NATURAL ENVIRONMENT RESEARCH COUNCIL

National Oceanography Centre, Southampton
UNIVERSITY OF SOUTHAMPTON AND NATURAL ENVIRONMENT RESEARCH COUNCIL

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Seasonal cycle of pan-Arctic volume, heat and FW fluxes during 2005-2006

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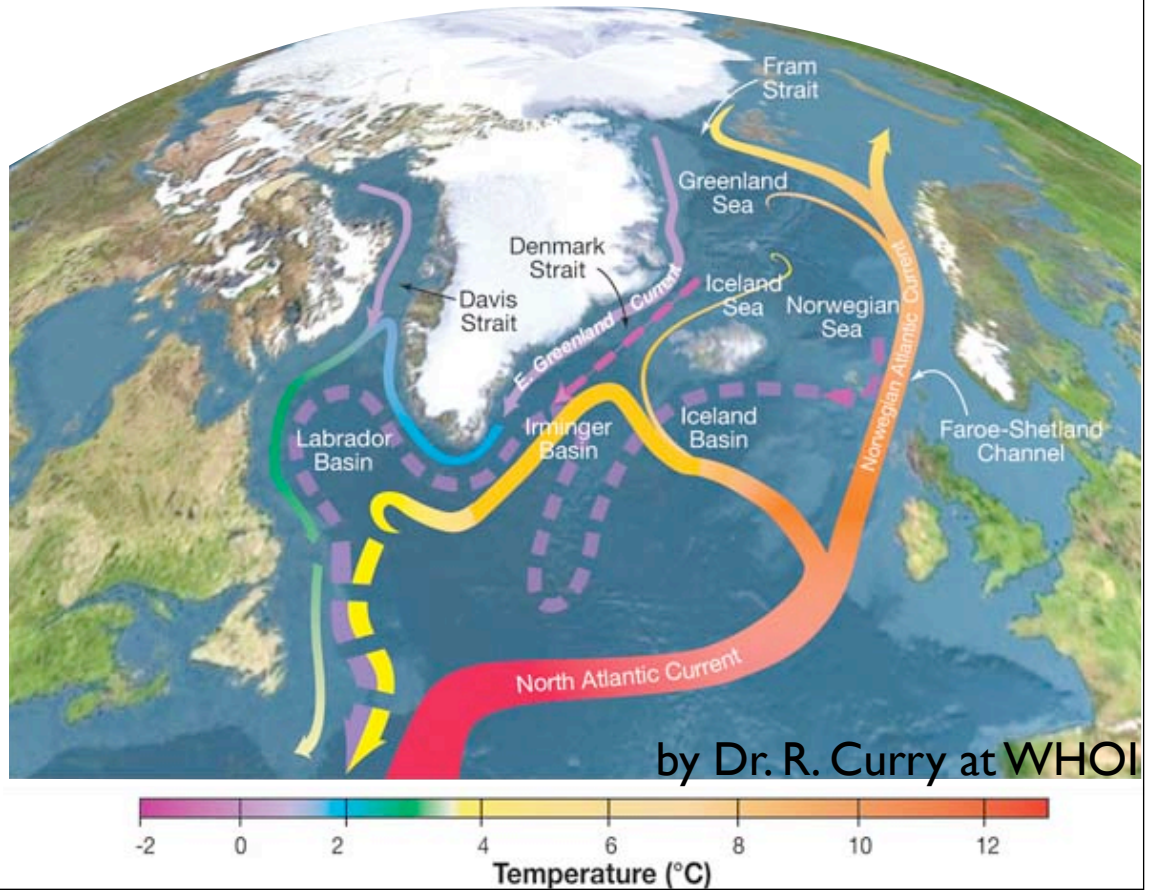

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- Summary

The changing Arctic

- September sea ice extent is decreasing at over 1% per year (Richter-Menge, 2010).
- Greenland ice cap is melting (Velicogna, 2009)
- Temperature is rising (polar amplification; IPCC, 2007).
- Russian river run off is increasing (Shiklomanov and Lammers, 2009).
- FW storage is increasing (McPhee et al., 2009; Rabe et al., 2011).

Arctic boundary observation system

8 years of boundary observation since 2004!

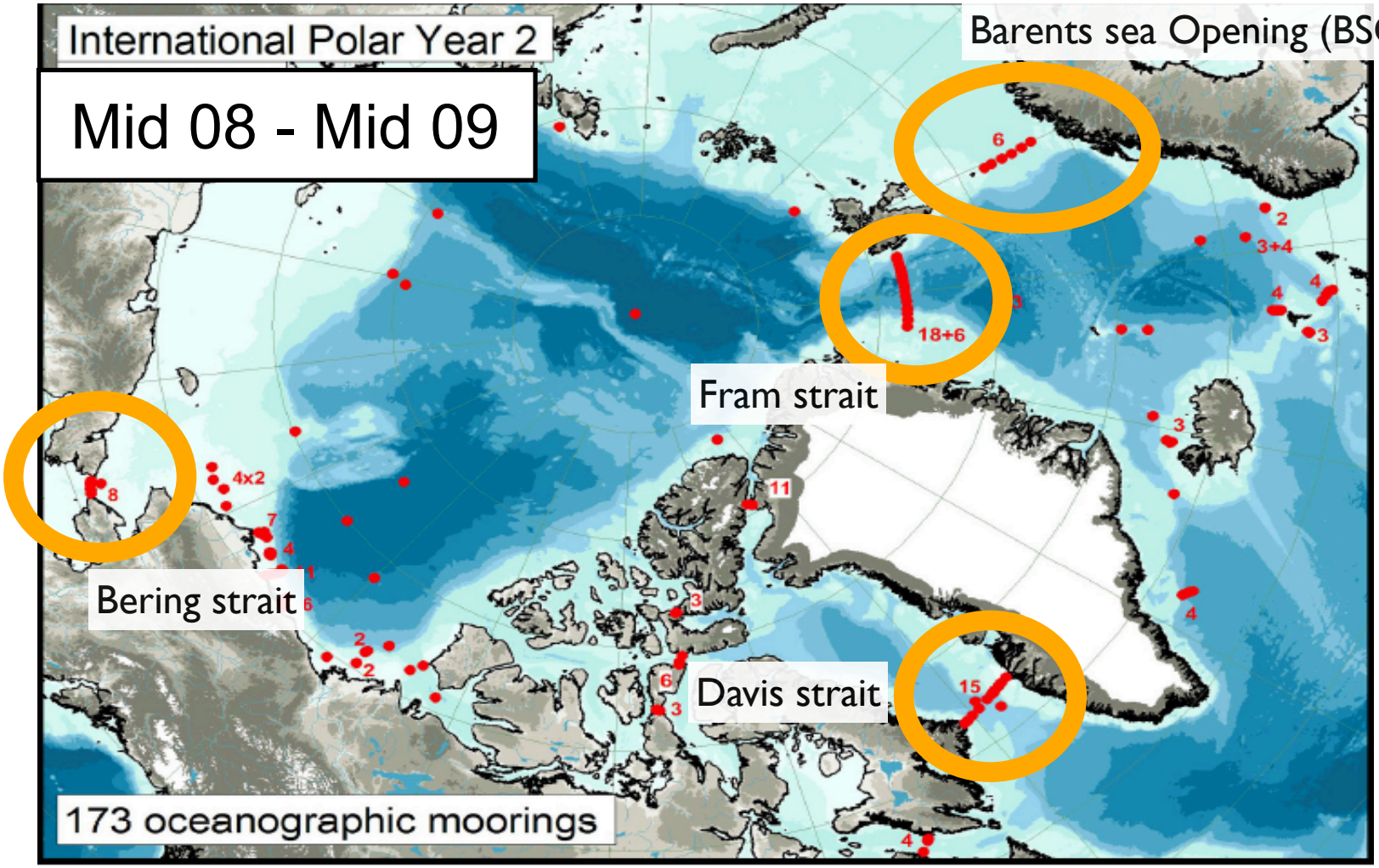


Fig. Mooring array during 2008-09

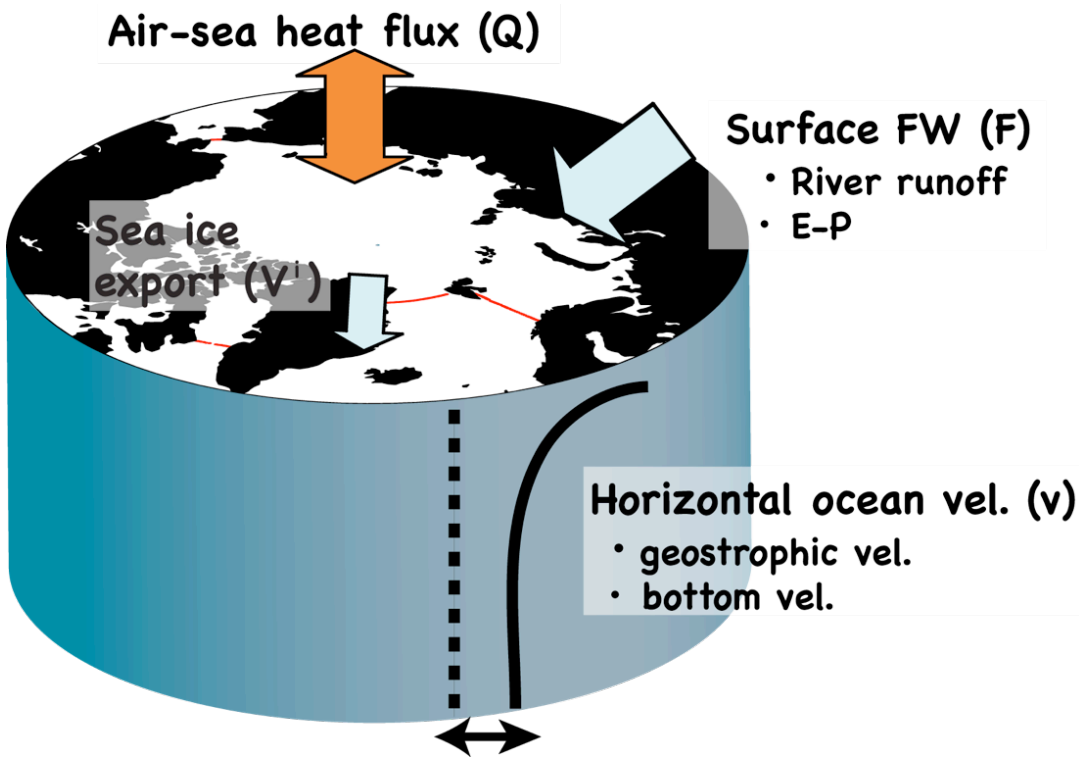
Dickson et al. (2009)

Arctic Ocean Box model

Volume: $\frac{\partial}{\partial t}\iiint dV = \iint_{bot}^{0} v dx dz + V^i + F$

Heat: $\frac{\partial}{\partial t}\iiint \rho c_p \theta dV = \iint_{bot}^{0} \rho c_p \theta v dx dz + \rho^i c_p^i \theta^i V^i + L + Q$

FW: $\frac{\partial}{\partial t}\iiint \frac{S\prime}{\bar{S}} dV = \iint_{bot}^{0} \frac{S\prime v dx dz}{\bar{S}} + \frac{S\prime^i V^i}{\bar{S}} + F$



Quasi-synoptic fluxes in summer 2005

Volume: $\frac{\partial}{\partial t}\iiint dV = \iint_{bot}^{0} v dx dz + V^i + F$

Heat: $\frac{\partial}{\partial t}\iiint \rho c_p \theta dV = \iint_{bot}^{0} \rho c_p \theta v dx dz + \rho^i c_p^i \theta^i V^i + L + Q$

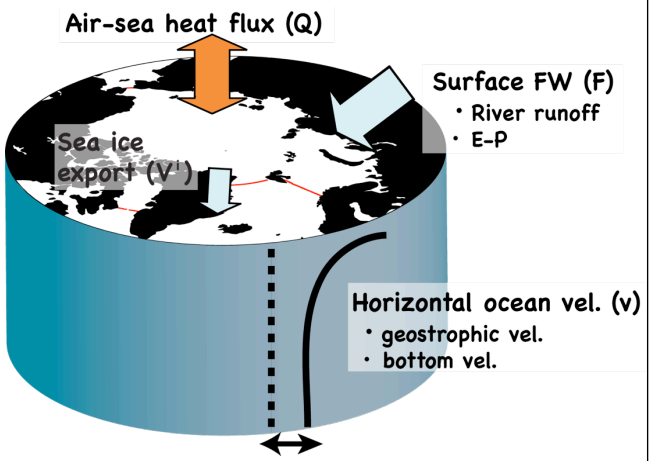
FW: $\frac{\partial}{\partial t}\iiint \frac{S'}{\bar{S}} dV = \iint_{bot}^{0} \frac{S' v dx dz}{\bar{S}} + \frac{S'^i V^i}{\bar{S}} + F$

zero

CTD&mooring

estimate

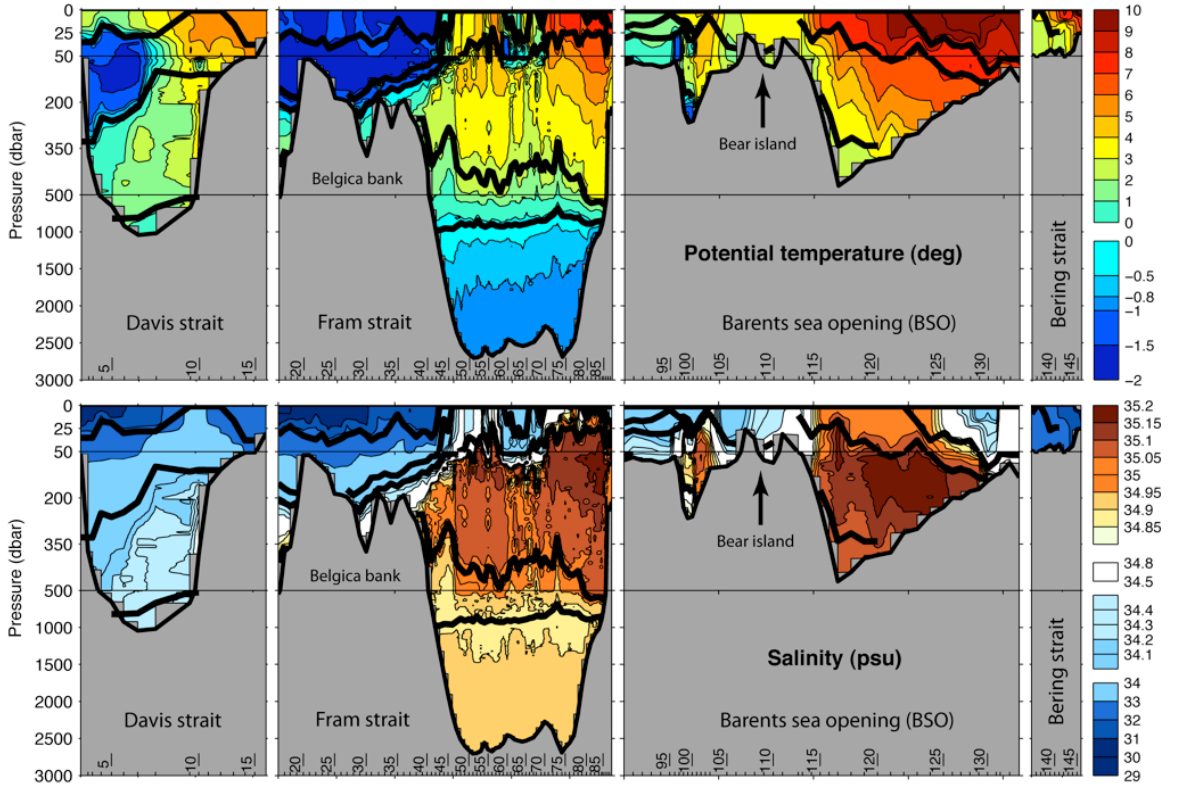
satellite



All data in 32 days!

- Net heat flux (Q): 189±37 TW (inc. sea ice)
- Net FW flux (F): 187±48 mSv (inc. sea ice)

Tsubouchi et al. [2012, JGR]

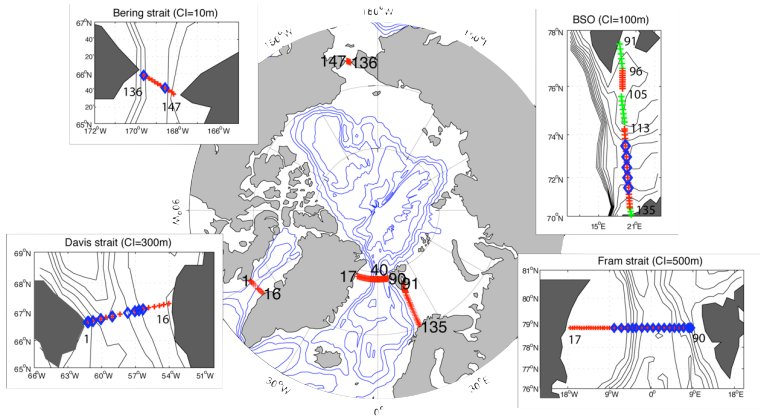


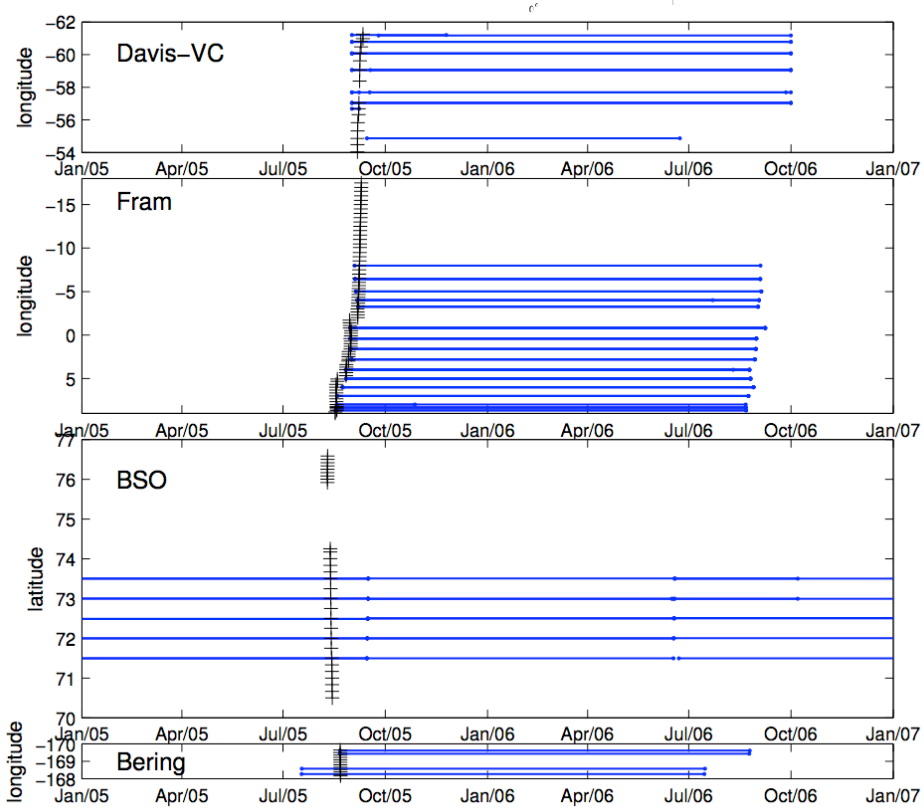
Objective of this study

"observation based" seasonal cycle of oceanic volume, heat, FW fluxes during 2005-06

Pan-Arctic mooring

- Data period: 05 Sep 2005 - 26 Aug 2006
- 135 moored instruments: 47 SBE, 74 RCM, 14 ADCP
- Sampling Rate (SR): 20-180 minutes
- Data sharing agreement with
  - Davis: Craig Lee (UW)
  - Fram west: Edmond Hansen (NPI)
  - Fram east: Eberhard Fahrbach (AWI)
  - BSO: Randi Ingvaldsen (IMR)





Pan-Arctic mooring location

- 135 instruments: 47 microCAT (T, S: blue), 74 RCM (T, (S), V: red), 14 ADCP (V: green)
- Quality of salinity obs. in AW (RCM) is relatively poor

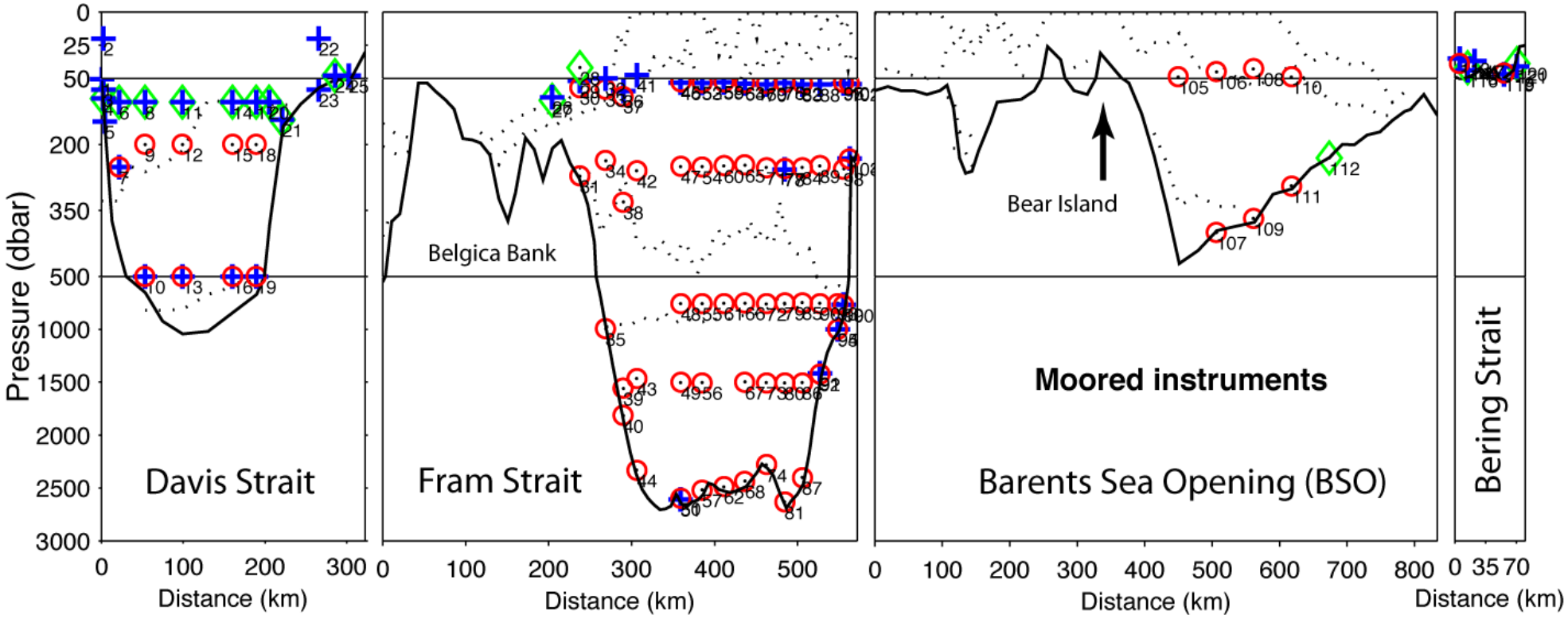


Fig. Mooring array in the Arctic four main gates

Method (1/2): filtering

(1) Tide killer filter: 11th butterworth. cut off freq. is 79.16 hours

(2) Gaussian filter: 10 days e-folding scale. Original SR -> 5 days time step.

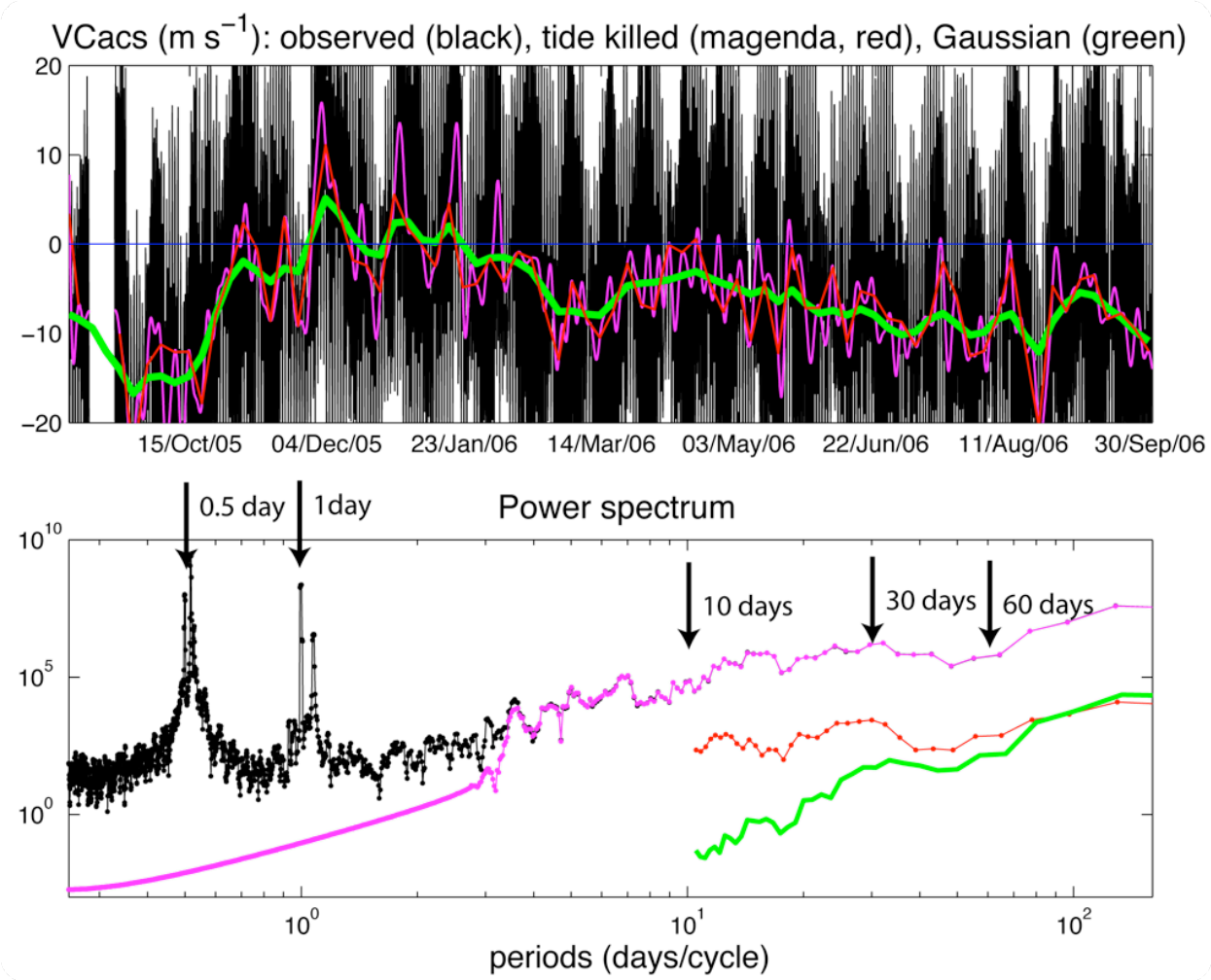
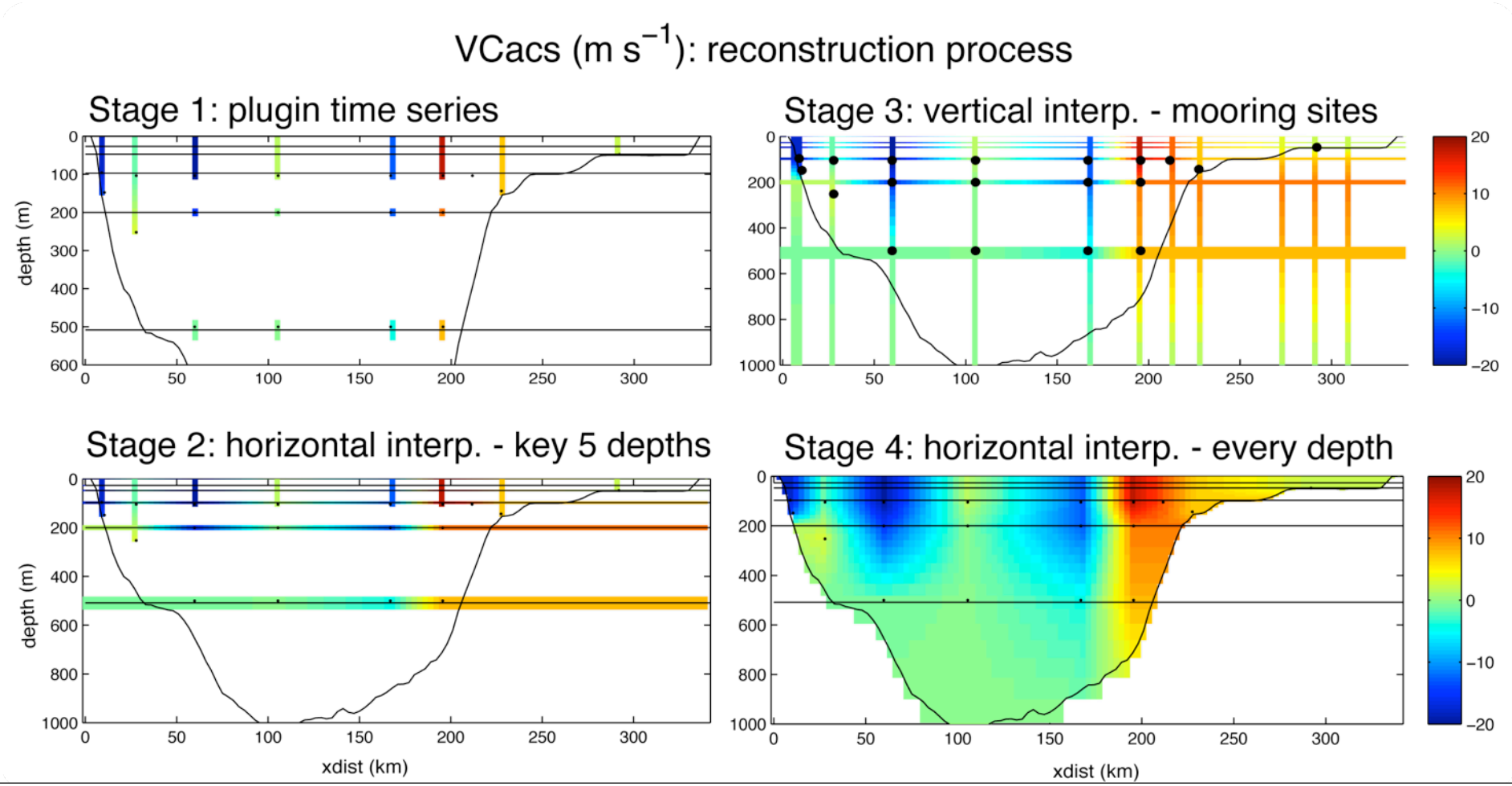


Fig. Cross-sectional Velocity at 200m at C2 mooring site.

Method (2/2): gridding

- Grid: 3km, 75 level layer, 5 days time step
- Above shallowest instrument - No stratification (T, S, V)



Some caveats of reconstruction

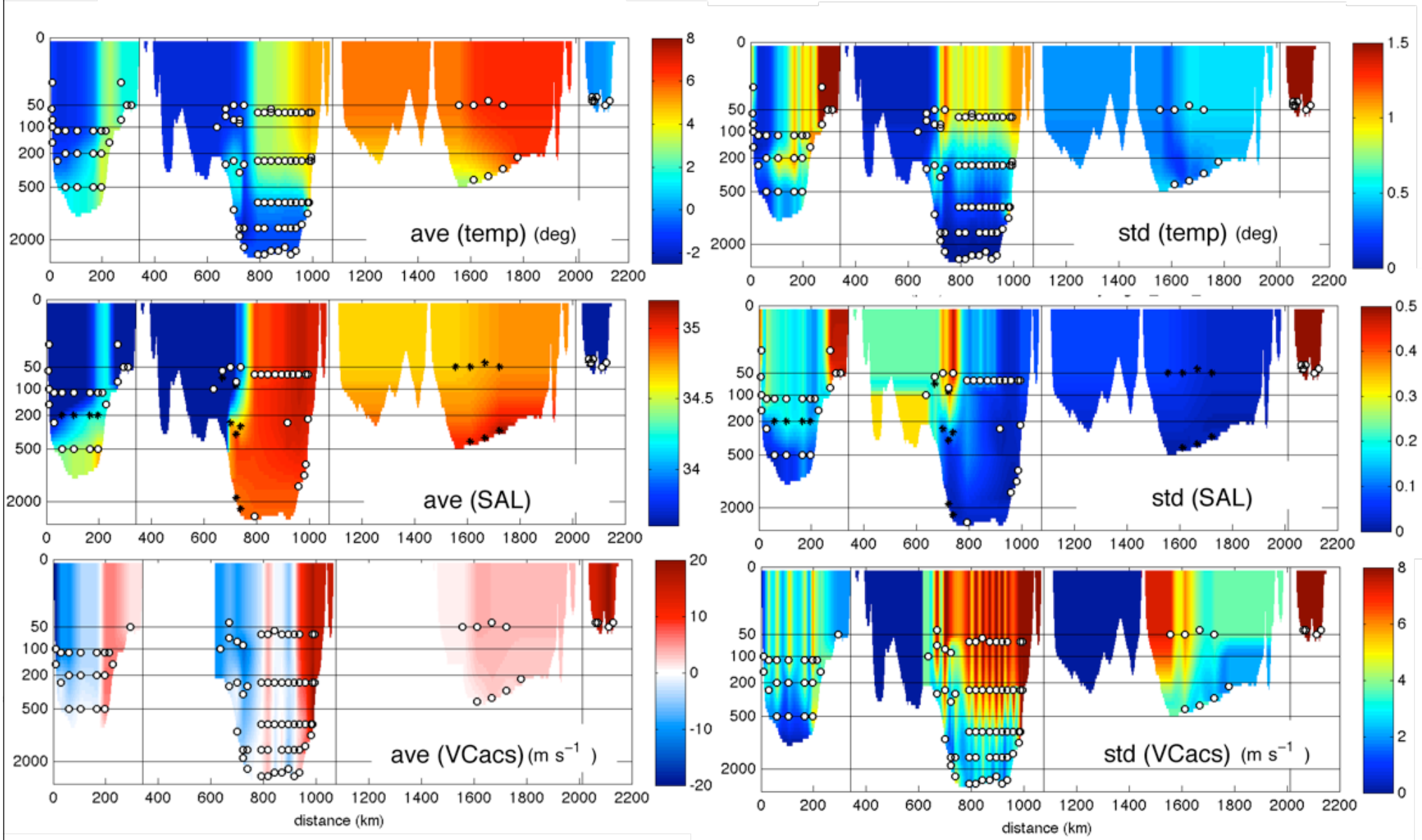
Facts

- No observation in upper 50 m
- No observation over Belgica Bank in Fram Strait and North of Bear island in Barents Sea Opening (BSO)
- Few SBE (good) salinity measurements in AW
- BSO mooring data is up to Jun 2006 at the moment

Treatments

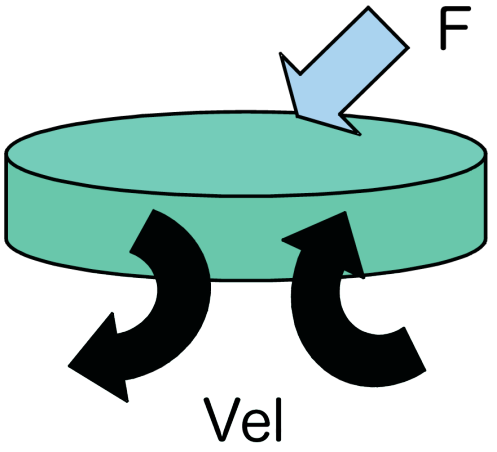
- Assume no stratification above shallowest instrument
- Put zero velocity over Belgica Bank and North of Bear island
- Be careful to interpret FW transport

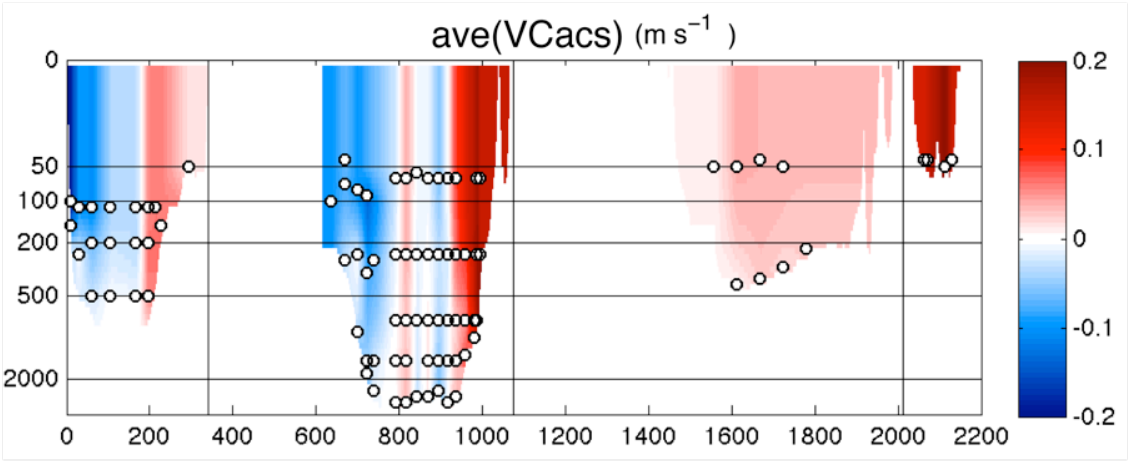
pan-Arctic T, S, V fields



pan-Arctic volume transports

$$\frac{\partial}{\partial t}\iiint dV = \iint_{bot}^{0} v dx dz + V^i + F$$





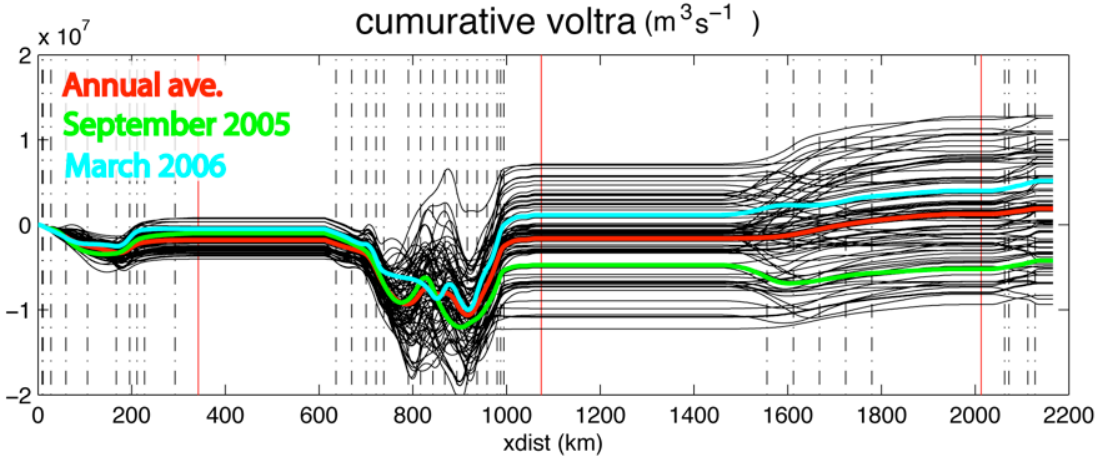


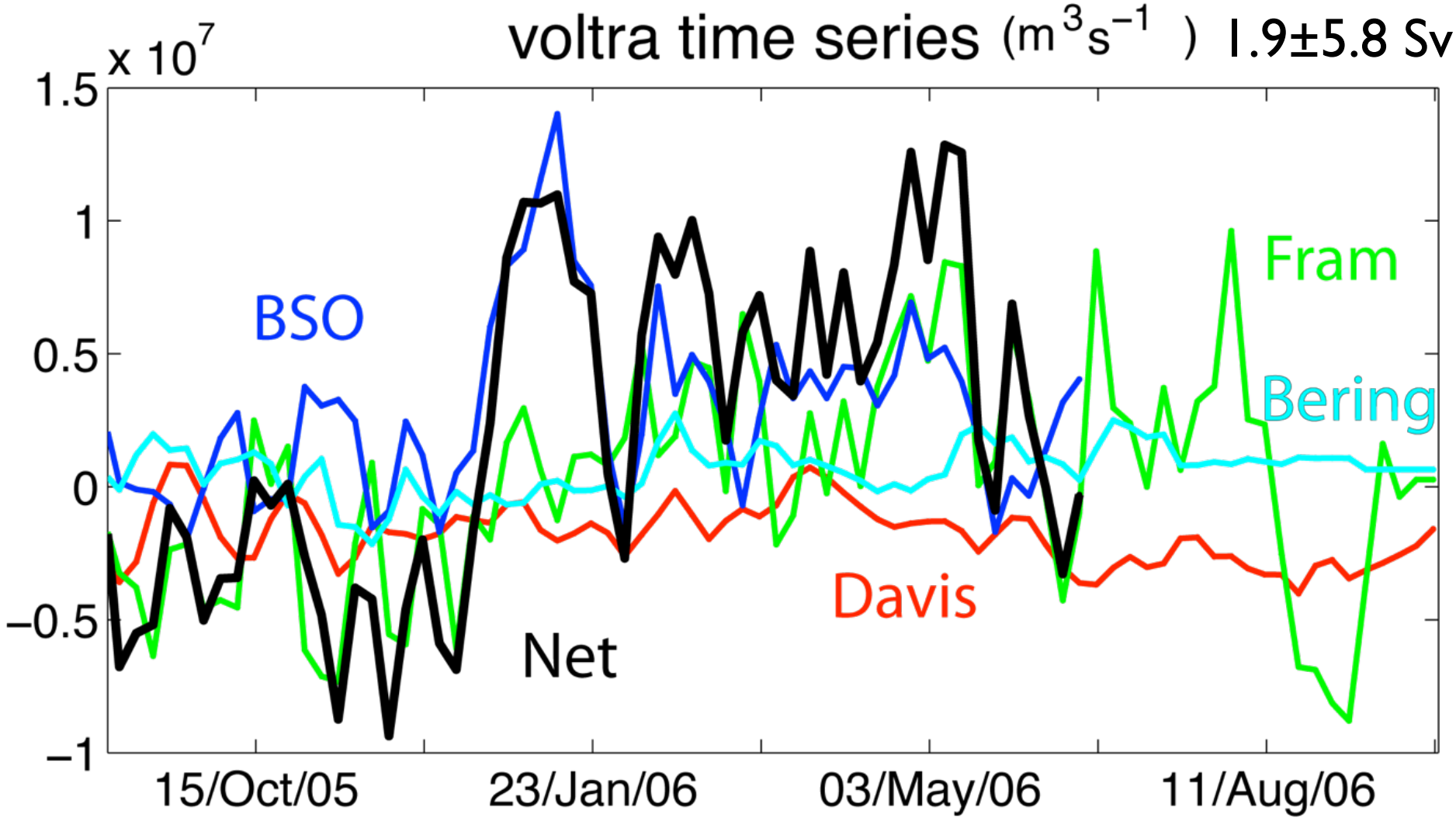
Table: pan-Arctic volume transport compared with previous estimates

	This study	reference
Davis	-1.8±1.1	-2.4±0.7(*1)
Fram	0.2±4.2	-2.0±2.7 (*2)
BSO	2.9±2.9	2.0 (*3)
Bering	0.7±0.9	0.8 (*4)
Net	1.9±5.8	-1.6

*1 Curry et al., 2011, *2 Schauer et al., 2008, *3 Smerdsrud et al., 2010, *4 Woodgatate et al., 2005

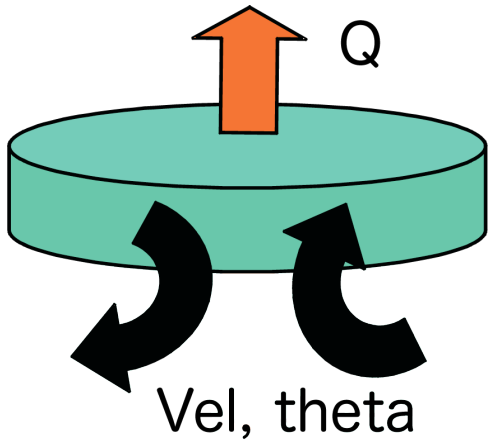
pan-Arctic Volume flux time series

- Net volume flux is dominated by Fram and BSO

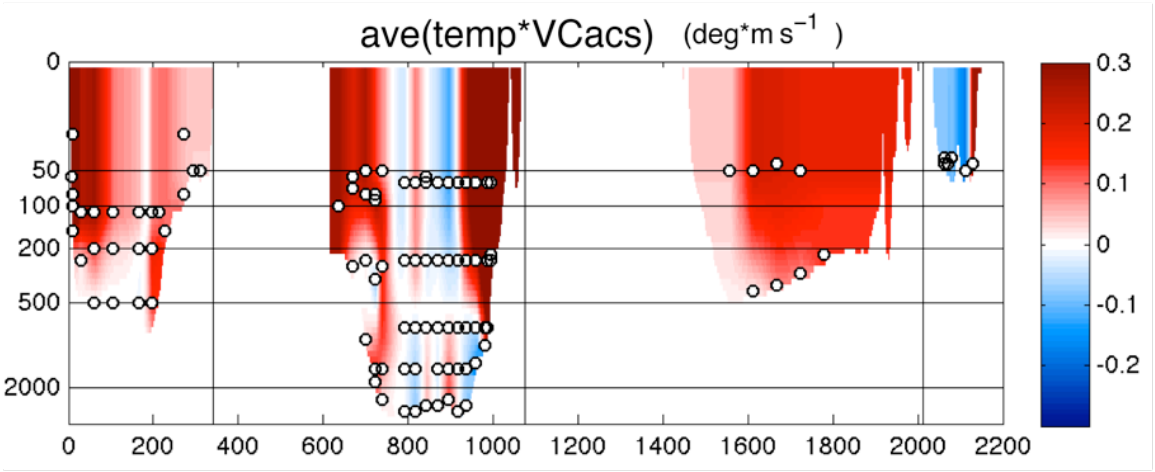


"Tentative" temperature transports

$$\frac{\partial}{\partial t}\iiint \rho c_p \theta dV = \iint_{bot}^{0} \rho c_p \theta v dx dz + \rho^i c_p^i \theta^i V^i + L + Q$$



Reference theta = 1.159°C



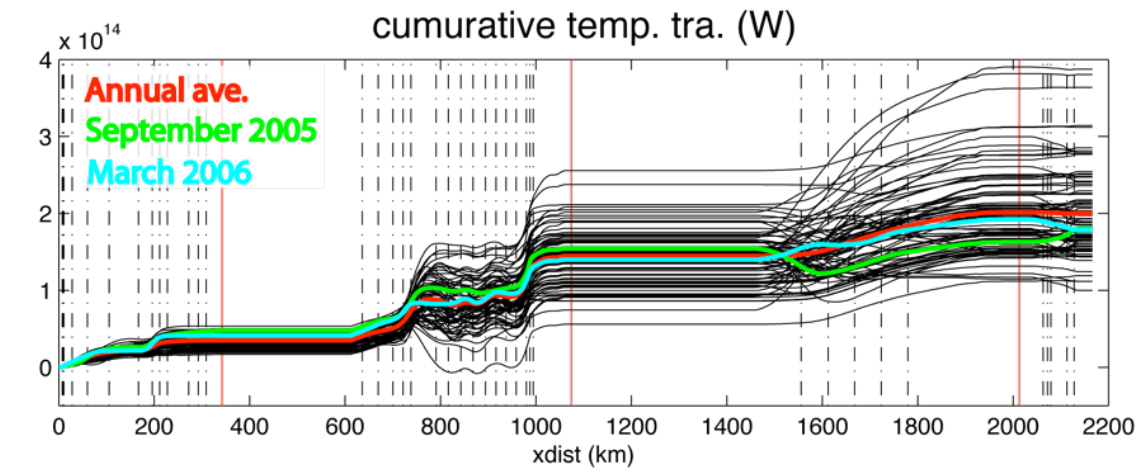


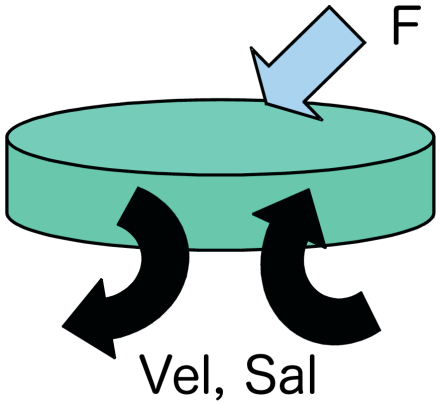
Table: pan-Arctic oceanic temperature transport compared with previous estimates

	This study	reference
Davis	35±9	28±3
Fram	109±36	43±17
BSO	57±50	86±19
Bering	-1±11	13±2
Net	201±59	189±26

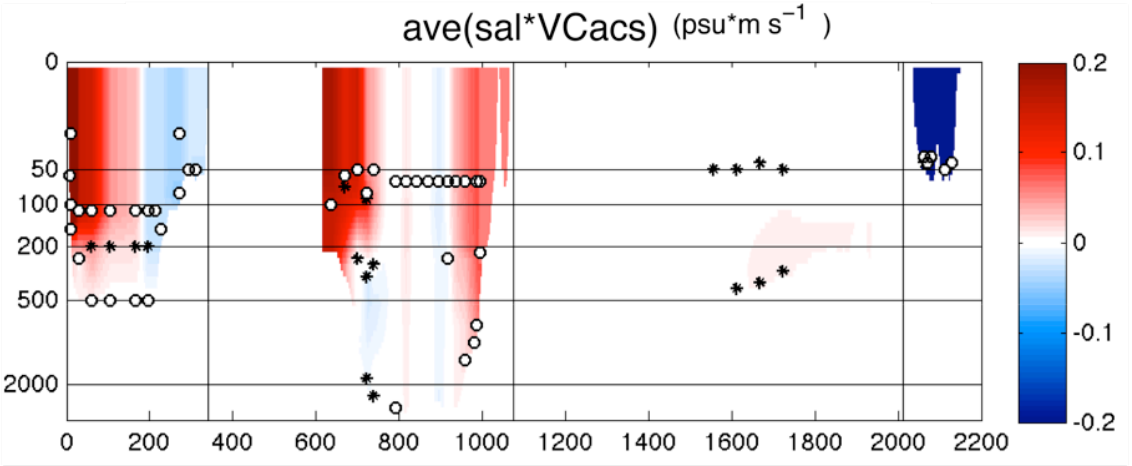
Reference: Tsucbouchi et al. [2012]

"TENTATIVE" FW transports

$$\frac{\partial}{\partial t}\iiint \frac{S\prime}{\bar{S}}\,dV = \iint_{bot}^{0} \frac{S\prime v\,dx\,dz}{\bar{S}} + \frac{S\prime^{i}V^{i}}{\bar{S}} + F$$



Reference salinity = 34.662



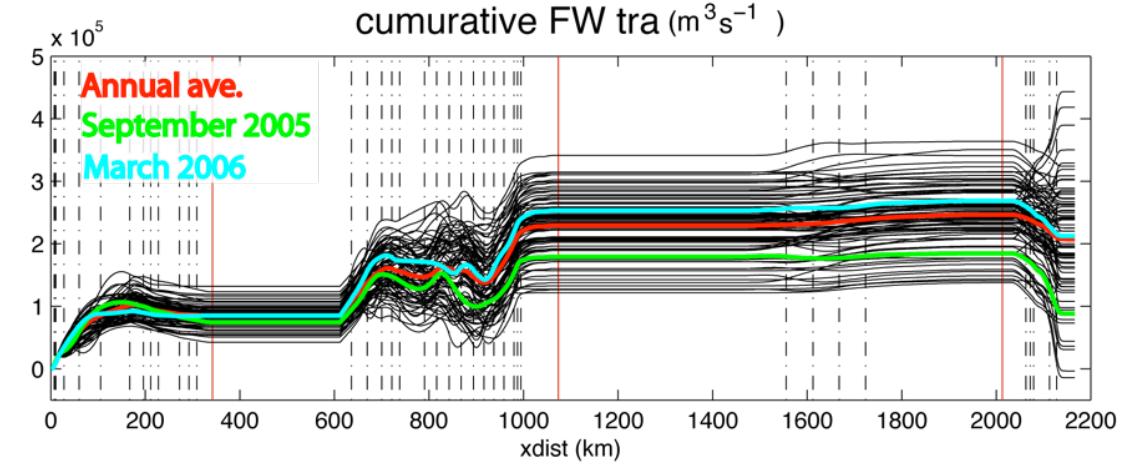


Table: pan-Arctic oceanic FW transport compared with previous estimates

	This study	reference
Davis	85±17	72-130
Fram	144±45	65-95
BSO	17±15	8
Bering	-39±71	-76
Net	208±89	69-157

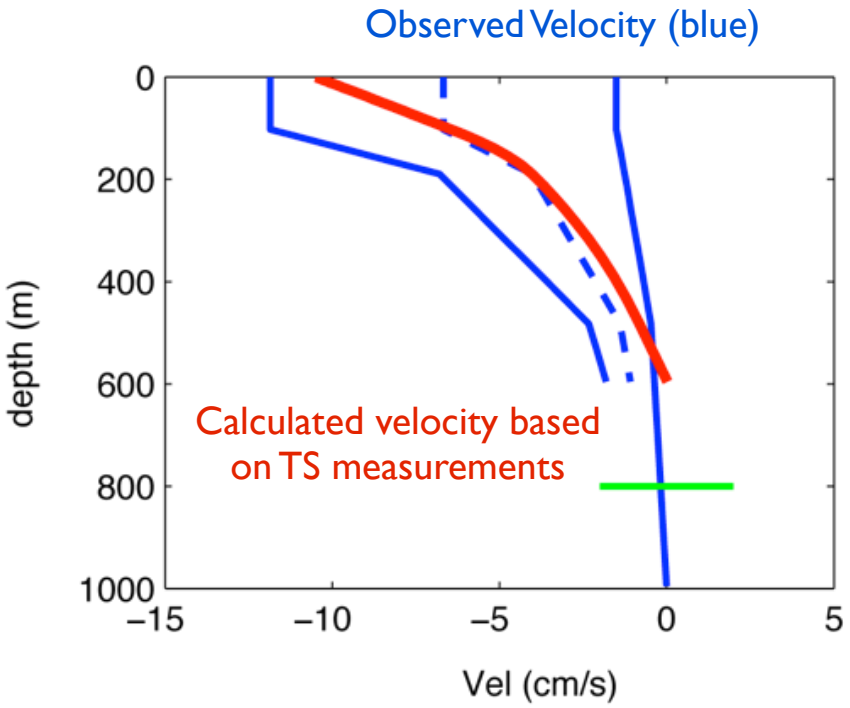
Reference: Dickson et al. [2007]

Reconstruction of Salinity

- We are able to estimate salinity using thermal wind relations

$$f\frac{\partial v}{\partial z} = g\alpha\frac{\partial T}{\partial x} - g\beta\frac{\partial S}{\partial x}$$

observed observed estimate



Figs: observed velocity (blue) and calculated velocity (red) in Davis Strait.

Future work

(1) Volume & salt conserved monthly velocity field

- include sea ice export
- apply inverse model to satisfy volume and salt conservation

(2) Monthly heat and FW flux time series

- reconstruct salinity using thermal wind relation
- upper 50m T&S stratification

(3) Assess reconstruction scheme using NEMO 1/12 output

- deploy virtual array and sub-sample NEMO TSV field
- apply same reconstruction schme

Summary

- Objective "observation based" full annual pan-Arctic boundary fluxes during 2005-06
- Net volume transport is 1.9±5.8 (Sv)
- "*Tentative*" temperature tra. is 201±59 (TW), FW tra. is 207±89 (mSv)
- More work are needed to finalise the results.

Acknowledgement

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- Dr. Edmond Hansen (NPI)
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- Dr. Randi Ingvaldsen (IMR)
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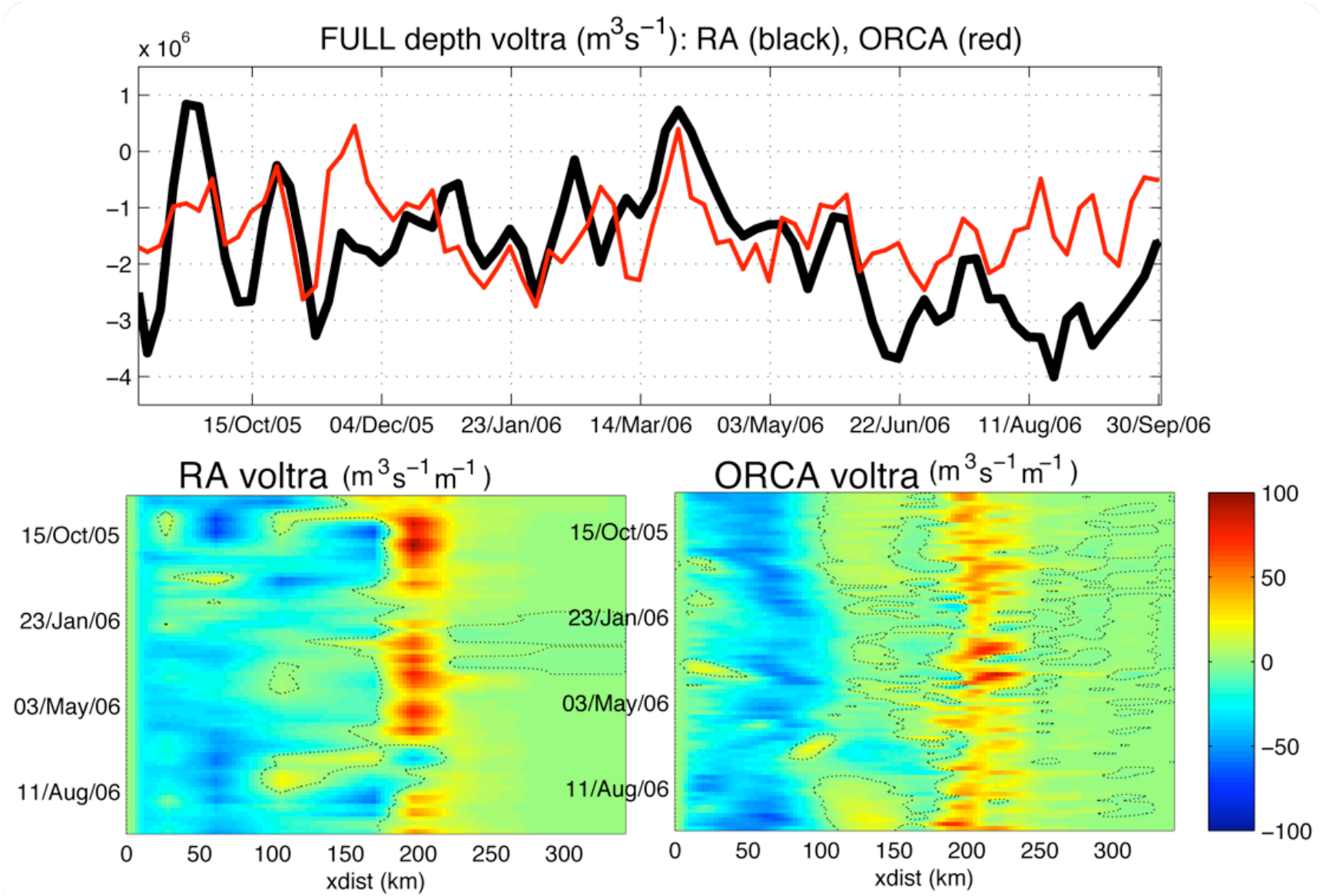
- Dr. Yevgeny Aksenov (NOCS)
- Mr. Stephen Fawcett (Uni. Southampton)

by Michio Hoshino

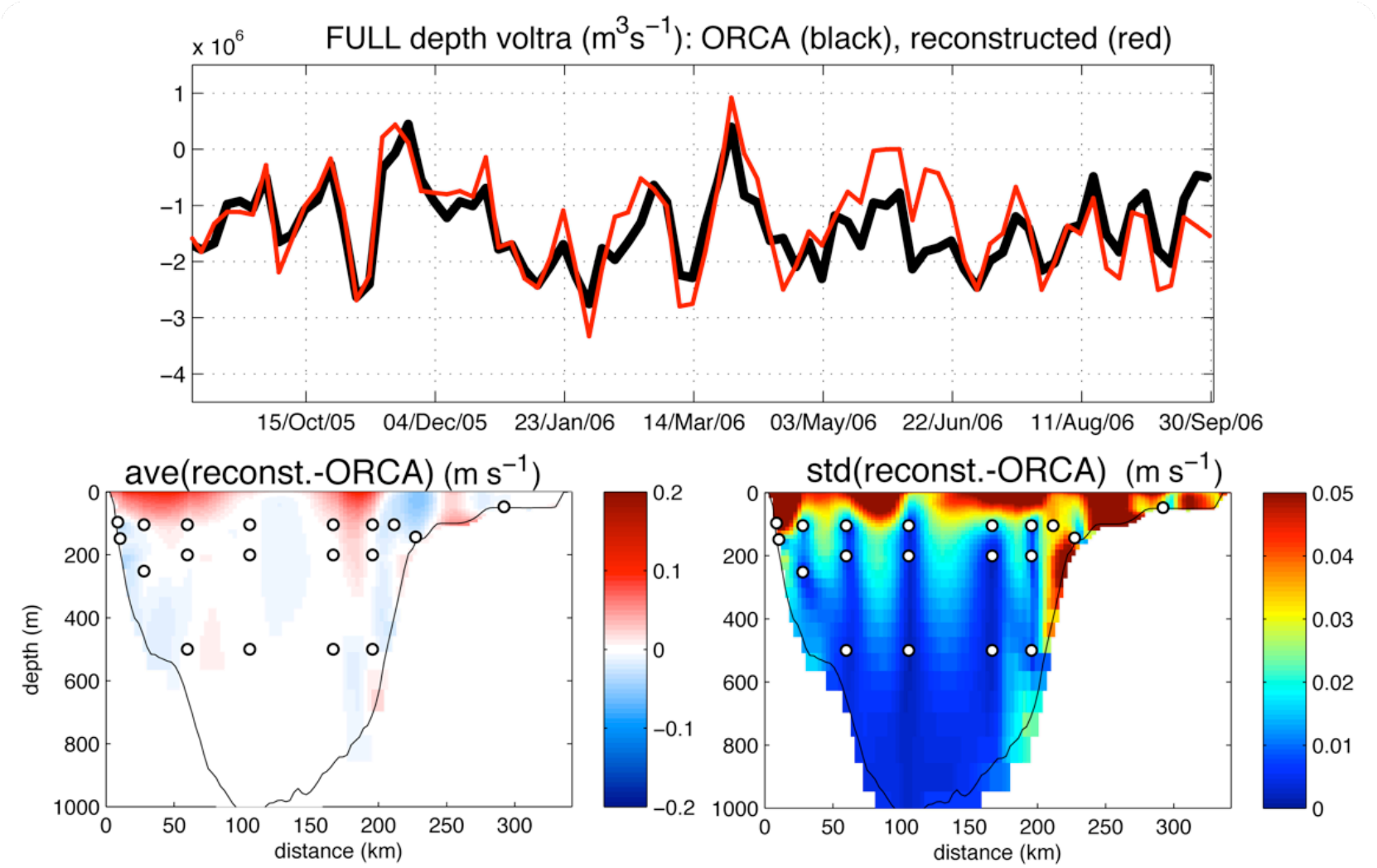
RA vs NEMO 1/12

- NEMO 1/12 produces similar velocity variability



Assessment of the reconstruction scheme

- Virtual array captures most of variability in NEMO 1/12
  - Difference: -0.10±0.49 (Sv).



Assessment of upper 50m Vel & Sal stratification

- Western part (0-100km) stratification is the most important.

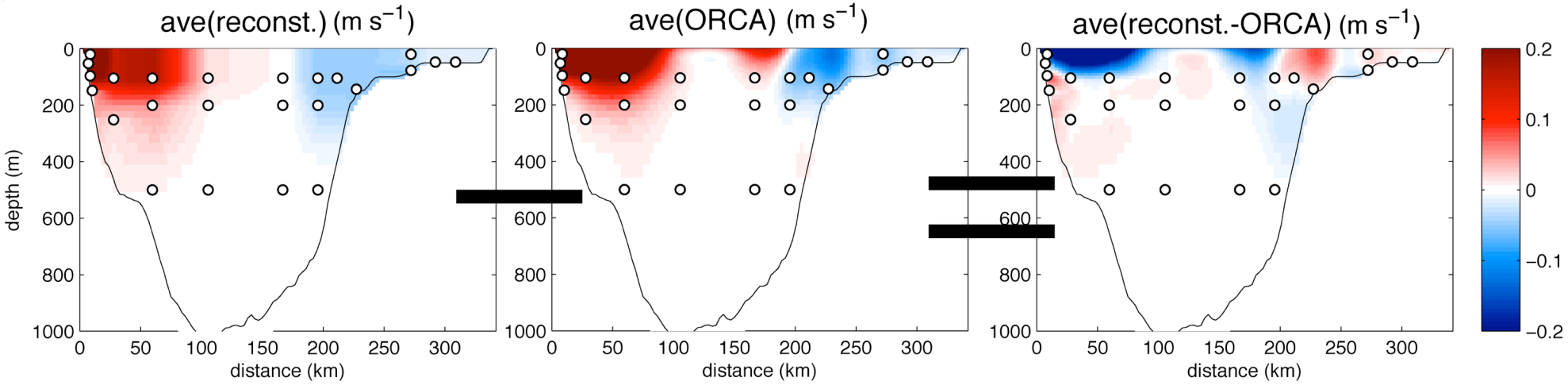


fig. S'V' plots

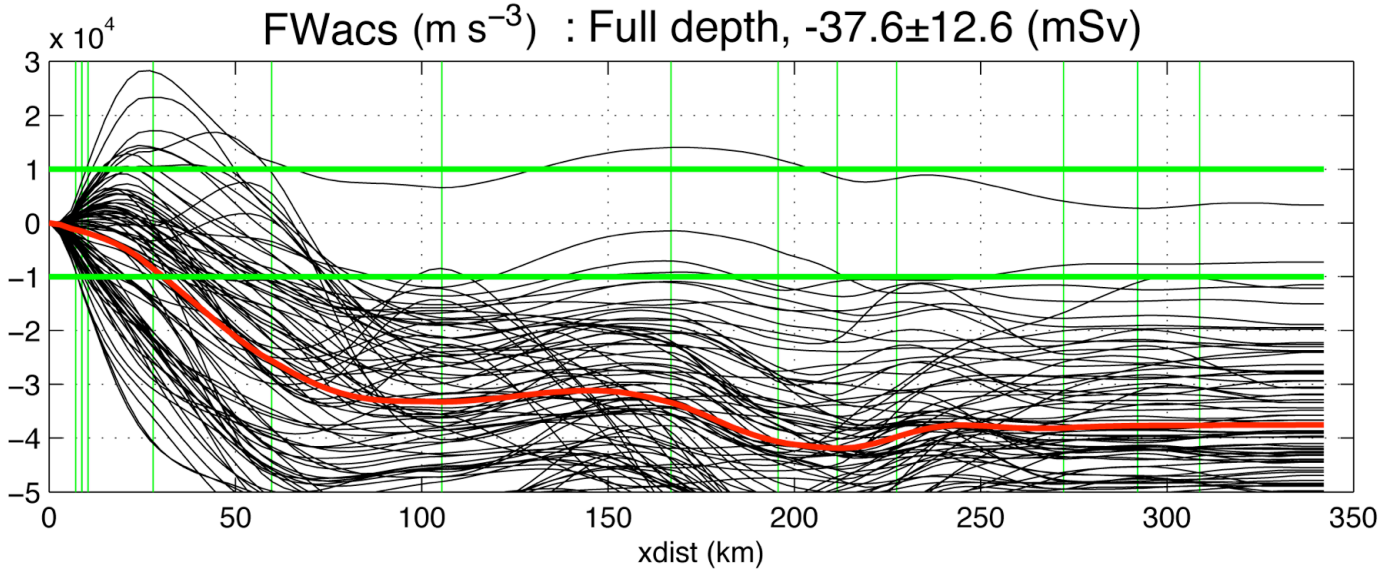


fig. accumulative FW transport of (reconst.-ORCA)

Summary of Assessment in Davis Strait

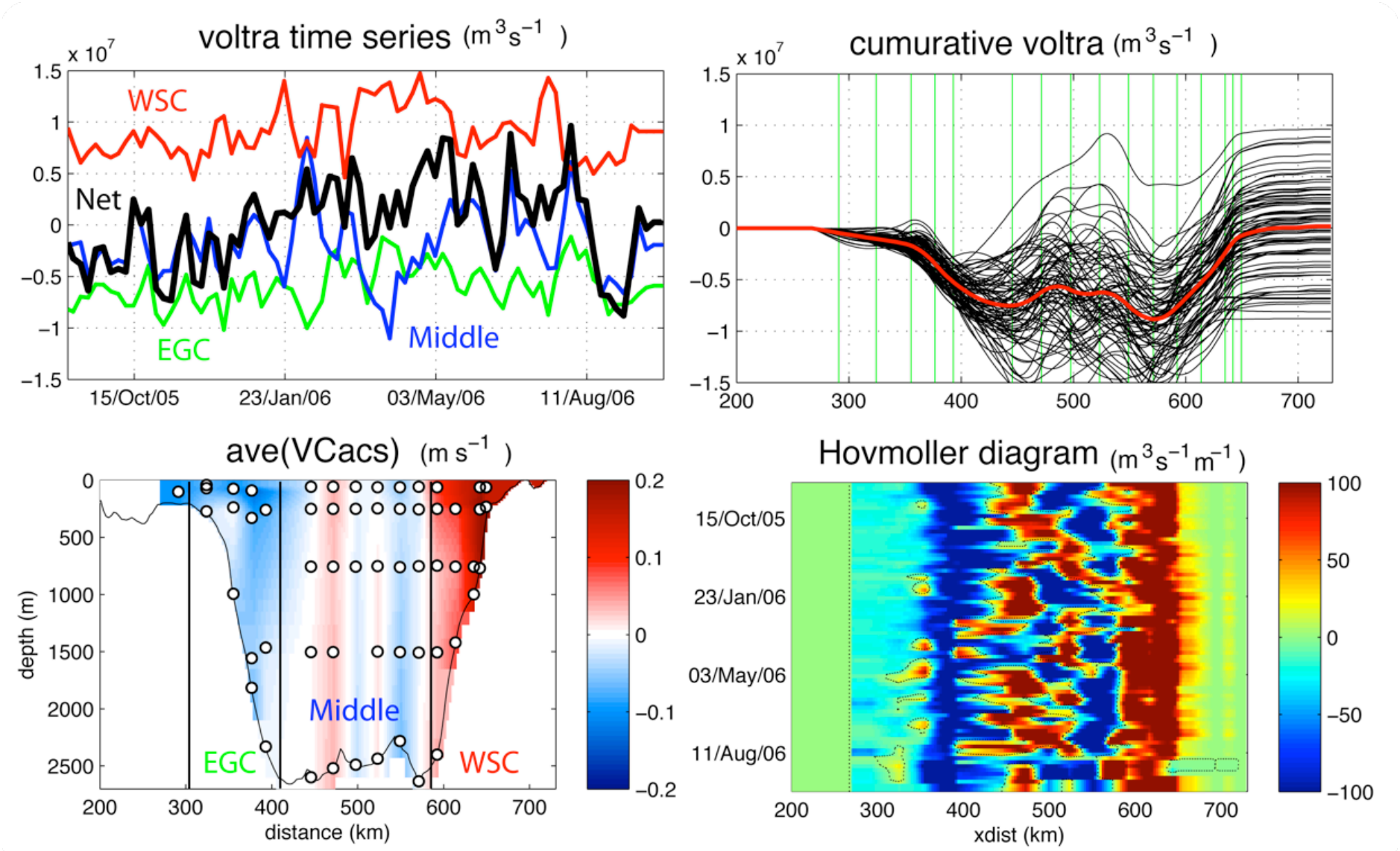
- We can reconstruct vel field within ±0.5 Sv accuracy and precision
- Upper 50m stratification is important for FW flux, but not for heat flux
- Target accuracy & precision: vol ±0.5 Sv, heat ±5 TW, FW ±10 mSv

Table: Difference between reconstructed transports and NEMO transports. VAall has no missing data, VAmis includes missing data.

	Volume tra. (Sv)	Temperature tra. (TW)	FW tra. (mSv)
VAall-ORCA	-0.43±0.48	-0.6±5.0	-10.8±9.0
VAmis-ORCA	0.10±0.49	-7.9±3.9	-37.6±12.6

Volume flux time series in Fram Strait

- Middle of Fram Strait is complicated region (Schauer et al., 2004 etc)



Outflow: observed T, S, V

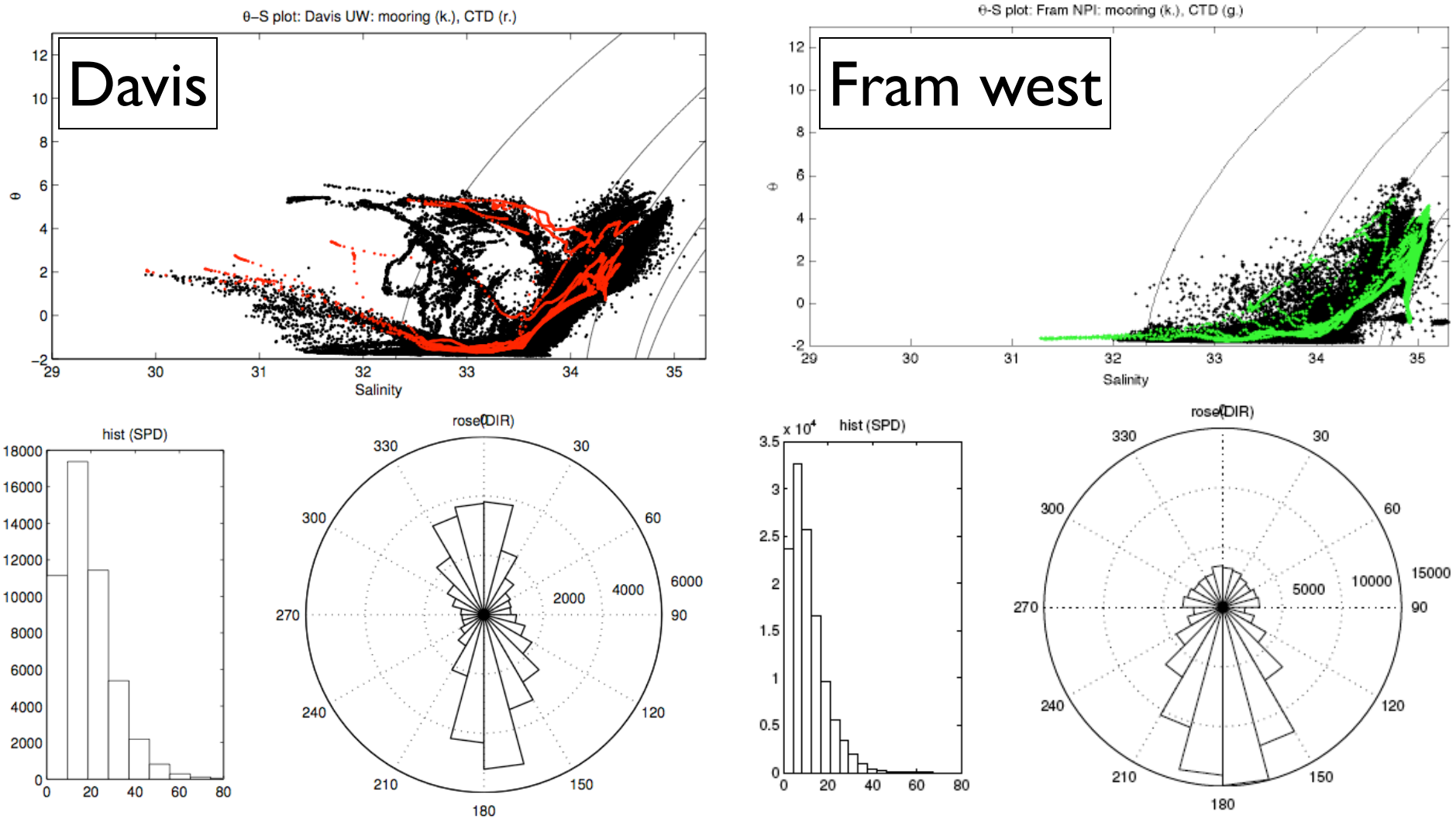
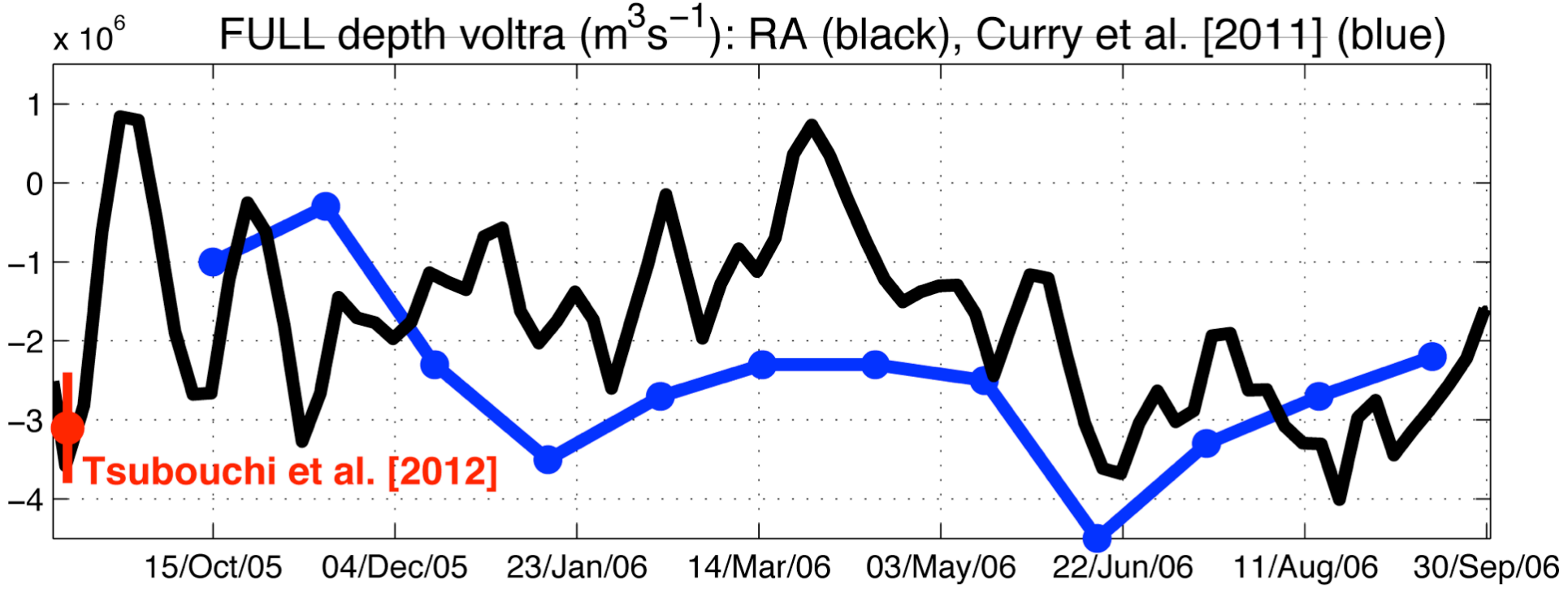


Fig. observed T, S, V in the Davis Strait and western Fram Strait

Volume flux time series in Davis Strait

- Volume flux is -1.78±1.11 Sv
- No clear seasonal cycle
- Consistent with Curry et al. [2011]* & Tsubouchi et al. [2012]



*Curry et al. [2011] is for 2004-2005.

Heat flux, FW flux

- No ref-sal, no ref-temp.
- Volume is balanced.

Volume: $V_{in}=V_{out}$

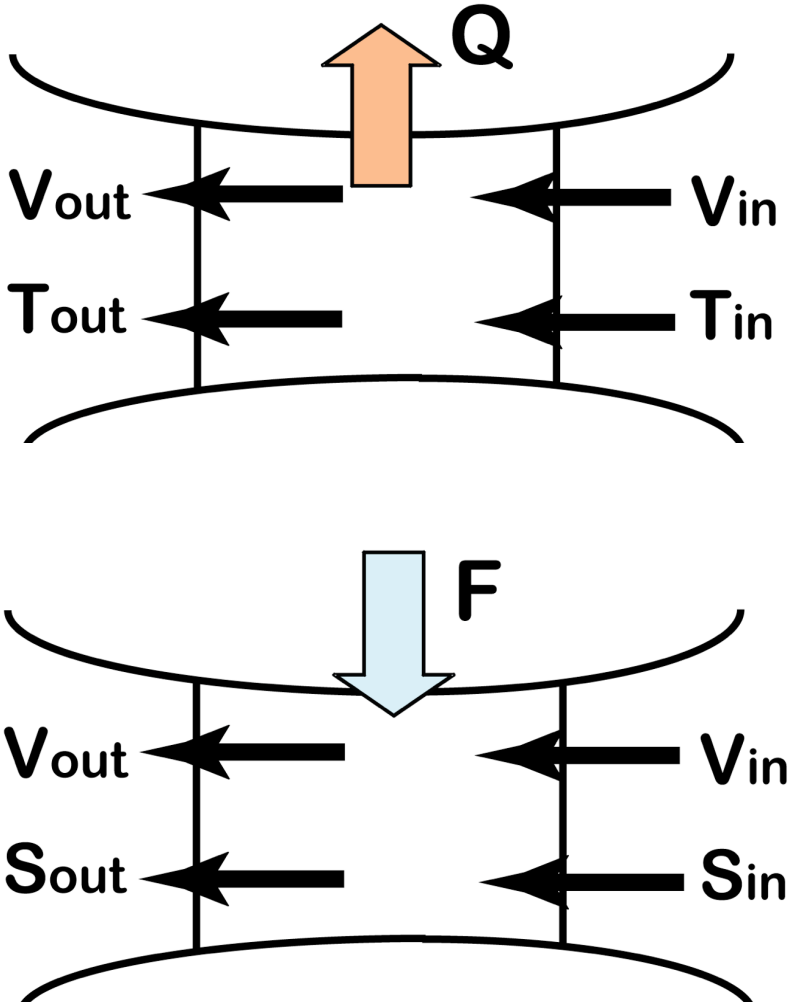
Heat: $V_{in}T_{in}=V_{out}T_{out}+Q$

$$Q = \rho C_p(T_{in}-T_{out})V_{in}$$

Volume: $V_{in}+F=V_{out}$

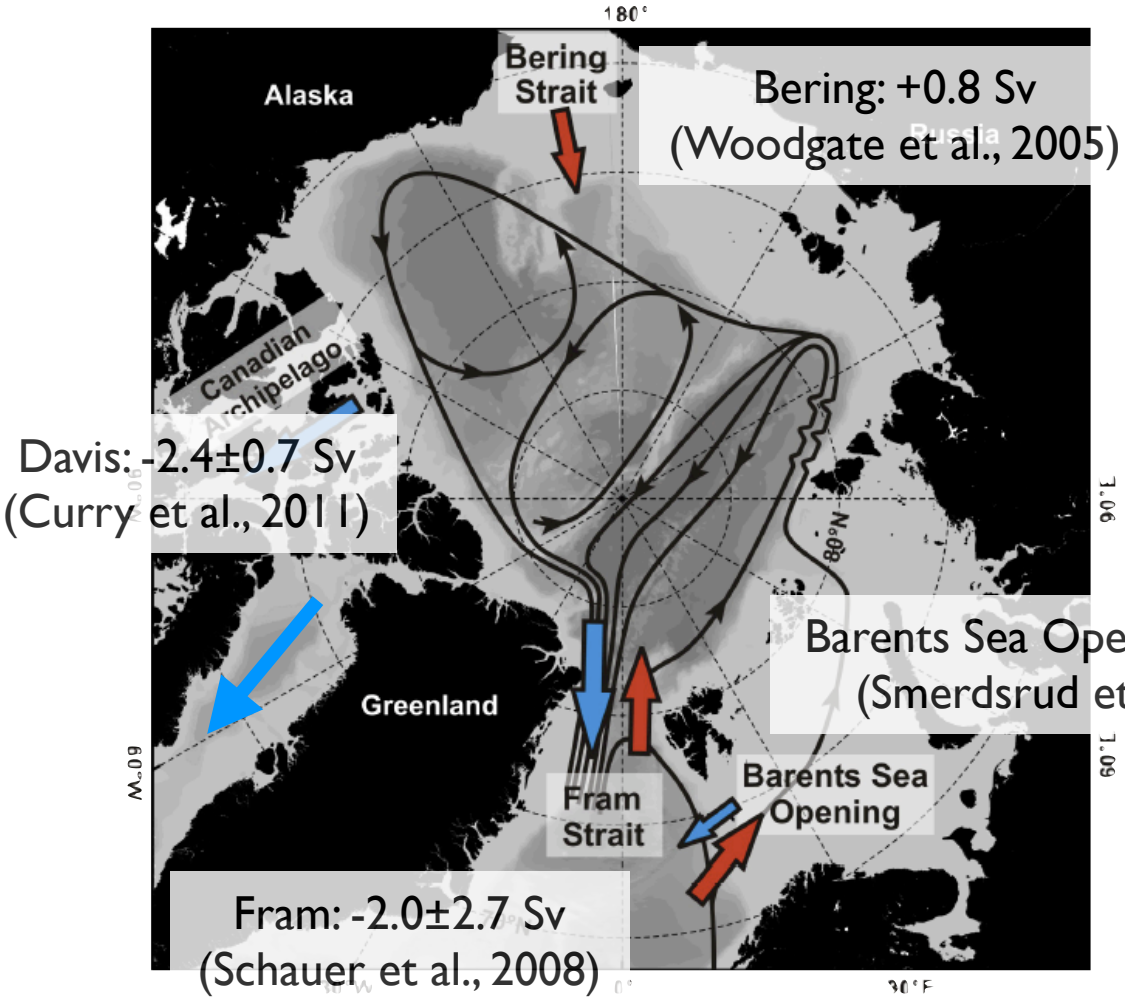
Salt : $V_{in}S_{in}=V_{out}S_{out}$

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



Arctic volume budget is not closed

- What we are missing to close the budget???



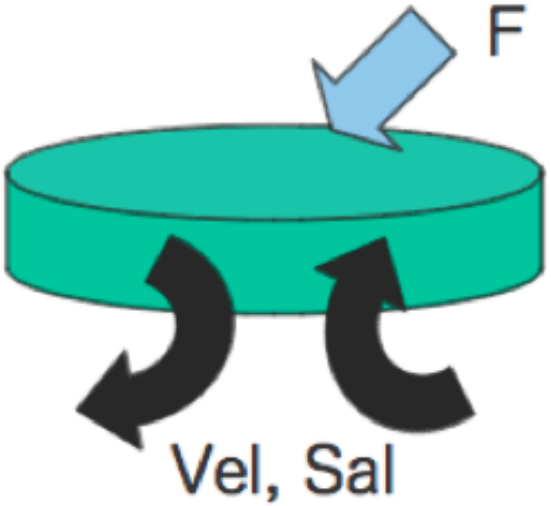
1.6 Sv deficit!

Fig. The latest annual mean volume transport in each main gate.

FW flux equation

- Consider volume and salt conservation.

$$volume: F + \oint V dx dz = 0, \quad Salt: \oint SV\, dx\, dz = 0$$



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

$$\oint \left(\bar{S} + S'\right)\left(\bar{V} + V'\right) dA = 0 \qquad (2)$$

From (1), $F + \bar{V}A + \cancel{\oint V' dA} = 0 \rightarrow F = -\bar{V}A$ (3)

From (2), $\oint \overline{VS}\, dA + \cancel{\oint \bar{V}S'\, dA} + \cancel{\oint V'\bar{S}\, dA} + \oint V'S'\, dA = 0$

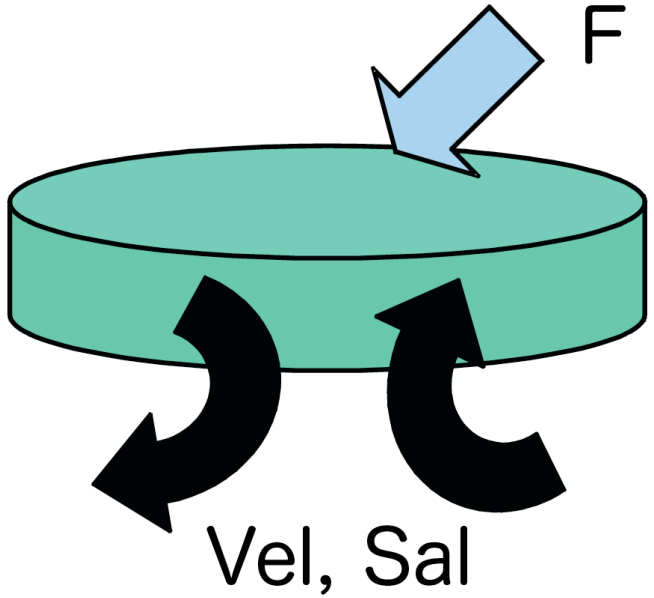
$$\overline{VS}A + \oint V'S' dA = 0$$

Substitute (3) $F\bar{S} = \oint V'S' dA$

$$F = \frac{\oint V'S' dA}{\bar{S}}$$

FW flux equation

$$F = \frac{\oint V'S'dA}{\overline{S}}$$



- $\overline{S}$ is mean salinity across boundary.
  - including Sea ice (6 psu), this is 34.654.
  - 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.

$$F = \frac{\oint V'S'dA}{\overline{S}}$$: S_{ref}=34.654

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