Ocean Sci. Discuss., 9, C1040–C1049, 2012
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Ocean Science Discussions

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Interactive Comment

Interactive comment on "Surface signature of Mediterranean water eddies in the North-East Atlantic: effect of the upper ocean stratification" *by* I. Bashmachnikov and X. Carton

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Received and published: 20 September 2012

We thank referee number 2 for his thorough analysis of our papers and for his suggestions.

Main remarks:

1-3. I'm surprised that this can be done at all for such small scale features, and I think that error bars should be estimated for the vorticity. One way to do this would be with a bootstrap technique in which the SSH observations are perturbed randomly and the vorticity calculated many times.

Reply: The following paragraphs are added to “Materials and methods”: “The accuracy of the computation of peak relative vorticity from AVISO data depends on the data accuracy of the altimetry missions, as well as on how far the closest altimetry track was from the center of the structure. When a track crosses the center of the surface signal, the along-track sea-level anomalies (SLA) are obtained with spatial resolution of 6-7 km and typical precision of about 2 cm (Chavanne and Klein, 2010), while in general the SLA error is less than 3 -4 cm (Fu and Cazenave, 2001). To estimate the error in relative vorticity calculation, resulting from the noise in the measured SLA, a vortex with a characteristic radius of 50 km, and a SLA drop of 5 cm across the radius, was constructed with a grid resolution of 30 km. At every grid-point SLA was further perturbed by a normally distributed random noise with the standard deviation changing from 1 to 1.5 cm and back to 1 cm along 5 consecutive SLA fields. This models the weekly sampling of a vortex moving with a speed of 3 cm s-1 from one Topex-Poseidon’s ground track to another. The mean peak vorticity at the eddy center was computed and its error was estimated using Student’s t-distribution. The experiment was repeated 30 times. The mean error in peak relative vorticity was about 2.5 10-6 s-1. Since meddies often generate surface SLA of bigger radius and the SLA drop across the radius may exceed 10 cm (Oliveira et al., 2000), this estimate is considered to be close to the upper bound of the related error.”

And I might have missed it, but I didn’t see a description of just how you estimated the vorticity.

Reply: This part was really missing and is now specified in Methods. Relative vorticity was taken proportional to the Laplacian of the sea-level height and computed using a 7-point stencil width which allows a reduction of the measurement noise (Arabic et al., 2012).

On p18 line 10 you discuss how a strong surface current can "shed the surface signature away", but this goes against your P-V model, which demands a relative motion between the Meddy and upper layer to form the anticylonic surface velocity. Perhaps

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you might clarify.

Reply: Indeed, this really needed clarification. Observations suggest that meddies while crossing the Azores current often loose connection with their surface signals. We see this mechanism in analogy of the mechanism of the shedding of a Taylor cone from a seamount; or trapping/"jamming" of meddy surface signature by other surface features.

The last paragraph was rewritten as: "A number of effects affecting the meddy signal itself were not taken into account here. Intensification of the meddy surface signal due to alignment with an existing surface anticyclone has been discussed above (meddy Ceres). Oppositely, too intensive background flow may cause the surface signal separation from the meddy, in a similar way as the detachment of a bottom trapped anticyclone from a seamount (Verron, 1986). This may be the reason for the sharp decrease in the intensity of the surface signals as meddies cross the Azores Current (Hyperion, Ceres). A possible loss of meddy surface signal may also be due to encompassing or blocking of the surface signal by an intensive surface structure. For example, when interacting with a surface intensified cyclone, a meddy may "dive" under it, which results in separation of the meddy surface signal and the meddy (Richardson et al., 2000, Carton et al., 2010). In these cases, the background flow field should also be considered in detail (Vandermeirsch et al., 2003a,b). When a meddy propagates with -drift velocities, resonance with the baroclinic Rossby waves may heavily damp the surface signals. Such effects should be studied with very high resolution models of the Northeastern Atlantic Ocean."

One dynamical question occurred to me: is the anticyclone induced by a Meddy ever strong enough to induce closed circulation so that the upper layer water is trapped above the Meddy? I would guess not, but your model could estimate whether this is likely.

Reply: Joint RAFOS and altimetry observations suggest that in the Subtropical NE

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Atlantic surface vorticity over a large meddy often reaches or may exceed that of surface eddies. For example, the last line in Table 2 gives evidence that relative vorticity anomalies over some meddies form the strongest anticyclonic structures in the 4x4 degree square surrounding the meddies 20 to 40% (and up to 90%) of the time. Again, the closed circulation in meddy surface signals is supported by the observation that relative vorticity at the sea-surface consistently decreases in its absolute value away from the meddy center (Figures 1-3, plates C). A reader may be misled by plates B of Figs 1-3, where we presented some particular situations in general not favourable for detection of the surface signal of meddies. To avoid this impression, on Plates A of the same figures more characteristic manifestations of meddies' surface signals are now presented. The plates A became a bit heavy, and (following the suggestion of Reviewer 1) the direction of propagation of meddies is now given in the figure captions, instead of arrows on the plot.

Minor presentation points:

I like your model, and think that the basics (conservation of PV of upper layer water that is compressed as the Meddy passes under, leading to anticyclonic vorticity and a high in SSH) should be explained in the abstract.

Reply: The abstract is now complemented with the sentences: "While pushing its way through the water column, a meddy raises isopycnals above. As a consequence of potential vorticity conservation, negative relative vorticity is generated in the upper layer."

You don't state exactly what the velocity and vorticity profile of a Rayleigh vortex is, nor give a reference. Why don't you show an example, along with the corresponding vorticity and SSH profiles, perhaps compared to one of the observations? It might be possible to include this in fig 5, and reference that figure at this point.

Reply: The missing equation of the radial profile of the azimuthal velocity of the Rayleigh vortex is now added to the Materials and methods. The references are also presented (p.4, 10-13).

fig 1 - State what the bathy contours in a and b are.

Reply: This is now included in the figure captions.

Fig 8a and b do not reproduce or print well due to colour selection. Reply: Colour scale is now changed to increase colour resolution for small meddies.

the lines on figure 7 are difficult to distinguish.

Reply: The markers have been changed. Arrows pointing from each meddy name to the relevant curves are inserted.

Please also note the supplement to this comment:

p.3, 21

Reply: Thank you, the error in the word “Hermite” is now corrected.

p.3, 29 This is unclear since you don’t give v_theta vs r. Would it help to graph it, the associated vorticity, and compare with observed? I find myself wondering what the velocity and vorticity profiles look like, and how the Rayleigh model compares to observations.

Reply: In the new version of the manuscript we now present the expression for the radial profile of the azimuthal velocity of the Rayleigh vortex. The comparison of the profiles derived in the manuscript with those of meddy surface signals are now presented on Fig. 5.

p.4, 19 Reply: “e” is the exponent, not a model parameter.

p.7, 16: why only the front slope, and not over the center? Is there a vortex interaction? Perhaps explain for those who haven’t read the cited papers.

Reply: Compression of isopycnals in the upper layer occurs only over the frontal slope of the meddy. Over the lee side the isopycnal simply returns to the initial position (we discuss this issue more in detail a bit later: p.9, 17 - p.10, 4). We agree that af-

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ter the surface signal is generated the vortex-vortex interaction may lead to change of the characteristics of the surface signal. Therefore, we add the phrases: “Further vortex-vortex interaction may lead to alignment of the two vortices or co-rotation of the structures around a common center (Polvani, 1991). When the radii of the vortices are smaller than or equal to the first Rossby deformation radius and when the initial separation of the centers is about half the meddy radius, the second evolution is the most probable one. Co-rotation does not result in any significant change in the parameters of the vortices (except for their relative position), and we may consider the characteristics of the meddy surface signal to remain as in the final stage of its formation process.”

p.8, 9

Reply: Thank you, the division sign was missing. This is now corrected.

p.9 This section is not as clear as the zero stratification case (sect 4.1), in terms of assumptions re p-v in the upper layer (unsteady or steadily propagating), and in simultaneously forgetting about the free surface and then figuring out the free surface displacement. I can see it in terms of solving the Laplacian equation driven by the Meddy displacement below, so that the disturbance should extend up by f/N times the Meddy radius, and that the free surface displacement is found by demanding that the pressure perturbation is provided by free surface. Perhaps if you start with such an explanation, the reader would find it easier.

Reply: Indeed the assumptions must be specified more clearly and the principle should be stated more explicitly. We propose the following paragraph to replace the former (now located before the calculation): “The principle of the calculation to follow is that we assume that the meddy drifts steadily with respect to the upper layer, and that the upper layer has zero potential vorticity anomaly. We solve the Laplacian in three dimensions and find the streamfunction in the upper layer, driven by the meddy displacement below. The disturbance extends by f/N times the Meddy radius. The free surface displacement is obtained by demanding that the pressure perturbation, thus calculated, is generated by the free surface elevation."

p.12, 7 I only skimmed from eq 3 to this point, so you should check carefully for typos.

Reply: Ok.

p.13, 4 root-mean square, since mean error is zero if not systematic

Reply: Thank you, this is corrected (the phrase is put in captions for Fig. 6).

p.14, 14 this needs more detailed explanation

Reply: This sentence was awkward. It is now replaced with "It is more difficult to reliably assess a decrease of the meddy radius with time (if any), since the RAFOS' positions relative to the meddy centre may be a result of their migration within the meddy."

p.18, 10 but a relative motion between the Meddy and the upper waters is exactly what your model requires to generate anticyclonic surface velocity.

Reply: We suggest that too intensive background flow may cause the surface signal separation from the meddy, in a similar way as it is observed for a bottom trapped anticyclone over seamounts. Please see the answer to the Main remark number 2.

Interactive comment on Ocean Sci. Discuss., 9, 2457, 2012.

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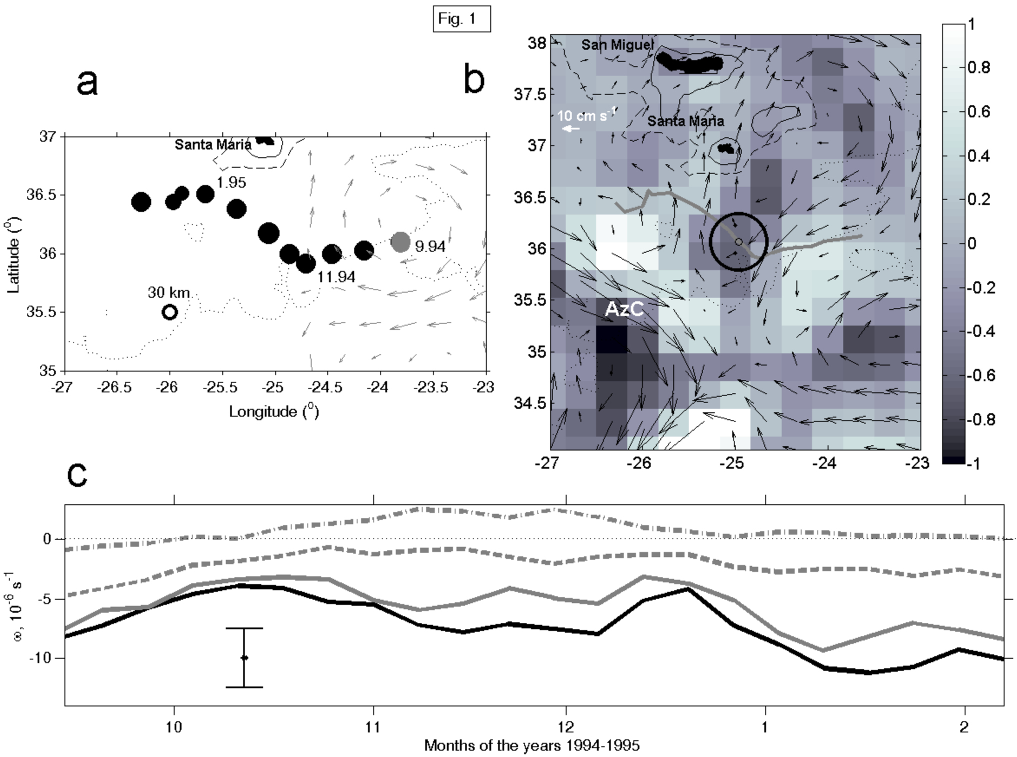

Fig. 1. Fig. 1. Temporal evolution of the characteristics of meddy Zoe and of its surface signature.

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Fig. 5

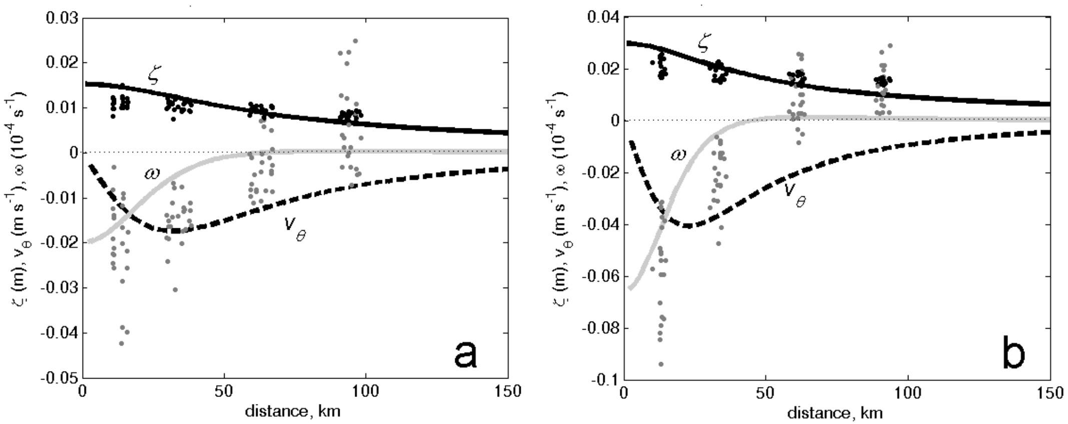

Fig. 2. Fig. 5. Radial profiles of SLA (m, solid black line), azimuthal velocity (m s-1, dash line) and relative vorticity (10-4 s-1, solid grey line) of the surface signal of a meddy. Observations are ov

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Fig. 8

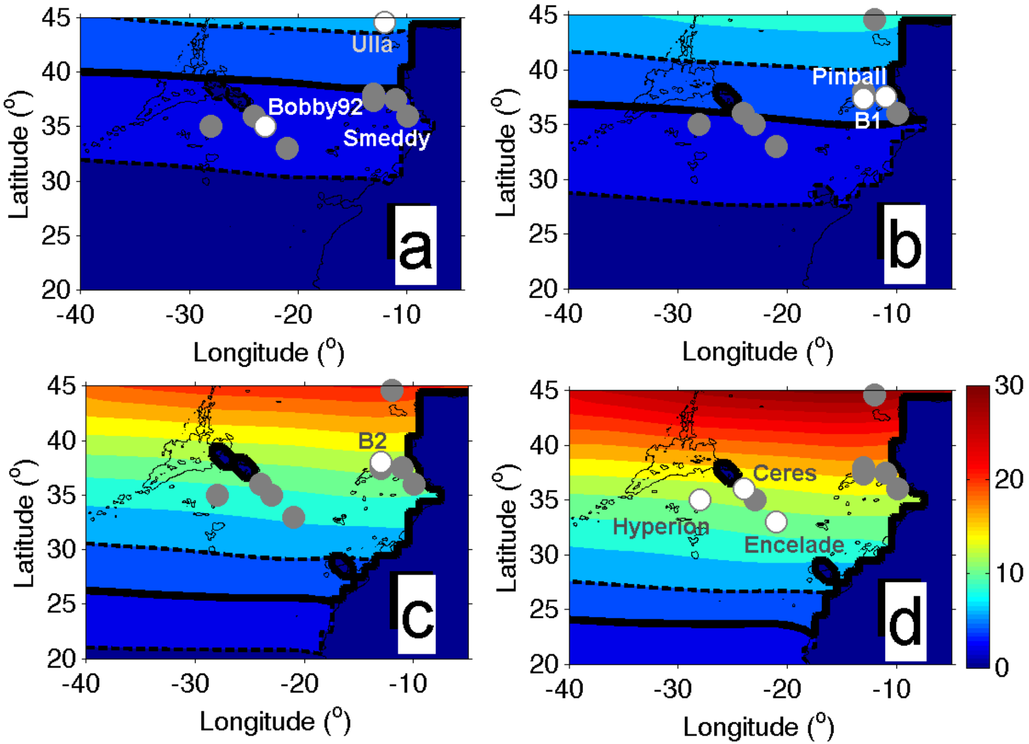

Fig. 3. Fig. 8. Sea-level anomaly (cm): (a) H = 1100 m, R= 20 km; (b) H = 800 m, R = 20 km, (c) H= 1100 m, R= 30km, (d) H = 800 m, R= 30 km.