An Idealised Modelling Study of an Arctic Dense Water Cascade Piercing the Atlantic Layer

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RESEARCH WITH PLYMOUTH UNIVERSITY

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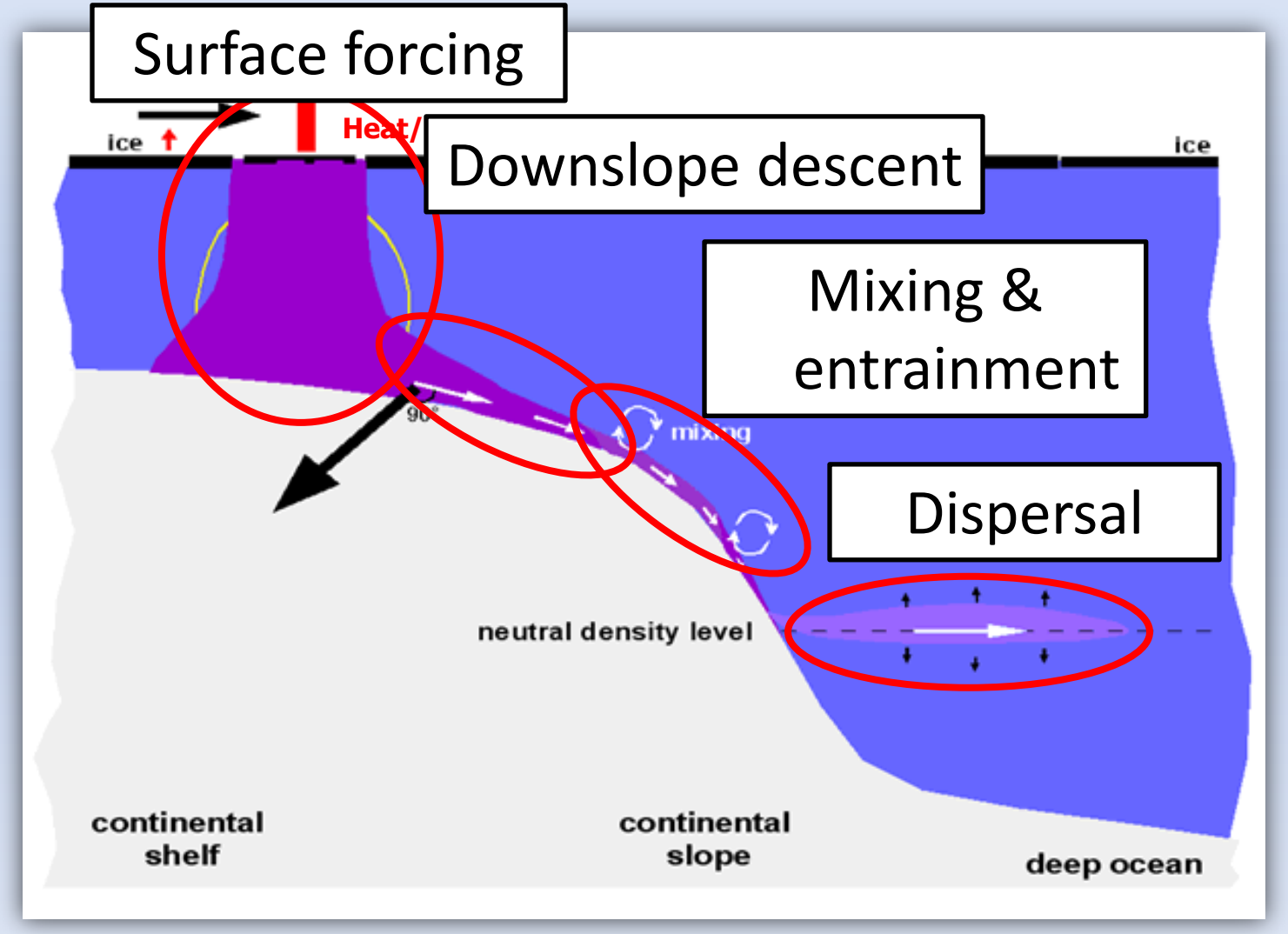
Dense water cascades



Graphics: RAPID project, NOC-L

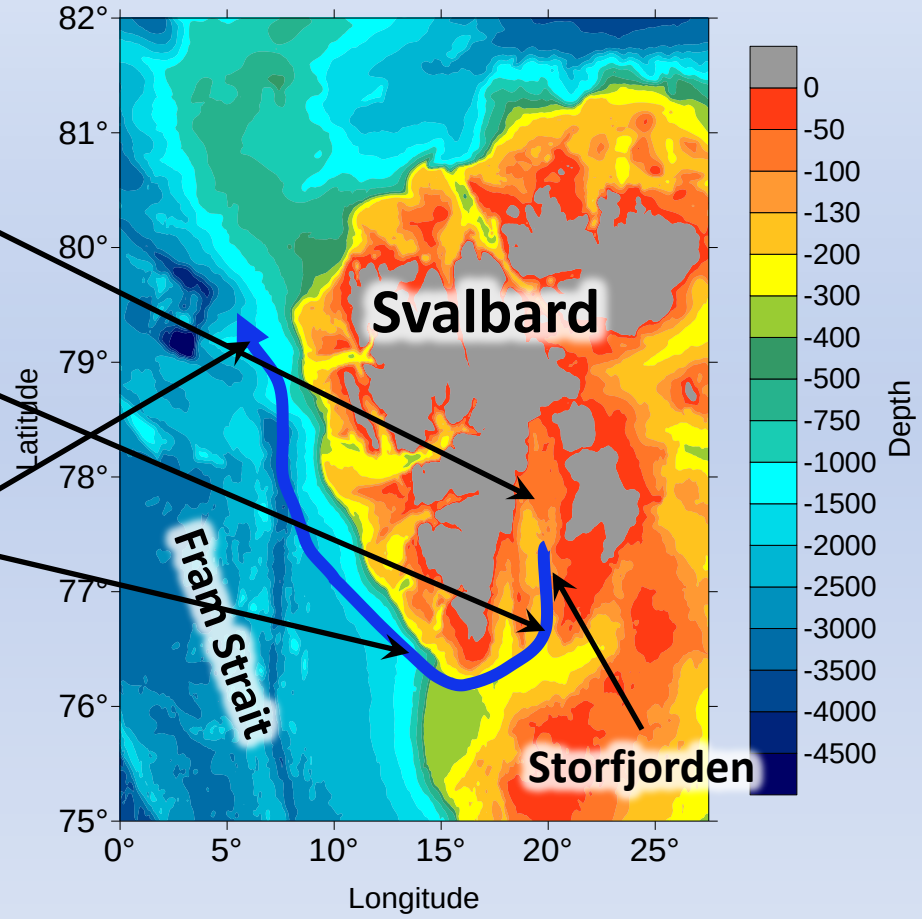
Storfjorden

Dense water formation

Sill at 115m

Plume encounters Atlantic Water at ~200-500m

In some years plume sinks to >2000m



Path: Quadfasel *et al.* (1988), Fer and Adlandsvik (2008). Bathymetry from IBCAO 2.23 (Jakobsson *et al.*, 2008)

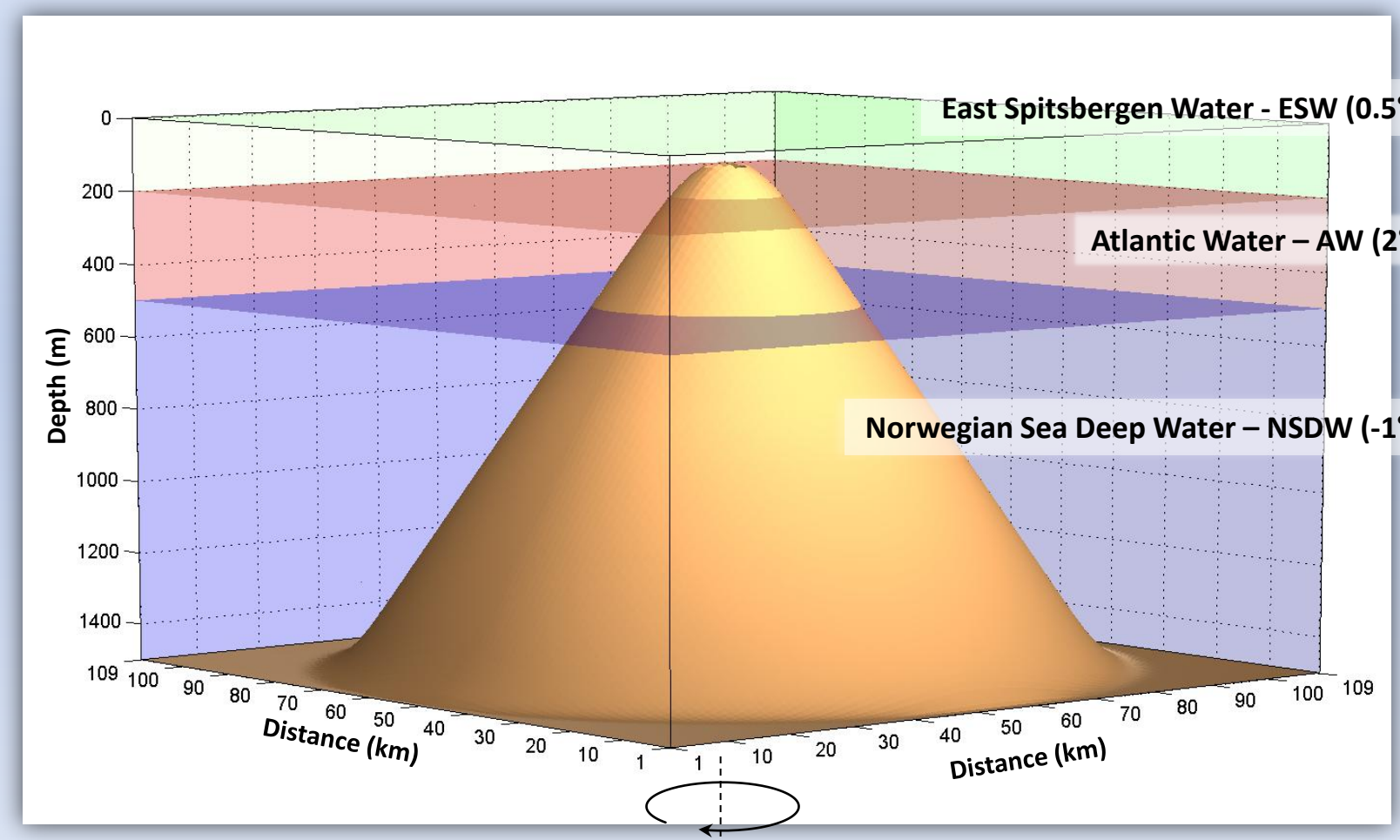
The big question

- In some years the Storfjorden cascade has been observed to **pierce** the Atlantic Layer and reach depths of over 2000m.
- At other times the cascade was **arrested** within the layer of Atlantic Water.
- The **eventual depth** of the cascaded waters has a proven effect on the maintenance of the Arctic halocline and (when piercing occurs) the ventilation of the deep Arctic basins.
- Can we **predict** when the cascade will be arrested and when it will pierce the Atlantic Water?

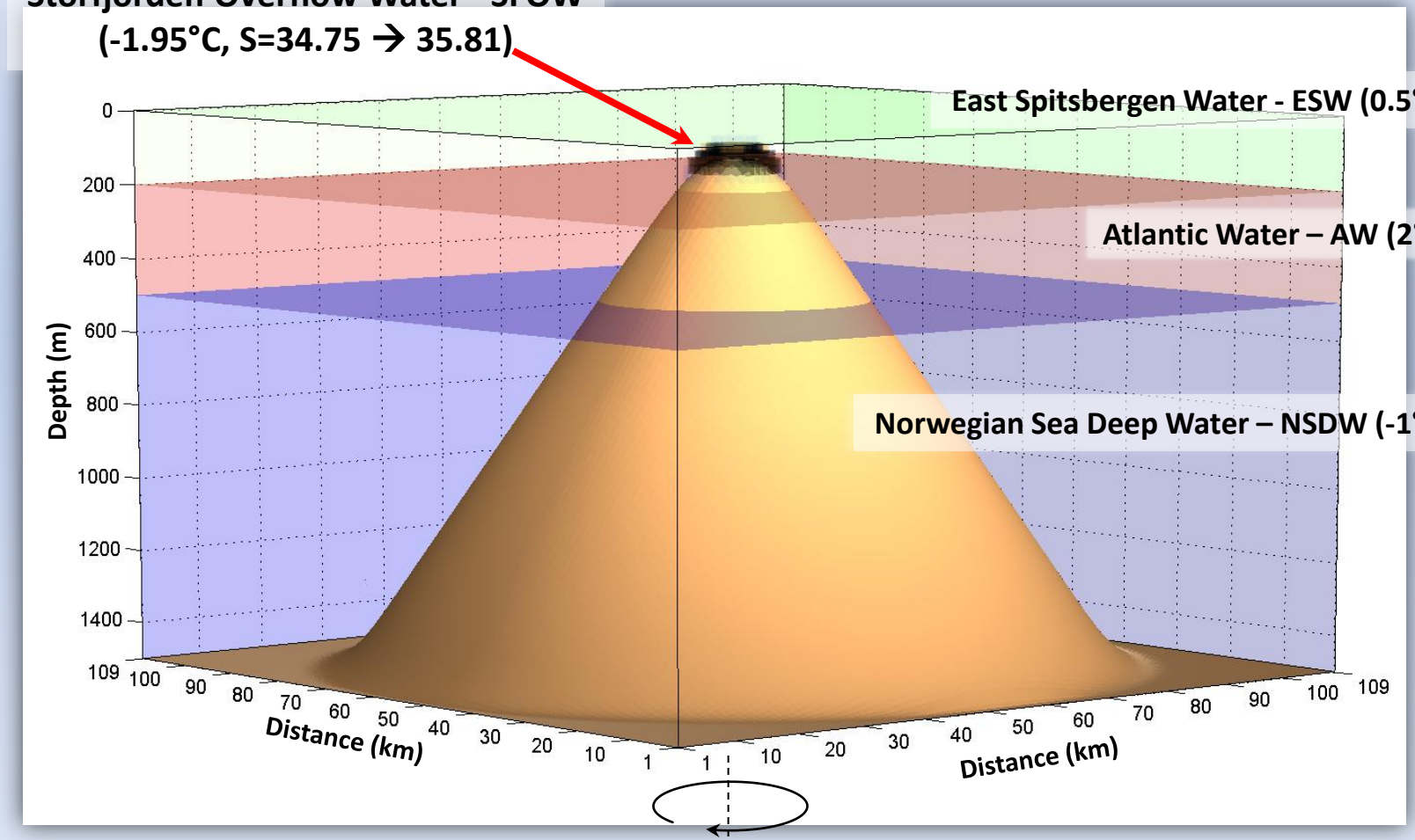
3-D numerical model

- Ocean circulation model **NEMO Shelf v3.2**
- ***Horizontal***: 109 x 109 grid (1km resolution)
- ***Vertical***: 42 levels
  - Modified *s*-coordinate system
    - Ivanov & Watanabe (2011), Enriquez *et al.* (2005)
  - Adapted Laplacian diffusion operator rotation
  - Bottom boundary condition
  - Vertical Piecewise Parabolic advection scheme
  - Pressure Jacobian HPG scheme

Model setup


East Spitsbergen Water - ESW (0.5°C, 34.75)
Atlantic Water – AW (2°C, 35.00)
Norwegian Sea Deep Water – NSDW (-1°C, 34.90)
Depth (m)
0
200
400
600
800
1000
1200
1400
Distance (km)
109 100 90 80 70 60 50 40 30 20 10 1
Distance (km)
1 10 20 30 40 50 60 70 80 90 100 109

Model setup


Storfjorden Overflow Water - SFOW
(-1.95°C, S=34.75 → 35.81)
East Spitsbergen Water - ESW (0.5°C, 34.75)
Atlantic Water – AW (2°C, 35.00)
Norwegian Sea Deep Water – NSDW (-1°C, 34.90)
Depth (m)
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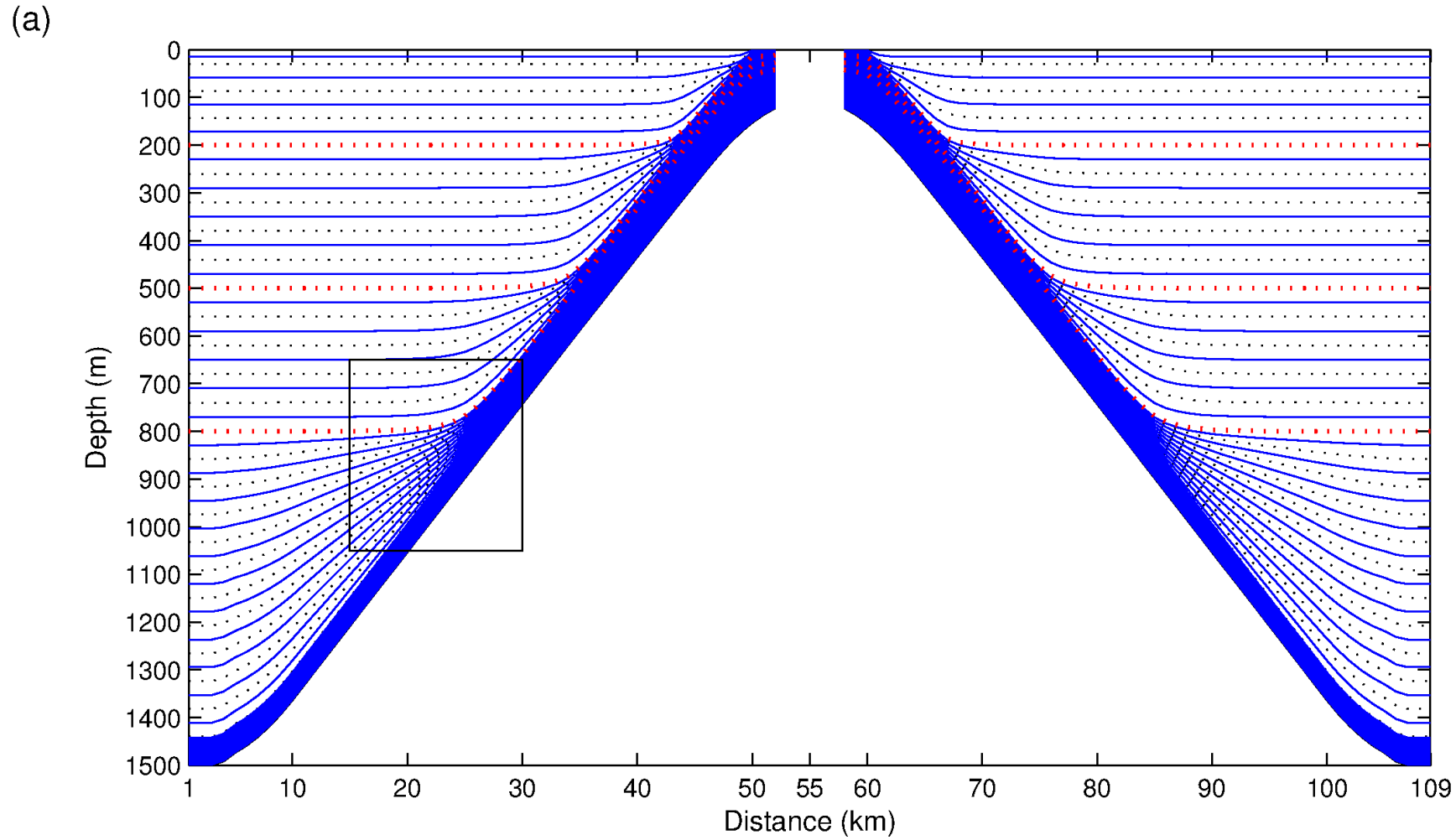
Distance (km)

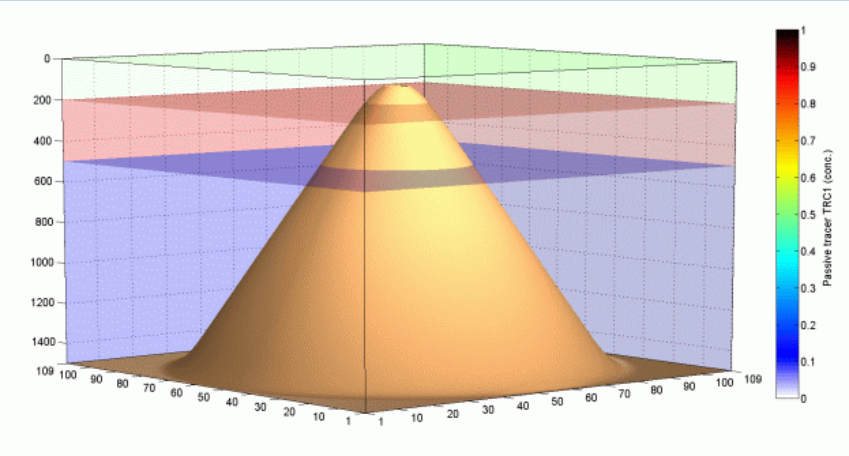
Modified *s*-coord. system



Wobus *et al.* (2012) Ocean Modelling, submitted

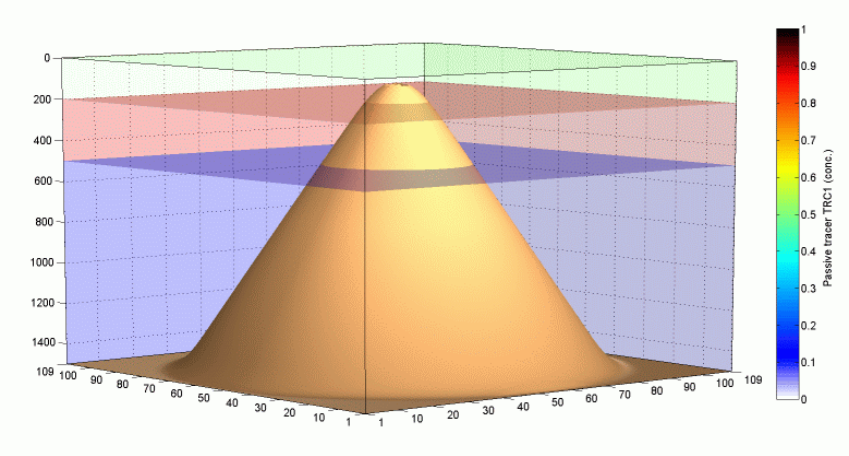
Modelled flow

Arrested within AW



Q = 0.01 Sv, S = 35.40

Piercing into NSDW



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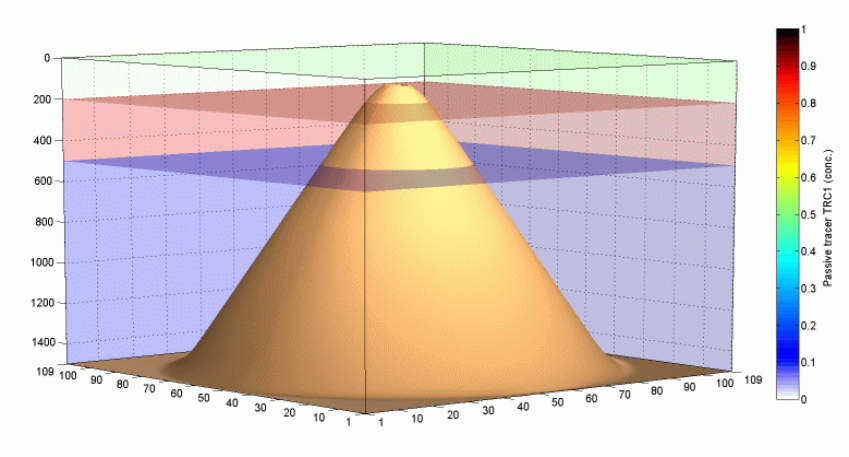
Modelled flow

Arrested within AW



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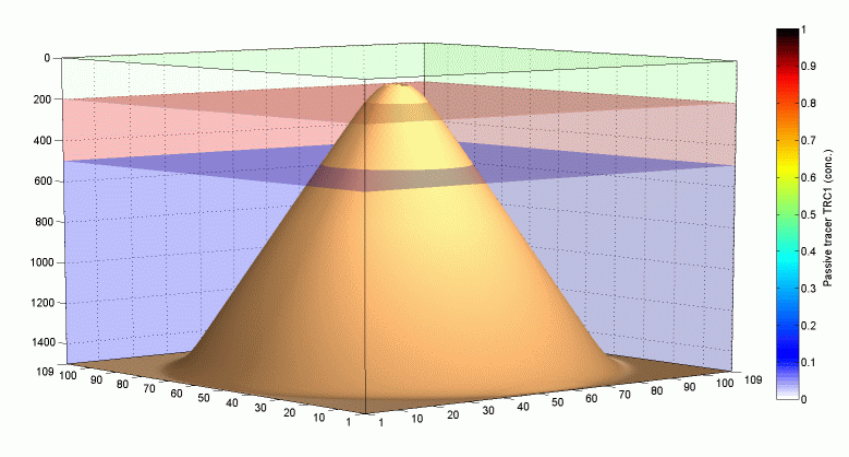

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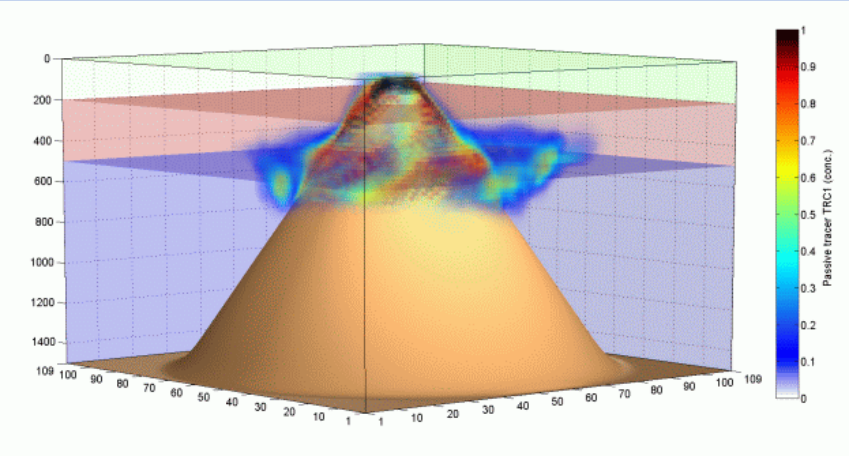
Modelled flow

Arrested within AW



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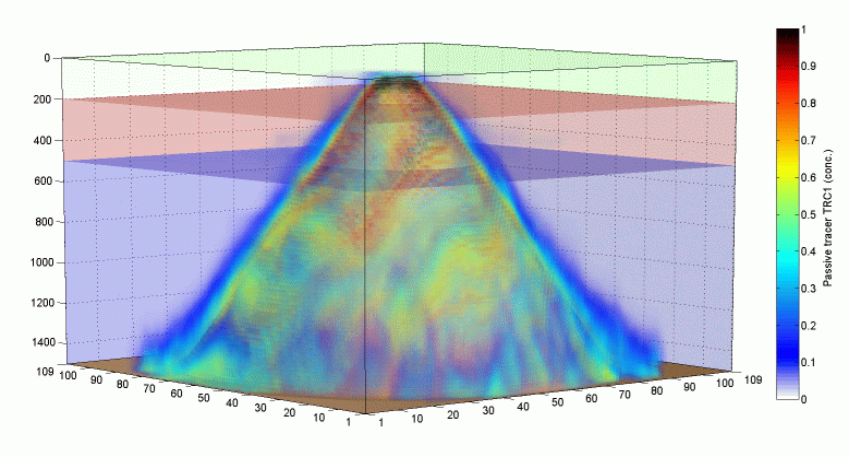


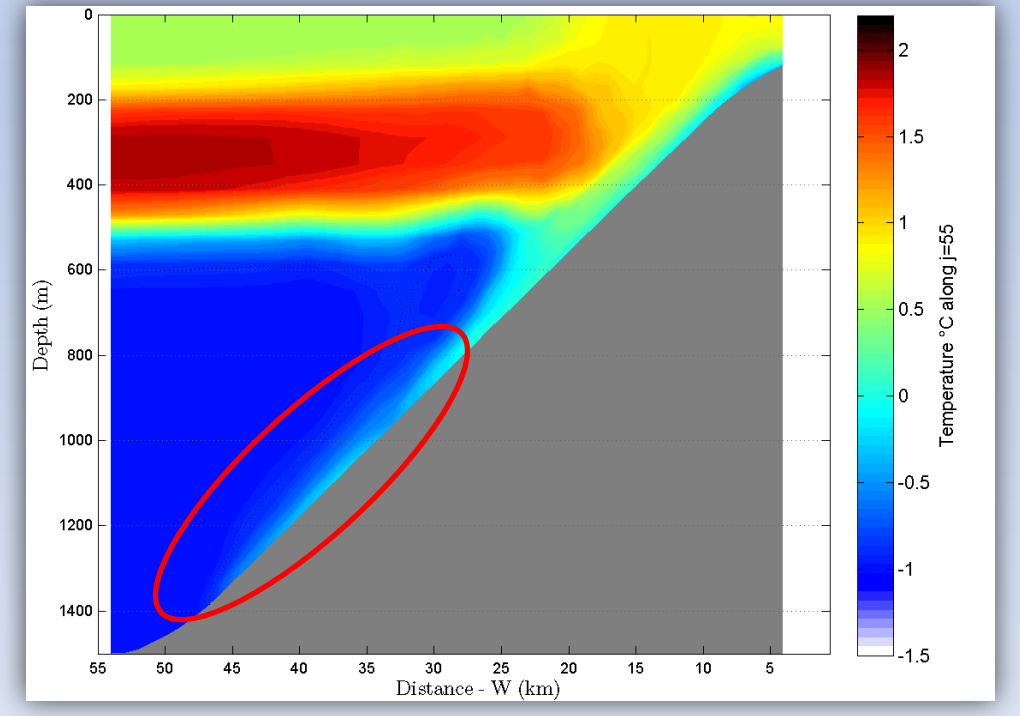
Q = 0.05 Sv, S = 35.20

Wobus *et al.* (2012) Ocean Modelling, submitted

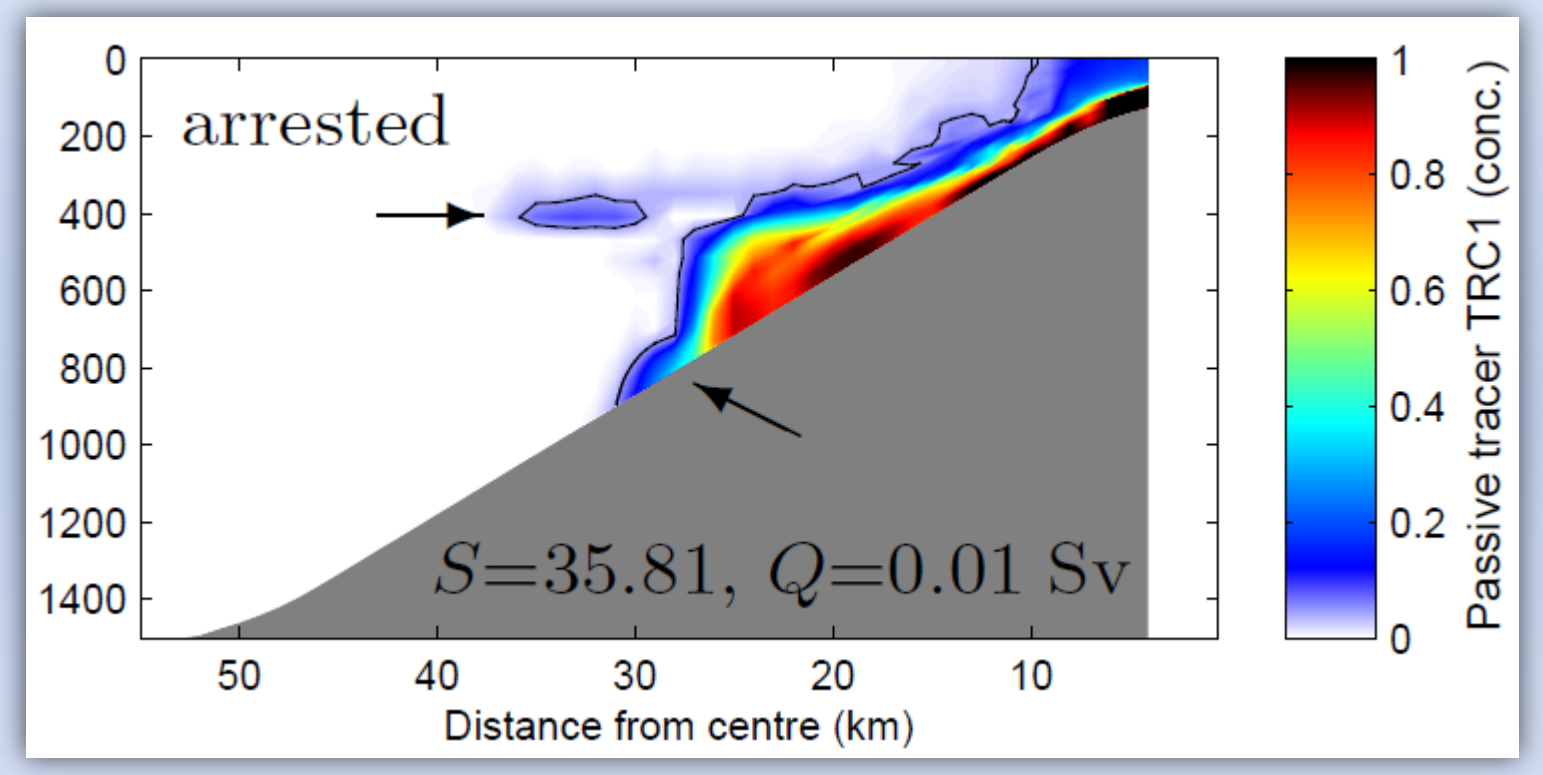
Deep warm signal

- In case of strong cascading the **piercing** of the Atlantic Layer results in a temperature gain in NSDW.

- This is caused by warming of the plume while it propagates through the warm AL



Cascading regimes



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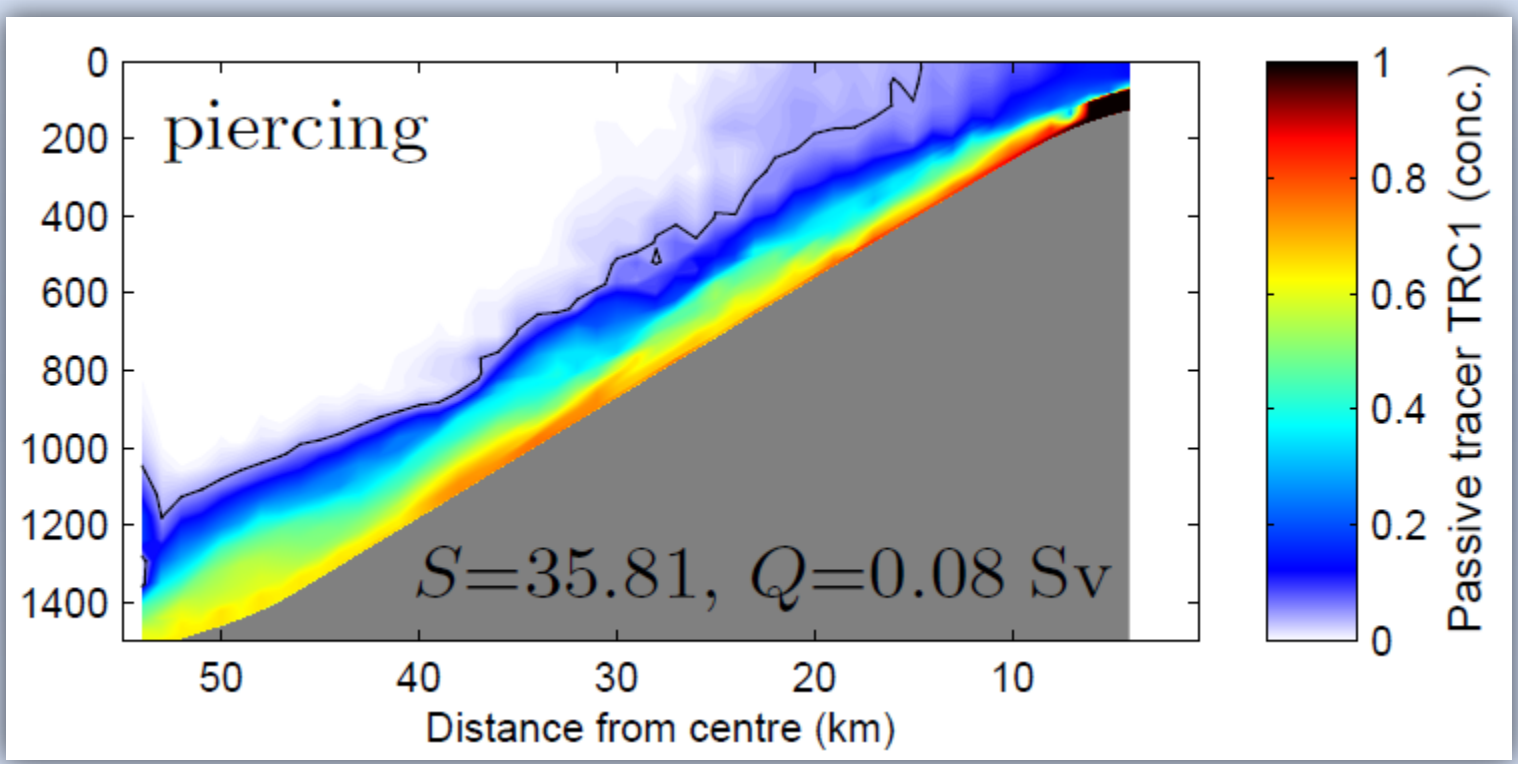

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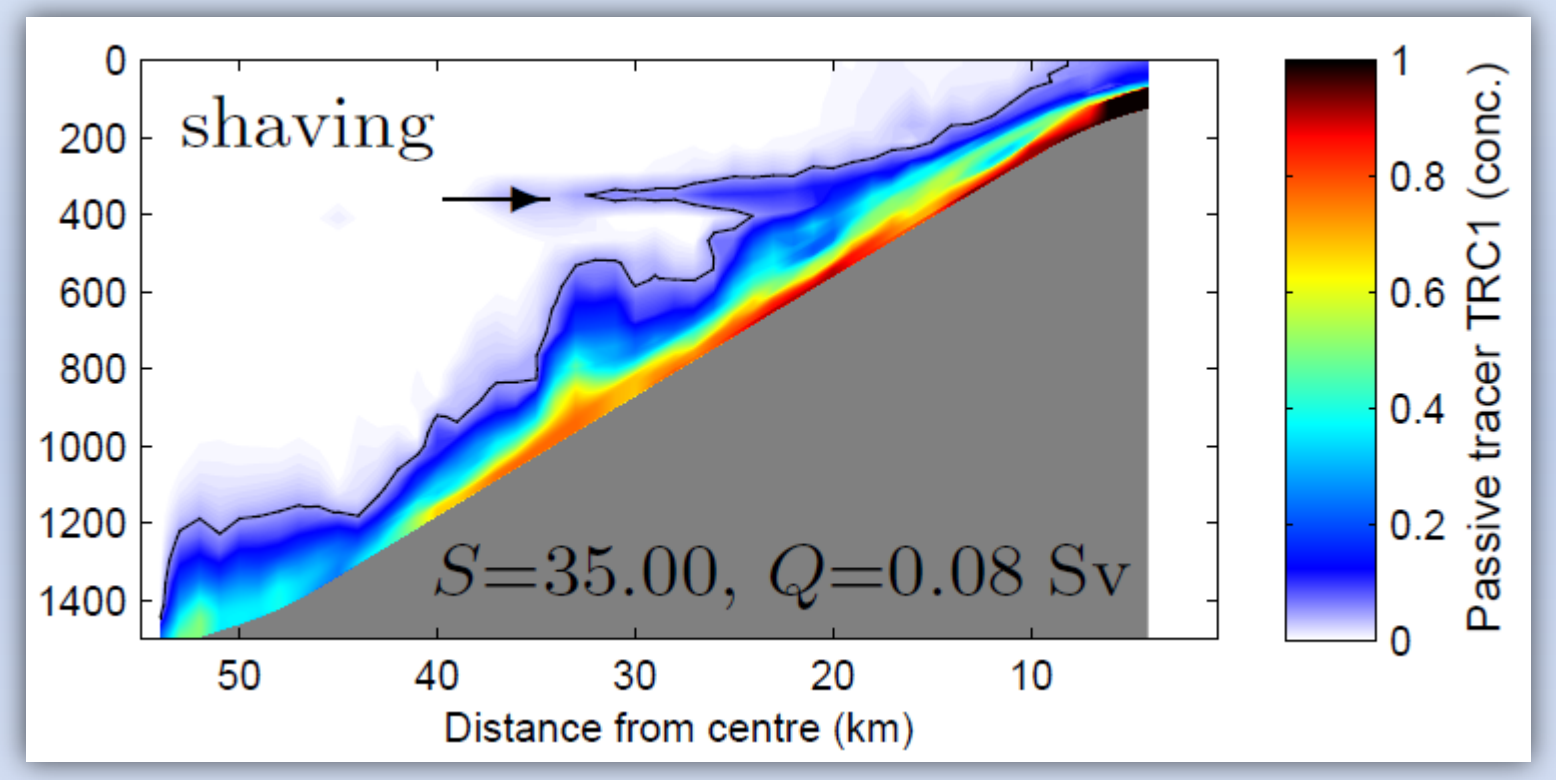
Cascading regimes



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Cascading regimes

- **Arrested**
  - plume remains within or just below the AL
  - Schauer & Fahrbach (1999)
- **Piercing**
  - plume pierces the Atlantic Layer and reaches 1500m
  - Quadfasel *et al.* (1988)

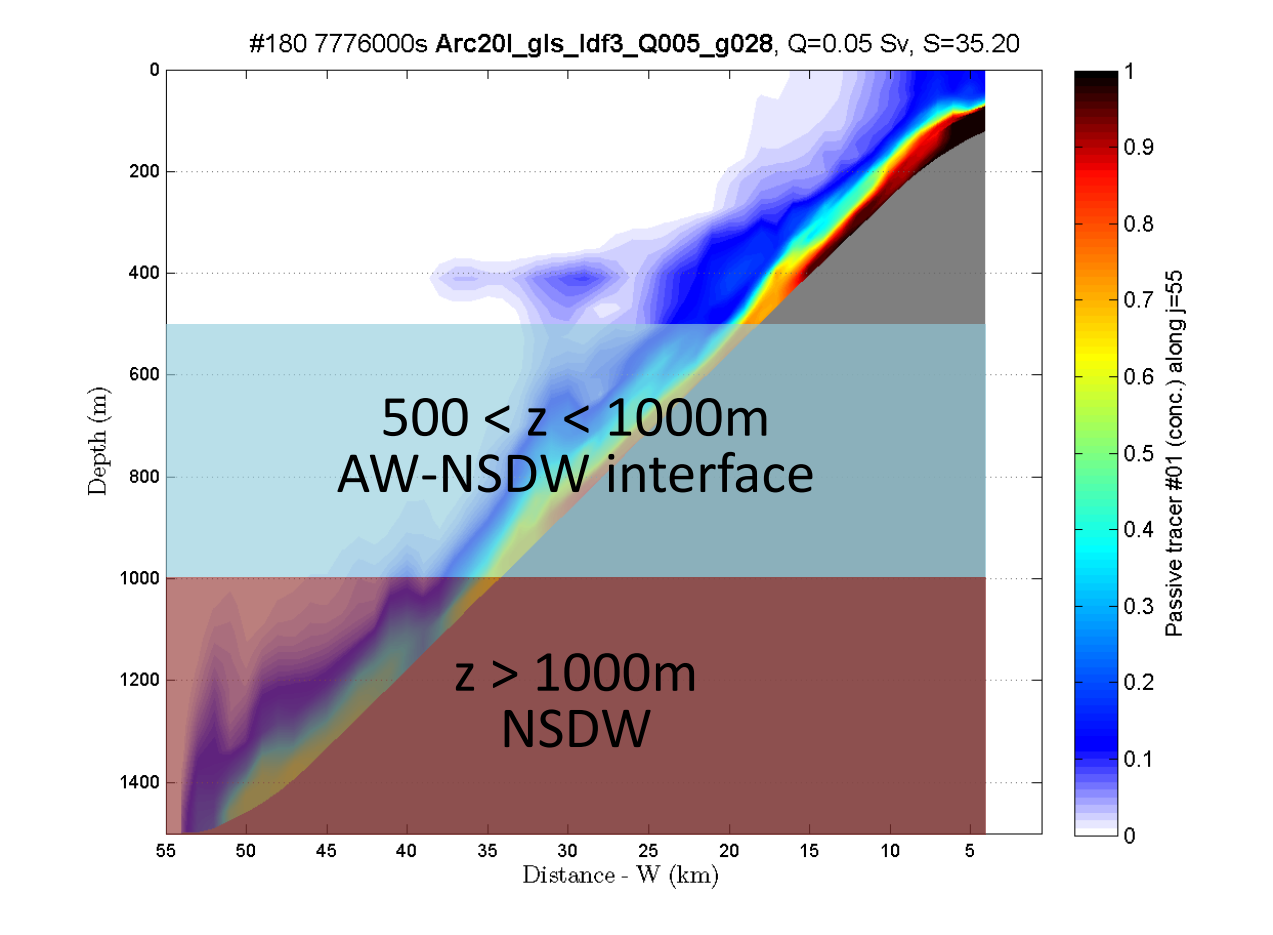
- **Shaving** (*intermediate regime*)
  - a portion of the plume detaches off the bottom, intrudes into the AL while the remainder continues its downslope propagation
  - Inferred from observations by Aagaard *et al.* (1985)

Can the regime be predicted from the initial conditions alone?

- Flow rate ***Q***
- Salinity ***S***

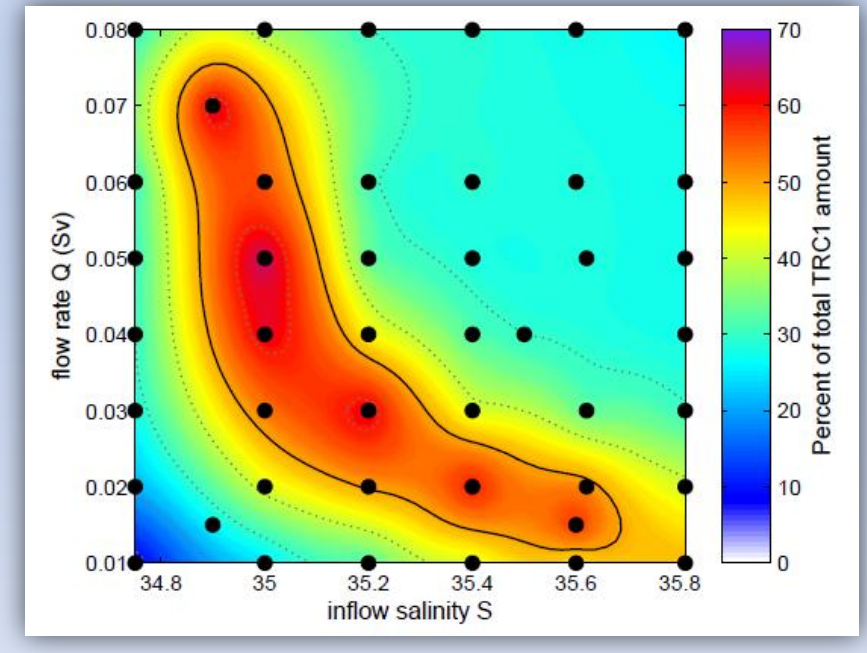
Tracer penetration

$$M_{\mathrm{TRC1}} = \int_V C_{\mathrm{TRC1}}\, dV$$

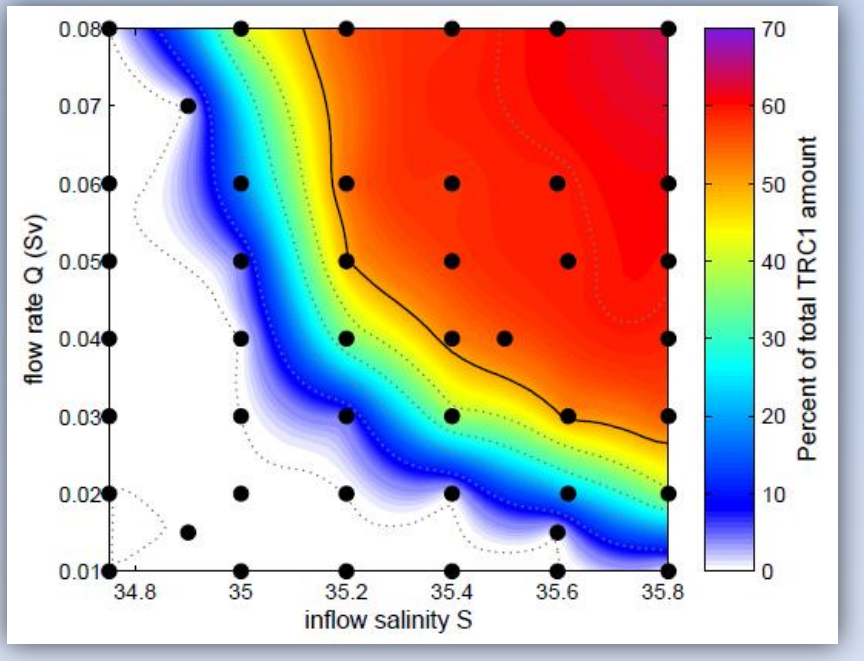


Tracer penetration (S-Q space)

500 < z < 1000m
AW-NSDW interface



z > 1000m
NSDW



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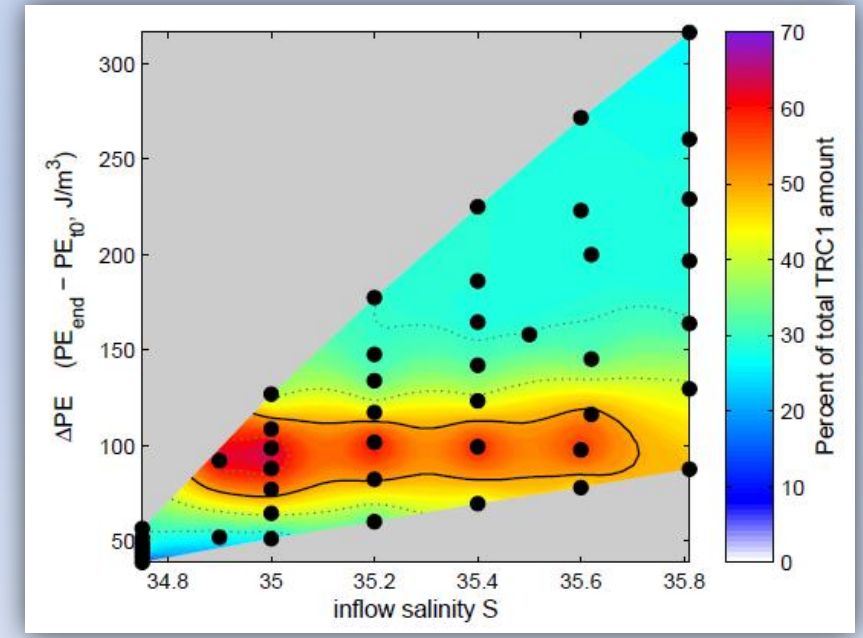
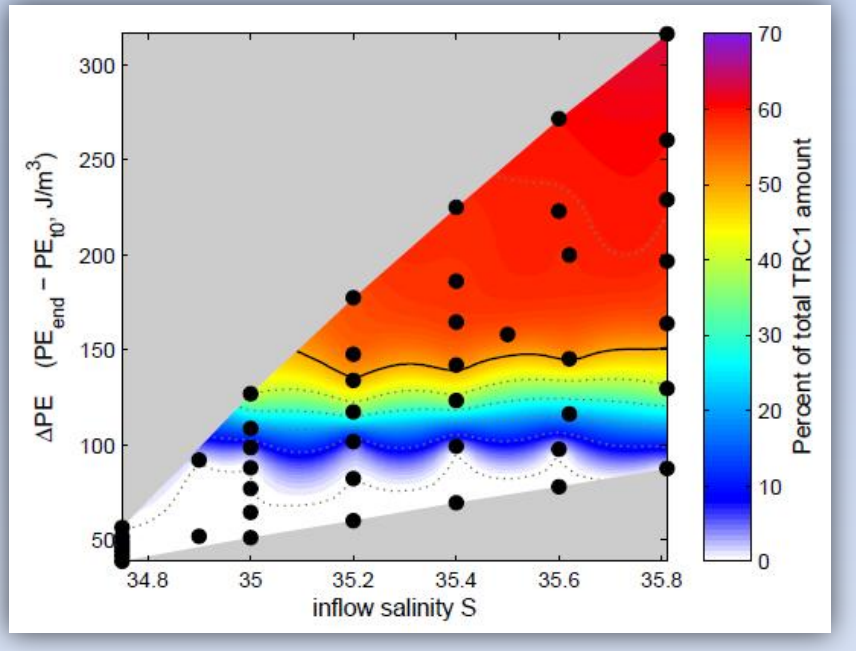
Tracer penetration (S-ΔPE space)

500 < z < 1000m
AW-NSDW interface



z > 1000m
NSDW



NOTE: Y-axis → $\Delta PE = PE_{end} - PE_{t=0}$ ($PE = \frac{1}{V_{tot}} g \int_V \rho z \, dV$, J/m^3)

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Conclusions

- Model reproduces well the essential features of the plume's mixing with Atlantic Water
  - e.g. **temperature increase** at depth, as well as warm upwelling
- Fate of the cascade (e.g. **depth penetration**) is predictable from initial conditions (*S* & *Q*)
  - Crucial forcing parameter is thus the flux of **potential energy** **(ΔPE)** into the system

Thank You

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References

- Wobus, F., G. I. Shapiro, M. A. M. Maqueda, J. M. Huthnance. 2011. Numerical simulations of dense water cascading on a steep slope. *Journal of Marine Research*, **69**, 391–415.
- Quadfasel, D.; Rudels, B. & Kurz, K. , 1988, Outflow of dense water from a Svalbard fjord into the Fram Strait, *Deep-Sea Research A*, **35**(7), 1143-1150.
- Rudels, B. & Quadfasel, D. , 1991, Convection and deep water formation in the Arctic Ocean-Greenland Sea System, *Journal of Marine Systems*, **2**(3-4), 435-450.
- Ivanov, V. V., G. I. Shapiro, J. M. Huthnance, D. L. Aleynik, P. N. Golovin. 2004. Cascades of dense water around the world ocean. *Progress In Oceanography*, **60**(1) 47–98.
- Shapiro, G. I. and A. G. Zatsepin. 1997. Gravity current down a steeply inclined slope in a rotating fluid. *Annales Geophysicae*, **15**(3) 366-374.
- Shapiro, G. I. and A. E. Hill. 1997. Dynamics of dense water cascades at the shelf edge. Journal of Physical Oceanography, **27**(11) 2381–2394.

Current work

- **Influence of cascading on larger-scale ocean circulation?**
  - Realistic bathymetry
  - Nested in global model
    - Open boundaries
    - Realistic initial conditions
    - Tidal forcing
  - Meteorological forcing
  - **Cascading under varying forcing conditions**