Overturning in the Subpolar North Atlantic: Insights from Observing System Simulation Experiments

Stefan Gary[1], Susan Lozier[1], Bill Johns[2]
[1]Duke University, [2]University of Miami
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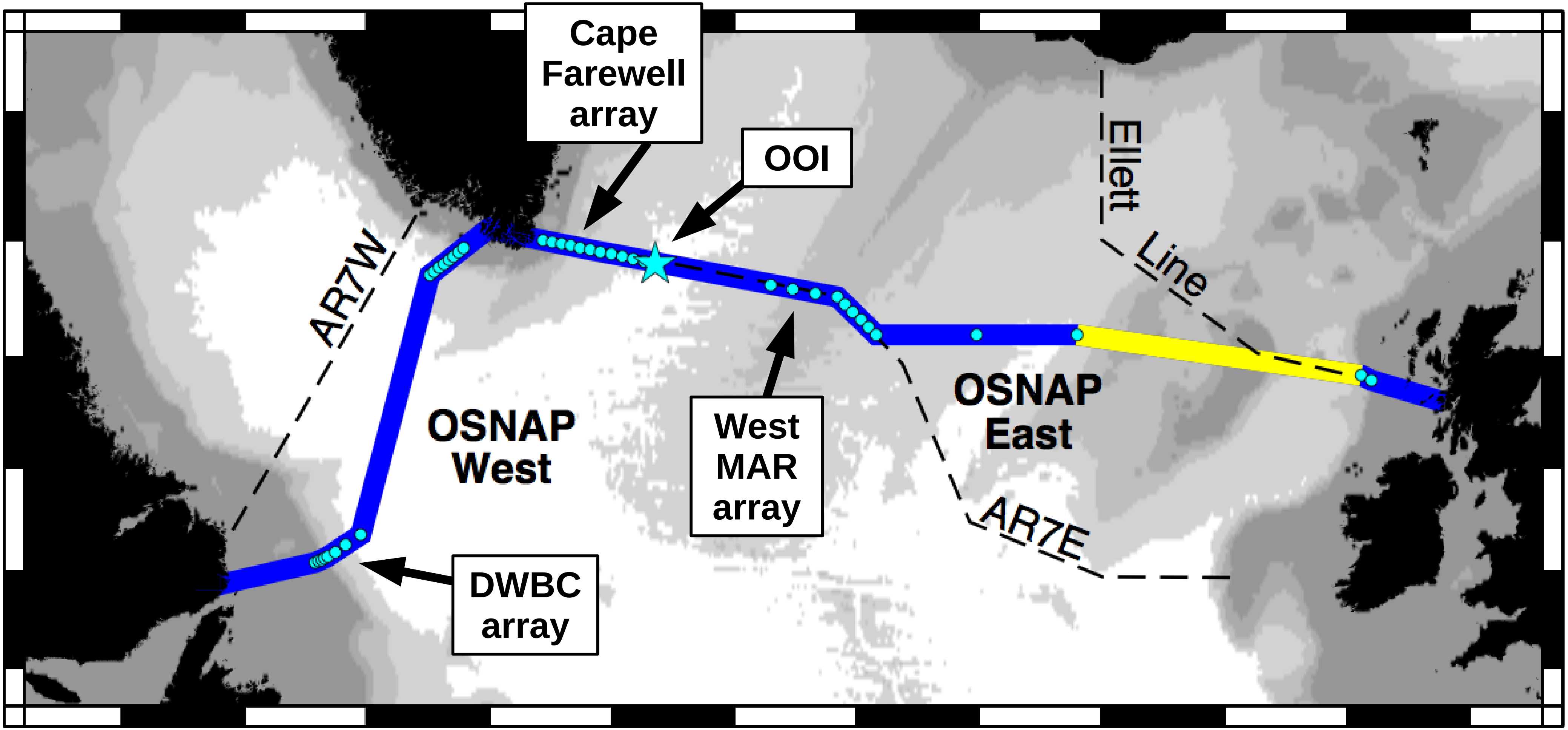
OSNAP goal: Obtain monthly time series of basin width integrated fluxes of mass, heat, & freshwater in the Subpolar North Atlantic.

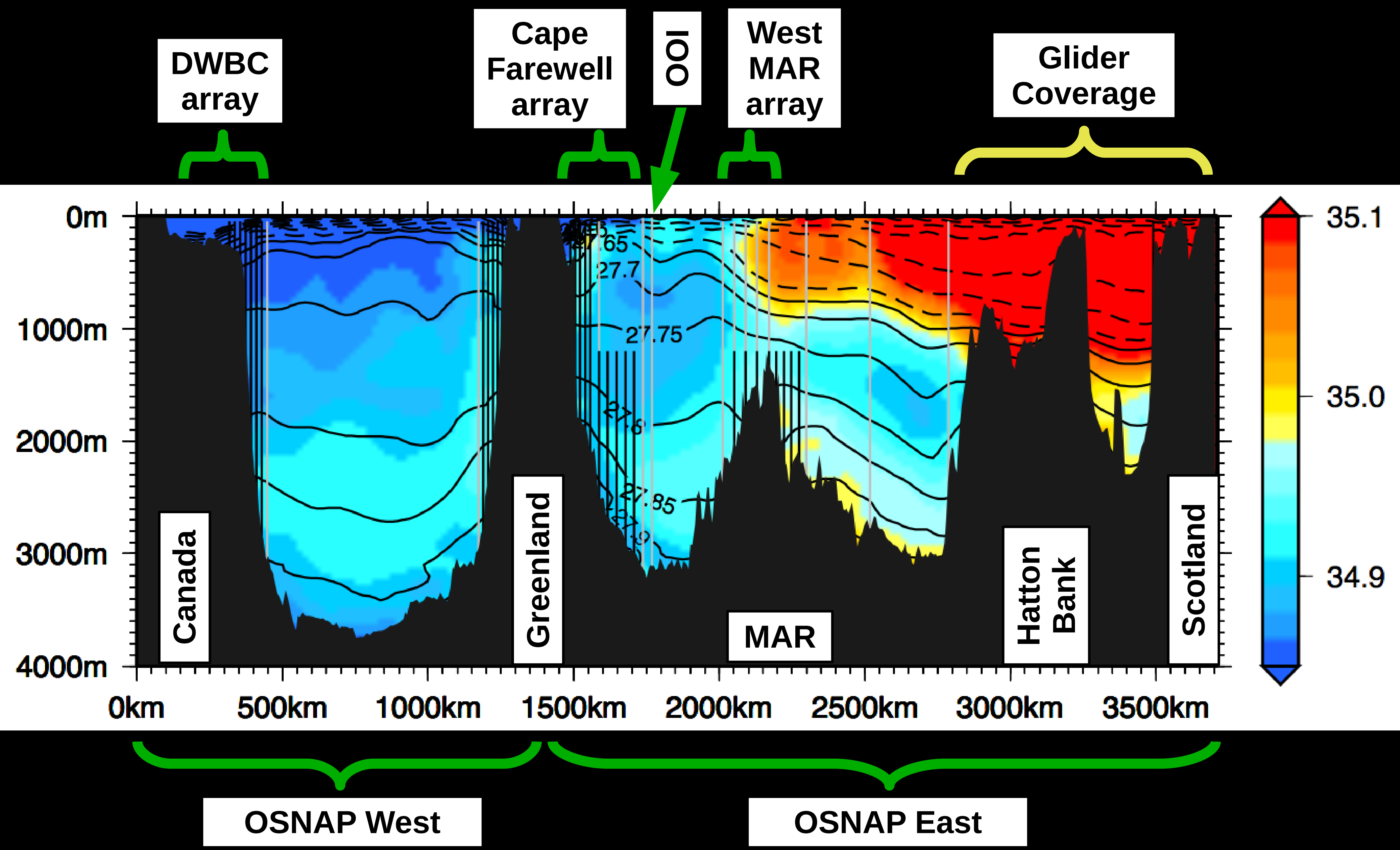
OSSE goal: Simulate the proposed observing system by subsampling a general circulation model.

Test the many possible configurations of the observing system. Which configurations are the most effective and why?

OSNAP West and East Map



OSNAP West and East Salinity Section



Salinity from a climatology constructed with Hydrobase 2 using World Ocean Database hydrographic data. σ_θ contour lines are 0.01 kg m^{-3} (solid) and 0.05 kg m^{-3} (dashed).

Model Specifics

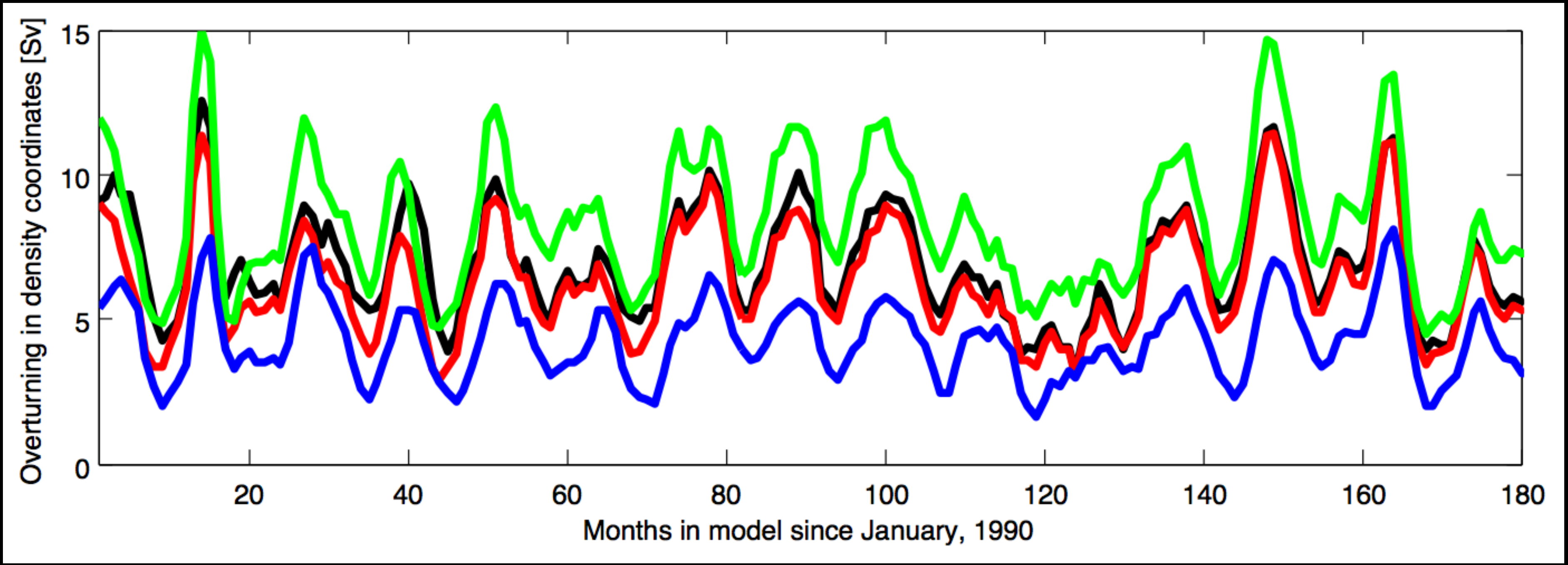
The Family of Linked Atlantic Modeling Experiments (FLAME) 1/12^{o} regional North Atlantic model (Böning et al., 2006) was specifically designed to match subpolar T/S (Czeschel, 2004).

FLAME compares favorably to hydrographic and Lagrangian observations for both the upper and lower limbs of the AMOC (Burkholder et al., 2011, Gary et al., 2011).

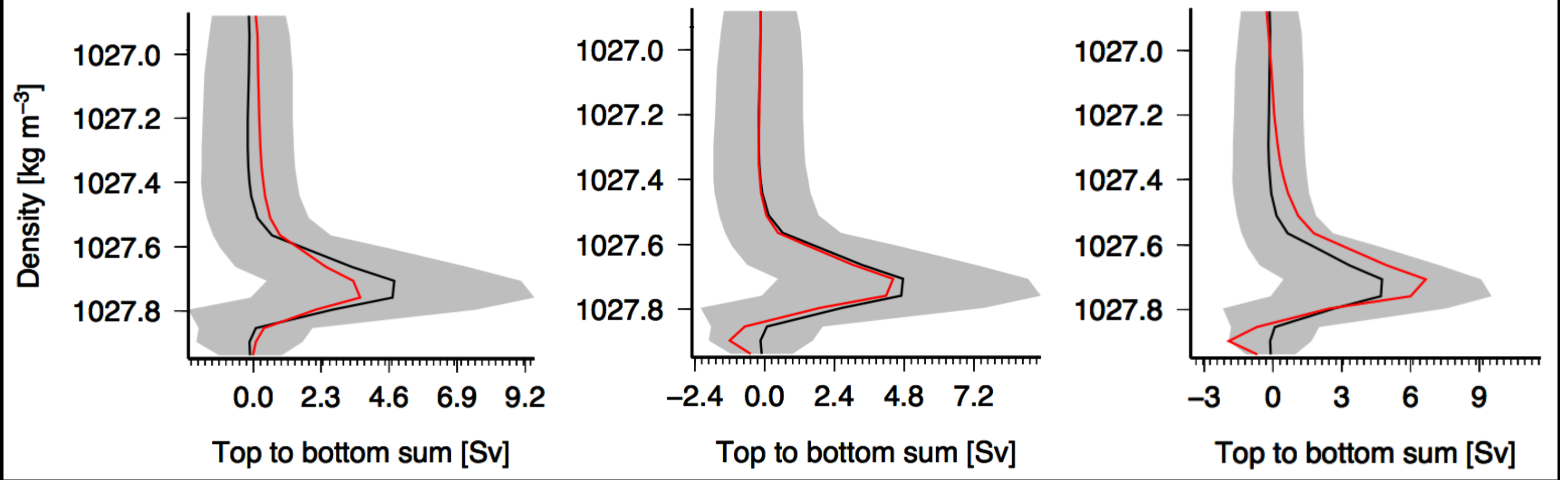
Focus on OSNAP West first, then East.

Key observations from the animation:
1) Strong boundary currents
2) Most of the integrated flux in the section is on the boundaries.
3) Strong barotropic flow
4) Strong variability in the shape of the overturning profile
5) Use max – min as an overturning criteria instead of just max.
6) Overturning in density coordinates matches LSW production but overturning in z-level coordinates is much lower.

OSNAP West OSSE comparison

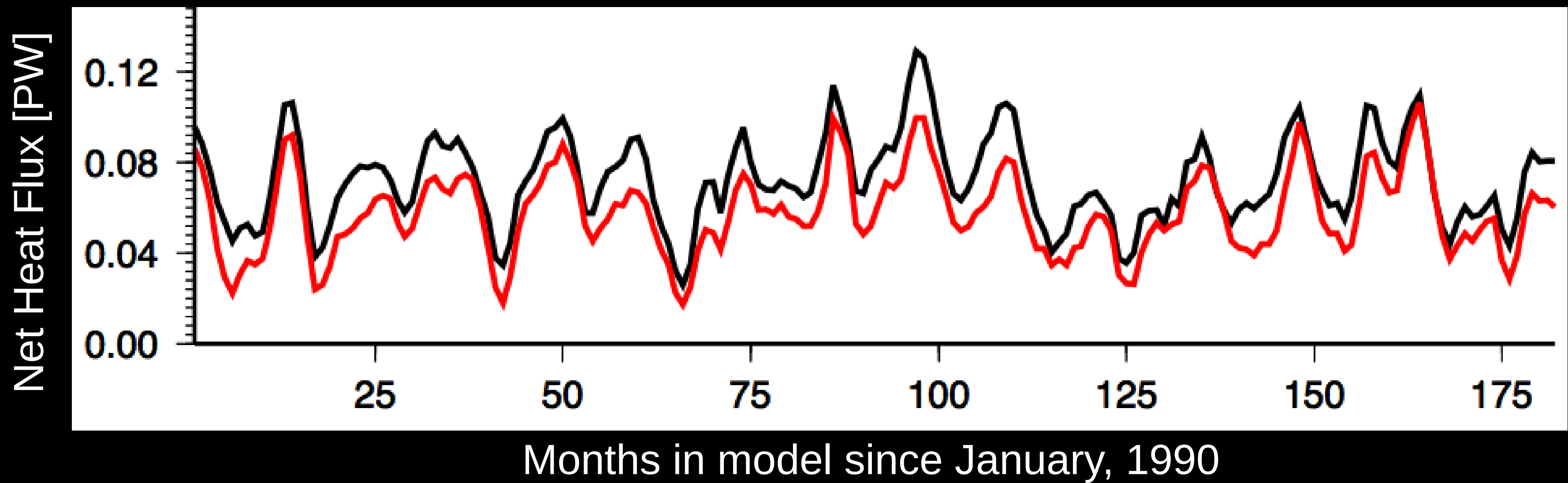


Geo. + Ek. everywhere		Ideal BC, Geo. + Ek. Interior		Subsampled BC, Geo. + Ek. Interior	
Mean:	4.3 ± 1.6 Sv	Mean:	6.3 ± 2.3 Sv	Mean:	8.4 ± 2.8 Sv
RMSD:	0.75 Sv	RMSD:	0.99 Sv	RMSD:	1.90 Sv
R^2 :	0.25	R^2 :	0.89	R^2 :	0.82



Reference Case
Mean: 6.9 ± 2.4 Sv

What about Heat and Freshwater fluxes?



Reference case (black)

mean: 0.072 ± 0.024 PW 0.058 ± 0.038 Sv

Ideal boundary, Geo. + Ek. in interior (red)

mean: 0.058 ± 0.022 PW 0.054 ± 0.038 Sv

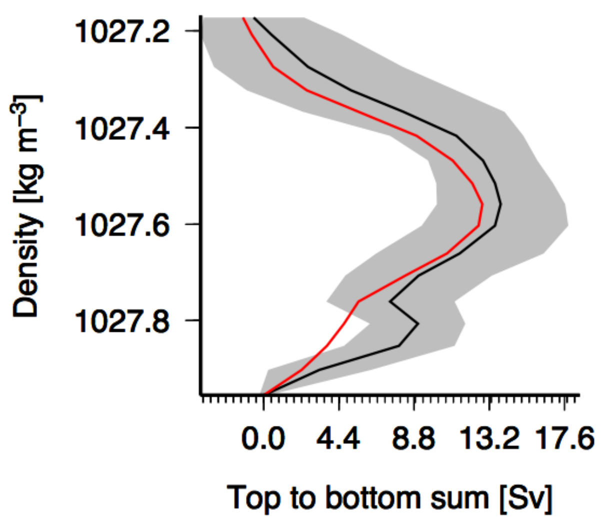
RMSD: 0.017 PW 0.004 Sv

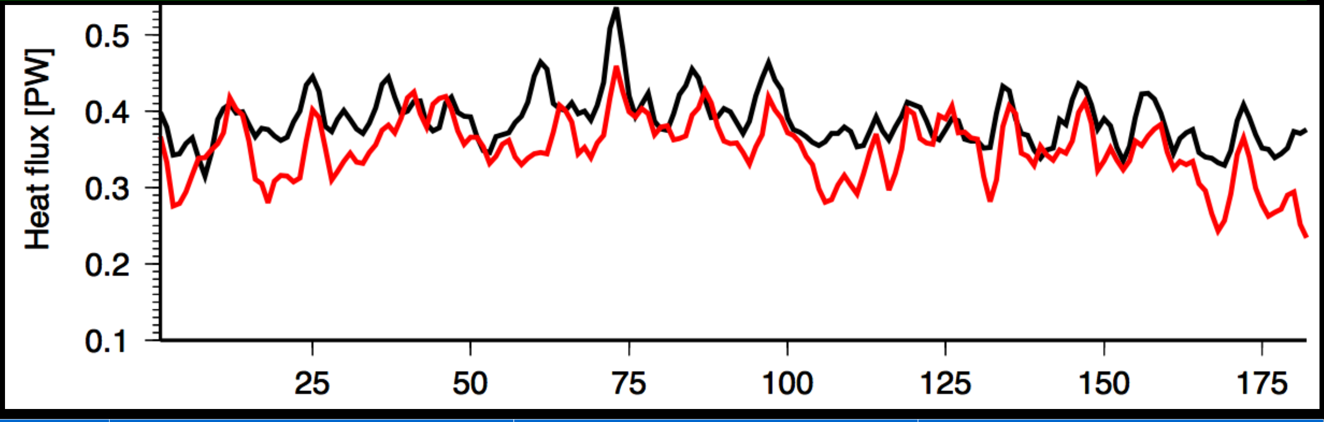
R^2 : 0.88 0.99

Subsampling in the boundary currents will reduce correlations, especially for the freshwater flux.

Adding Argo profiles nudges the mean OSSE net heat flux towards the ideal.

OSNAP East





	z-level	*ρ*-level	heat	FW
Ref. Case Mean	8.1 ± 0.1 Sv	15.3 ± 2.2 Sv	0.39 ± 0.04 PW	0.28 ± 0.05 Sv
Ideal boundaries, geostrophic flow and Ekman flux applied to interior				
mean	4.3 ± 0.8 Sv	14.7 ± 2.6 Sv	0.35 ± 0.06 PW	0.29 ± 0.05 Sv
RMSD	3.7 Sv	1.6 Sv	0.05 PW	0.02 Sv
R^2	0.25	0.67	0.48	0.80
*Subsampled boundaries, geostrophic flow and Ekman flux applied to interior (shown above)				
mean	4.3 ± 0.8 Sv	14.9 ± 2.8 Sv	0.35 ± 0.06 PW	0.29 ± 0.05 Sv
RMSD	4.1 Sv	1.7 Sv	0.06 PW	0.03 Sv
R^2	0.24	0.64	0.39	0.70
Geostrophic flow and Ekman flux applied to the whole section (no direct velocity reference)				
mean	5.2 ± 0.7 Sv	7.4 ± 1.4 Sv	0.17 ± 0.03 PW	0.18 ± 0.04 Sv
RMSD	3.1 Sv	8.0 Sv	0.22 PW	0.10 Sv
R^2	0.33	0.64	0.48	0.79

Conclusions

(1) At least ~70% of the variability of the overturning on the OSNAP lines is captured by moorings and gliders.

(2) At least ~50% of the variability of net heat flux is resolved.

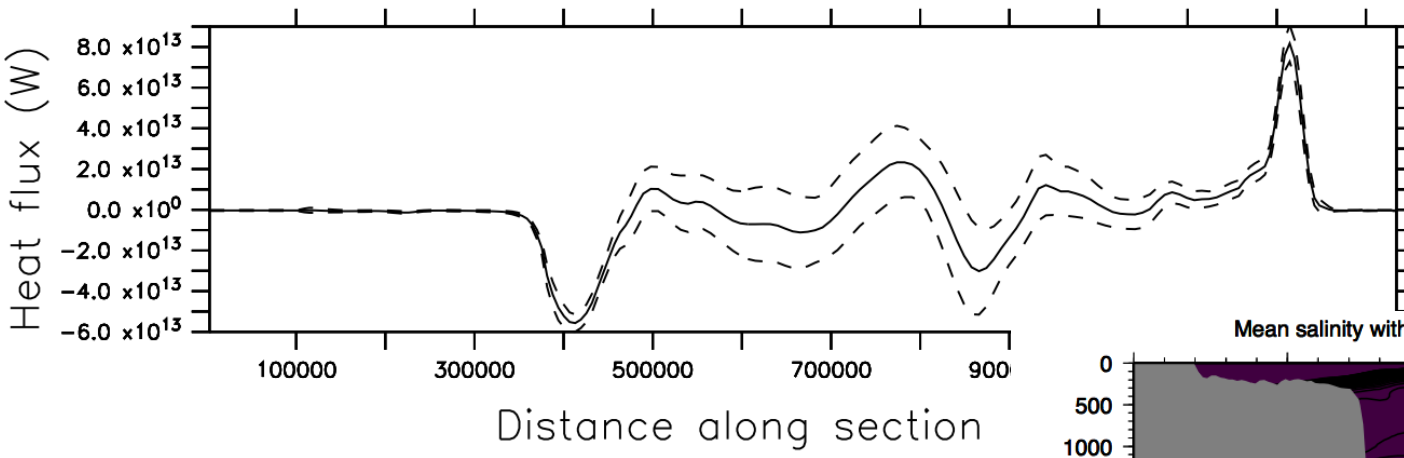
(3) At least ~80% of the variability of net freshwater flux is resolved.

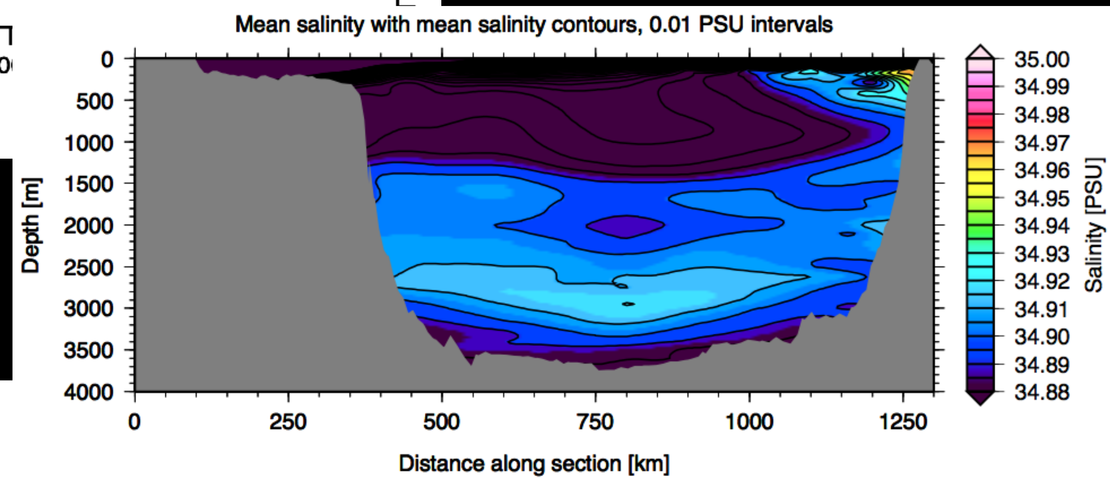
(4) Accurate measurements at the boundaries are crucial for reconstructing the magnitude of overturning.

(5) T/S from the Argo array benefits basin-interior geostrophic calculations as well as the determination of net heat flux.

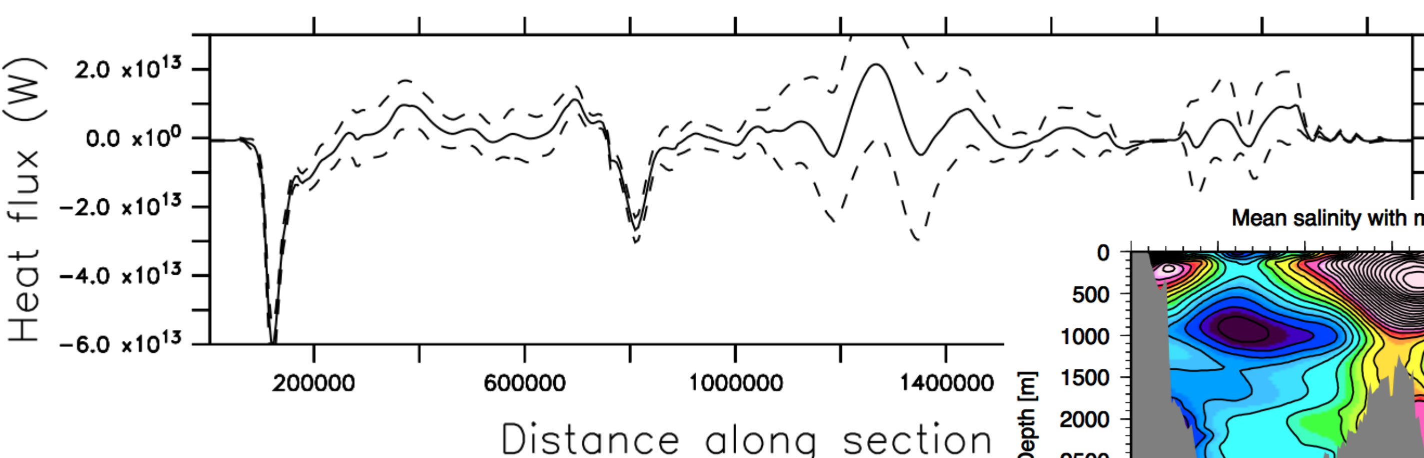
OSNAP WEST	***z*-level**	***ρ*-level**	**heat**	**FW**
Ref. Case Mean	1.6 ± 0.6 Sv	6.9 ± 2.4 Sv	0.072±0.024 PW	0.058 ± 0.038 Sv
Ideal boundaries, geostrophic flow and Ekman flux applied to interior				
mean	1.4 ± 0.7 Sv	6.3 ± 2.3 Sv	0.058±0.022 PW	0.054 ± 0.038 Sv
RMSD	0.42 (0.36) Sv	0.99 (0.83) Sv	0.017 (0.016)PW	0.004 (0.004) Sv
R^2	0.53 (0.66)	0.89 (0.91)	0.88 (0.90)	0.99 (0.99)
Subsampled boundaries, geostrophic flow and Ekman flux applied to interior				
mean	2.0 ± 0.7 Sv	8.37 ± 2.8 Sv	0.064±0.025 PW	0.044 ± 0.026 Sv
RMSD	0.80 (0.65) Sv	1.90 (1.73) Sv	0.012 (0.010)PW	0.026 (0.020) Sv
R^2	0.28 (0.32)	0.82 (0.86)	0.88 (0.91)	0.71 (0.70)
Geostrophic flow and Ekman flux applied to the whole section (no direct velocity reference)				
mean	1.6 ± 0.6 Sv	4.3 ± 1.6 Sv	0.047±0.017 PW	0.026 ± 0.026 Sv
RMSD	0.75 (0.61) Sv	2.9 (2.8) Sv	0.29 (0.28) PW	0.037 (0.035) Sv
R^2	0.25 (0.29)	0.70 (0.78)	0.65 (0.68)	0.81 (0.81)
Ideal boundaries, geo. flow & Ek. flux applied to interior + 5 **unref.** Argo floats per mon.				
mean	1.4 0.7 Sv	6.3 2.3 Sv	0.058 0.022 PW	0.054 0.039 Sv
R^2	0.53 (0.66)	0.89 (0.91)	0.88 (0.90)	0.99 (0.99)
Ideal boundaries, geo. flow & Ek. flux applied to interior + 5 **ref.** Argo floats per mon.				
mean	1.5 0.7 Sv	6.4 2.3 Sv	0.060 0.023 PW	0.054 0.039 Sv
R^2	0.61 (0.69)	0.90 (0.91)	0.83 (0.87)	0.99 (0.99)

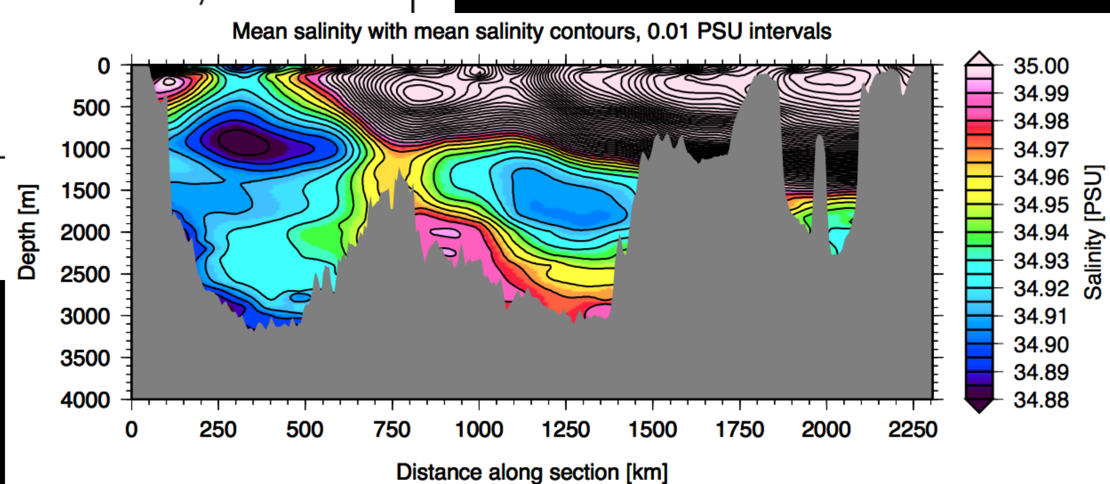
OSNAP WEST



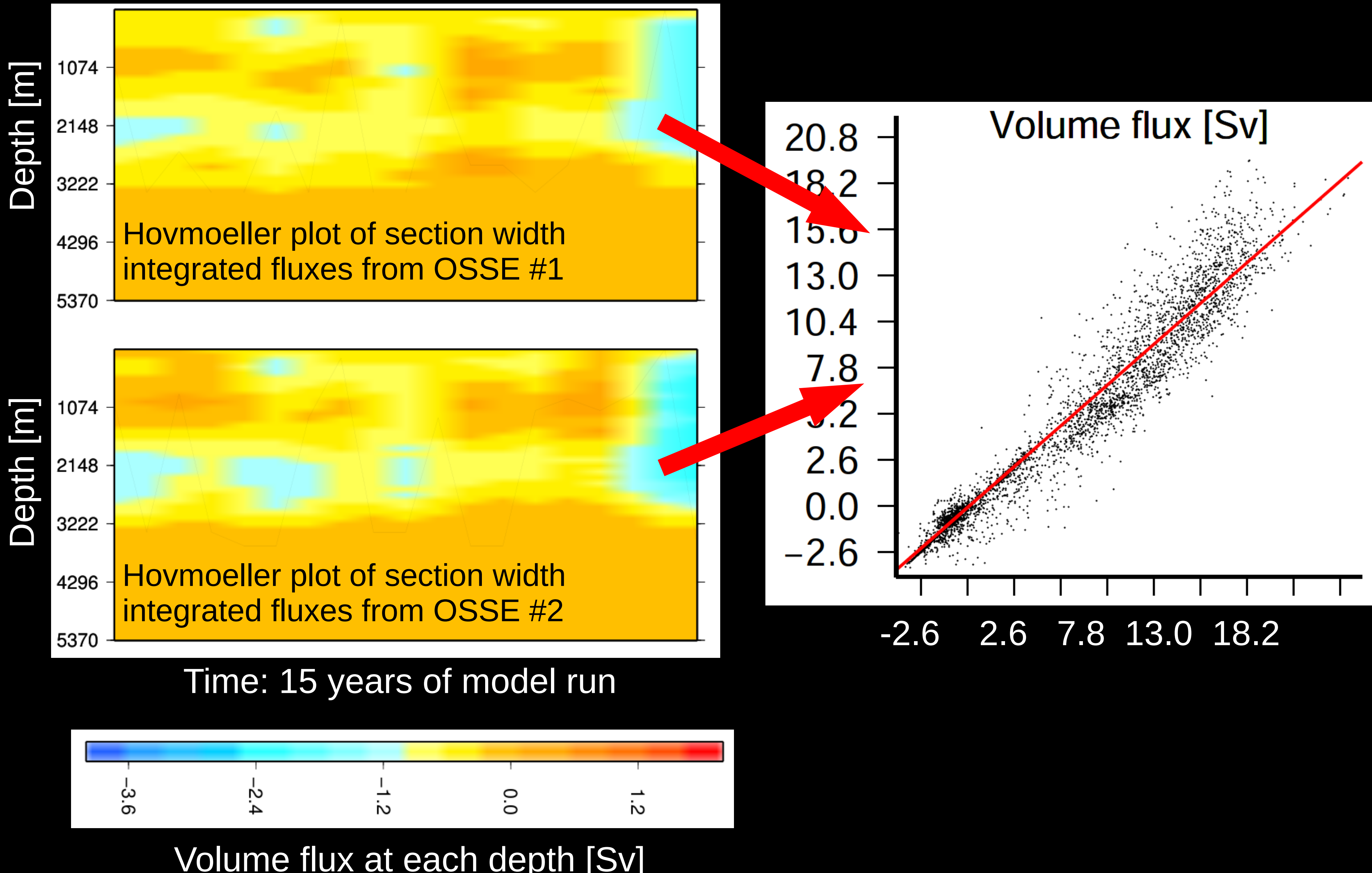


OSNAP EAST





Comparisons between OSSE's – collapsing depth and time dimensions into a single correlation



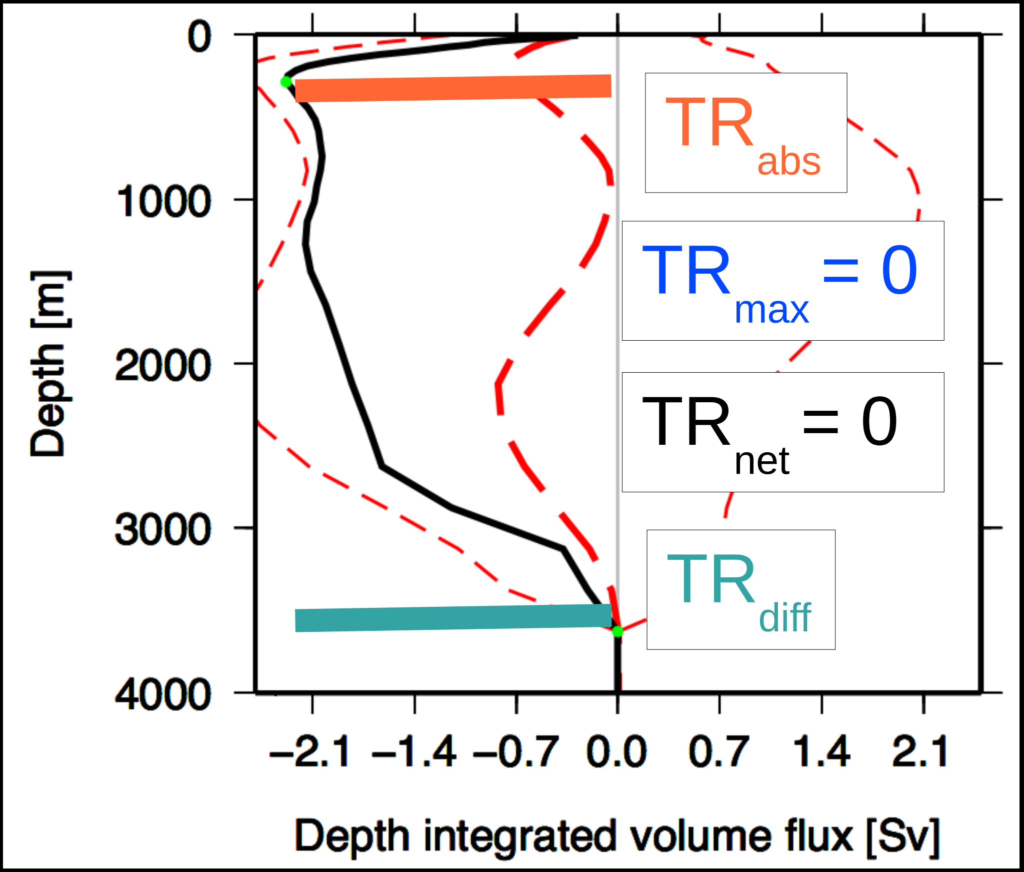
Comparisons between OSSE's – extracting an overturning profile time series

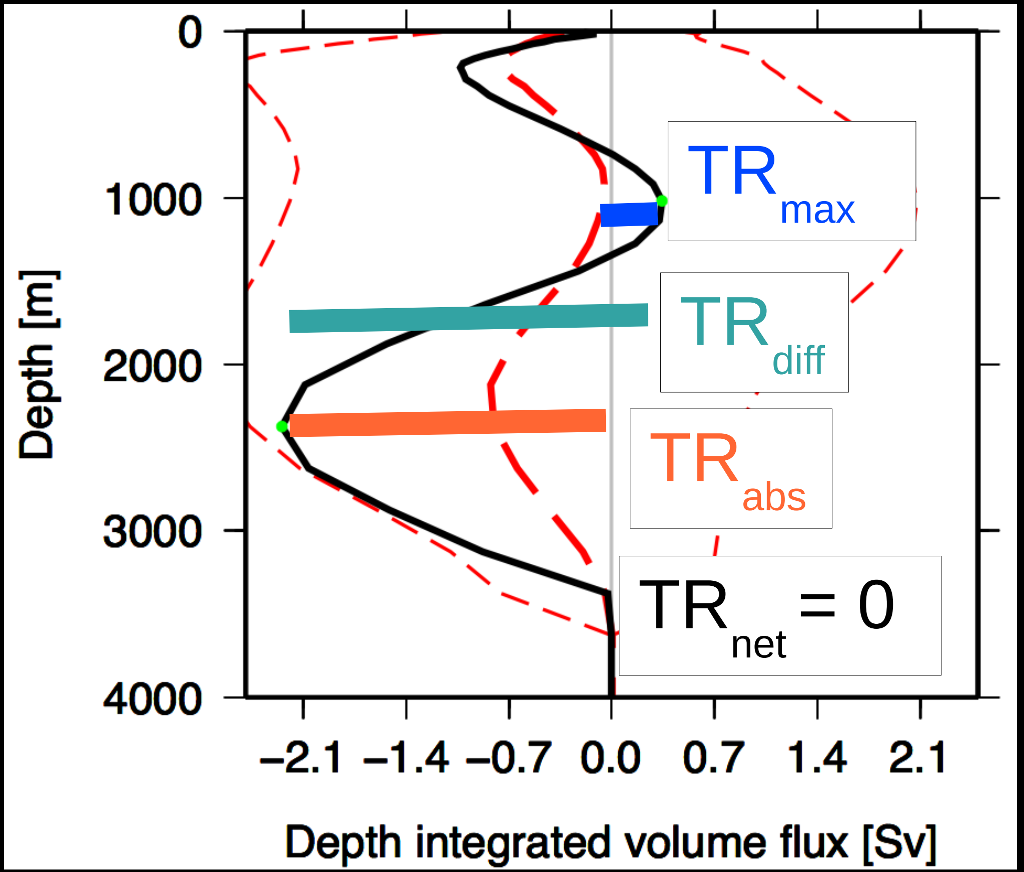
TR_{max} = max value of depth integrated flux.

TR_{abs} = max of absolute value of depth integrated flux.

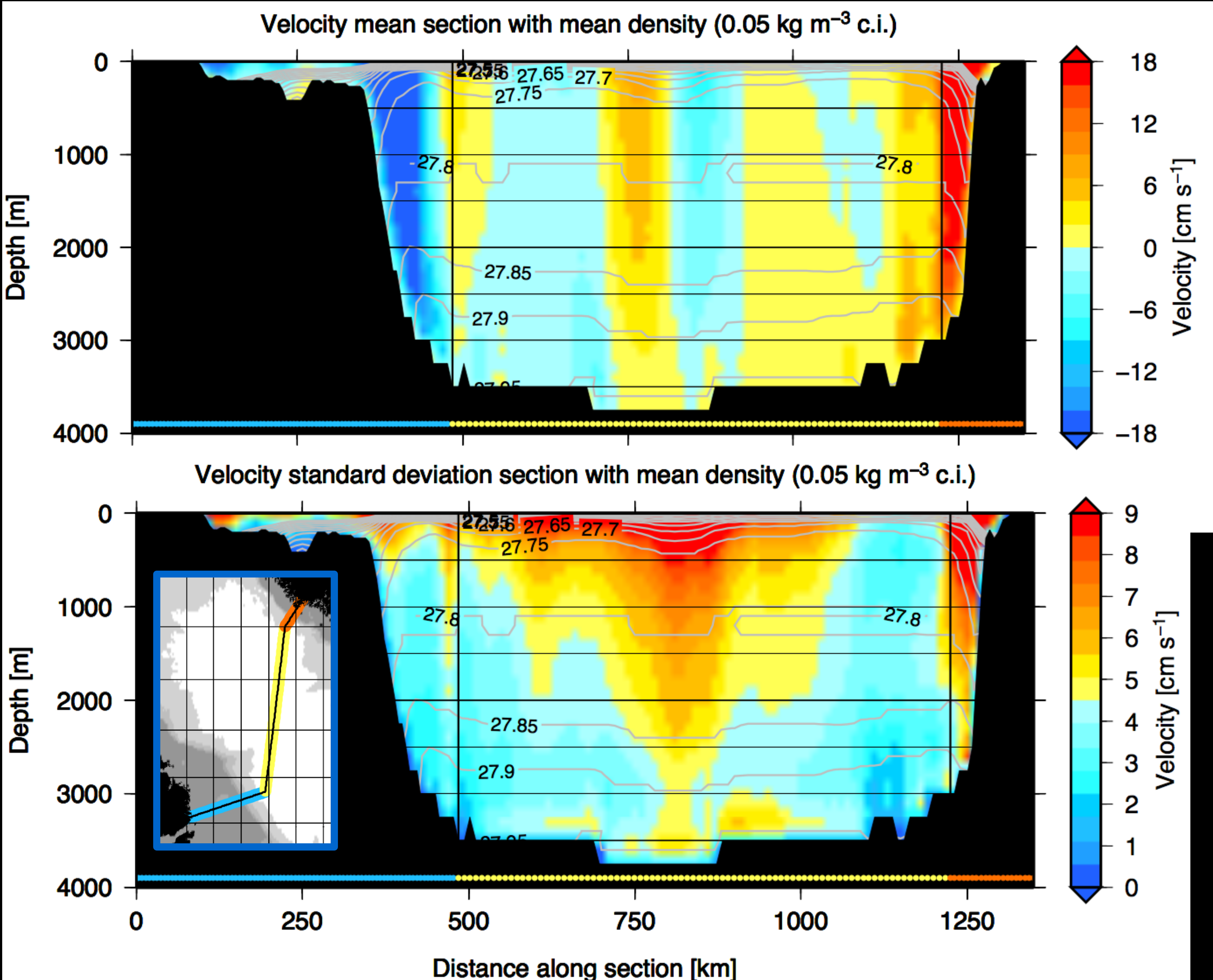
TR_{diff} = difference between max and min depth integrated fluxes

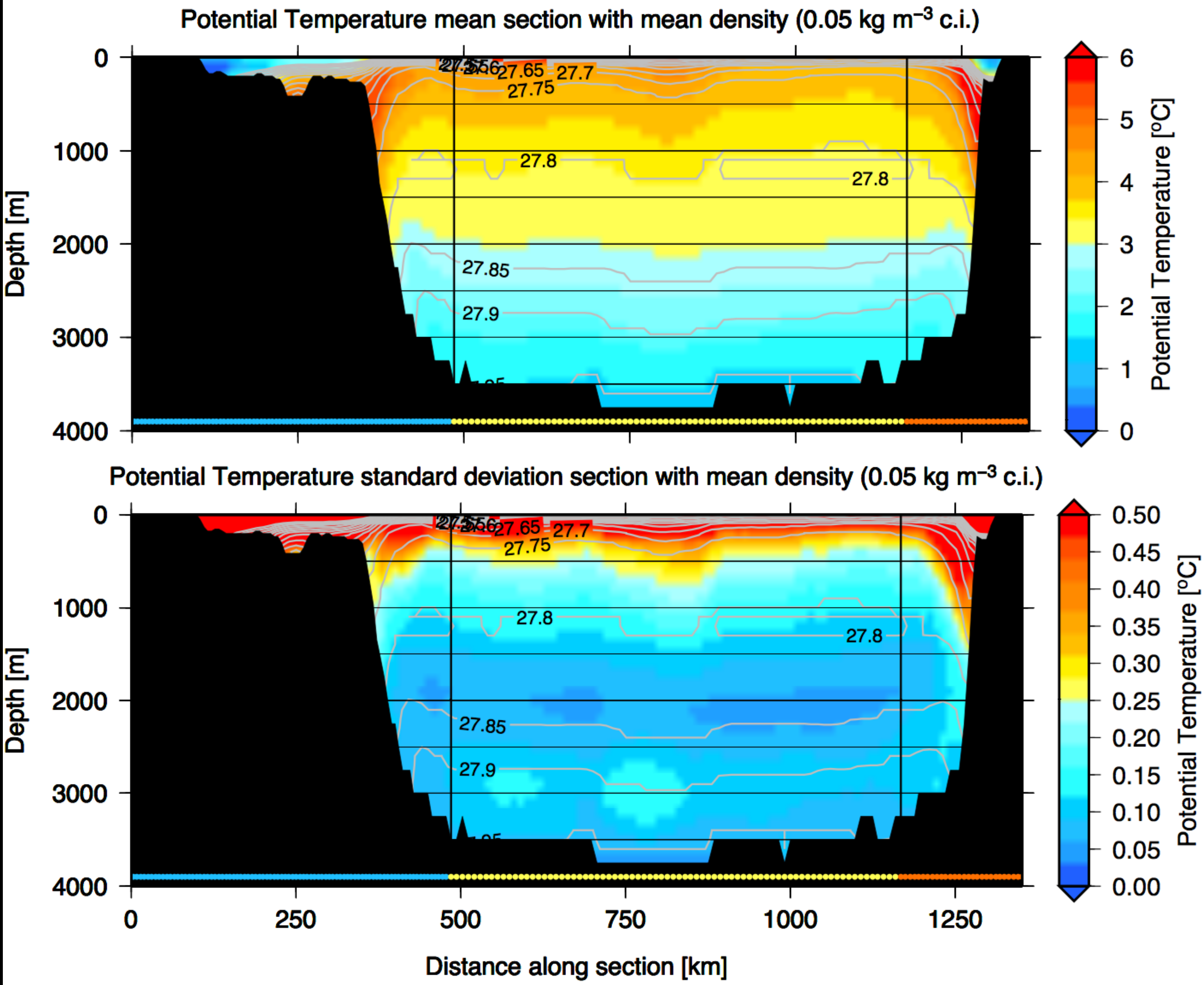
TR_{net} = net depth integrated flux **(Heat, Salt, & Mass)**

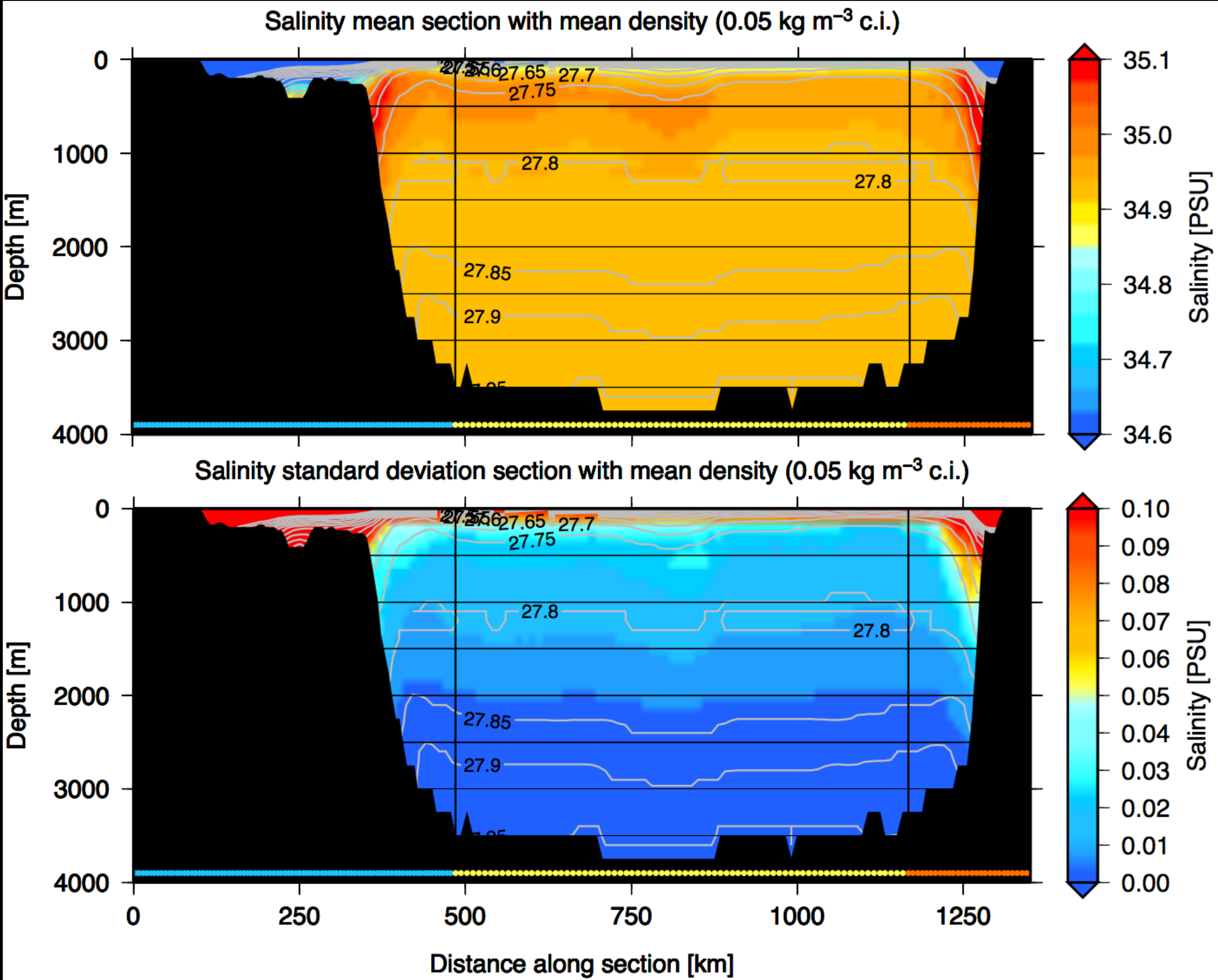




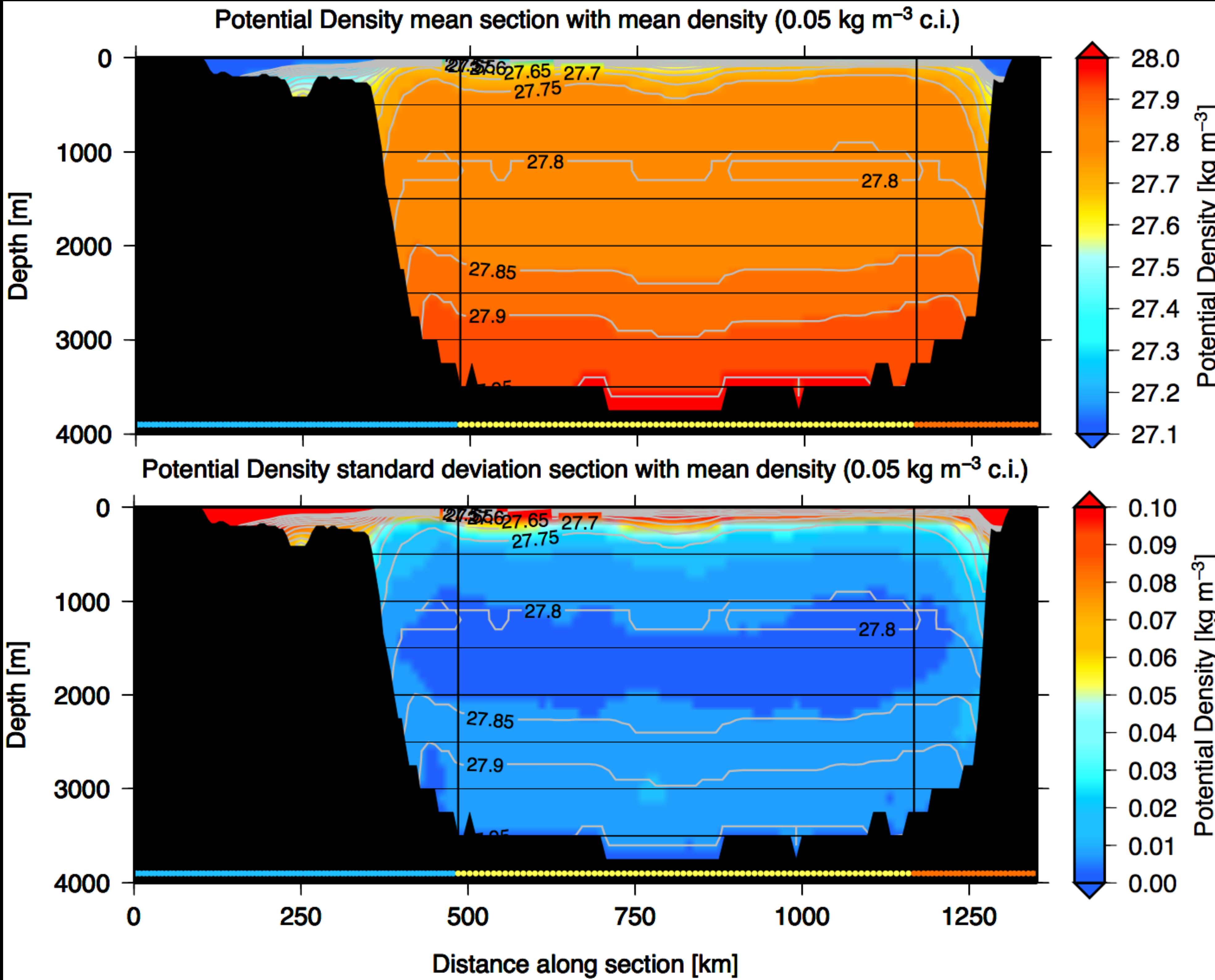
OSNAP WEST, WGC array 100 km inshore




Potential Temperature mean section with mean density (0.05 kg m⁻³ c.i.)
Depth [m]
0
1000
2000
3000
4000
27.65
27.7
27.75
27.8
27.8
27.85
27.9
Potential Temperature [ºC]
0
1
2
3
4
5
6
Potential Temperature standard deviation section with mean density (0.05 kg m⁻³ c.i.)
27.65
27.7
27.75
27.8
27.8
27.85
27.9
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0
250
500
750
1000
1250
Distance along section [km]



Salinity mean section with mean density (0.05 kg m⁻³ c.i.)
Depth [m]
Salinity [PSU]
35.1
35.0
34.9
34.8
34.7
34.6
27.65
27.7
27.75
27.8
27.85
27.9
Salinity standard deviation section with mean density (0.05 kg m⁻³ c.i.)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
1000
2000
3000
4000
250
500
750
1250
Distance along section [km]


Potential Density mean section with mean density (0.05 kg m−3 c.i.)
Depth [m]
0
1000
2000
3000
4000
27.65
27.7
27.75
27.8
27.8
27.85
27.9
Potential Density [kg m−3]
28.0
27.9
27.8
27.7
27.6
27.5
27.4
27.3
27.2
27.1
Potential Density standard deviation section with mean density (0.05 kg m−3 c.i.)
Depth [m]
0
1000
2000
3000
4000
27.65
27.7
27.75
27.8
27.8
27.85
27.9
Potential Density [kg m−3]
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
250
500
750
1000
1250
Distance along section [km]

Signal loss for geostrophy, endpoints, & ARGO

(relative to reference case)

100 x R^2
Monthly

		z - coordinates		ρ - coordinates		+0.03 +/- 0.04
OSSE Case	Metric	Volume	Heat	Volume	Heat	Flux Correction +/- 1 std [Sv]
Full depth T & S at offshore edge each boundary array, SSH ref., Ekman	Hov.	87.2	88.3	95.6	97.2	-1.03 +/- 3.32
	TR_{max}	77.9		93.2		
	TR_{diff}	56.2		93.3		
	TR_{abs}	79.6		93.0		
	TR_{net}	0.1	93.5	0.6	94.4	
T & S at offshore edge of boundary arrays + 5 ARGO flts per month, SSH ref., Ekman	Hov.	71.8	85.3	94.9	96.7	-1.31 +/- 3.29
	TR_{max}	71.0		93.8		
	TR_{diff}	56.2		93.9		
	TR_{abs}	69.9		93.7		
	TR_{net}	0.6	93.7	2.9	93.8	

Signal loss moving WGC array endpoint inshore

(relative to reference case)

100 x R^2 Monthly | **z** - coordinates | ρ - coordinates | +0.03 +/- 0.04

OSSE Case	Metric	Volume (z)	Heat (z)	Volume (ρ)	Heat (ρ)	Flux Correction +/- 1 std [Sv]
Original position T & S at offshore edge each boundary, SSH, Ekman	Hov.	87.2	88.3	95.6	97.2	-1.10 +/- 3.28
	TR_{max}	77.9		93.2		
	TR_{diff}	56.2		93.3		
	TR_{abs}	79.6		93.0		
	TR_{net}	0.1	93.5	0.6	94.4	
West endpt 100km IN T & S at offshore edge each boundary, SSH, Ekman	Hov.	27.8	75.4	91.2	95.6	-5.98 +/- 3.34
	TR_{max}	67.4		91.3		
	TR_{diff}	52.8		90.2		
	TR_{abs}	46.4		91.0		
	TR_{net}	0.1	91.5	1.3	88.9	