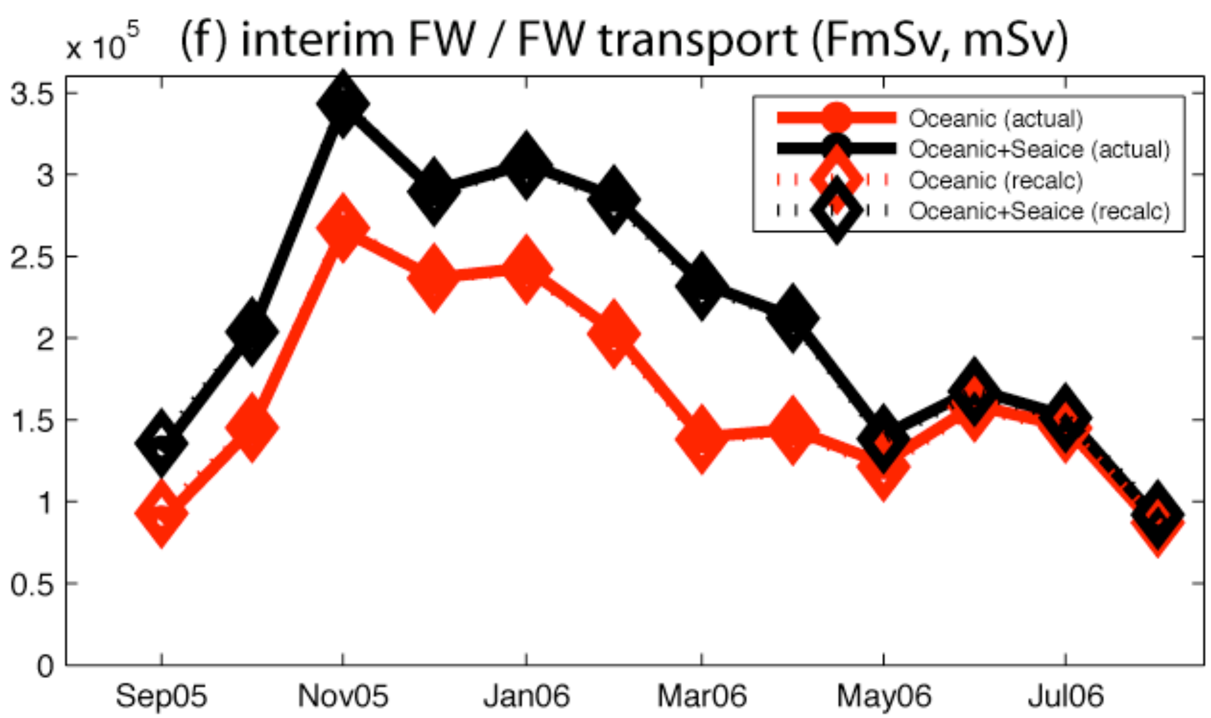


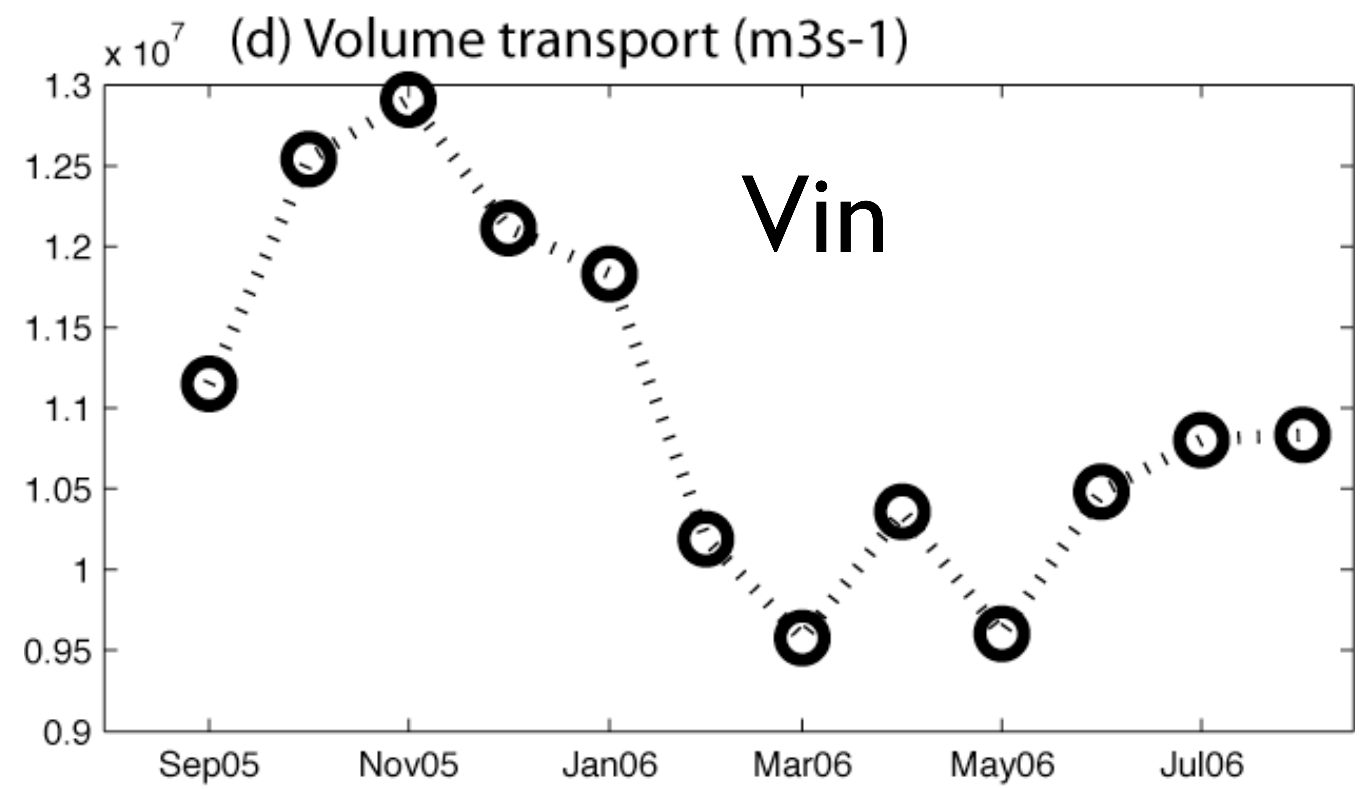
$$F = (S_{in}^{oi} - S_{out}^{oi})V_{in}/S_{out}^{oi}$$



ΔS 1.0 &12(Sv) ~ 352 (FmSv)
ΔS 0.3 & 9 (Sv) ~ 79 (FmSv)

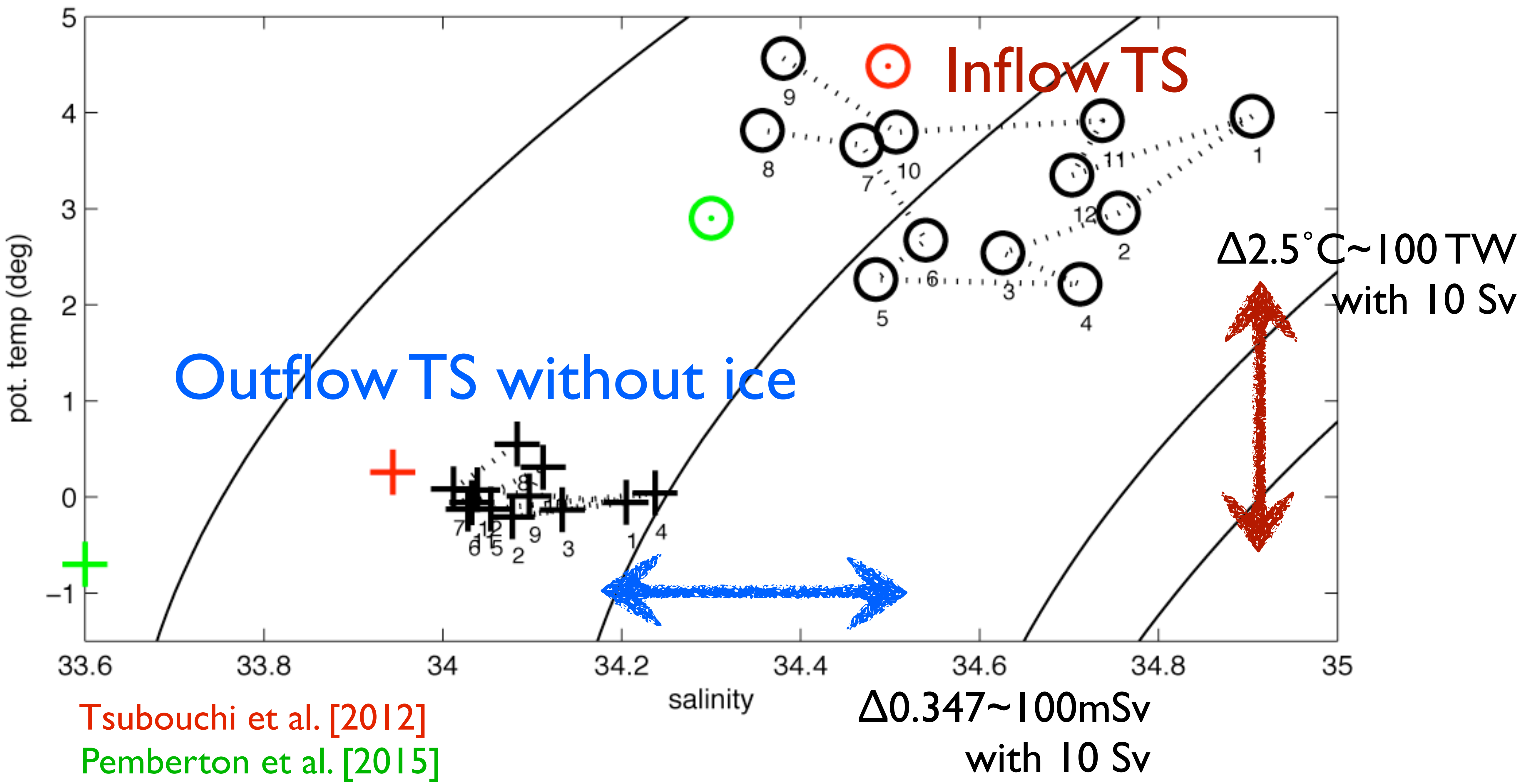






TS volumetric plots

Inflow T&S varies by 2.0 (deg) and 0.5 (psu)
Outflow T constant around 0 (deg).



Volumetric TS diagram

- Inflow: T 3.24, S 34.64, ρ 27.57.
- Outflow: T 0.83, S 34.32, ρ 27.51.
- Difference: T 2.42 decrease, S 0.31decrease, ρ 0.06 decrease.

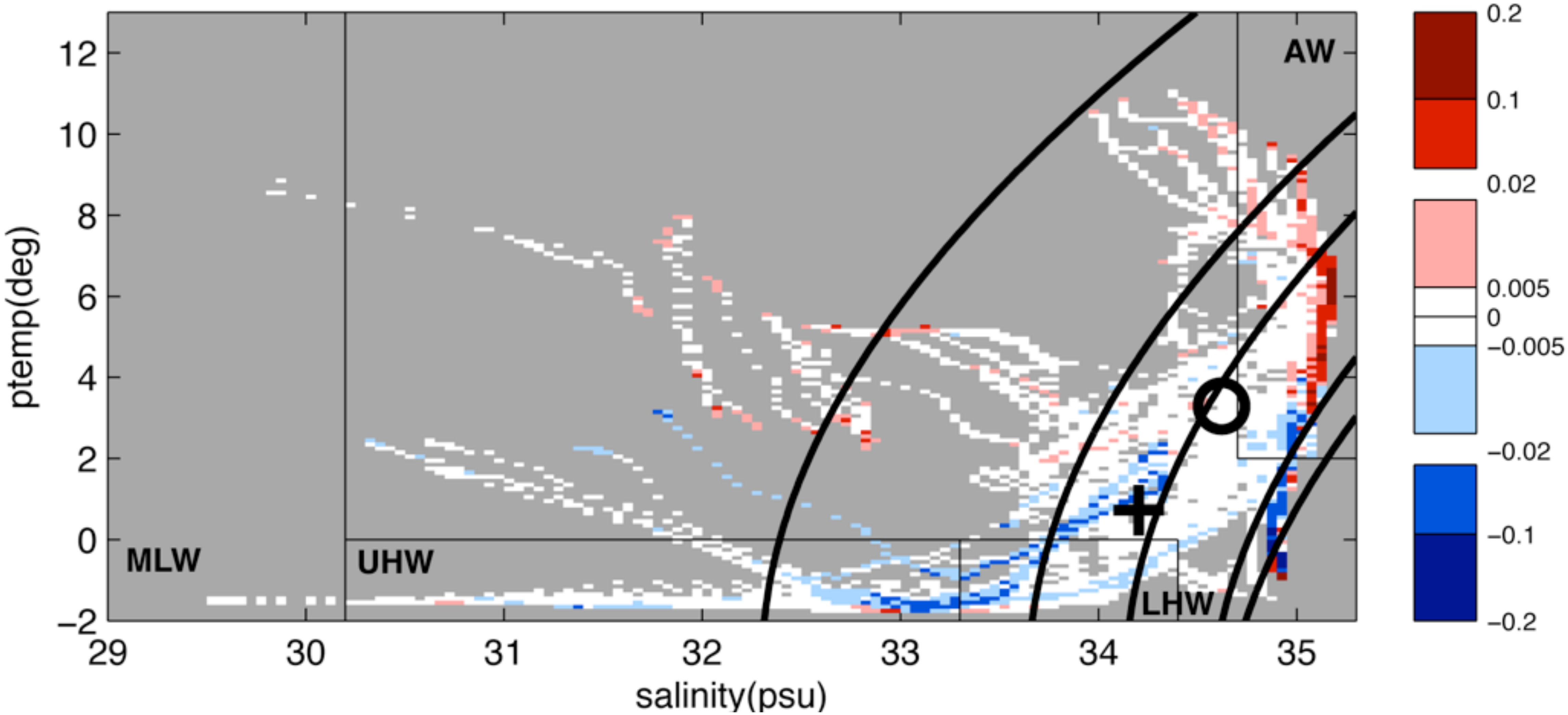


Fig. Net transport (Sv)