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Acoustic Doppler Current Measurement (FP 24)

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Introduction and Motivation

- Ocean currents are crucial for the Earth's climate system as they are responsible for mass and heat transport.
- E.g. the Gulf Stream provides Northern Europe with fairly moderate temperatures (with regard to the corresponding latitudes).
- **LADCP** (Lowered Acoustic Doppler Current Profiler) allows indirect measurement of horizontal current velocity.
- Mass and heat transport can be obtained from **velocity profiles**.
- Data analysis from a June 2002 research cruise about 25 km east of the coast of **Guadeloupe** (Caribbean) shall be performed here.

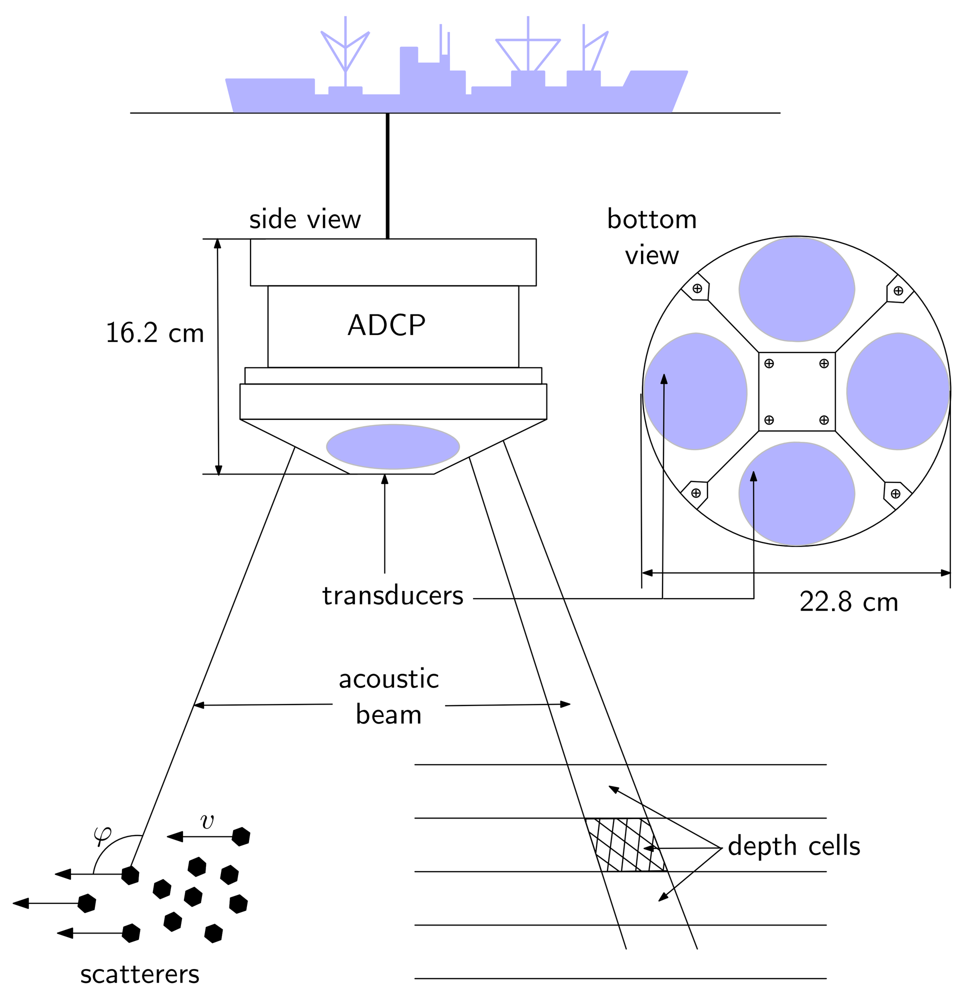
Principles of LADCP Operation

- The ADCP instrument is lowered into the ocean. Its transducers both emit and receive acoustic signals (frequency $f = 300$ kHZ).
- The emitted signals are backscattered by moving targets (plankton). The backscattered signals are Doppler shifted.
- Let the relative velocity between sound source and scatterer be v and the speed of sound in water be c. The angle between emitted/backscattered beam and the direction of scatterer movement is φ.

  Assuming $v/c \ll 1$, the Doppler frequency shift is

  $$\Delta f = 2f\frac{v}{c}\cos\varphi$$

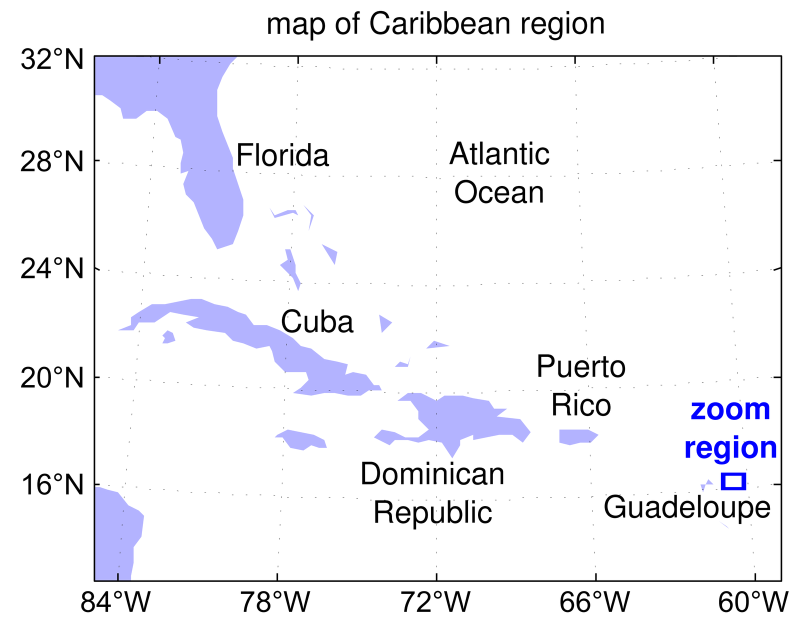
- The velocities are averaged over depth cells (or bins). A velocity profile can be obtained from these average values.



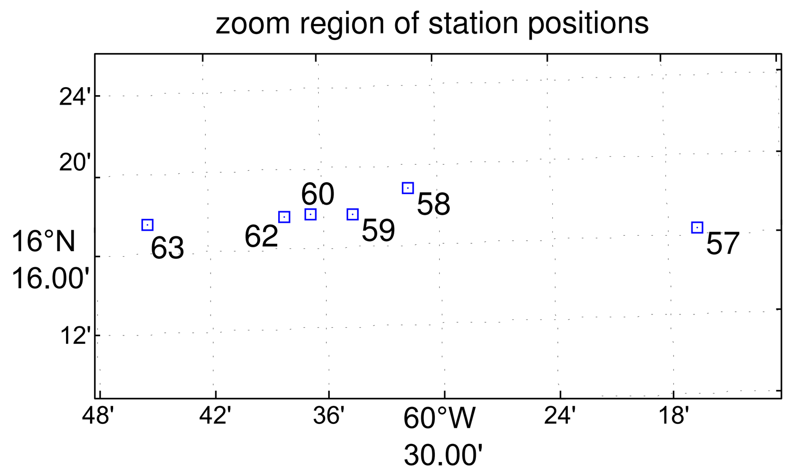
Collected Data

- The data were collcted on the German research vessel *Meteor* in June 2002.
- Moorings were performed at several stations, six of which (M1-M6) are used for data analysis here (also displayed on the map below).

map of Caribbean region



zoom region of station positions



Velocity Profile Computation

Inverse Solution

- To obtain the ocean velocity $\boldsymbol{u}_{\text{ocean}}$, solution of the following linear system is required:

  $$\boldsymbol{u}_{\text{ADCP}} = \boldsymbol{u}_{\text{ocean}} + \boldsymbol{u}_{\text{CTD}} + \boldsymbol{u}_{\text{noise}}$$

  $\boldsymbol{u}_{\text{ADCP}}$ is obtained via frequency shift, $\boldsymbol{u}_{\text{CTD}}$ is the velocity of the lowered carousel the ADCP instrument is fixed on.

- The linear system is large, but also over-determined. Therefore, it is possible to add further constraints, like bottom tracking.

Shear Solution

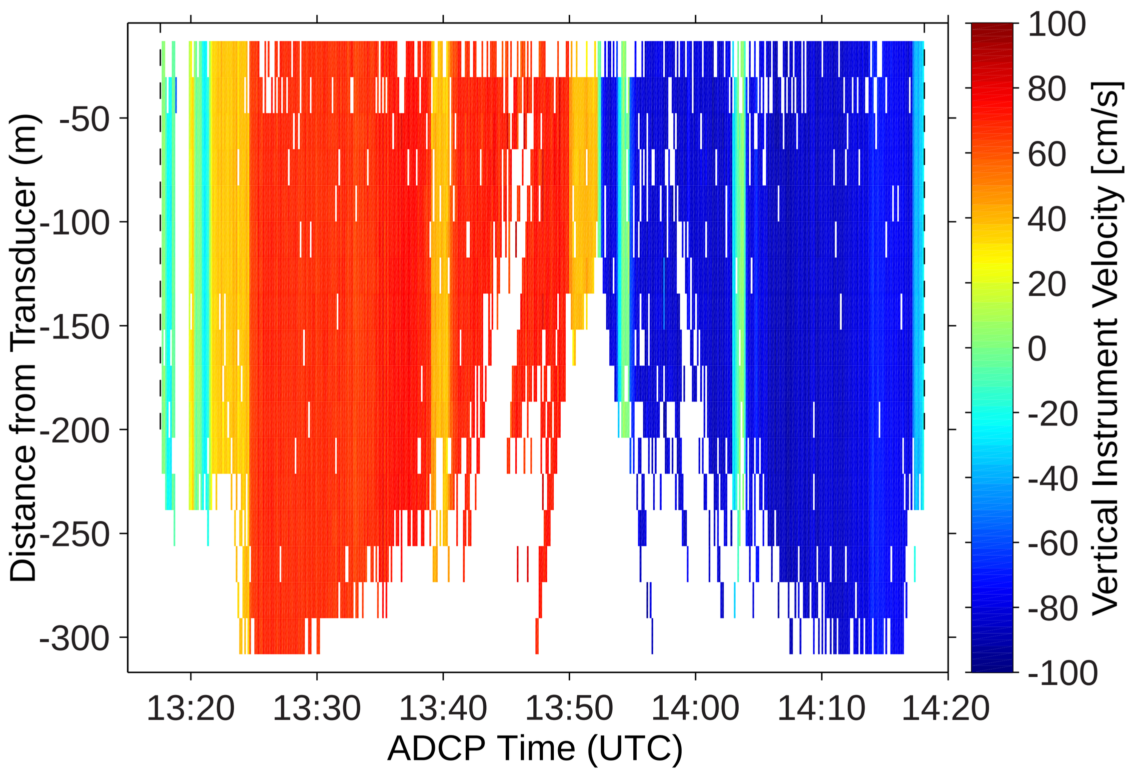
- A more simple, but usually less reliable method.
- Further constraints cannot be added. See *absolute velocity* below.

Data Analysis

- The following anlysis is based on data recorded at station M5.
- The images were created using Christan Mertens' LADCP Matlab toolbox (not published).

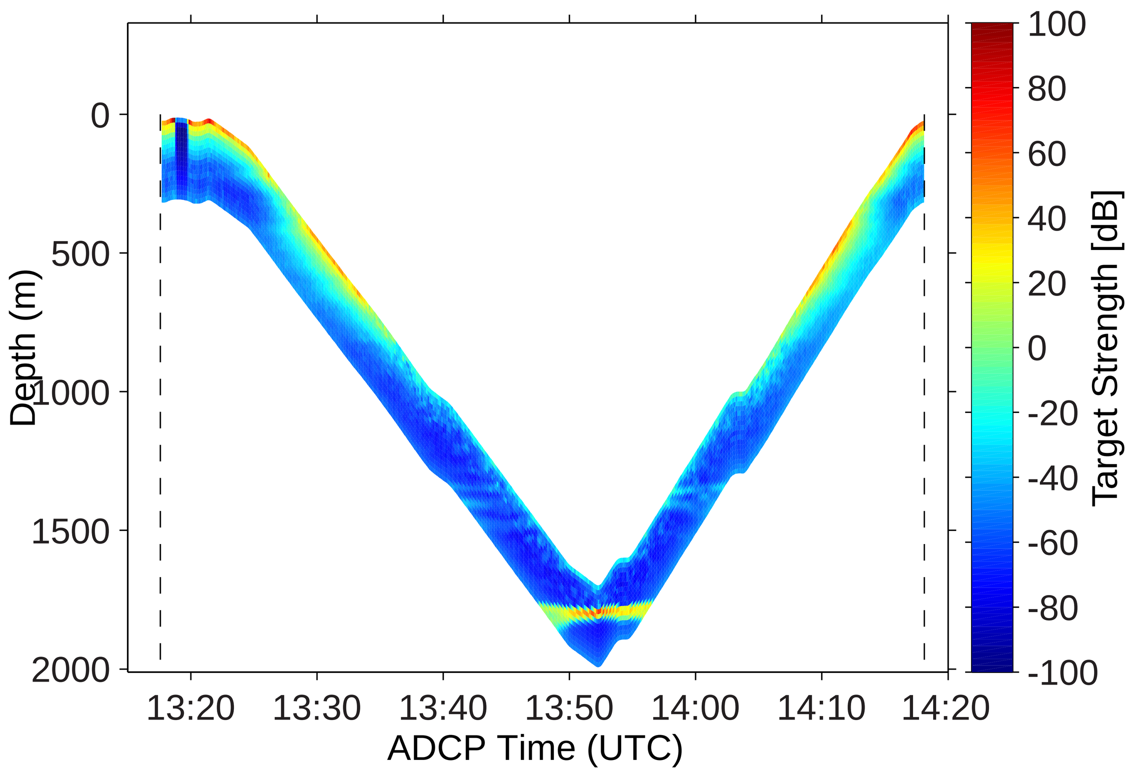
ADCP Instrument Vertical Velocity Profile

- The colorbar shows moderate and low instrument velocities close to the surface (both lowering and raising) and to the bottom.
- The distance from the transducer (i.e. its range) is always negative because only one (downward looking) ADCP instrument is employed.
- The toolbox performs several initial quality checks and automatically rejects useless data, hence some data gaps in the image.



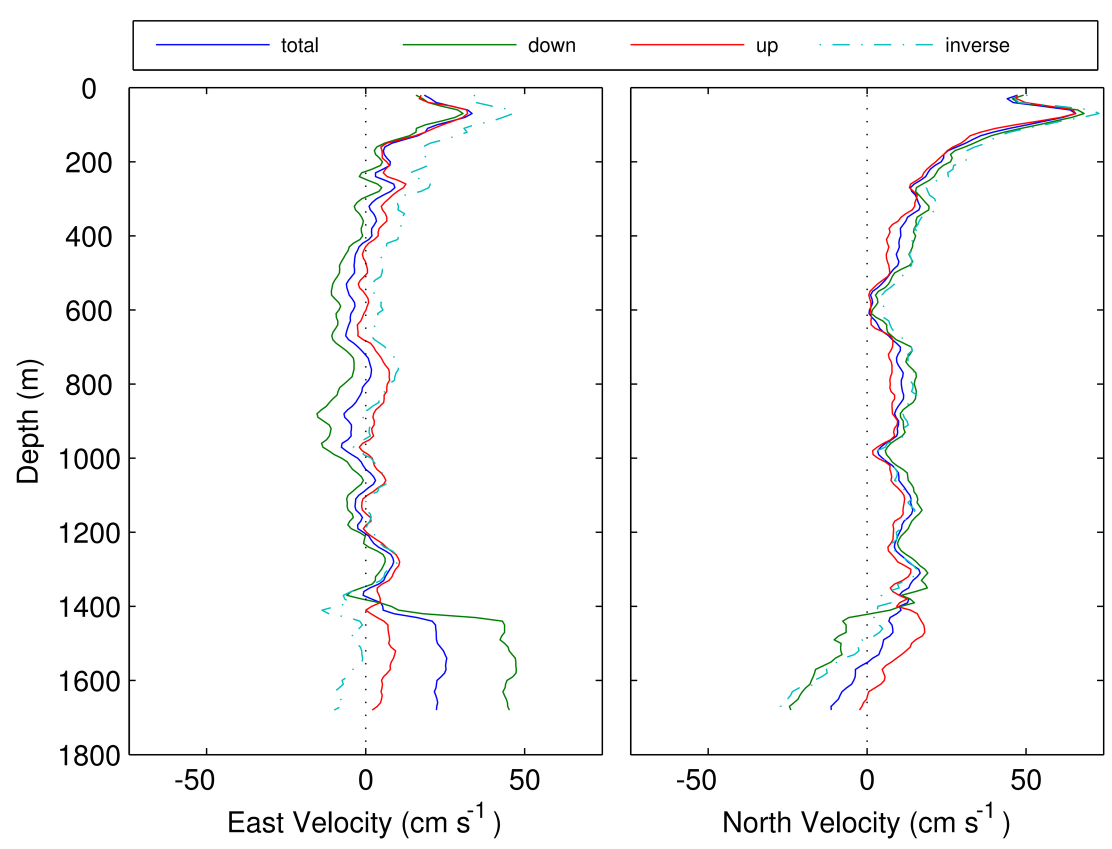
Target Strength

- The target strength basically represents plankton distribution. However, the high values close to seafloor and surface in the figure below are due to reflection.
- Apparently, there is too little light and food for plankton at deeper sea levels. Conditions seem to be best at about 500 m below the surface.



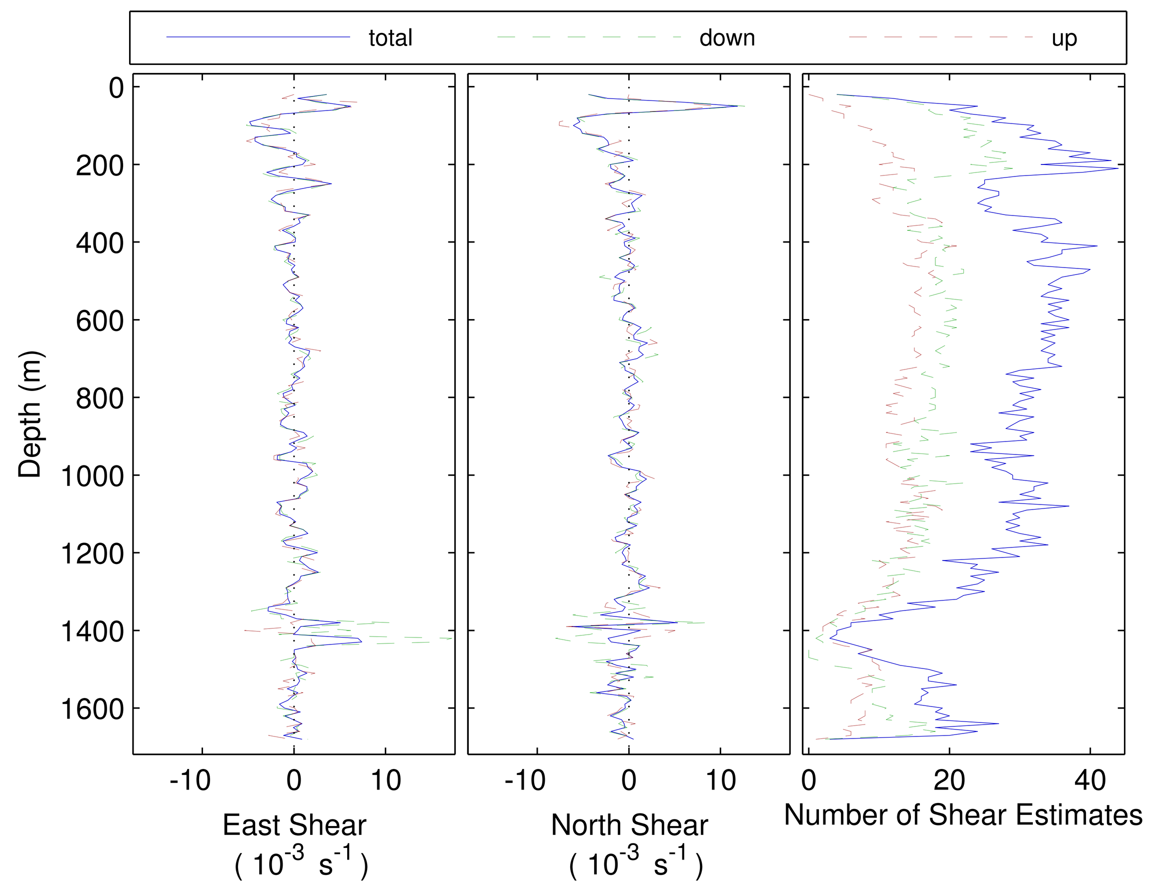
Absolute Velocity Profile

- In the images below, N-S and E-W velocities computed via shear (lines) and inverse (dashed line) solutions are plotted.
- The total shear solution coincides reasonably well with the inverse solution.
- There is a notable divergence close to the bottom where the inverse solution is more trustworthy due to bottom track.
- The shear solution's peaks and curves recorded on downcast are fairly well reproduced on upcast.
- There is practically no missing or rejected data in the profiles → good data quality.



Shear Profiles

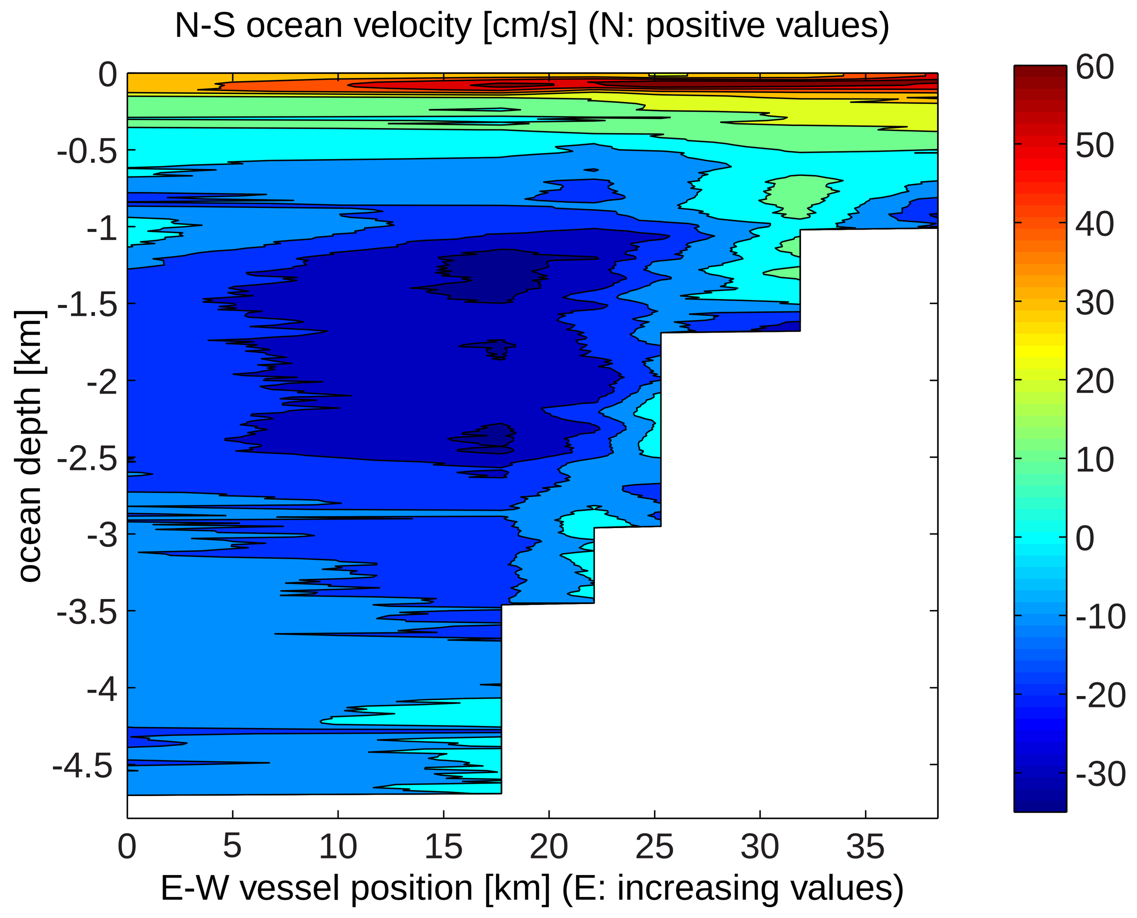
- Shears are average velocity differnces between neighboring depth cells.
- Upcast and downcast profiles coincide well and suggest good data. However, at depths of about 1400 m, data quality suffers from interferences with signals echoed back from the seafloor.



Complete Velocity Section and Flux

- The velocity section is basically a contour plot of the ADCP measured velocity data (see figure below).
- The vessel is westward-bound. The velocity section yields a prevailing southward-bound current.
- Remarkably, a shallow current close to the surface has the opposite direction (northward-bound).

N-S ocean velocity [cm/s] (N: positive values)



Flux Computation and Error Estimation

- The flux in north-south direction (i.e. perpendicular to vessel motion) is given by

  $$\Phi = \sum_i \boldsymbol{A}_i \cdot \boldsymbol{u}_i = \sum_i A_i \cdot v_i$$

  where i is the number of depth cells, $\boldsymbol{A}_i$ is the area element and $\boldsymbol{u}_i$ is the ocean velocity. In the last expression, v_i is the velocity in N-S direction.

- Assuming $\Delta A = 0$, error propagation yields

  $$\Delta\Phi = \sum_i \frac{\partial\Phi}{\partial v_i}\Delta v = \sum_i A_i \cdot \Delta v$$

- It is reasonable to choose $\Delta v = 5$ cm/s. The result is a negative flux (i.e. in southern direction):

  $$\Phi = (-6.01 \pm 7.74) \cdot 10^6 \frac{m^3}{s}$$

Conclusions

- The analysed data is almost seamless and yields mostly **consistent results**.
- Shear and inverse solutions coincide reasonably well. In cases of divergence in ocean bottom proximity, the inverse solution appears more trustworthy.
- **Velocity sections** make it possible to differentiate between currents close to ocean surface and e.g. currents close to ocean bottom and even to compute the volume flux Φ.
- Even some conclusions about plankton habitats are possible.

References

[1] Fischer, J. and M. Visbeck, 1993: *Deep velocity profiling with self-contained ADCPs*, J. Atmosph. and Oceanic Technol., 10, 764-773.

[2] Visbeck, M., 2002: *Deep velocity profiling using lowered Acoustic Doppler Current Profiler*: Bottom track and inverse solutions. J. Atmosph. Oceanic Technol., 19, 794-807. .