

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

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Response to anonymous Referee #2 First of all we thank referee number 2 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:

The link of the meddy to the surface eddy is not made clear in the text and the satellite observations do not appear to show any evidence of the meddy, but only of this proposed different, but connected, surface anticyclone. The observations presented in this manuscript are interesting and represent an important contribution to the study

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of mesoscale eddies. If the authors can clearly make the link between the satellite observations and the meddies, this manuscript would be a worthy publication.

Response: Please, see the response to the next two comments.

Page 3076, Line 4: The use of the term “resolution” in the description of the SSH data is not correct but the data have a wavelength resolution closer to 2 degrees (see appendix A of Chelton et al., 2011b). This wavelength resolution resulting in the ability to resolve eddies with an approximate Gaussian SSH structure with an e-folding scale of ~ 40 km at 30 degrees of latitude. Therefore the statements that the AVISO SSH fields have a resolution of $1/3$ degree is not entirely correct. The same is true for the discussion of the resolution of the SST fields, however I’m not aware of what the true resolution of these data are. I recommend that the authors replace the word “resolution” with a statement along the lines of “the fields are smoothed and interpolated to a grid with spacing of $\sim 1/3$ degree.” This misinterpretation of the resolution limitations of the satellite observations leads to what I believe to be a major issue with this paper that needs to be addressed prior to publication. The observed meddies have a radial scale of ~ 7 -10 km. The authors then show that the meddies are observed to coexist with a different anticyclonic eddy above them with a radius of ~ 25 km. This upper-eddy is still too small in spatial scale to be resolved by the merged SSH fields used in this study.

Response: This comment presents a critical issue to the results of the manuscript, and we need to discuss this in detail.

In what concerns ability to detect surface signature of meddies, we should make three observations.

1. First of all, following the referee suggestion, we avoided the word “resolution”, when speak about AVISO altimetry. The second paragraph at p-5 (Materials and Methods) now looks like:

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“The surface signatures of the selected meddies were studied using the gridded “updated” AVISO altimetry data with the grid-cell size of about 30x30 km and weekly temporal resolution (AVISO). Chelton et al. (2011) developed a global empirical criterion for the spatial resolution capability of the altimetry data of the AVISO “reference” series (i.e. where data from only 2 satellites are used). These authors, considering sea-surface height eddy-like perturbations approximated with the Rayleigh vortex model, claimed that the mean e-folding scale of the related sea-level anomaly in our study region (35N) is 36 km. Meanwhile, when an eddy is situated close to an altimetry track the spatial resolution of the detected signals increases several times. Also, the usage of the “updated” AVISO series (for our study periods we get data from 3 satellites) decreases the time interval between the sampling along the same tracks and increases signal-to-noise ratio of the resulting AVISO products. Therefore, Chelton’s scale presents rather the lower limit of the “true” eddy-resolving scale of AVISO altimetry data.”

2. Experimental results suggest that various meddies nearly always coupled with a surface anticyclone. The following text has been added into Introduction: “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.” “For several meddies tracked by with deep-floats in the subtropical Atlantic evidences

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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).”

3. The presented scale of 25 km is the dynamic radius (R), i.e the radius of maximum azimuthal velocity, which definitely does not represent a boundary of the surface signal, neither the e-folding scale. The following discussion is added in the beginning of Section 3.2:

“Relatively to the period of the in-situ measurements, the meddy was tracked forward and backward with the gridded AVISO altimetry data (Fig. 4a). With the radius of the maximum azimuthal velocity of 25 km at the sea-surface, the e-folding scale of Chelton et al (2011) is 36 km. The theoretical results by Bashmachnikov and Carton (2012) as well as results of numerical modelling (Filyushkin et al., 2011), showed that the expected shape of the meddy surface signal should be closer to that of the Burgers vortex, which has significantly larger e-folding scale then the Rayleigh vortex. In fact, a vortex forced by vertical velocity at its lower boundary (as it happened for the meddy

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surface signal) has a solution of the Burgers vortex (Wu et al., 2006). With $R=25$ km, the e-folding scale of the sea-level anomaly in the Burgers vortex should be over 80 km, and the relative vorticity should change the sign at the distance of 50 km from its centre. Both scales above clearly exceed the resolution limit found by Chelton et al (2011), which justifies our ability to detect and securely track with AVISO altimetry a surface signal even of a comparatively modest meddy, as Meddy 1.”

We would also like to note that meddy dynamic radiuses are typically larger than 10 km. The estimates most often met in literature are up 30-35 km (Tychensky and Carton, 1998, etc.). So, the Meddy 1 with the dynamic radius of 12 km is a rather modest example. Consequently, dynamic radius of surface signals of most of the observed meddies also should be much larger (Bashmachnikov and Carton, 2012). For example, as it can be derived from altimetry the dynamic radius of the surface signal of Meddy 2 was of order of 50 km (this is now specified in the section 3.3, p.13),. Therefore, the radius of the negative vorticity anomaly over the meddy should be of order of 100km, much bigger than the Chelton’s threshold. This reconciles the observational evidences of meddies surface signals being clearly detected in AVSIO altimetry maps, and the resolution limitations found in Chelton et al.

Infrared SST images have initial resolution of 1.1x1.1 km, as stated in the text.

Page 3078, Line 3: The authors show that the meddies are collocated with an anticyclonic surface signal, which they call the “meddy surface signal.” It is not clear from the text why this is observed, nor how these upper-eddies influence the dynamics of the meddies. It is also not clear if the upper-eddies are permanently linked to the meddies. This could result in the SSH and SST observations of the upper-eddies not always be collocated with the meddies below. On Page 3078, the author states “... This suggest that we are dealing with two connected, but different eddies.” This idea needs to be further developed and clarified as the satellite observations appear to not be of the meddy, but of these “different eddies.”

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Response: Part of this comment repeats the previous one. For mechanism of generation of meddy surface signal, the following paragraph is added to the Introduction: “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 Sub-tropical 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).” At present there are no researches on the influence of the upper eddy on the dynamics of a meddy. We may only suggest that the surface eddy, being much weaker than the meddy, should not principally change the dynamics of the latter.

Interactions of the two eddies of equal strength was studied by Polvani (1991). The following text is added on p.8 (the last paragraph):

“This suggests that we are dealing with two different eddies, interacting one with another.

The mechanism of generation of the meddy surface signal (see Introduction) implies that a meddy surface signal represents a stand-alone vortex, forced by a meddy. Further dynamics of such connected vortices, separated by the distance of less than two eddy diameters, should be co-rotation around a common centre (Polvani, 1991). In our case, as the radius of the surface signal is twice of that of the meddy, it should generally overlay the meddy at all stages of the interaction.”

Minor Comments:

Page 3073, Line 11-19. It would be clearer if the outline of the paper was placed at the end of the introduction section.

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Response: We now placed the outline at the end of the Introduction.

Page 3078, Line 16. Add "is" between "It" and "more" in the second sentence that starts on this line.

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

Page 3079, Line 1. Insert "to" between "easy" and "obtaining", change "obtaining" to "obtain."

Response: Thank you, the typo is now corrected.

Line 5. If the SSH anomaly is compared relative to the closest SLA minima, does this minima change in time? What if the meddy propagated into the vicinity of a cyclonic eddy, would the new minima be the centroid of the cyclones and hence the meddy SLA would be referenced to a new minima and could change, even if there were no changes in the SSH signature of the meddy?

Response: The estimate of SLA is now changed to another reference level and the corresponding corrections are made at Fig. 4b (new numeration): "The reference level was estimated individually for every track by removing a local linear trend over 700 km of along-track distance."

This new computations did not affect the results of the Section. The re-computed SLA of the meddy surface signal slightly decreased, but stayed in the same range of 5-10cm, and its time variations did not change.

Page 3084, Lines 1-27. This description of why the authors expect meddies to have a cold SST signature needs to be moved to the introduction. Placing this discussion in the last section leaves the reading wondering why the authors expect to see cold SST anomalies in the cores of meddies.

Response:

We agree with the referee that the previous observations described in the Discussion

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(p. 3084, lines 2-9) rather fit to Introduction. They are moved there together with Fig. 8 (new Fig. 1): "In this paper we describe observational evidences of meddies forming a specific signature in sea-surface temperature (SST), which may further be exploited into methods of remote identification of meddies (as well as other intensive deep anticyclonic eddies). Examples of vertical profiles of temperature and salinity showing uplift of isopycnals above a meddy compared with the surrounding ocean are presented in Fig. 1 (a,b). The meddy was observed near Seine seamount and described in detail in Bashmachnikov et al. (2009b). Also, observations at the Kiel-276 mooring (Siedler et al., 2005) showed that as a meddy was passing across the mooring, a cold temperature anomaly was observed at upper current meters (at 200 - 500 m levels)."

The lines 10 and below present a discussion of the new results presented in this manuscript and are adequate rather to the Discussion section.

Page 3090, Figure 2b. Please add intermediate tick marks on the x axis and a background grid to the figure.

Response: The intermediate marks on x-axis are added, but the background grid made it difficult to read the panel. So we decided to not to add grid-lines to the panel.

Figure 3a. It is not clear to me where the SSH signature of the meddy is in this figure?

Response: In the new version a circle is added to the figure to show the position of the meddy surface signal, as well as that of the anticyclone discussed below.

Page 3092, Figure 4a. It is not clear if the advection of SST is a result of the surface currents of the meddy, or just meanders of the background current. This figure is not convincing in the argument that meddies can be observed in SST data.

Response: We agree with the referee that this figure shows a complicated situation and at least should not come first. In the new version we changed the narration: we first examined former Fig. 6 (Fig. 5 in new numeration), which presents time varia-

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tion of SST over the meddy and shows that SST anomaly over the meddy is nearly always negative; then pass to Fig. 5 (Fig. 6 in new numeration) which presents a clear meddy signal in SST, and finally come to the former Fig.4 (Fig. 7 in new numeration) to show that cold SST anomaly not always overlays a meddy. We would like to keep this figure since it allows comparing the trends in satellite derived SST and simultaneous in-situ observations with the thermometer of the shipboard ADCP to give additional confidence to the satellite data used in the manuscript.

We also agree that the cold plume may be not related to meddy surface signal. Therefore, we also add a this possibility:

“The difference may result from advection of the SST anomaly by the AzC with a speed exceeding that of the meddy translation. The latter may happen when the meddy dynamic signal at the surface is weak as compared to the background advection. This condition is verified by the end of July 2010, after the meddy had separated from the AzC meander. During 25 days (up to the time of the cruise), the surface dynamic structure associated with Meddy 1 travelled 100 km south-southeast with an average speed of 4.5 cm s⁻¹. If travelling with the locally observed speed of the AzC (12 cm s⁻¹), the SST anomaly during the same period should be advected 1.3km further south with respect to meddy position at the end of August 2010. This estimated separation between the meddy centre and the centre of the cold plume is only about 30 km bigger than the observed one. The cold anomaly, though, may also result from water transport from the north by the meandering AzC.”

Figure 5. The dominant influence of the meddy on SST in these two figures (a and b) appears to be the advection of SST around the meddy and not a cold-core, as is hinted at in the text.

Response: We agree with the referee that, in this particular situation, the mechanism of warm water wrapping should be important, but the effect of colder water advection from north also make some input to formation of the negative anomaly. In the new

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version of Discussion (last paragraph) we described this mechanism the following way:

“As the meddies, described in this manuscript, moved south or south-west, warmer water from the south is entrained along the southwestern edge of the meddy surface signal. At the same time, colder water is wrapped along its eastern 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 water stays at its periphery.”

Through: Replace ARGO with Argo, as Argo is not an acronym, but a name chosen to emphasize the strong complementary relationship of the global float array with the Jason satellite altimeter mission. Argo was the ship upon which Jason sailed (Greek mythology).

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/C1401/2012/osd-9-C1401-2012-supplement.pdf>

Interactive comment on Ocean Sci. Discuss., 9, 3071, 2012.

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