Mesoscale activity in Drake Passage: satellite and in situ data comparison

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ABSTRACT:

The Southern Ocean, the only ocean that circles the globe without being blocked by land, is home to the largest of the world's ocean currents, the Antarctic Circumpolar Current (ACC). While the ACC is the major inter-ocean link, our understanding of the variability of the ACC and the impact of such variability on the climate system is rudimentary. Monitoring the ACC transport is essential for understanding the coupling of this major current with climate change. It is not an easy matter since the current is concentrated in highly variable narrow bands of swifts currents and since energetic eddies of all sizes are numerous.

Our experimental set up is designed to use the complementarity between satellite altimetry and in situ observations. In January 2006, 10 currentmeter moorings were deployed in the Drake Passage below track 104 of the altimetric satellite JASON-1 and two high-resolution full depth hydrological sections (CTD and LADCP) were carried out along this track within three weeks.

We use satellite data (ocean color, sea surface temperature, altimetry) to describe the mesoscale activity during the cruise. Then, we carry out a Jason-1 data validation along track 104 comparing in situ data with the altimeter data . Finally, we evaluate the Rio05 Mean Dynamic Topography along the satellite track.

1- Drake Passage

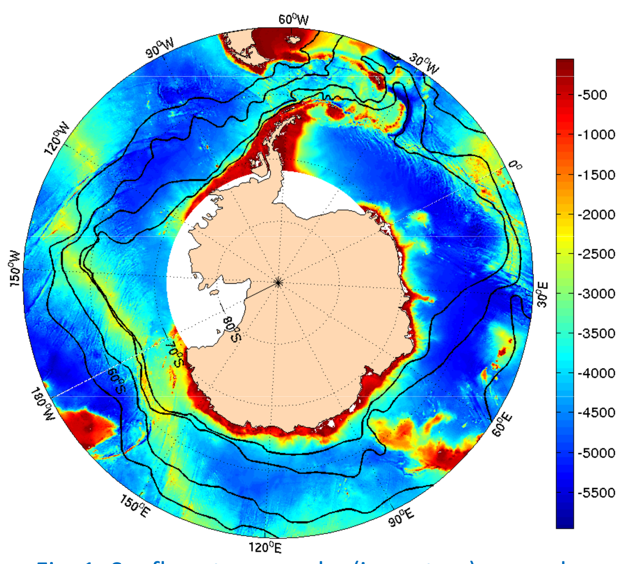


Fig. 1: Seafloor topography (in meters) around the Antarctica. Black lines represent the ACC fronts

The Antarctic Circumpolar Current (ACC), the world's largest current in terms of volume and mass transport, is constricted to its narrowest extent (about 700 km) at Drake Passage (DP).

The ACC is closely associated with three deep-reaching oceanic frontal systems, from north to south:

- the **Subantarctic Front** (SAF),
- the **Polar Front** (PF),
- the **Southern ACC Front** (SACCF).

The **Antarctic Polar Frontal Zone** (APFZ) is the region located between the SAF and PF.

The mean location of these deep-reaching fronts, from Orsi et al. (1995), reflects the bottom topography.

- East of DP, bathymetry is deep and flat (> 5000m).
- At DP, the seafloor rises (near 3700m) and is crisscrossed by a number of fracture zones and ridges that delimit small basins often textured with abyssal hills or depressions.
- West of DP, the South Sandwich Islands act as a barrier to the ACC, forcing it to deviate to the north and to proceed through narrow sills

The major topographic features in DP are:

- the West Scotia Ridge (WSR) oriented east–west at mid-distance between the tip of South America and the Antarctic Peninsula.
- the Phoenix Antarctic Ridge (PAR) and the Shackleton Fracture Zone (SFZ) that rise to nearly 1500m

These ridges delimit the Yaghan Basin (YB) to the northeast and the Ona Basin (OB) to the southeast.

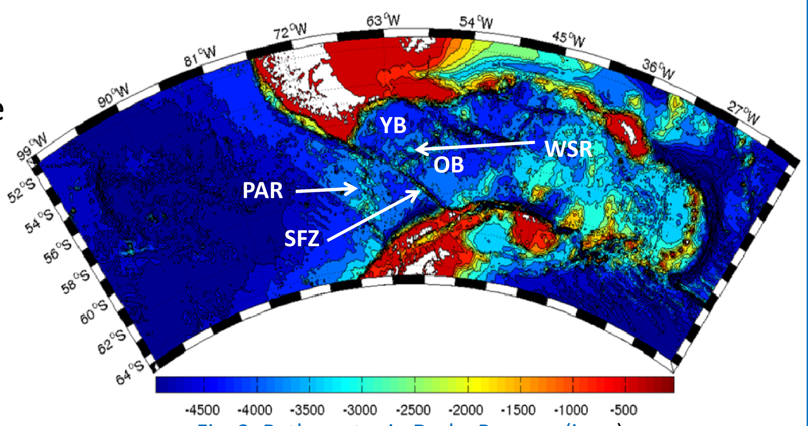


Fig. 2: Bathymetry in Drake Passage (in m)

2- Experimental program: DRAKE 2006-2009

Fig. 3: Mooring locations and CTD stations

In January-February 2006, an expedition across Drake Passage (ANT-XXIII/3) took place on board Polarstern.

A mooring array (red dots) was deployed below the track 104 of the altimetric satellite JASON-1 and two high-resolution sections of CTD/LADCP stations (white dots) were carried out along this track in three weeks (Fig. 3).

Leg 1 of the cruise: 16 January to 26 January 2006 (way south)
Leg 2 of the cruise: 31 January to 6 February 2006 (way back)
The moorings, recovered and reinstalled in February 2008, will be brought up in March 2009.

Temperature, velocities across track and neutral density, measured during the cruise, are shown below.

- Temperature sections show the high contrast between the north and the south of Drake Passage. Note the cold intrusion, in Leg1, near the SAF at 200m deep.
- Velocity sections show:
  - the banded structure of the ACC with large values both eastward and westward
  - the perturbation of the flow due to the topography

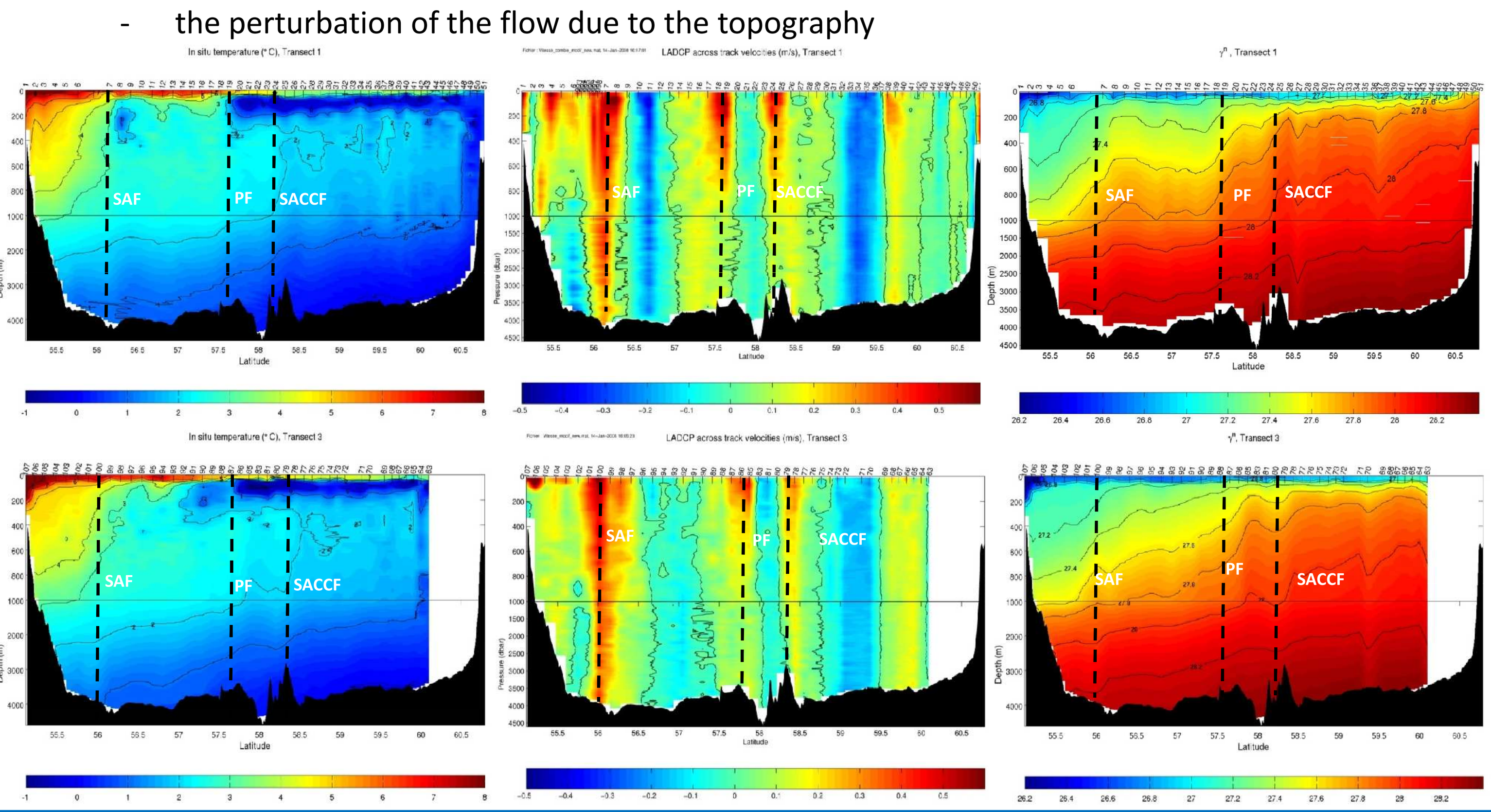


Fig. 4: Temperature, cross-track velocity and neutral density sections. leg1 at the top and leg 2 at the bottom.

3- Mesoscale Activity during the cruise 2006

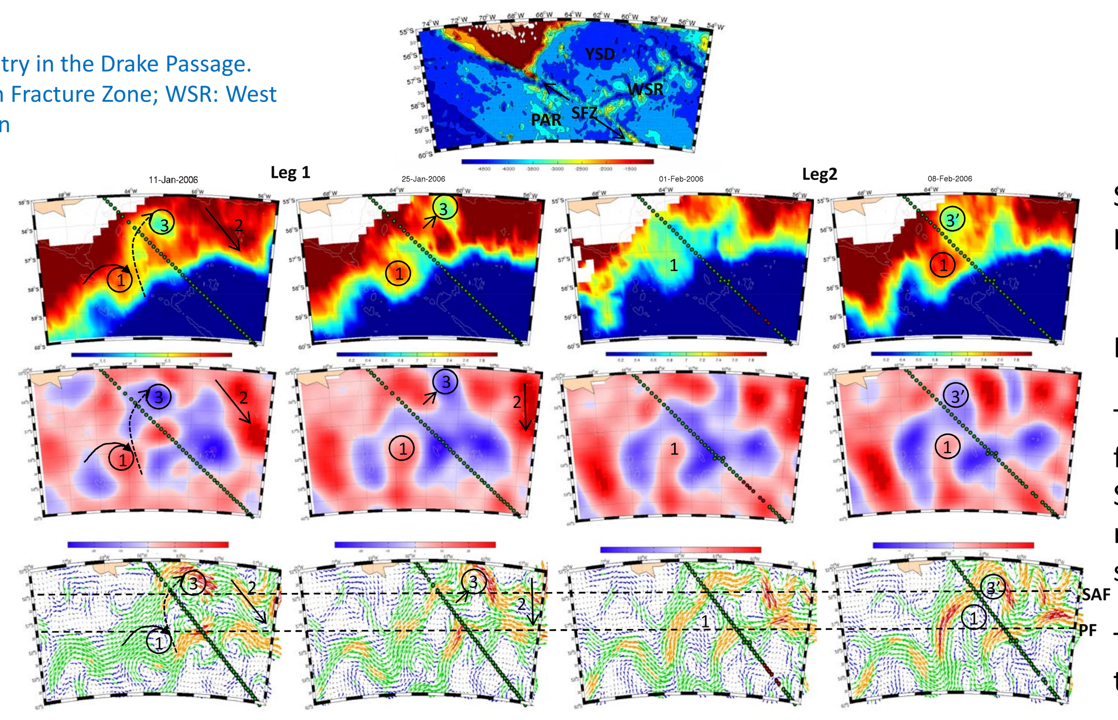


Fig. 5:
1st row: Elargement of the northern bathymetry in the Drake Passage. PAR: Phoenix Antarctic Ridge; SFZ: Shackleton Fracture Zone; WSR: West Scotia Ridge; YSD: Yaghan Seafloor Depression

2nd row: Sea Surface Temperature (SST) in °C from AMSR-E

3rd row: Sea Level Anomaly (SLA in cm)

4th row: Surface geostrophic velocity field (SLA+Rio05).
Colors are the amplitude of the velocities: 10<Vblue <20cm/s; 20<Vgreen <40cm/s; 40cm/s<Vorange<60cm/s; V red>60cm/s

Green dots are the CTD stations
Red dots are CTD stations which are concomitant with the satellite image.

The **SAF** follows the bathymetry:

- Feature **(1)** on the maps (fig. 5) shows a meander over the SFZ (57-59°S, 63-66°W).
- Feature **(2)** shows a second meander at (56-57°S, 53-58°W), with the SAF joining the PF. It closes the circulation in the Yaghan Basin (YB).

Feature (1) stays nearly at the same location although weakening whereas feature (2) is advected further east.

Surface geostrophic velocity fields show westward flows that can be attributed to the presence of mesoscale eddies. Deep penetrating cyclonic eddies from the south enters the YB as illustrated by the 1st column of images.

- One of them (feature **(3)**) is observed on January 11 and it is advected to the north.
- Another cold eddy (feature **(3')**) is visible at the end of the cruise (8th of February)

Eddy features are also observed on the hydrological section during the 1st leg between stations 7 and 10 (fig. 4).

The **PF** has a strong surface-temperature signature (T=6°C). It stays at roughly the same location ~57.5°S below the satellite track. The front becomes less intense ($V_{(leg1-leg2)}$=15 cm/s) between the two legs.

Surface geostrophic velocity fields show a branching of the PF going to the south (from 57.7°S to 58.5°S) with westward velocities. It is not clear on the SST images maybe due to the seasonal thermocline. However the LADCP sections (leg1 stations 20-23 and leg2 stations 80-83), show negative cross-track velocities (V=-10cm/s).

The **SACCF** has no clear signal in SST and in altimetry. However, an outstanding bloom of Chl_a in Ona basin documents the turbulence of the SACCF after crossing the SFZ (Fig. 6)

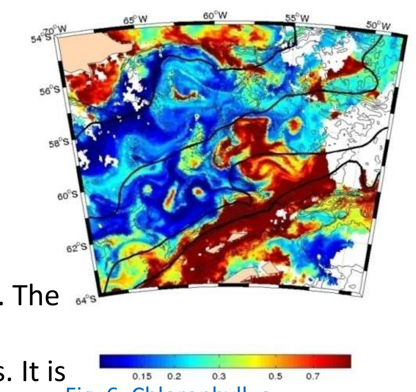


Fig. 6: Chlorophyll_a concentration (mg/m3) MODIS Aqua, 4-km resolution, 8-Day composite image:17/01/06 => 24/01/06 Black lines are the front positions by Orsi et al., 1995.

4- SLA along JASON-1 track and dynamic height from CTD

SLA is highly variable showing differences (top panel) as high as 40cm in only 10 days.

As example, in the Antarctic Polar Frontal Zone (APFZ):

- high positive anomaly (~20cm) at 57.3°S corresponds to an anticyclonic eddy (visible the 15/01 only).
- the eddy disappears 10 days later and is replaced by a high negative anomaly (~30cm).

South to the PF:

- high positive anomaly (~20cm) at 59.5°S corresponds to an anticyclonic eddy along the SFZ (visible the 25/01 and 04/02).

A comparison between the dynamic height anomalies (bottom panel) and the SLA shows:

- high negative anomaly (~20cm) at 56.3°S corresponds to a cyclonic eddy in the APFZ during the leg2 which is not represented in SLA.
- an eddy in the APFZ is also documented. However, The dynamic height anomaly localizes it further south than the SLA.
- a branch of the PF meanders southward (~58.4°S)

In situ data was gathered over 21 days whereas satellite flew in a few seconds over the track three times (15 Jan, 25 Jan and 04 Feb). Thus, these differences illustrate an aliasing.

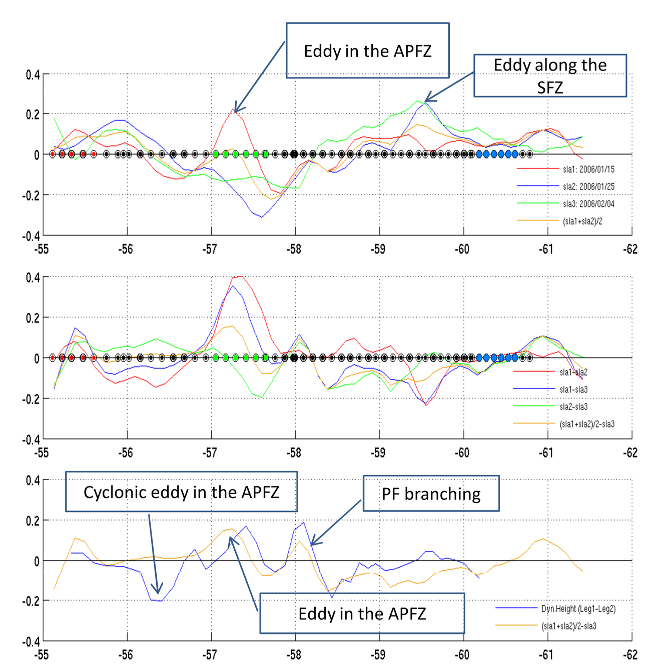
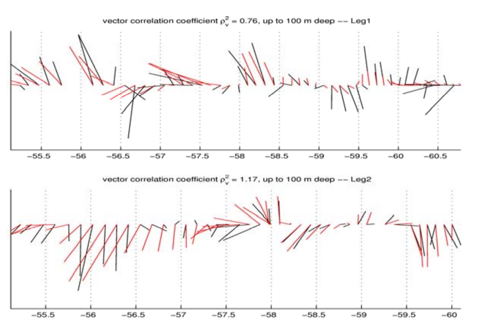


Fig. 7:
Top: SLA (in m) along the JASON-1 track in January-February 2006.
Middle: Difference between the three SLA
Bottom: Dynamic height (leg1-leg2 in blue) is equivalent to an anomaly and is compared to a composite of SLA (in orange)
The location of the CTD station at the time of the satellite pass, are colored as the corresponding SLA.



A Vector Correlation Coefficients (VCC) between the velocities from the LADCP and the velocities from the satellite gridded product (thus SLA+RioO5) , interpolated along the track 104, leads to:
$\rho^2_{leg1} \approx 0.76$ and $\rho^2_{leg2} \approx 1.17$ (perfect correlation =2)

Fig. 8:
Velocity vector from the LADCP (in black) and altimeter product (in red) to compute the Vector Correlation coefficient (VCC). LADCP velocities are averaged between 0-200m .
Top: 1st leg, Bottom: 2nd leg

5- Evaluation of Rio05 Mean Dynamic Topography

Rio05 Mean Dynamic Topography is a combined product based on GRACE mission, altimetry and in situ data (hydrologic and drifters data) over 7 years (1993-1999) .

- Dynamic height is computed from the CTD data (fig. 8) with two reference pressures: one at 2000db, the other at a depth of isopycnal 27.86 (neutral density).
- Surface height referenced to the depth of isopycnal 27.86 is close to Rio05

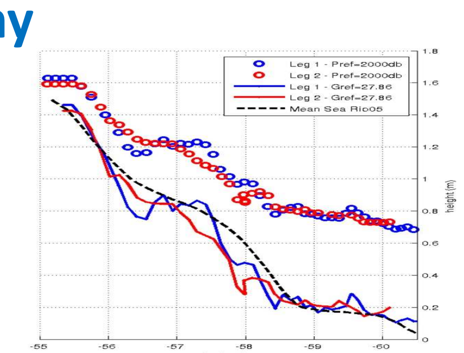
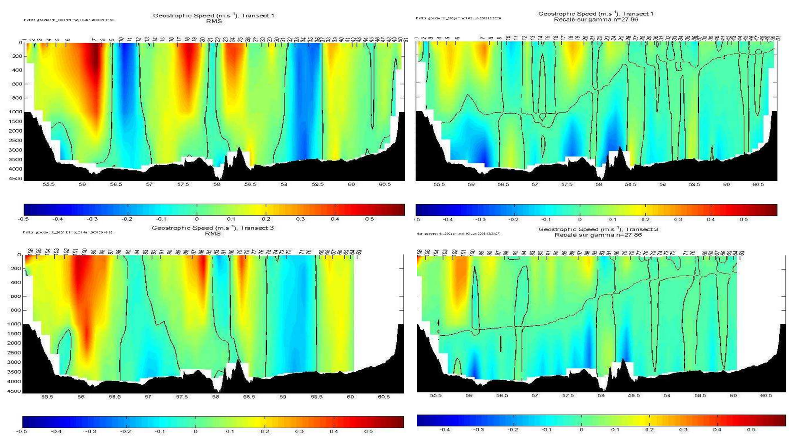


Fig. 8: Dynamic height at 2000db (blue and red dots) and at the isopycnal 27.86 (blue and red lines) and Rio05 (dashed black line)



Geostrophic velocities referenced with the LADCP (fig. 4) and the geostrophic velocities set up with the reference pressure at isopycnal 27.86 are compared. Geostrophic velocities from the isopycnal 27.86 show:

- weaker intensity than the velocities referenced with the LADCP (fig. 4)
- reversal flow below the reference pressure
- very small transport

Fig. 9:
Top and bottom left: geostrophic velocities referenced with the LADCP (leg1 and leg2). The associated transport is equal to 137.33 Sv (leg1) and 120.45 Sv (leg2).
Top and bottom right : same as the left panels using a reference pressure at isopycnal 27.86. The associated transport is equal to 79.19 Sv (leg1) and 45.26 Sv (leg2).

Is Rio05 incorrect along the track during the cruise?

Geostrophic velocities are integrated starting from the southernmost to the northernmost station using the following equation: $Z_{n+1} = (V.f.\Delta x) / g + Z_n$,
Where: Z_n and Z_{n+1} are the Sea Level at the stations n and n+1,
V is the velocity and **Δx** the distance between n and n+1,
f is the Coriolis parameter and **g** is the gravity.

Rio05 curve along the track falls within the error bars and the mean sea level from the geostrophic velocities is approaching Rio05. However, the error bars indicate that the data for the two legs are not sufficient to correct precisely Rio05.

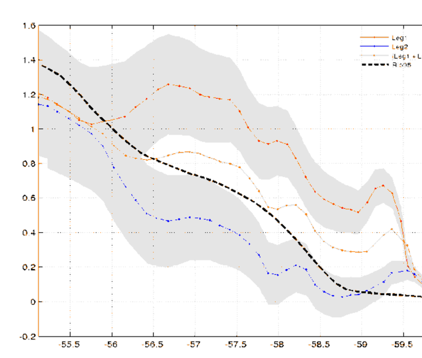


Fig. 10:
Sea level along track 104, computed from the geostrophic velocities , is compared to Rio05.
Gray areas represent the error in Leg 1 and 2, taking a systematic error on, at the surface, on LADCP equal to 3.5cm/s

Perspectives ...

- Using the ADCP from the moorings, three year time series will be available to conduct a fine validation the JASON-1 data along its track #104. Also these data could help to bring a correction of the Mean Sea along the section. It will give a more precise absolute dynamic topography and consequently, more accurate geostrophic velocities.
- In addition, an estimation of the ACC surface transport along the JASON-1 track could be done using a complete data set of satellite data , 3-year time series of ADCP (moorings) and hydrological sections (2005, 2008)
- Finally, we could explore the possible relationship between the SAM index, SST field and basin trapped modes (Barré et al., 2008) in Drake Passage.

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