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A synthetic geoid in the Azores Current area

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Abstract:

The main limitation of altimetry is due to the poor knowledge of the geoid elevation. Usually the geostrophic circulation deduced from altimetry contains only the variable part of the sea surface height. However, the permanent part of the circulation (i.e. the synthetic geoid) can be determined from in situ measurements. The hydrographic and Lagrangian data obtained during the SEMAPHORE-93 experiment have been used to estimate synoptically the mesoscale surface circulation in July and October 1993. Independent calculations of the synthetic geoid at both periods have been deduced by subtracting the altimetric sea level anomaly field to the in-situ field. Compared to climatological fields, the synthetic geoid –representing the permanent circulation lacking in the altimetry– evidence a steeper pattern of the Azores Current. Such a technique can be used to improve climatological circulations whenever in-situ measurements are available at the synoptic scale.

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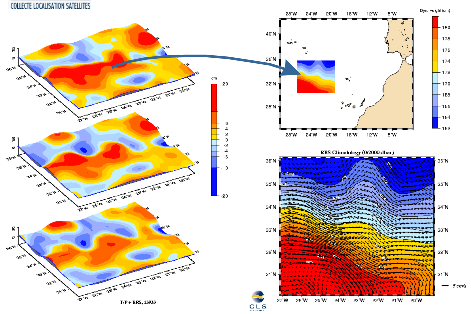
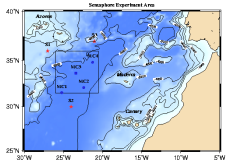


T/P combined with ERS-1 or ERS-2 altimetric data provide synoptic maps of the ocean mesoscale circulation every 10 days (here, from July 27 to August 16, 1993, in the Azores current area). Because the geoid is poorly known, altimetric mean profiles (which contain the geoid plus the permanent ocean circulation) are calculated from repeat orbit altimetric missions. Then this mean height is subtracted to each individual altimetric pass to provide Sea Level Anomalies along the satellite ground tracks. Maps are obtained by optimal interpolation. The lacking mean oceanic circulation could by provided by a climatological dataset (e.g., Robinson et al., 1979). Climatological fields are usually to smooth, and calculated with several decades of hydrological measurements, while the mean altimetric height correponds to a specific period.



From July to November 1993, an oceanographic experiment: SEMAPHORE-93 took place in Azores current area. Several hydrographic surveys were conducted, current meters and Lagrangian floats were released.

The in-situ dataset provide a synoptic view of the total mesoscale circulation at a given day

Altimetric data provide the synoptic Sea Level Anomaly map the same day

The difference betwen this two fields:
IN SITU MAP - SLA MAP = SYNTHETIC GEOID (SG)
Is the mean circulation lacking in the altimetric data

This technique can be used if the in-situ data and the SLA map provide the same scales of the mesoscale geostrophic circulation. Moreover the different in-situ data do not give the same ocean information:

- Barotropic component is incomplete in the hydrographic dynamic height
- XBT profiles allow a poor description of the Mediterranean Water Tongue and the Meddies
- Surface buoys velocities contain ageostrophic components
- The data coverage is not homogeneous in space and time

Mapping the ocean mesoscale circulation by a multivariate objective mapping technique :

Ocean fields are usually mapped by univariate optimal interpolation (e.g., Bretherton et al., 1976). For the ocean geostrophic circulation, where the dynamic height field and the velocity field are associated by the geostrophy, a multivariate optimal interpolation has been developed (e.g., Le Traon and Hernandez, 1992 ; Hernandez et al., 1995). The observations can be sparse values of velocities (current meters, drifters...) or dynamic height (hydrographic data). The estimated field can be the velocity field, or any geostrophically related field (dynamic height, vorticity...), as follow :

$$Estimate = \sum_i \sum_j A_{ij}^{-1} C_{ix} O_j \quad \text{and} \quad Error = Var \cdot \left(1 - \sum_i \sum_j C_{jx} A_{ij}^{-1} C_{ix}\right)$$

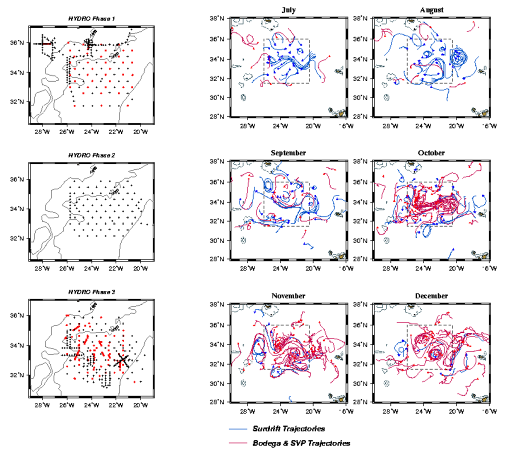
- the observation vector : ${}^{T}O = (u....,v....,h....)$ contains dyn. height, velocities etc....
- the observation covariance A_{ij} matrix is based on correlation <U,H>, <H,U>, <H,H>, <U,U> plus the budget error
- Assuming isotropy and horizontal non divergence (geostrophy) of the fluid, these correlations are linked :

$$F(r) = \langle U_{//} U_{//}(r) \rangle = \frac{-1}{r}\frac{dC}{dr} \quad , \quad G(r) = \langle U_{\perp} U_{\perp}(r) \rangle = \frac{d^2C}{dr^2} \quad \text{and} \quad C(r) = \langle H\, H\,(r) \rangle$$

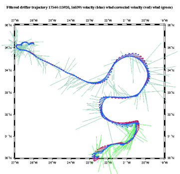
$$\langle U_i U_j(r) \rangle = (F(r) - G(r))\,\frac{r_i r_j}{r^2} + G(r) d_{ij} \quad , \quad \langle H\, u(r) \rangle = r_2\, F(r) \quad \text{and} \quad \langle H\, v(r) \rangle = -r_1\, F(r)$$

- The dynamic height correlation function $\langle H\, H\,(r) \rangle$ is based on previous study (Le Traon and De Mey, 1994 ; Hernandez et al., 1995), and used both f or the SLA mapping and dyn. height mapping of SEMAPHORE data
- The error budget is deduced from the SEMAPHORE data analysis

Hydrological surveys were performed during 3 main phases (July, September, and October/November), while 15-meter depth drogued buoys (red) and 150-meter depth drogued buoys (blue) were released since July 1993. These data are providing independent synoptic view of the mesoscale circulation in July and October. Thus, we have mapped the ocean circulation in **July 22, 1993** and **October 29, 1993**.

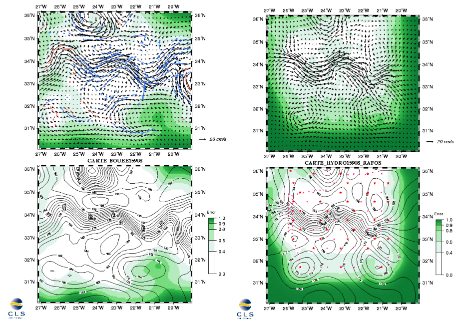


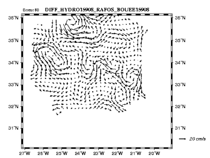
Dynamic heights from 0/2000 dbar have been calculated from CTD (red) and XBT (blue) profiles. (XBT salinity is deduced from local T-S relations, and XBT profiles located near Meddies were removed from the dataset). From RAFOS floats drifting at 2000 m-depth, the geostrophic circulation has been calculated (by multivariate mapping technique). This circulation has been added to the dynamic height, providing the barotropic component.



To reduce the surface buoy ageostrophic components, 6-hours wind fields have been interpolated along the trajectories. The wind driven component (i.e. Ekman drift) is calculated and deduced to the buoy velocities. Then, 3-day low pass filter is applied to remove inertial oscillations and the major tide components.

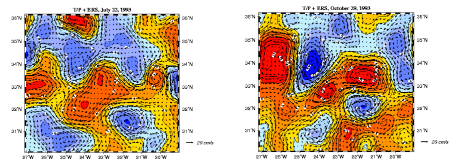
The multivariate mapping has been performed at the 2 dates. First, an analysis of the data-error budget and the data sampling has been done by estimating the ocean circulation separately with buoys or hydrographic data. In the exemples below (July 22), because more than 30 buoys were advected along the Azores Current path, the corresponding circulation (left) is described more widely than in the hydrographic map (right). Green shading indicates mapping error level, from 40% to 100 % of the mesoscale field variance (i.e., the 40% treshold level corresponds to 5-6 cm rms and 6-7 cm/s rms precision). On the top figure are plotted the velocity observations (if present) and the estimated geostrophic velocity field. The bottom figure represents the dynamic height observations -if present- (red crosses for CTDs and red dots for XBTs) and the estimated geostrophic height. The same representation is used to plot the multivariate mappings (next column). Note that the combination of buoy and hydrographic data allows a better description of the mesoscale circulation (as shown by the mapping error levels)

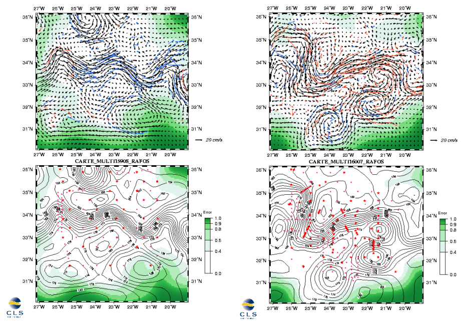




Velocity differences between the hydrographic and buoys estimations show that the mesoscale features have been well described by both set of data when observations are available. The differences are mainly due because buoy velocities give a more intense flow field into the jet and the eddies. In order to get the same spatial sampling than altimetry, the buoy velocities were less weighted in the multivariate mapping.

From July to October, the Azores Current path has shifted from nearly zonal, centered at 34°N, to a north-south flow at 25°W, meandering towards the east around strong cyclonic/anticyclonic eddies. These features are represented in both the altimetric SLA mapping (top) and the multivariate in-situ mapping (below). However, the in-situ dynamic height maps already exhibit a meridional slope, lacking in the altimetry:



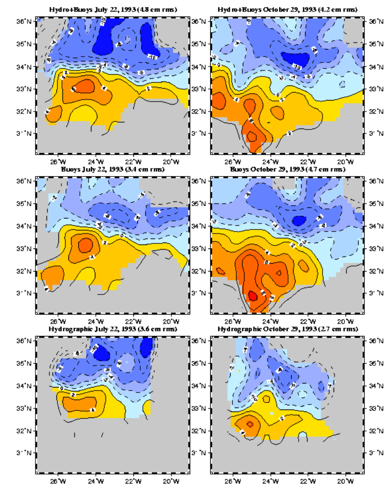


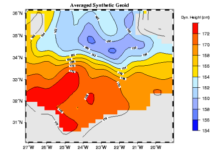
The SG field is calculated by subtracting the SLA field to the in-situ field, ***where the two fields offer a significant precision***. Thus, the SG field have been calculated only where mapping error levels are lower than 40% of the mesoscale oceanic variance.

Because we have two independant (i.e. decorrelated) mesoscale situation, we can calculate two independant estimates of the SG field (one in July, the second in October). These two fields should be close, since they both correspond to the same permanent oceanic circulation lacking in the altimetry.

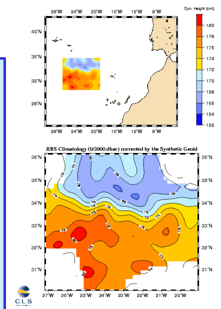
In order to quantify the impacts of the different oceanic dataset, we have calculated the SG fields relative to 1) the hydrographic circulation mapping, 2) the buoys circulation mapping, and 3) the multivariate (buoys+hydro) circulation mapping.

The 6 SG estimates below are plotted with the spatial mean removed, and only for mapping error level lower than 40%. Spatial RMS are also indicated. The fields show +10/-10 cm anomalies, associated to a meridional slope, and an intensified eastward current at 34°N. Buoys provide a larger estimate coverage of the SG (at the 50-100 km resolution) compared to hydrographic data. 150-200 CTD/XBT are necessary for a 400 x 500 km area, whereas 40 buoys sample 800 x 400 km area. Note that the multivariate SGs are not much wider than the buoys SGs, but by combining both types of data, the fields are less noisy.





Although the eddy fields were different, we observe an overall similarity between the SGs, showing the interest of this technique. The small features present differently in the hydro. and buoys SG show the precision level of the method. The difference between the July and October SGs (2.5 cm rms, compared to the SG RMS = 4-5 cm) gives also an estimation of the accuracy. An averaged SG has been calculated (above) with the 2 multivariate SGs. The RBS climatology (top part of the poster) has been corrected with the averaged SG (below). The Azores Current is strenghened and ajusted, the southern branching is also observed.



Conclusion:

A synthetic geoid (SG) can be estimated by subtracting at a given date the altimetric SLA to an in-situ mesoscale field, with a 2.5 cm accuracy. Estimating such a field at the spatial altimetric resolution (50-100 km) is data-costly. Multivariate analysis, here with buoys and hydrographic data provide better sampling and accuracy. Any type of in-situ mesoscale measurements can be used, providing they are compatible with altimetry. The SG technique can be applied to improve climatological fields, in particular in the North Atlantic where lots of intensive oceanographic experiments were conducted. In the Azores Current area, the SG will be added to the 6-year combined T/P+ERS SLA maps, providing a unique time serie of the total mesoscale circulation. A validation can also be performed, using more recent measurements in the area (SEMAPHORE-94, CANIGO...)