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Ocean Science
Discussions

Interactive comment on “Manifestation of two meddies in altimetry and sea-surface temperature” *by* I. Bashmachnikov et al.

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First of all we thank referee number 1 for a thorough analysis of our paper and for suggestions which helped to improve the manuscript. The referee comments and the changes introduced in the text are listed below.

Main comments: 1) I would be very careful in stating that any subsurface eddy can be tracked from the ocean surface: this statement is admittely not very strong in the manuscript, but it is included in the abstract as well as in another couple of places within the main text. This is because, as the authors surely agree, upper ocean vorticity can be determined by so many different processes (strong currents, surface eddies, atmospheric forcing) that only subsurface eddies propagating in regions devoid of such strong processes are likely to imprint a detectable surface signal.

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Response: For a comparatively dynamically calm region, as the subtropical NE Atlantic, a number of previous observational and theoretical studies showed that most of meddies (except for very small ones) form a surface signal which is sufficiently strong, stable, and permanently connected with the parent meddy for long periods of time. Introduction is now enlarged to provide a number of evidences of this: “In the pioneering work of Käse and Zenk (1987) the existence of surface anticyclonic signals over meddies was first identified using surface drifter trajectories. Since then a number of in-situ observations of meddy dynamic signals at the sea-surface were obtained (Pingree and Le Cann, 1993a,b; Paillet et al., 2002, etc., see also a review in Bashmachnikov et al., 2009a). On average, the peak relative vorticity of the surface signals was around -0.1*f (where f is the Coriolis parameter), around 30% of the peak relative vorticity of the parent meddies. The peak azimuthal velocities of the surface signals ranged from 5 to 15 cm s-1, comparable with the peak azimuthal velocities of surface eddies in the subtropical Northeast Atlantic (Shoosmith et al., 2005). Combining along-track altimetry data with in-situ observation of several meddies, Oliveira et al. (2000) demonstrated positive anomalies of sea-level height of order of 10 cm coupled with the meddies. The observed radiuses of the anomalies were 30-75 km and the azimuthal velocities were inside the abovementioned range, obtained from in-situ observations. The mechanism of generation of a meddy surface signal is the compression of the upper layer vorticity tubes by a moving meddy. By virtue of conservation of the upper layer potential vorticity, the anticyclonic eddy in the upper ocean is formed. Upper layer stratification, though, can significantly reduce the intensity of the signal as it reaches the sea-surface. For climatic stratification, theoretical results suggest that in the Subtropical Atlantic moving meddies with the dynamic radiuses of at least 15 km should generate a sea-level anomaly exceeding the AVISO altimetry noise level (Bashmachnikov and Carton, 2012). For several meddies tracked by with deep-floats in the subtropical Atlantic evidences of high stability of their surface signals were obtained. Statistical analysis of the surface signatures of those deep tracked meddies showed that the meddies were accompanied with an anticyclonic signal 90 to 100% of the time of observations (6 to 18 months), and the relative vorticity of their surface signals was, on average from -0.05 to -0.10 f (Bashmachnikov and Carton, 2012). Also, 20 to 40% of the time of observations the meddy surface signals represented the most intensive surface eddies in the surrounding area (the radius of the area was taken of 3-4 times the radius of the meddy surface signal). Stability and relatively high intensity of meddy surface signals allowed uninterrupted surface by-tracking by means of satellite altimetry of the meddies with known trajectories for periods from several months up to one year (Stammer et al., 1991; Pingree and Le Cann, 1993a; Pingree, 1995; Bashmachnikov et al., 2009a). In spite of comparatively high intensity and stability of meddy surface signals, two situations were identified when meddies temporary lose their surface signatures: soon after a meddy had crossed the axis of the Azores Current (AzC), and after a meddy entered in a close interaction with a surface cyclone (Bashmachnikov et al., 2009a, Carton et al., 2010)."

The phrase of meddy tracking is removed from the abstract, as it is not of principal importance.

2) Judging from the red arrows in Fig. 1a and also from Fig. 1d, it seems that the velocities are more representative of an anticyclonic eddy northern boundary (the velocities are west-southwestward). Therefore, I wonder if the surface eddy signal isn't shifted to the south of transect 2, which would be in better agreement with the SST signal shown in Fig. 4a.

Response: Form the analysis of the positions of the centres of the meddy and of its surface signal we got that the former is situated 5 km south of transect 2, and the latter is about 10 km south of the transect line (p.3077, line 29 – p. 3078, line 3). Those distances, though, are much smaller than the distance to the centre of the cold SST anomaly (around 100 km south of the transect line). In the new version of the manuscript this fact is mentioned at p.12, 3rd paragraph: "The centre of the cold SST anomaly is observed south of the Meddy 1 position. The separation is close to 100 km and far exceeds that of the centre of the dynamic surface signal of the meddy (about

10 km to the south of the meddy centre).”

3) end of page 3082, discussion about surface water convergence: if the surface signal of the anticyclone is characterized by positive SLA, then I would expect surface flow divergence and subsurface convergence towards the center of the eddy (upwelling).

4) page 3084, last paragraph starting with row 10: why would colder fluid entrained from the north be advected towards the center and warmer fluid from the south be wrapped around the eddy core? That would indicate a surface convergence process. It seems to me that the second mechanism described by the authors (lateral entrainment along doming isopycnals) may be more plausible in this case.

Response: Those two comments are connected and we reply here to both. As the meddy surface signal is formed it dominates the near-surface dynamics. The surface anticyclonic eddy is associated with the convergence at the sea-surface and downwelling in the center. At the same time, we agree with the referee that the mechanism of lateral entrainment along doming isopycnals may have stronger input in the formation of a negative SST anomaly over a meddy. In the new version of Discussion we added the following text: “Theoretical considerations suggest that the centre of a meddy surface signal should generally be generated over the front-side slope of the meddy relative to the direction of its motion (Bashmachnikov and Carton, 2012). When the surface signal is formed, the coupled system propagates in both layers with approximately the same velocity and, due to larger radius, the surface anticyclonic signal shields the layer over the meddy from a background flow even when its centre is shifted relative to the meddy centre. Therefore, the secondary circulation in the upper layer should be dominated by the anticyclonic meddy surface signal and the sea-surface convergence should be observed. In our cases, as the meddies moved south or south-west, entrainment of warmer water along the southwestern edge of the meddy surface signal was observed. At the same time, colder water is wrapped around along its northeastern edge. Due to doming of isopycnals over the meddy, the colder (denser) water more readily converges towards the centre of the surface signal, while less dense warmer

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water stays at its periphery."

Suggestions (and some questions) about the presentation:

1) In the Introduction, it would be nice to show a typical meddy temperature/salinity anomaly profile, to use as a reference for meddy water characteristics. An estimate from the mentioned ARGO profiles could be used for example (ARGO data are mentioned on page 3076, but not shown). This figure could also contain a second

Response: This is now done using CTD profiles of previous observations in the new version Fig. 8 (Fig. 1, in new numeration). The figure is now moved from Discussion to Introduction. Mean salinity anomalies at the MW level, obtained from the Argo float, are shown in Fig. 8 (Fig. 7 in old numeration)

2) page 3073: I could not understand very well the mechanism described in the sentence on row 23-24 ('This is attributed to formation of beta-gyres...'): could you please elaborate a bit more?

Response: Since this item does not have direct connection with the main results of the paper and not to increase further the Introduction (already long), we decided to limit ourselves to phenomenological description and to removed these phrases from the text. A description of formation of beta-gyres in meddies is given, for example, in Morel (1995) or Vandermeirsch et al. (2001). A summary is given in Bashmachnikov and Carton (2012). "Propagation of meddies in the ocean may be a result of various mechanisms. The simplest such mechanism is the advection of a meddy by an ambient currents (currents at the depth of the meddy, or barotropic currents). But typically a more efficient process is the advection of a meddy by "beta gyres", which is the formation of an antisymmetric internal dipole circulation inside the meddy that, in turn, advects the meddy (Morel, 1995). "Beta gyres" in a meddy may be formed by planetary, baroclinic or topographic beta effects. Due to baroclinic beta effect, "beta gyres" are formed via a vertical tilt of the isopycnals above or below a meddy, which leads to vertical squeezing or stretching of the meddy, which becomes horizontally asymmetric.

As a result a meddy may be advected by a baroclinic ambient current (for instance a current in a layer only above or below the meddy). For baroclinic currents, direct advection by the current may be annihilated by beta gyres associated with the mean-flow potential vorticity gradient (Vandermeirsch et al., 2001), leaving other effects to dominate."

3) page 3076, row 25: it seems to me that also the zonal eddy currents between the surface and 300 m are changed by the filtering (Fig 1d). They are quite reduced with respect to the unfiltered signal, suggesting a much more southwestward flow than the one depicted in Fig. 1b.

Response: To be more precise, the phases were changed to: "The ADCP current in transect 2 with the AzC contribution removed is presented in Fig. 2d. As expected, the filtering did not change the overall structure of the currents in and over the meddy. Even in the easternmost upper part of the section the filtering only led to accentuation of the anticyclonic structure over the meddy, now becoming more symmetric relative to the centre of the deep anticyclonic signal."

4) page 3077: the description of how the eddy center and radius are estimated should be clarified at a number of points: *) did you use filtered or unfiltered velocities? *) how do you choose xw,xe (points of minimum velocity between 2 maxima within a region identified by the altimetry as an eddy)? *) alpha is current direction with respect to what? *) how are yw and ye defined? Do you really need them? Isn't it simply, for both w and e: yc=-(xc-x)tan(beta) and R=sqrt((xc-x)ËĘ2+(xc-x)ËĘ2 tanËĘ2(beta))?

Response: This is now defined in the text (p.7, last 2 paragraphs): "To derive the centre location of the eddy at a certain depth level from in-situ observations, we adopt a model of a circular eddy, whose azimuthal velocity increases from the centre, reaches maximum at a certain distance (dynamic radius of the eddy, R) and further decreases back to zero level. With this model, any velocity section crossing the eddy inner circle of radius R will detect, at each depth level, two peaks of the modulus of current velocity at the distance R from the eddy centre and, a velocity minimum in-between. Therefore, and considering that at the current maxima the eddy signal is the least affected by the background noise, the position of the eddy axis at each depth level can be obtained by simple trigonometric use of the (x,y) location coordinates and the velocity directions of the two current maxima. The just explained approach, was applied to the ADCP measurements carried along the approximately zonal transect 2, with the AzC influence minimized by the filtering procedure, as described above (Fig. 2d). At a given depth level, the coordinates of the velocity maxima are identified by (x_w, y_w) and (x_e, y_e) (w identifies the western and w the eastern maxima) and the current directions relative to geographic north are alfa_w and alfa_e, respectively."

Selection of the points of maximum eddy velocity for computations is done since there the signal-to-noise ratio should be at minimum. Two points also gives two independent estimates of the eddy centre, which adds reliability to the results.

5) Sections 2.2 and 2.3: for the purposes of tracking the meddy surface signal, it would be very useful to see animations of relative vorticity and SST anomalies (and maybe SSH). Perhaps it is possible to add them as additional supporting material?

Response: The animations for surface dynamic signals of meddies 1 and 2 are uploaded.

6) Fig. 4a and 5: I think it would be better to show SST anomalies with respect to a mean climatological monthly ïňĄeld, rather than the absolute SST values (the authors speak about anomalies in the text, but absolute values are actually shown).

Response: In this work we talk about SST anomalies of meddy centre relative to the surrounding water, and not relative to a climatic mean. This is now specified in the text. Therefore, subtracting climatic mean will not enhance the visual results, but will induce additional noise in the image. To make it easier to evaluate difference in SST inside and outside of the core of the meddy surface signals discussed, we now present SST results as the SST anomalies, computed by subtracting the spatial mean, i.e. the mean value of SST over the presented area.

7) page 3080, rows 22-23: ’SST anomaly ... should be advected 1.3deg further south’: further south with respect to what location?

Response: This is computed relative to ADCP transect 2. This is now mentioned in the text.

9) page 3083, row 23: by ’surface dynamical anomalies’ is it meant SSH and relative vorticity anomalies?

Response: Here we meant both. This is now specified in the text: “Negative SST anomalies over the two studied meddies were less stable than their surface dynamic anomalies (in either sea-level or in relative vorticity).” Dynamic radius of a meddy surface signal is rather stable in time and the values are closely coupled.

10) Figures 1a, 3, 4a and 5 are busy figures and would greatly benefit from a much larger size (in the current version, it is sometimes difficult to distinguish vectors, contours or specific colors). Other suggestions about reducing visual complexity: *) do you need to show topography contours in Fig. 1a, 4a and 5? *) Fig. 1a would benefit from a simpler color palette for SSH (either monocolor or bicolor). It would help in better identifying the velocity vectors. A bicolor color palette could also be used in Figs. 3a, 4a and 5, if showing SST anomalies.

Response: Topography is removed from the referred figures. Instead, a new panel is added (new Fig. 1c), showing bathymetry and altimetry tracks. The colour palette of Fig. 2a (old Fig. 1a) is changed, but for other figures bicolour palette complicates visual identification of the ocean structures discussed in the text.

11) Fig 1a caption: I would use cm/s and not mm/s. Could remove ’Present’ and ’Present the’ after (b) and (c), respectively.

Response: Thank you. This is done in the new version of the figure.

12) Fig. 6 caption: the two sets of red and blue lines are not described separately (as done for Fig. 7b, for example).

Response: New Fig. 5. In fact, blue and red lines were identified. To make caption clearer we changed it to: “The red lines are SST25-SST100 and mean relative vorticity in the 25-km circle around the vortex centre; the blue lines are SST50-SST100 and mean relative vorticity in the 25-50 km ring around a vortex centre.”

13) in a few places within the manuscript, the words ’The later ...’ should be ’The latter..’.

Response: Thank you, this is corrected in the new version of the manuscript.

Please also note the supplement to this comment:
http://www.ocean-sci-discuss.net/9/C1392/2012/osd-9-C1392-2012-supplement.pdf

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