Modelling the Nordic Seas

1. Oceanic heat transport along the Norwegian Atlantic Slope Current (JGR-oceans, in revision)
2. Ongoing ideas

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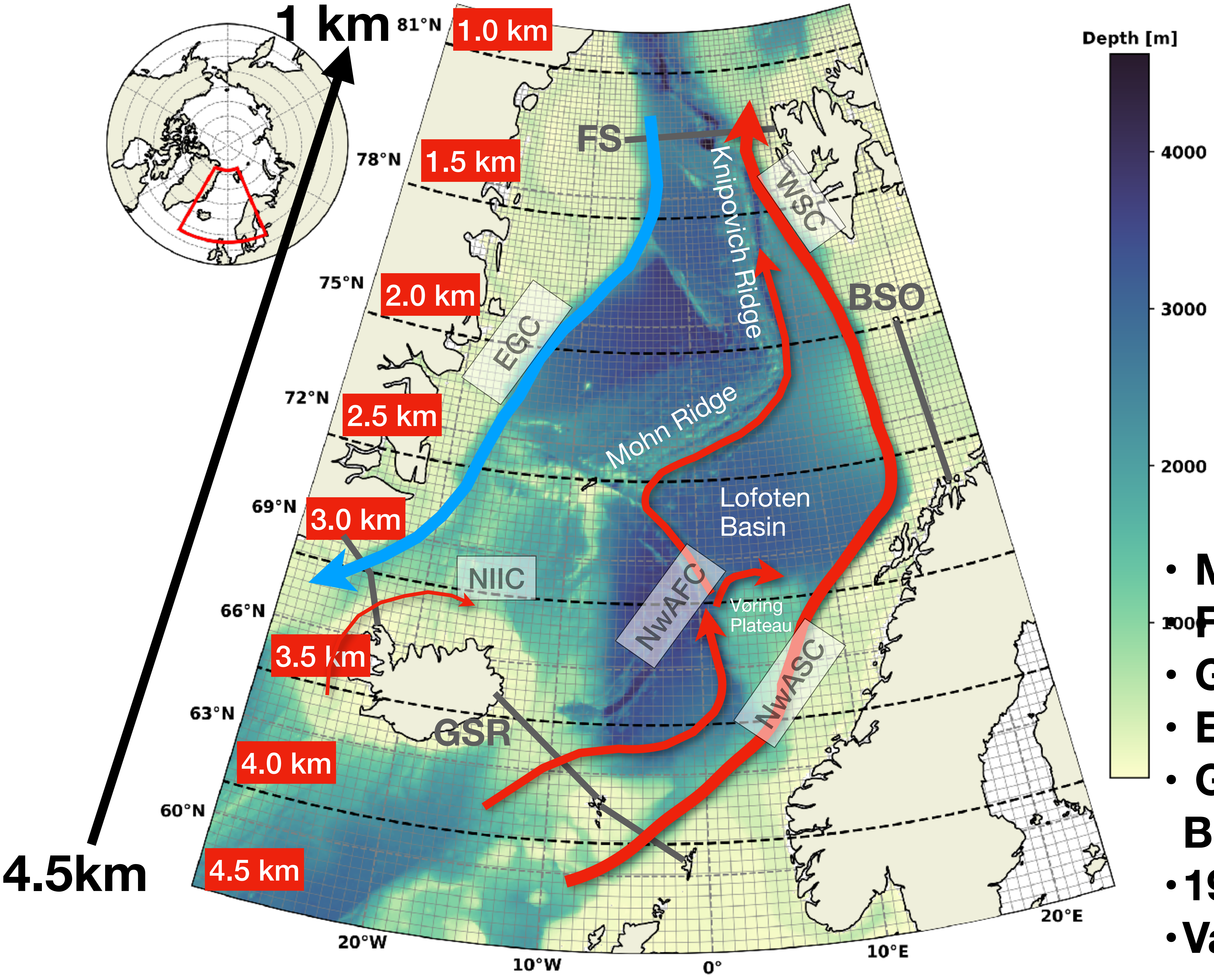
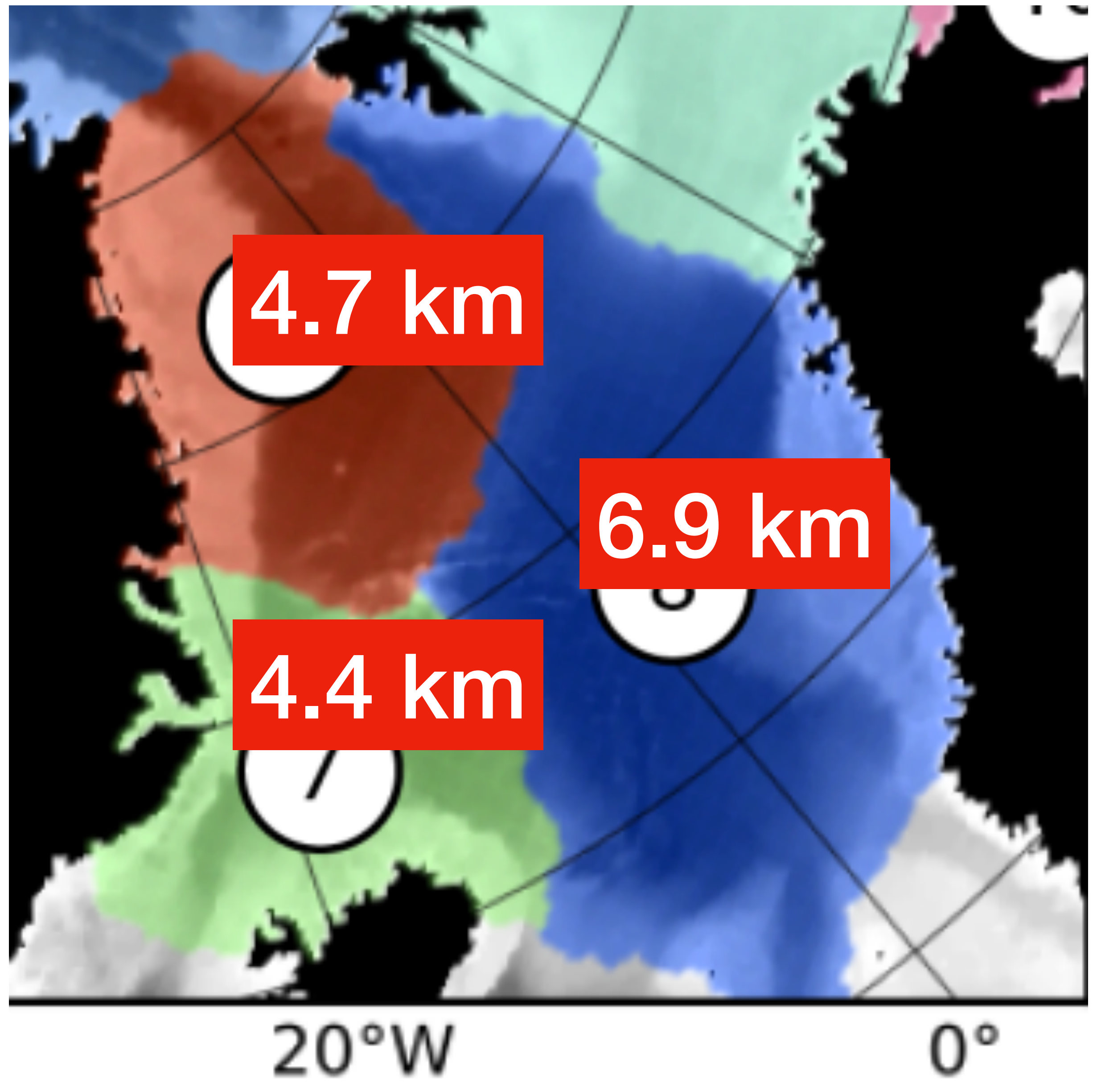


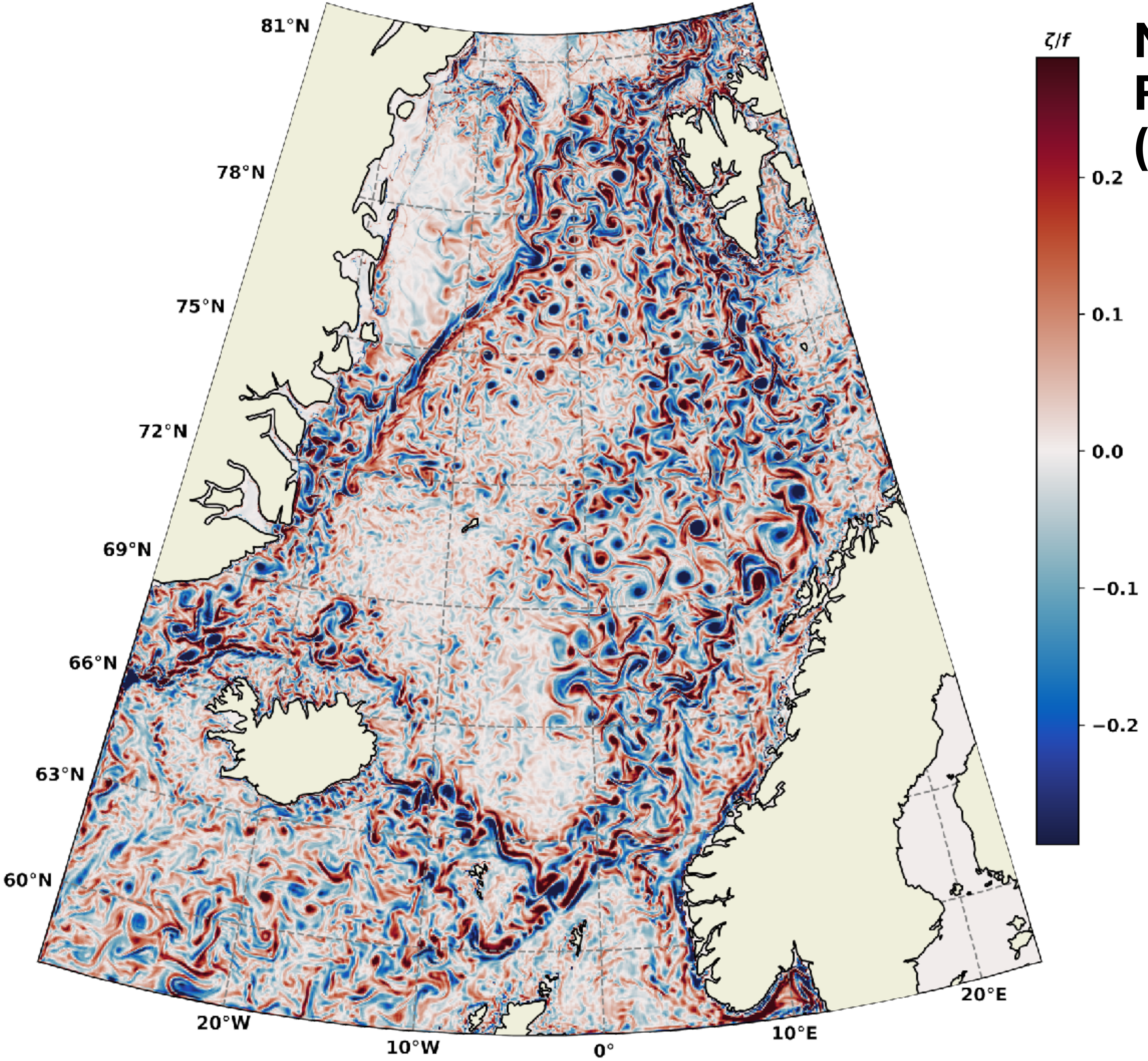
Rossby radius



Nurser, A. J. G., & Bacon, S. (2014)

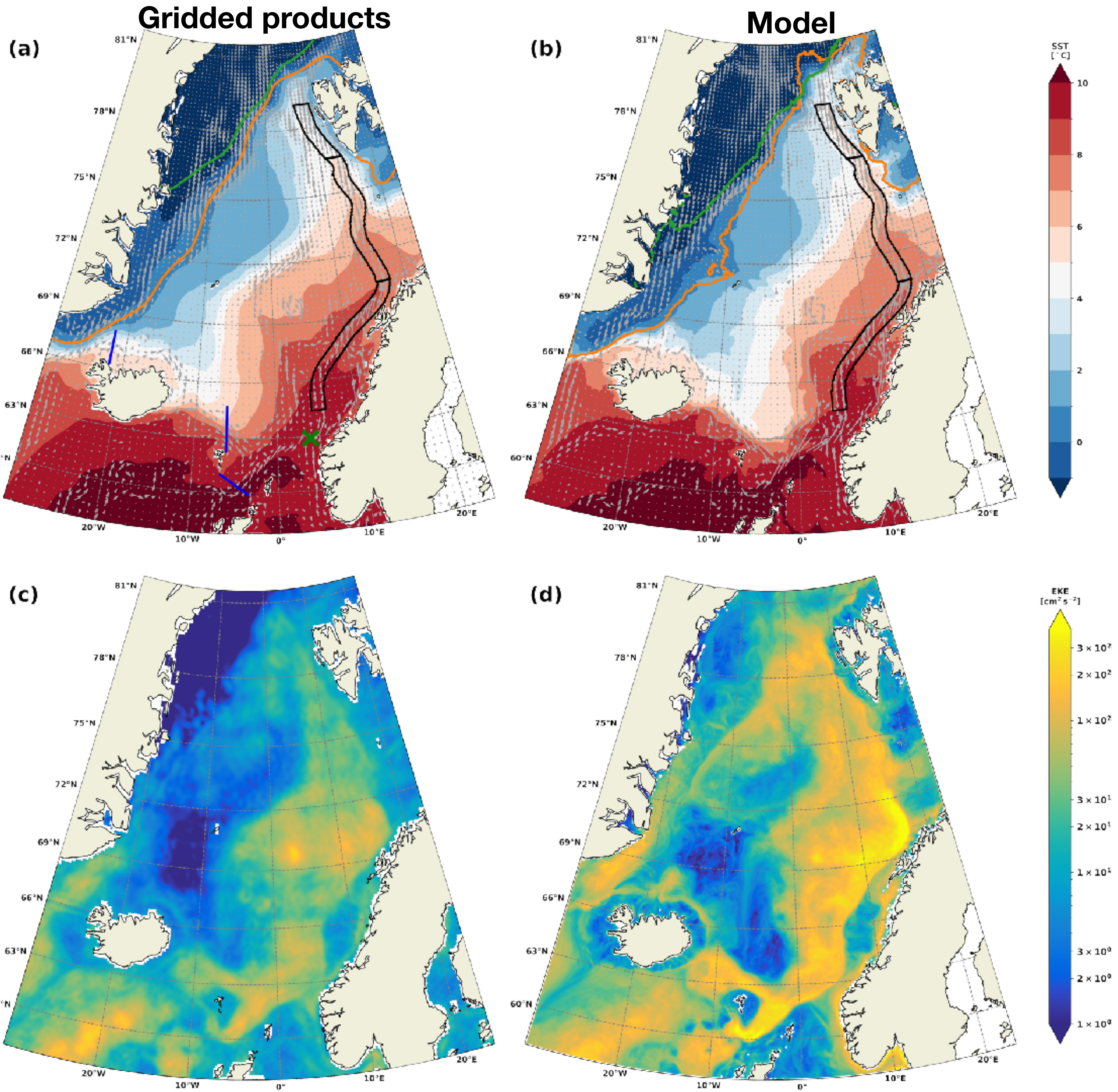
- MITgcm
- Forced by ERA5
- GLORYS
- Eddy-permitting ~ resolving
- Greenland runoff from Bamber et al 2018
- 1993-2016
- Variable bottom drag coef

Normalized Surface Relative Vorticity (Ro)



SST/ velocity

EKE



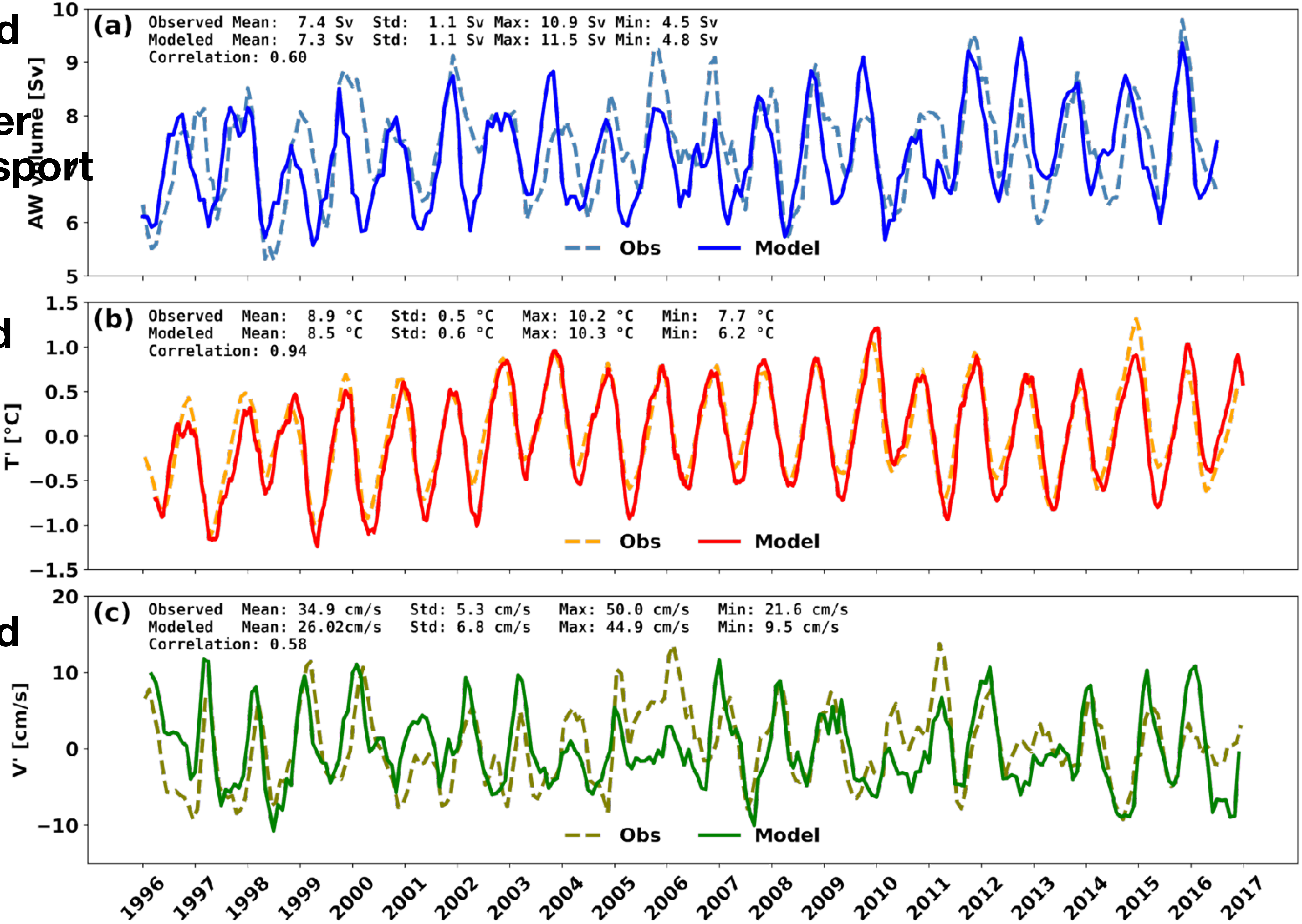
Offshore branch NwAFC is weaker

Onshore NwASC seems realistic compared to moored T and V

Modelled and observed Atlantic Water Volume transport

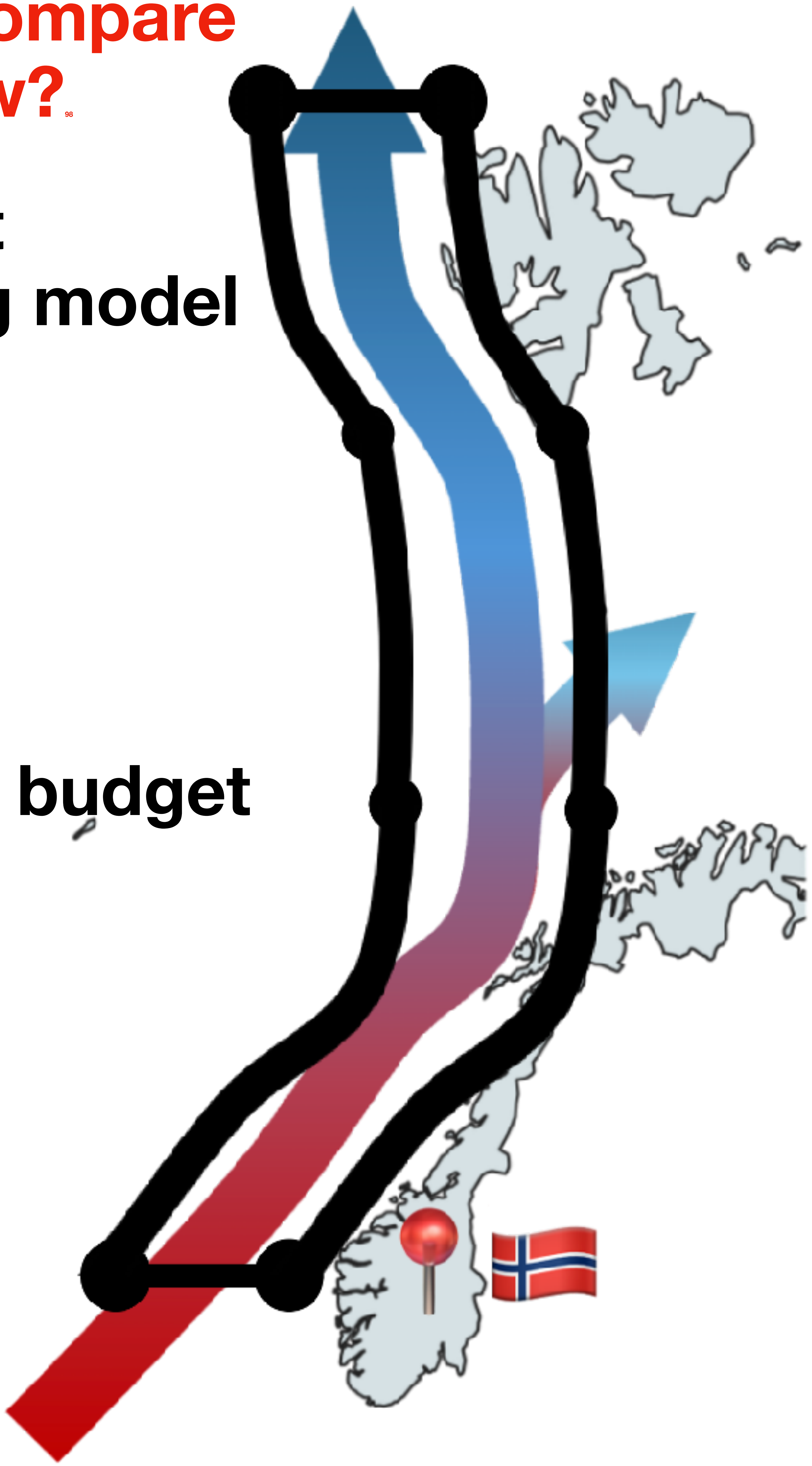
Modelled and moored T’

Modelled and moored V’



Question: How does the eddy-induced heat transport compare to air-sea heat fluxes or heat transport by the mean flow?

Motivation: Eddy heat fluxes suggested to be important surface observation (Isachsen et al 2012) and 1D mixing model (Huang et al 2023), a budget analysis is lacking due to modeling challenge



Methods:

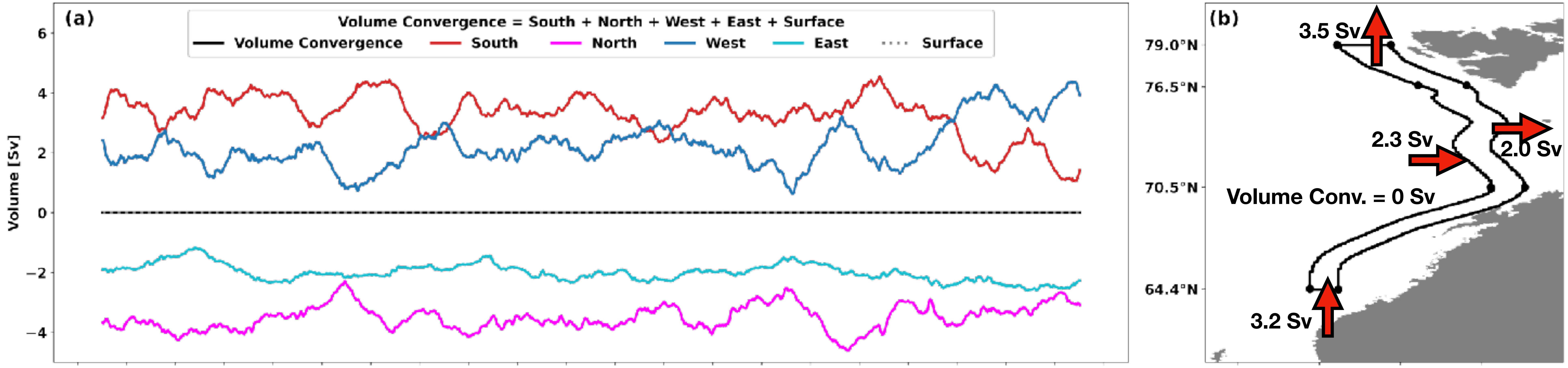
1. Define a "strip" along the current —> 2. volume/heat budget

3. Reynolds Decomposition to identify eddy

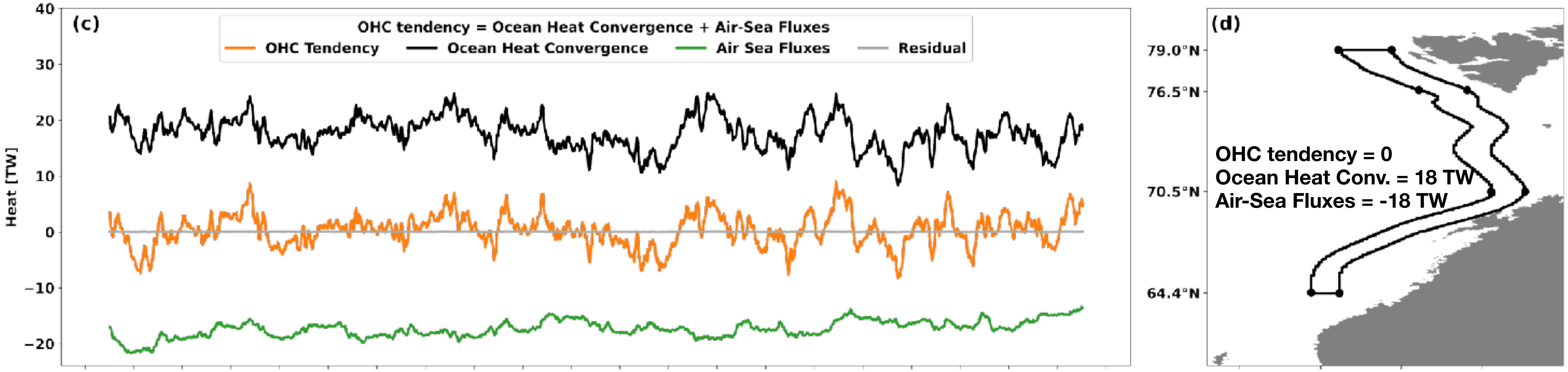
$$T = \overline{T}_{\text{clim}} + T', \qquad \mathbf{V} = \overline{\mathbf{V}}_{\text{clim}} + \mathbf{V}'$$

Seasonal climatological cycle, e.g., mean over DJF, MAM, JJA, SON in 1996-2016

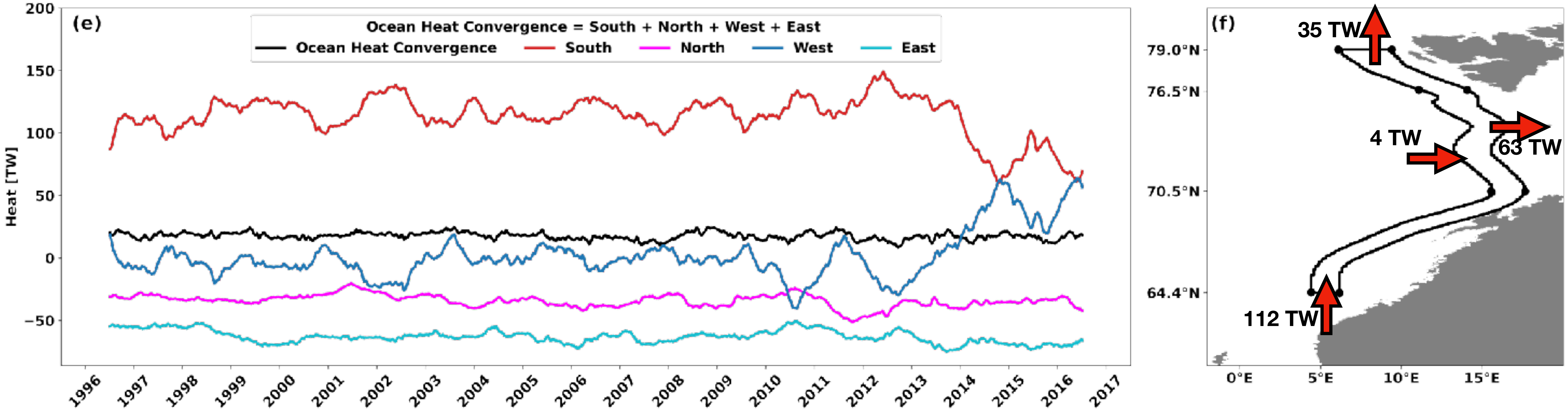
Volume budget

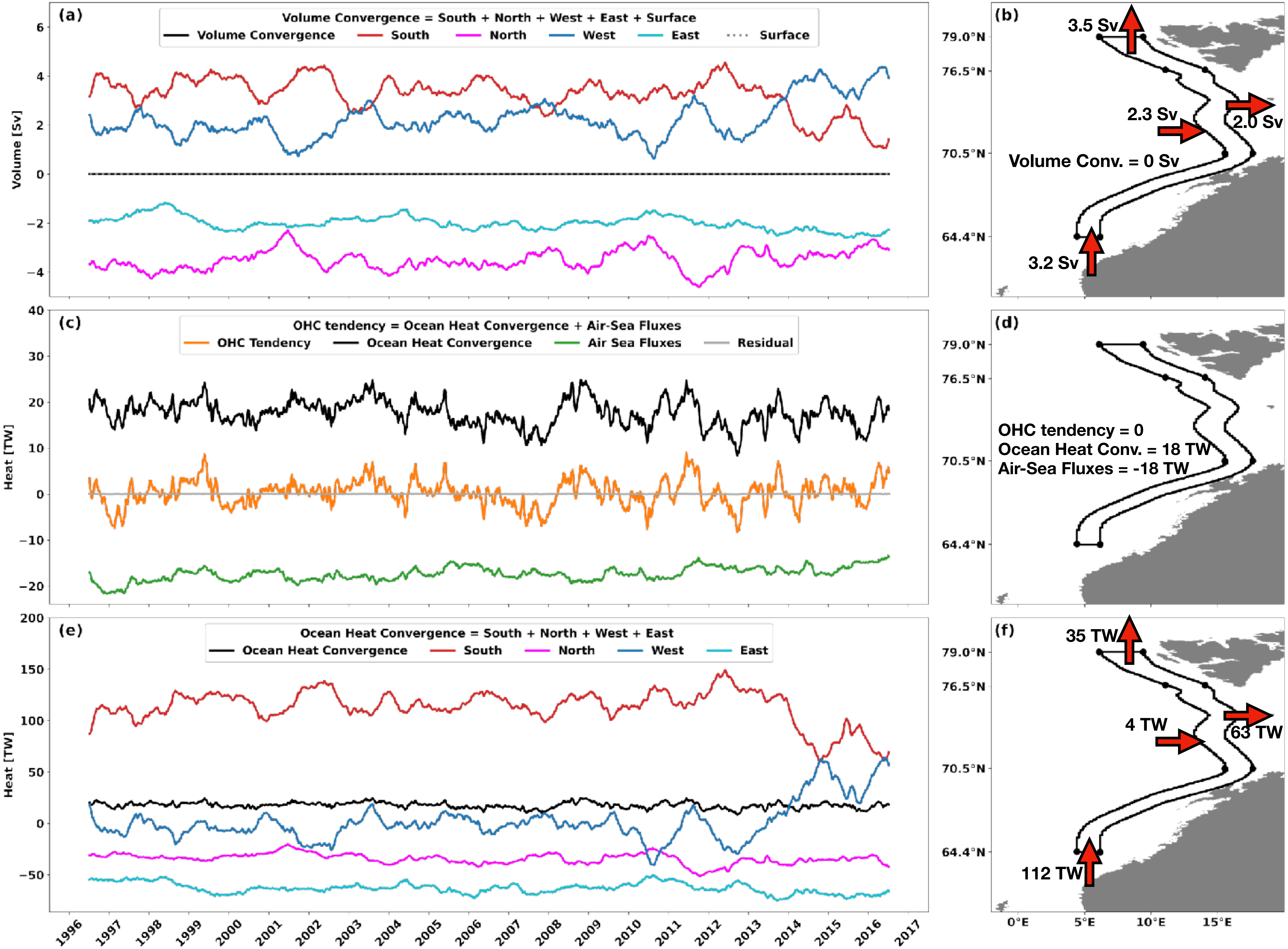


Heat budget



Ocean heat convergence attributed to boundaries with $T_{\text{ref}} = 0^\circ\mathrm{C}$




(a)
Volume Convergence = South + North + West + East + Surface
Volume Convergence
South
North
West
East
Surface
Volume [Sv]
6
4
2
0
−2
−4
(b)
3.5 Sv
2.3 Sv
2.0 Sv
Volume Conv. = 0 Sv
3.2 Sv
79.0°N
76.5°N
70.5°N
64.4°N
(c)
OHC tendency = Ocean Heat Convergence + Air-Sea Fluxes
OHC Tendency
Ocean Heat Convergence
Air Sea Fluxes
Residual
Heat [TW]
40
30
20
10
0
−10
−20
(d)
OHC tendency = 0
Ocean Heat Conv. = 18 TW
Air-Sea Fluxes = -18 TW
79.0°N
76.5°N
70.5°N
64.4°N
(e)
Ocean Heat Convergence = South + North + West + East
Ocean Heat Convergence
South
North
West
East
Heat [TW]
200
150
100
50
0
−50
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
(f)
35 TW
4 TW
63 TW
112 TW
79.0°N
76.5°N
70.5°N
64.4°N
0°E
5°E
10°E
15°E

Heat budget

$$\underbrace{\rho C_p \int_V \frac{\partial T}{\partial t}\, dV}_{\text{OHC tendency}} = \underbrace{\rho C_p \int_V - \nabla \cdot (\overline{\mathbf{V}}_{\text{clim}}\, \overline{T}_{\text{clim}})\, dV}_{\text{mean flow}} + \underbrace{\rho C_p \int_V - \nabla \cdot \langle \mathbf{V}'T' \rangle\, dV}_{\text{eddy}} + \underbrace{\int_V Q_{\text{atm}}\, dV}_{\text{Air-sea fluxes}}$$

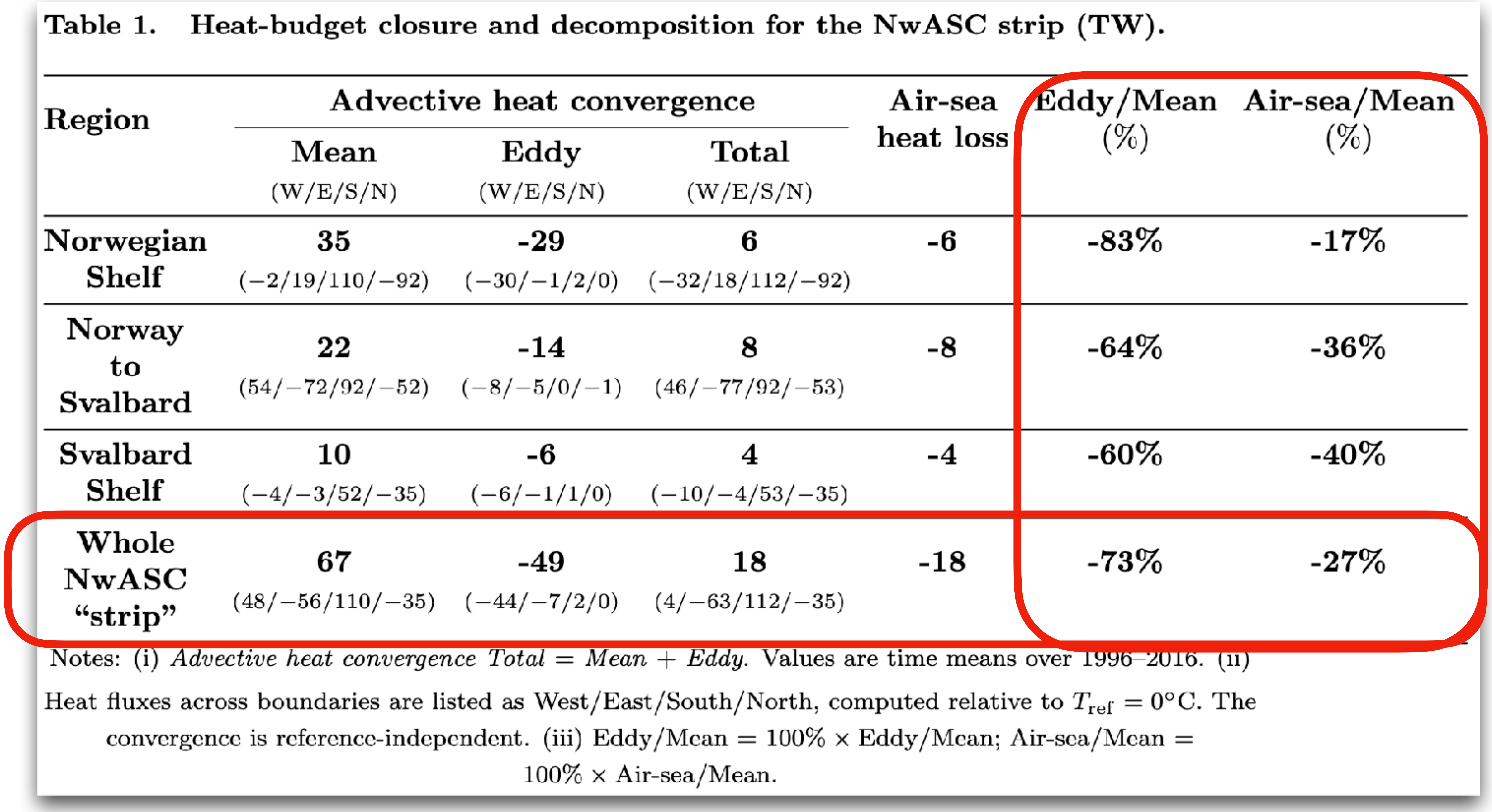


Table 1. Heat-budget closure and decomposition for the NwASC strip (TW).

Region	Advective heat convergence			Air-sea heat loss	Eddy/Mean (%)	Air-sea/Mean (%)
	Mean (W/E/S/N)	Eddy (W/E/S/N)	Total (W/E/S/N)			
Norwegian Shelf	35 (−2/19/110/−92)	-29 (−30/−1/2/0)	6 (−32/18/112/−92)	-6	-83%	-17%
Norway to Svalbard	22 (54/−72/92/−52)	-14 (−8/−5/0/−1)	8 (46/−77/92/−53)	-8	-64%	-36%
Svalbard Shelf	10 (−4/−3/52/−35)	-6 (−6/−1/1/0)	4 (−10/−4/53/−35)	-4	-60%	-40%
Whole NwASC "strip"	67 (48/−56/110/−35)	-49 (−44/−7/2/0)	18 (4/−63/112/−35)	-18	-73%	-27%

Notes: (i) *Advective heat convergence Total* = *Mean* + *Eddy*. Values are time means over 1996–2016. (ii) Heat fluxes across boundaries are listed as West/East/South/North, computed relative to $T_{\text{ref}} = 0°\text{C}$. The convergence is reference-independent. (iii) Eddy/Mean = 100% × Eddy/Mean; Air-sea/Mean = 100% × Air-sea/Mean.

Spatial pattern

$$\underbrace{\rho C_p \int_V \frac{\partial T}{\partial t}\, dV}_{\text{OHC tendency}} = \underbrace{\rho C_p \int_V -\nabla\cdot(\overline{\mathbf{V}}_{\text{clim}}\,\overline{T}_{\text{clim}})\, dV}_{\text{mean flow}} + \underbrace{\rho C_p \int_V -\nabla\cdot\langle \mathbf{V}'T'\rangle\, dV}_{\text{eddy}} + \underbrace{\int_V Q_{\text{atm}}\, dV}_{\text{Air-sea fluxes}}$$

Heat conv./div. by mean flow

Eddy heat conv./div.

Net air-sea heat loss

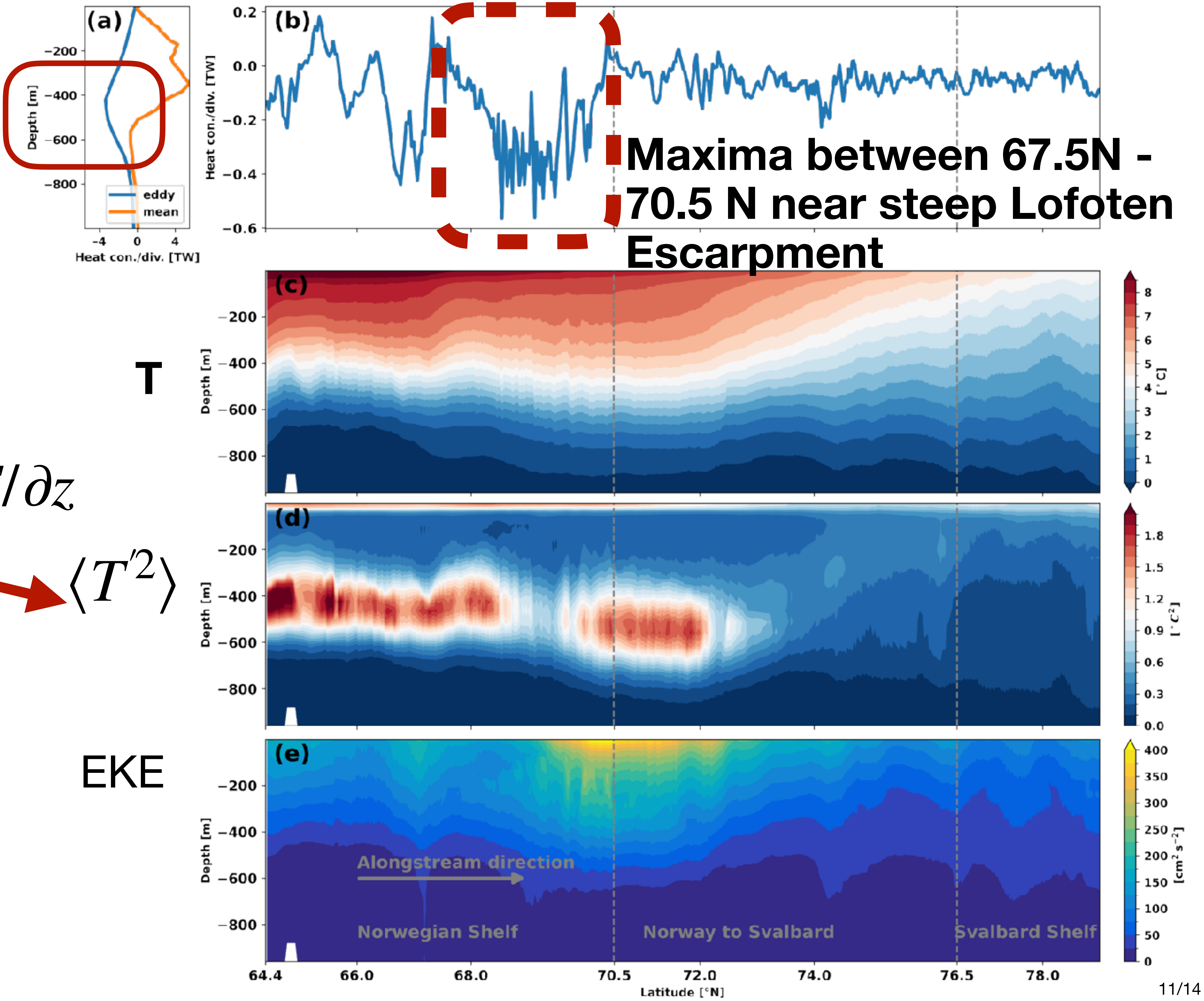
Eddy heat flux vectors

Depth and latitudinal dependence

$$\rho C_p \int_{?} -\nabla \cdot \langle \mathbf{V}'T' \rangle \, d?$$

Centered at ~ 400 m, associated with temperature gradient $\partial T/\partial z$

$\langle T'^2 \rangle$



Maxima between 67.5N - 70.5 N near steep Lofoten Escarpment

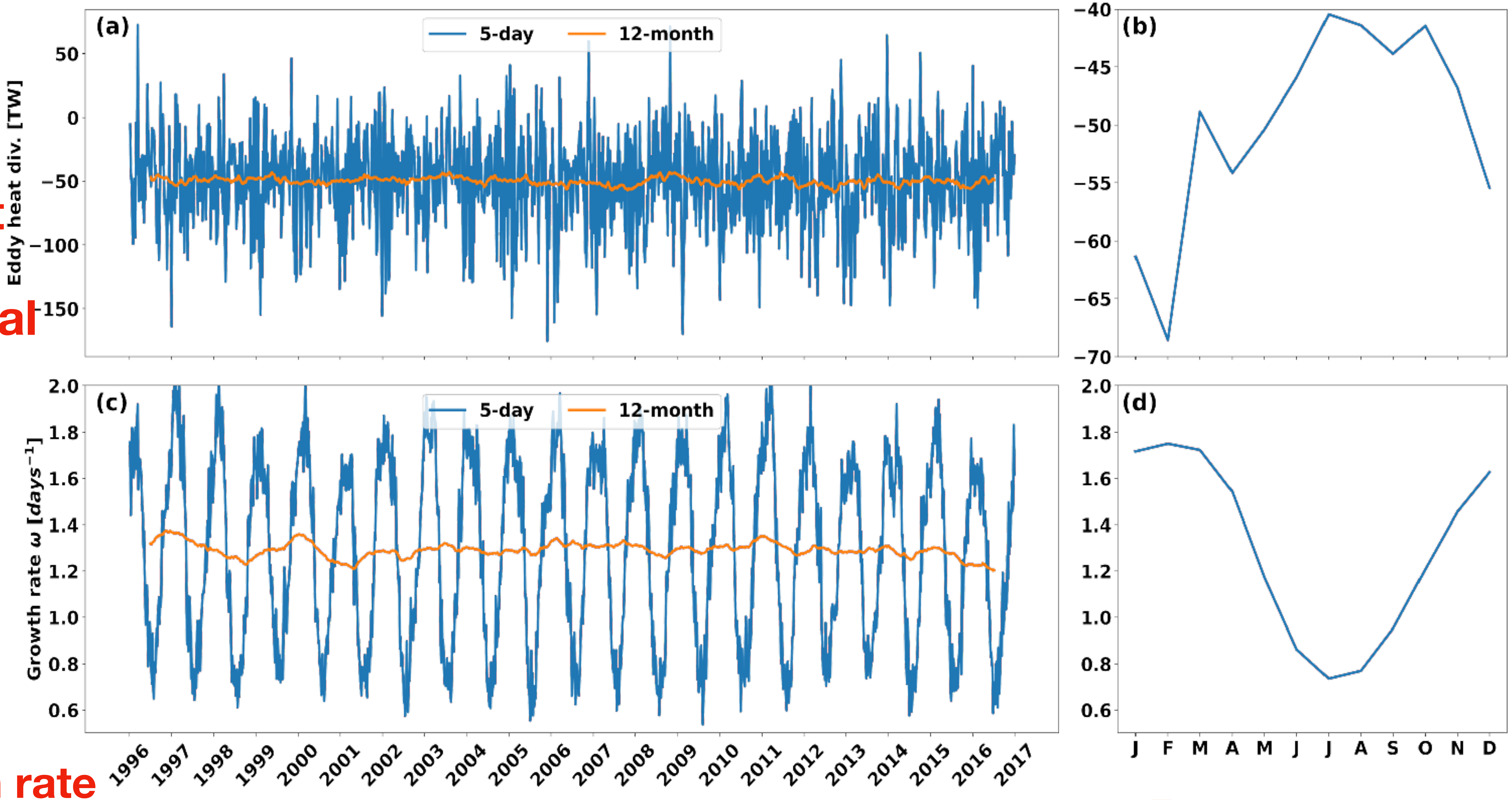
T

EKE

Temporal variability

$$\rho C_p \int_V - \nabla \cdot \mathbf{V}'T'\, dV$$

Stable eddy heat divergence ~ 49 TW on interannual timescale



Stable Eady growth rate (Baroclinic instability) on interannual timescale

But obvious seasonality

Takeaways

- Eddy heat divergence (cooling) along the Norwegian Atlantic Slope Current (NwASC) largely offsets more than 70% heat convergence (warming) by the mean flow

- Eddy heat divergence peaks subsurface (near steepest Lofoten Islands)

- Eddy heat divergence remains relatively stable on interannual timescales, even though obvious seasonality

Ongoing ideas:

Deep Eddies in Fram Strait; convective vortex in Greenland Sea; Marginal Sea ice; Freshwater in EGC

e.g, Long-lived / depth-intensified vortex in Greenland Sea & linkage with deep convection

Can modellers life be easier?

As easy as online shopping?

Configure a model by drawing a region

- Inputs-ready
- Bugs-avoided

Run a model fast and cheap

- Cloud-hosted
- Computation-optimized
- Analysis-ready, e.g, budget closure

Integrate specific needs/functions

- Data assimilation
- Sensitivity Experiments
- Senario-experiments
- Pre-cooked Validation

Operate for services

- Science question
- Policy-informing
- Shipping routes
- Aquaculture
- Environment-monitoring
- Early-warning