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Monitoring the Norwegian Atlantic Current using gliders:

Estimates of volume fluxes in the western branch of the Norwegian Atlantic Current from Seaglider transects

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iAOOS and the Seaglider project

- Central part of IAOOS: Monitor the heat and freshwater pathways in the arctic and subarctic
- Seaglider project: i) Secure the *continuation of Station M ocean* time series, and ii) make *autonomous transects of the Norwegian Atlantic Current* using gliders (iAOOS WP 1.2 & 3.2).

Background

- Traditional monitoring of the western branch of the Norwegian Atlantic Current (NwAC):
- Direct-current measurements in the western branch of the NwAC, the Norwegian Atlantic Frontal Current (NwAFC)
- Dynamic method & the use of a presumed level of no motion
- Satellite altimetry
- ADCP

Background

- Absolute geostrophic cross-track velocities from the glider positions and its hydrographic data, obtained from three zonal transects at 66°N outside the Norwegian Continental Shelf, and eight transects along the Svinøy Section.

About underwater gliders

- Underwater gliders:
  - A glider is a type of AUV.
  - Gliders are based on Stommels vision (Stommel, 1989).
  - Gliders change bouyancy rather than using propulsion to move. This, and their low speeds assure very long ranges in the ocean.
  - Act like airplane gliders.
  - There are three different main sites in the US for development and production of gliders.

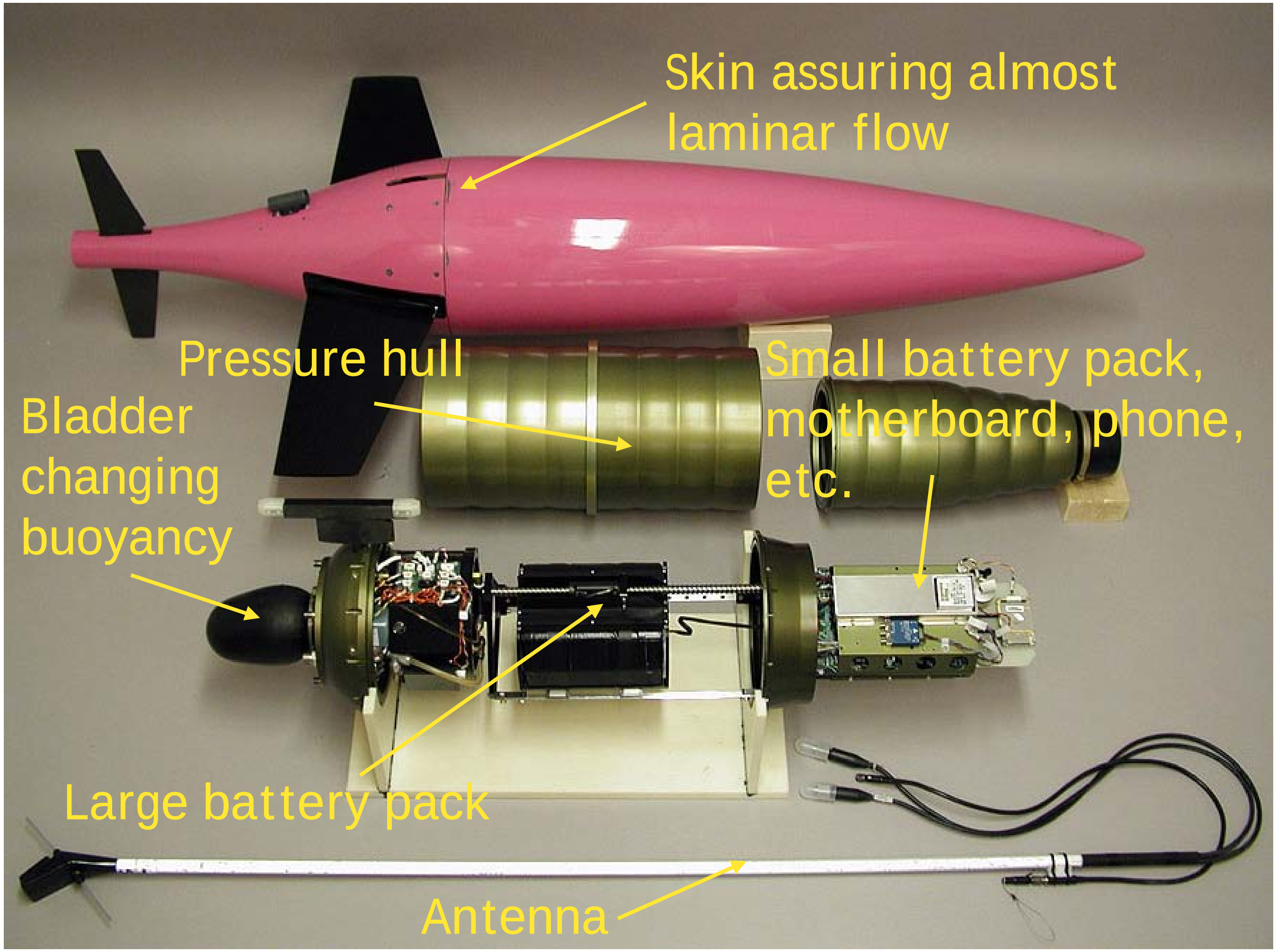
The Seaglider

- Result of a joint effort between APL-UW and UW School of Oceanography

The Seaglider

- Dimmensioned to be handled by two engineers/scientist in the field.
- Two battery packs; the largest driving the mechanics, the smallest running the sensors, the motherboard, the GPS and the onboard cell phone
- Isopycnal hull

The Seaglider



Skin assuring almost laminar flow

Pressure hull

Small battery pack, motherboard, phone, etc.

Bladder changing buoyancy

Large battery pack

Antenna

The Seaglider

- A typical dive:
  - four km in the horizontal, to 1000 m depth, during little less than eight hours
  - Typical horizontal velocity: 20-25 cm/s.
  - ”Throttle”: More rapid change of bouyancy.
  - ”Saw tooth” shaped glider tracks in the vertical. GPS position and data sent via the Iridium system after each dive.

The Seaglider – example tracks

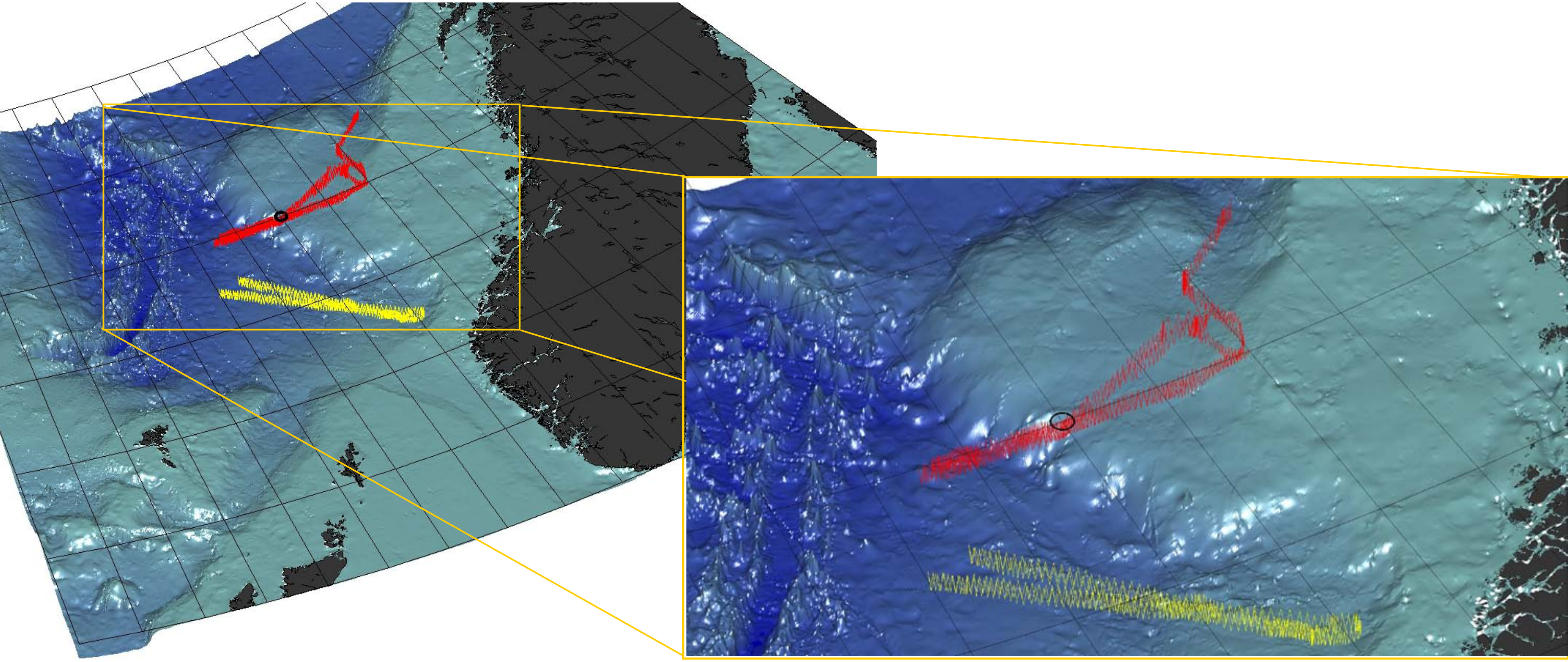


Fig 1. The Seaglider tracks during the IAOOS Seaglider experiment until end of March 2009. Red line: Seaglider SG-017 track for the OWSM Section. Note: The glider was sent from the OWSM Section to the southern limit of the Lofoten Basin for recovery assisted by the Norwegian Coastal Guard. Yellow line: Seaglider SG-160 in the Svinøysund Section. Ocean Weather Station Mike is shown by a 10 km range circle.

The Seaglider

- …Advantages
  - Many different sensors. Measurements in very rough weather is possible
  - No need for continous ship operations => ”low cost”
  - Indirect measurement of currents
  - Very high spatial resolution

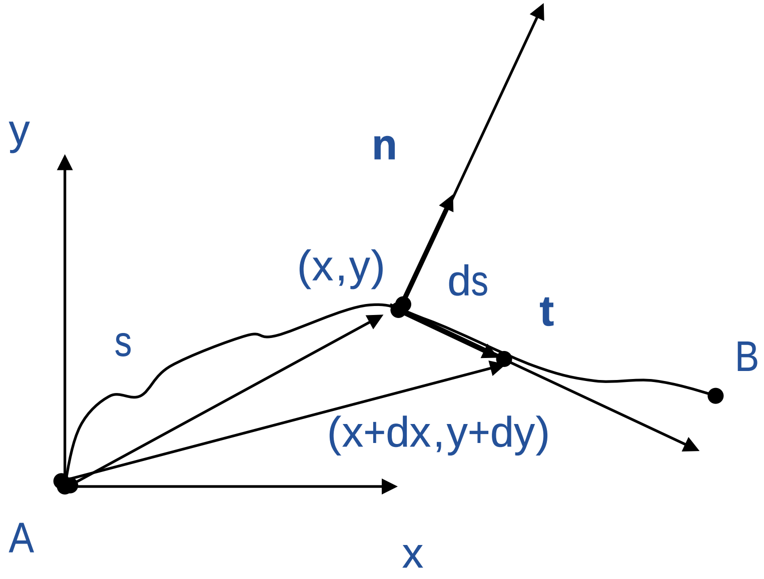
The Seaglider

- Disadvantages:
  - Small velocities =>”synoptic snapshots” impossible. But…
  - Difficult to make straight tracks => Conventional sections impossible.
  - Need for “continuous” monitoring (Weekends/Holidays); night shifts (rarely)
  - New technology, currently being improved
  - Problems coping with strong currents and small depths

Method - geostrophy

$$\mathbf{t} = \frac{dx\mathbf{i} + dy\mathbf{j}}{\sqrt{dx^2 + dy^2}} = \frac{dx\mathbf{i} + dy\mathbf{j}}{ds},$$

$$\mathbf{n} = \mathbf{k} \times \mathbf{t} = \frac{-dy\mathbf{i} + dx\mathbf{j}}{ds}$$

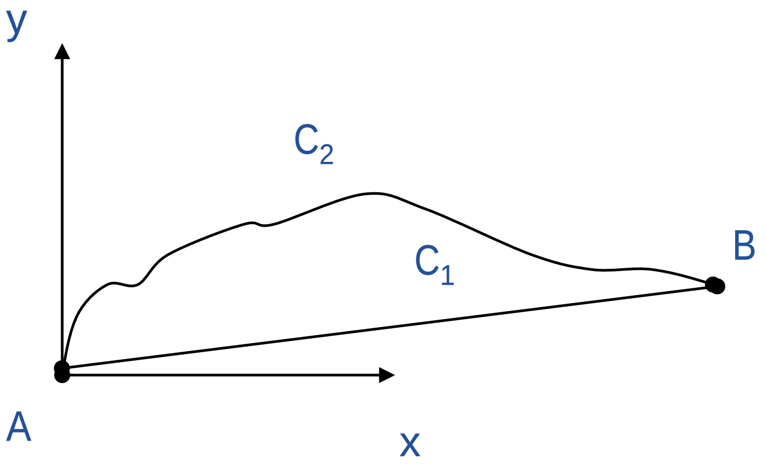


$$\rho_0 f\, \mathbf{k} \times \mathbf{v} = -\nabla p + \mathbf{R} \quad \Big| \cdot \mathbf{t}$$

$$-\rho_0 f\, v_n = -\frac{\partial p}{\partial s} + R_t$$

$$\bar{v}_n = \frac{1}{S}\int_0^S v_n\, ds = \frac{1}{\rho_0 f S}[p(s=S) - p(s=0)] - \frac{1}{\rho_0 f S}\int_0^S R_t\, ds$$

Method - geostrophy



$$(\bar{v}_n)_{C_2} = \frac{1}{\rho_0 f S}[p_B - p_A] - \frac{1}{\rho_0 f S}\int_0^S R_t\,ds$$

$$(\bar{v}_n)_{C_1} = \frac{1}{\rho_0 f L}[p_B - p_A] - \frac{1}{\rho_0 f L}\int_0^L R_t\,d\hat{x}$$

$$(\bar{v}_n)_{C_2} S = (\bar{v}_n)_{C1} L$$

$$|p_B - p_A| >> \left|\int_0^L R_t\,d\hat{x}\right| \Rightarrow \int_0^L R_t\,ds = \int_0^S R_t\,d\hat{x}$$

Geostrophy along C$_1$ implies Geostrophy along C$_2$.

Method - geostrophy

$$\rho_0 f \frac{\partial v_n}{\partial h} = g \frac{\partial \rho}{\partial s}, \quad h = -z$$

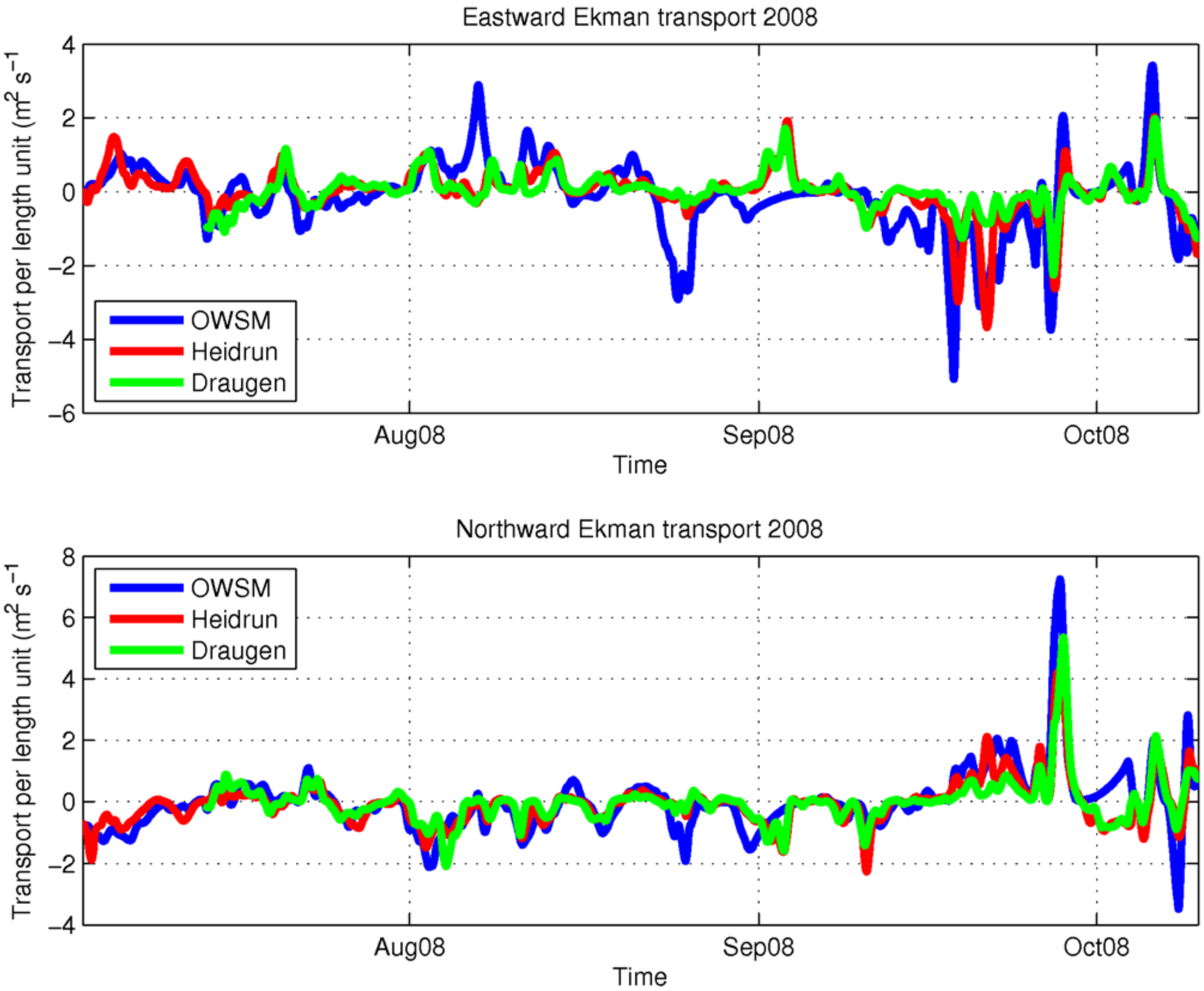
$$\rho_0 f (v - v_0) = g \int_{-\zeta}^{h} \rho_s \, dh \cong g \int_{0}^{h} \rho_s \, dh, \quad h >> |\zeta|$$

$$\int_0^H v \, dh \cong v_0 H + \rho_0^{-1} f^{-1} g \int_0^H \int_0^{\hat{h}} \rho_s \, d\hat{h} \, dh$$

$$v = U + \rho_0^{-1} f^{-1} H^{-1} g \int_0^H \left(H \rho_s - \int_0^{\hat{h}} \rho_s \, d\hat{h} \right) dh$$

Method – Ekman transports

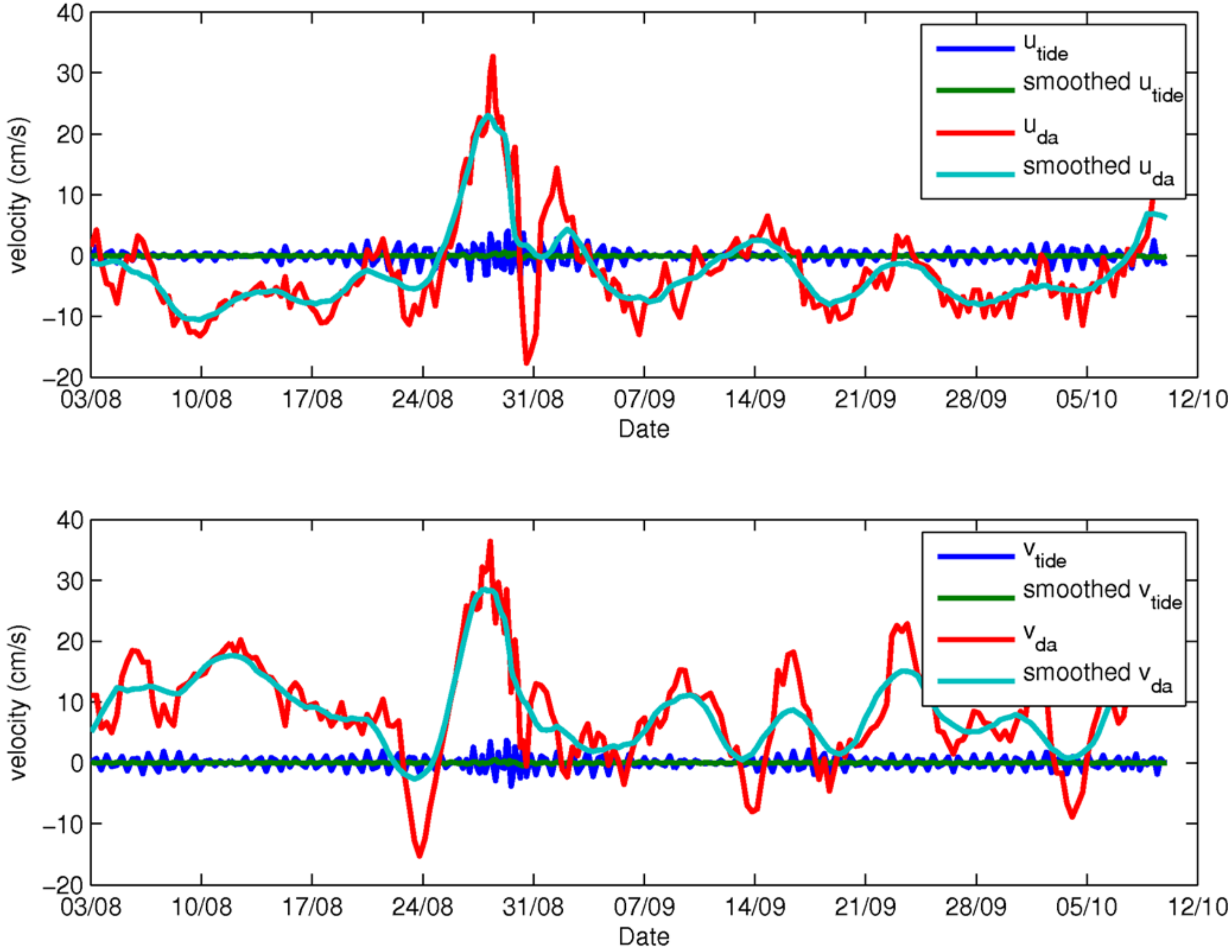
- Summer Ekm. tr. ?
- Mean current
- Wind data: OWSM, Heidrun, and Draugen
- OWSM summer transects: Dive-by-dive effect small
- Other seasons



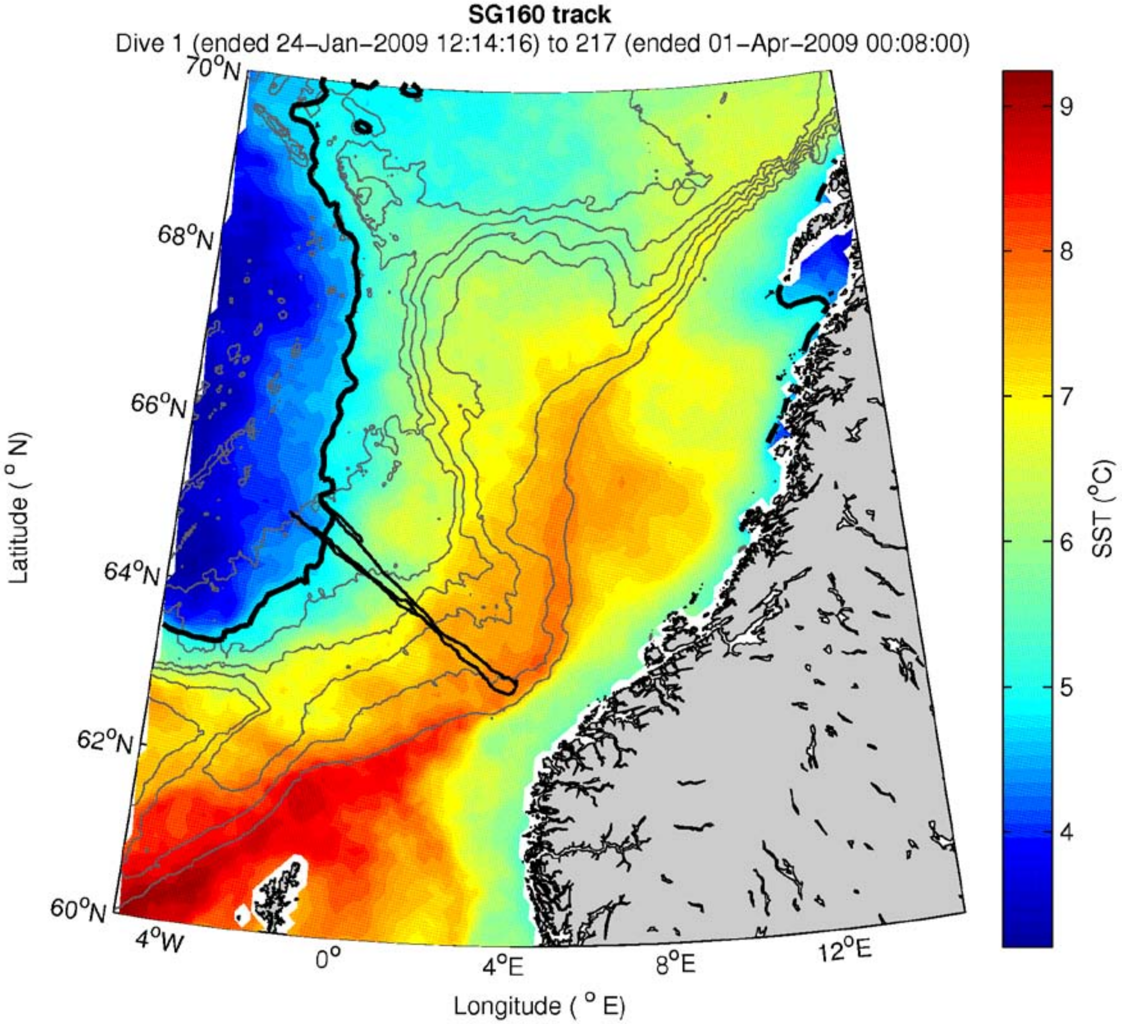
Method – the tide

- Maps of M2 tidal constituents: ~3 cm/s!
- OTPS
- Peak mean tidal current during a dive: 5 cm/s!
- Average over several dives: Effect small (12 dive: 7mm/s & 5 mm/s
- Long-time average: SMALL CURRENT!

Depth averaged velocity versus modelled tidal current velocity dive 145 to dive 370



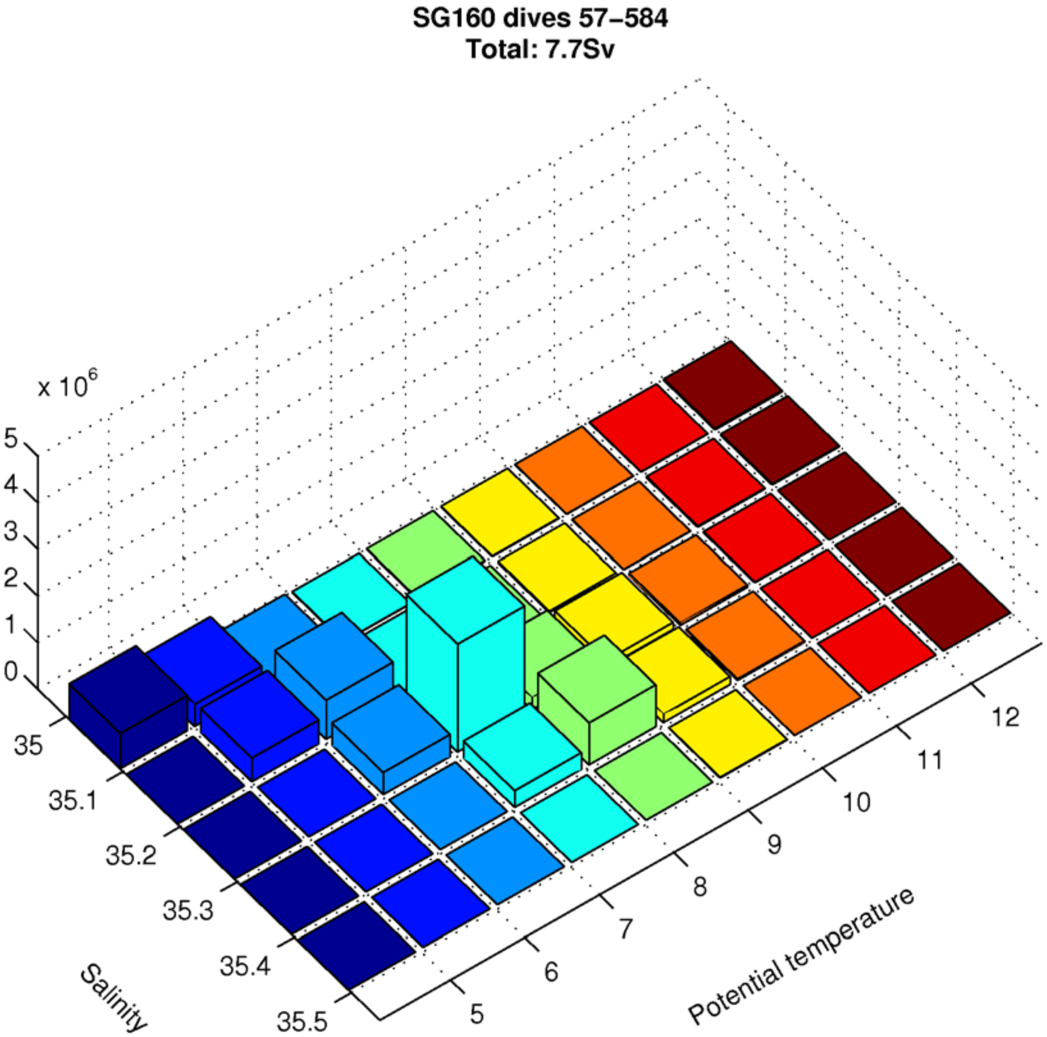
Results



SST from satellite data(Jan-Mar 2009, provided by S. Eastwood) & SG-160 tracks. Black, thick line is 4.8°C. Note: Traditional Svinøy Section stops at 64°40’N, 0°E.

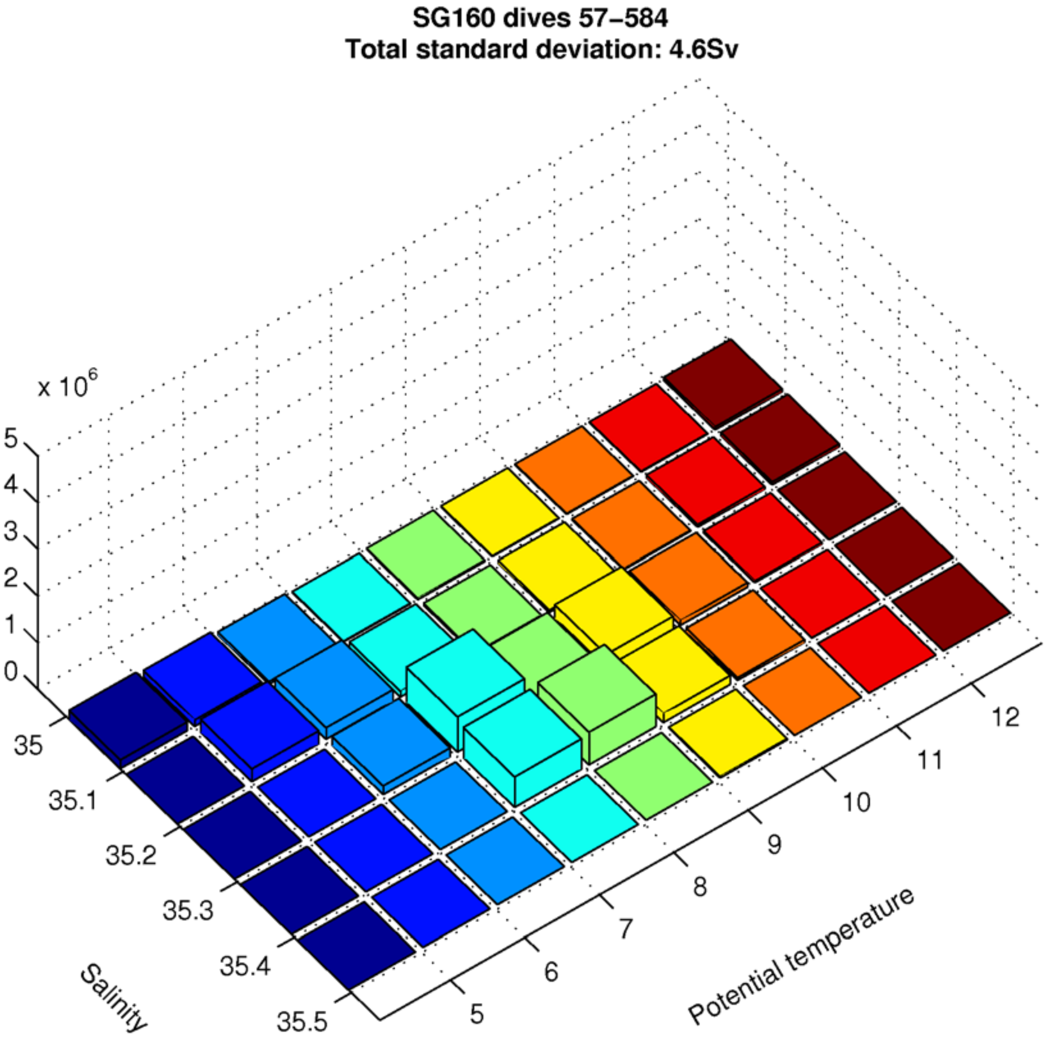
Results

- Total volume flux 7.7 Sv (?!)
- Important volume flux of cold water
- Volume flux for bottom depth > 2500m: 1.5 Sv (50% colder than 6°C => ?
- Extension of Svinøy Section important? NO!
- Why high volume fluxes?



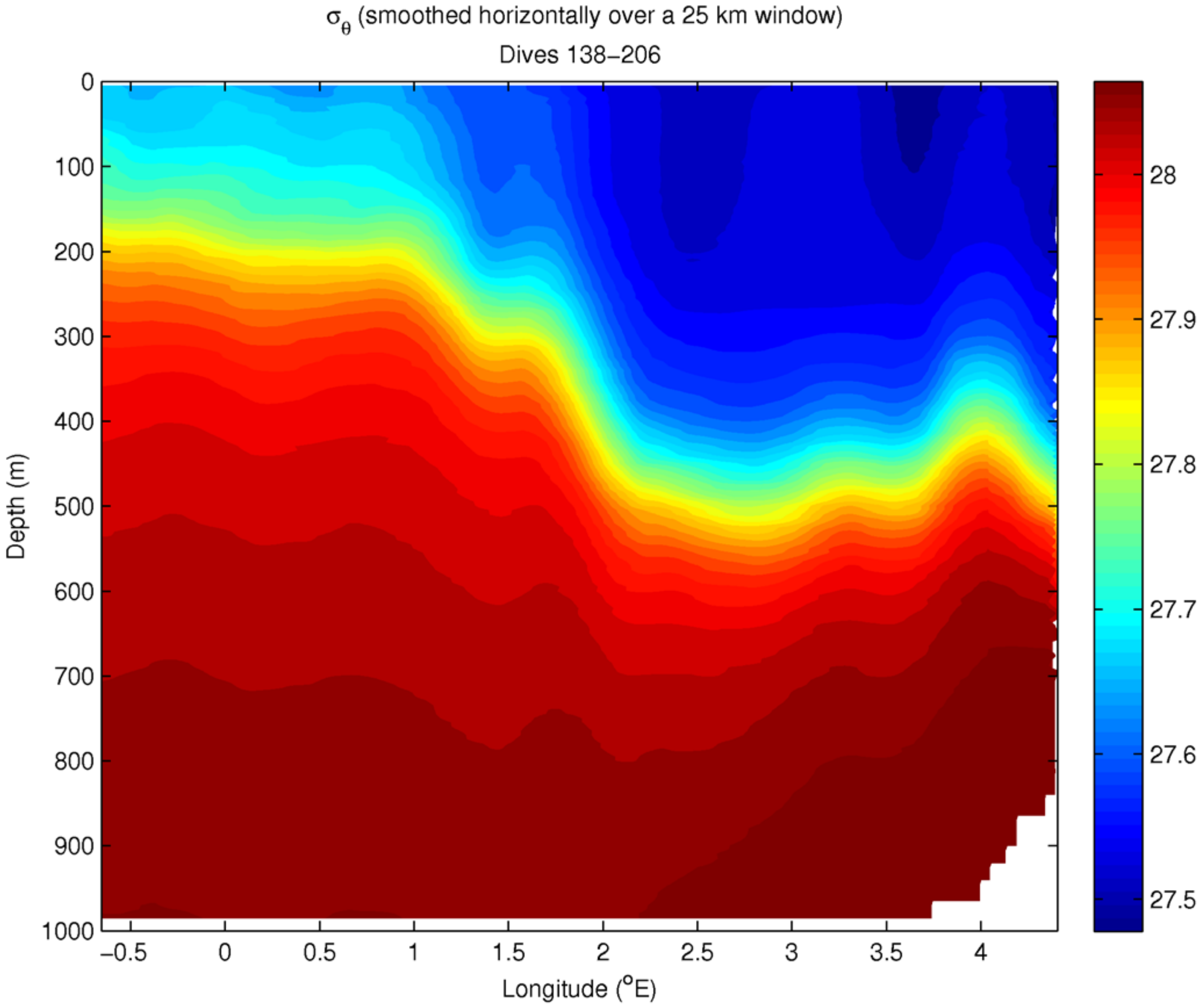
Results

- From qualitative examination of data from eigth transects: Eddy activity seemed strongest where the (mean) current is strongest, shoreward of the abyss
- This is reflected in the variation of the volume fluxes in TS space



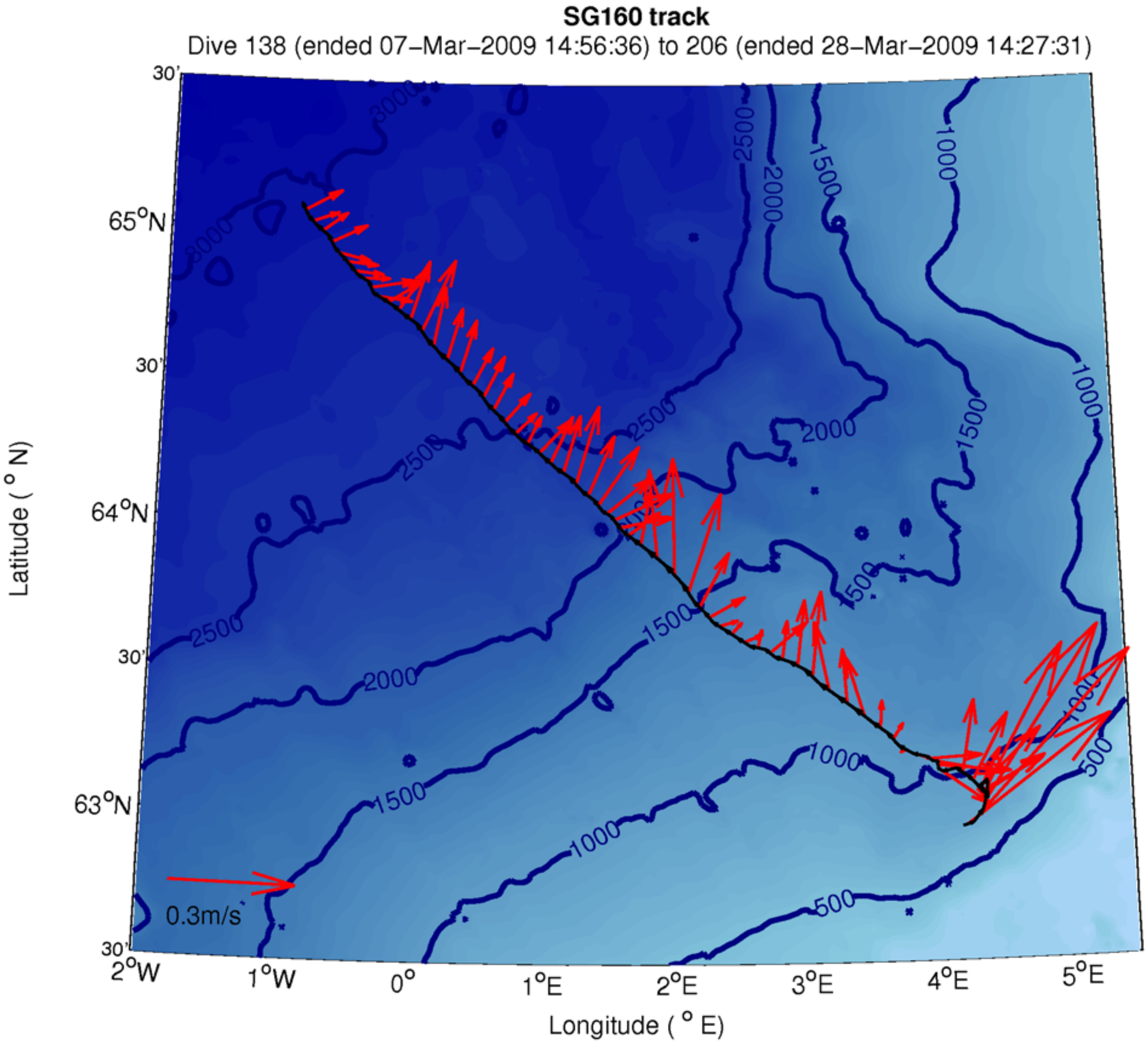
Results

- Density surfaces west of ~1°E...
- Recirculation cells / eddies
- Anything new?



Results

- DAC west of ~1°E.
- Signs of recirculation?
- NwASC? (Note type of orbit.)
- NwAFC

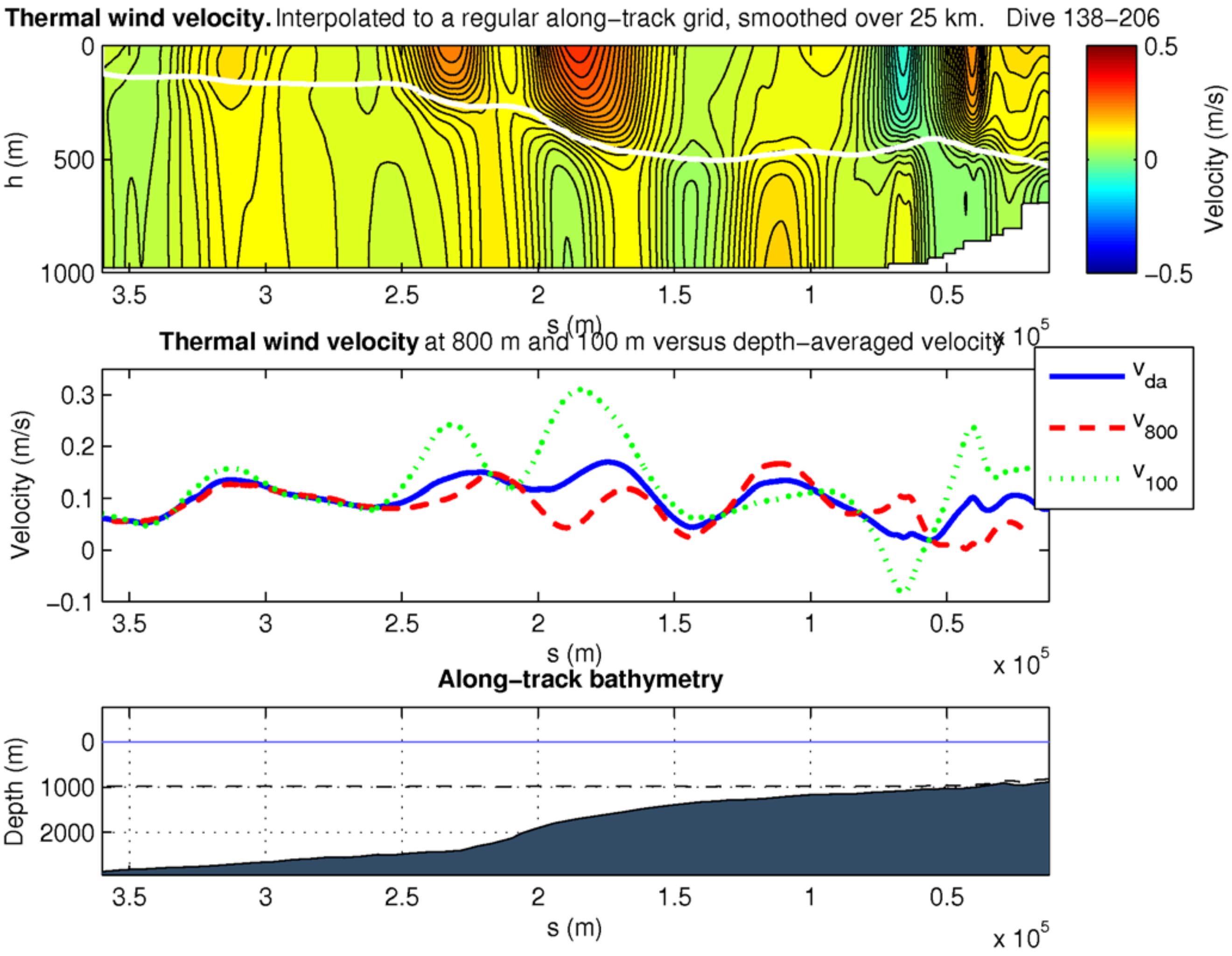


SG160 track

Dive 138 (ended 07–Mar–2009 14:56:36) to 206 (ended 28–Mar–2009 14:27:31)

Results

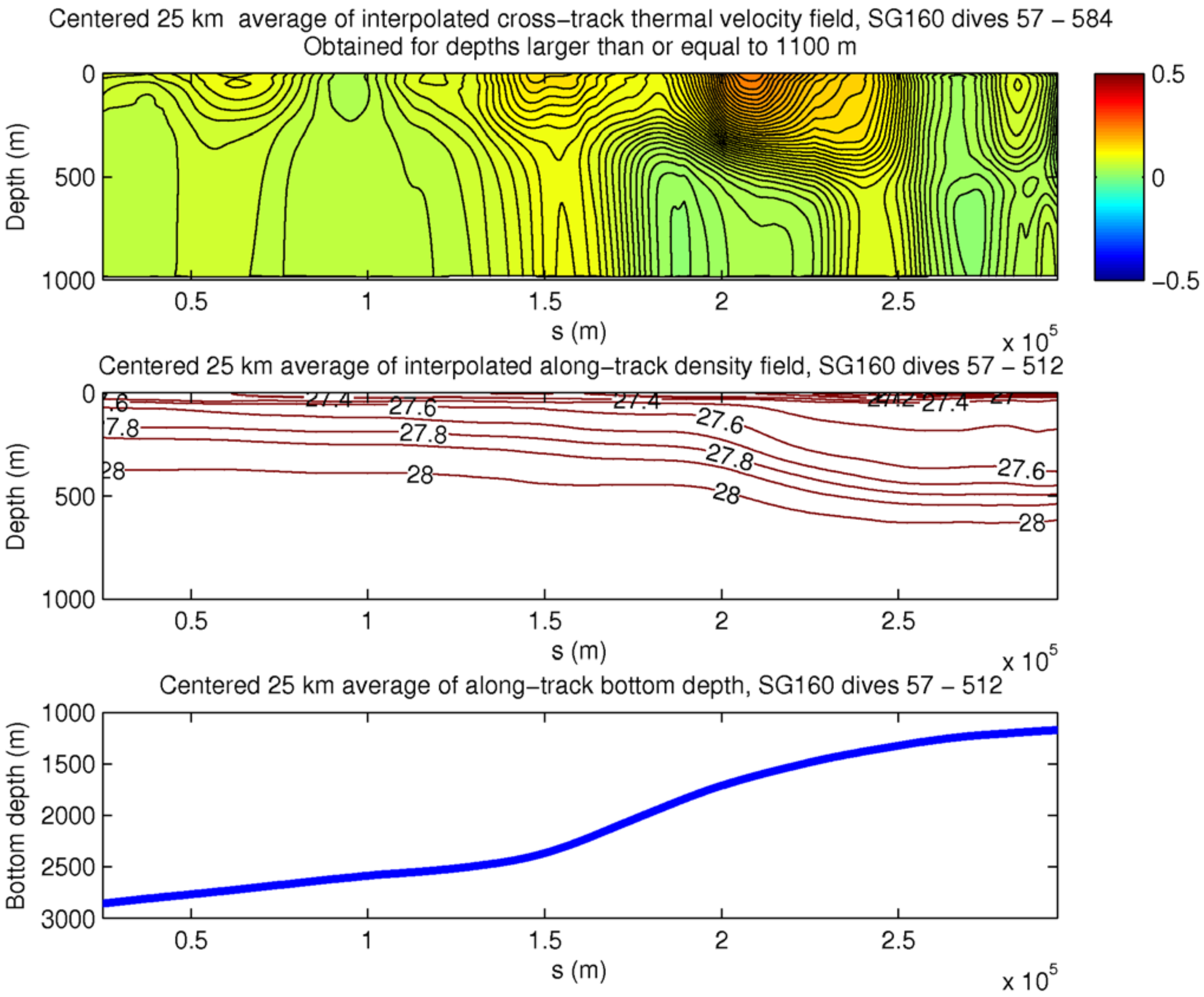
- Distribution of AW?
- General “drift”
- Main core moving from one transect to another, but…
- Gyre?
- Recirculation zone offshore of 1000m bottom depth
- Deep currents?



Results

Average of transects

- Two cores: Position and strength (level of “barotropy”)
- Qualitatively consistent with obs. from SE3 (Orvik et al 2001)
- Poleward drift
- Deep currents



Centered 25 km average of interpolated cross–track thermal velocity field, SG160 dives 57 – 584
Obtained for depths larger than or equal to 1100 m

Centered 25 km average of interpolated along–track density field, SG160 dives 57 – 512

Centered 25 km average of along–track bottom depth, SG160 dives 57 – 512

Discussion

- Density gradients at 800 m small compared to those in the upper layers

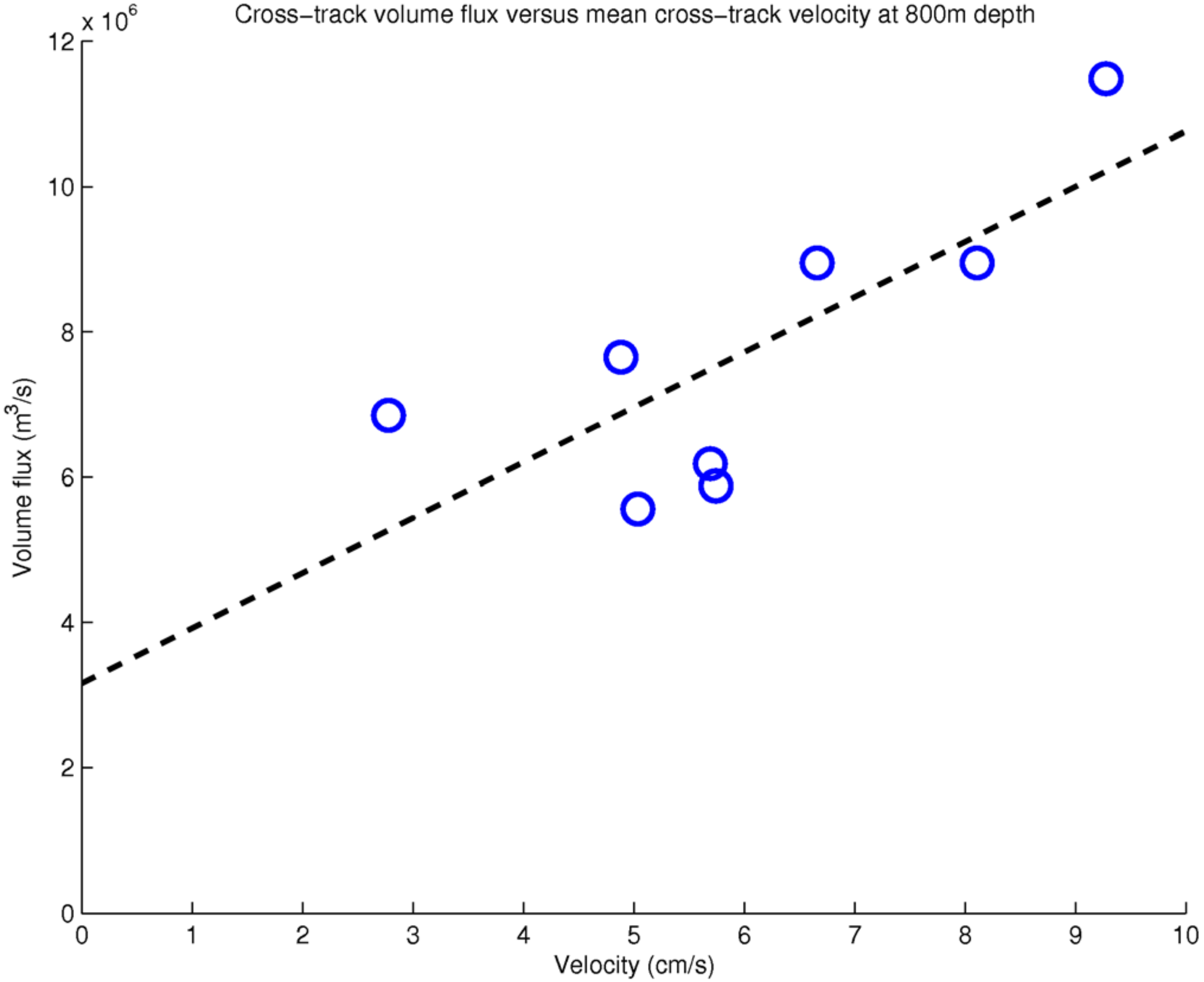
⇒Velocity at 800 m can be an adequate representation of the barotropic velocity component in the upper layers

⇒In theory, the cross-track volume flux per length unit must then depend linearly (approximately) on the velocity at 800 m depth.

Discussion

Average of transects

- Mean of eight regression lines obtained from omitting one transect at a time (in Sv when the mean velocity at 800m is in cm/s)



Discussion

- Mean regression line

$$T = (0.76 \pm 0.081) \cdot \bar{v}_{800} + 3.2 \pm 0.14$$

- “Baroclinic” volume flux:
  - 3.3 ± 0.8 Sv
  - Sparse data, could not see any seasonal signal.

Concluding remarks

1) Volume flux larger than previously reported
2) Entrainment
3) Recirculation / gyre?