Ocean Sci. Discuss., 9, C137–C143, 2012
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Ocean Science Discussions

Interactive comment on "Particle aggregation in anticyclonic eddies and implications for distribution of biomass" *by* A. Samuelsen et al.

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Thanks for the positive feedback, constructive comments and suggestions provided by the two reviewers. Our response to each of them is outlined below.

Reply to reviewer # 1.

According to your suggestion we have changed the title to "Particle aggregation at the edges of anticyclonic eddies and implications for distribution of biomass".

Regarding comments on vertical velocity: The last two sentences in the abstract have been removed. It is difficult to analyse vertical velocity and validating this model field is a challenge because of the lack of measurements. We have not considered the effect of cooling or heating on the vertical velocity. However, solar penetrative heating

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Interactive Discussion

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is probably not large since the incoming irradiance at almost 70° N from March to April is not particularly large. Cooling on the other hand could be important during this period, and especially in this region where there is a large influx of warm water from the south. As for the diffusion of isopycnals, we consider this as a mixing process that moves as much water upwards as downwards, and so has no net effect on the vertical velocity, at least on the spatial scales considered here. Motivated by your comment about the mean vertical velocity, we computed the 20-day average of the vertical velocity. Because the eddy is drifting, the center of the eddy was determined and shifted in space to co-locate the eddy before the average was computed. The center of the eddy was determined by locating the grid-point with minimum density. This was not done for the five-day averages in the discussion paper because we judged that the eddy moved sufficiently little in only five days. The 20-days average of vertical velocity is much more uniform around the eddy than the instantaneous vertical velocity. We see now that the mean vertical velocity has a structure with distinct upwelling in the middle and predominantly downwelling along the edges accompanied by a few patches of upwelling. This fits well with the behaviour of the particles and the reviewer's assessment that the eddy has "mean upwelling at the center and mean downwelling along the edge" and is consistent with the eddy decaying.

We treated the divergence field the same way as the vertical velocity field in order to obtain a corresponding 20-day average of the divergence field (see Figure 2). We now find strong convergence on either side of the eddy, and the mean convergent areas stay fairly constant in space. This is contrary to the vertical velocity, vorticity, and patch of particles, which rotate around the eddy with time. So even though much of the aggregation probably occurs in the convergence areas, advection also transports the particles around the eddy and that is why we don't see a distinct spatial correspondence between particle concentration and the divergence field. Some additional sentences concerning the mean vertical velocity and divergence has been added to section 3.1 and 3.2 of the paper.

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Regarding depth for particle release: Our choice of depths was motivated by the echograms where we repeatedly saw a prominent signal both in the surface and below 600 meters. We will keep this comment in mind for future experiments, and it is particularly interesting in view of the patch of high biomass at approximately 300 meters depth slightly to the side center of the eddy in figure 7 in the discussion paper.

Sections 4.2 concerning 'real life' complications: We added the sentence ". Fish and marine mammal often have preferences for depth, temperature and salinity, and may either avoid or seek the eddy depending on their particular preference." in the last paragraph of section 4.2.

Regarding biomass origin: We point out this mechanism in the introduction on page 189, line 18. However, in the case of the eddy observed in November 2009 it seems unlikely that the high biomass concentration originates from the coastal water because the core of the eddy consists of coastal water and also has low biomass.

We have modified the conclusion by removing the word 'definitely' from the sentence "The evidence from these numerical experiments definitely points towards the mechanism for aggregation at the surface being of physical origin."

The typos have been corrected

Reply to reviewer #2

Regarding the use of a single eddy for analysis: We will certainly consider expanding the study to include more eddies in the future. We have done simulations where particles were released in other eddies and we see aggregation of particles along the edge in all of them, but these numerical experiments have always been on prominent and partly isolated eddies, similar to the one in this study. It would also be interesting to study smaller eddies as well as the difference between eddies spinning up versus eddies spinning down, since the mean vertical velocity may be different depending on

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whether the eddy is intensifying or weakening. For this first study, we wished to have an eddy that was fairly isolated from other eddies in order to avoid the effect of eddy-eddy interaction. Having this as a reference will aid further analysis of more eddies. We also wanted to study a cyclone, but cyclones are smaller than anticyclones and in our model simulation (as we also mention in the discussion) they often last only a few days, sometimes a week. As such the model simulation on particle dispersion in cyclones is limited by their short existence. Regarding representativeness of an isolated eddy: The following sentence was added to the first paragraph of section 4.2: "Although isolated eddies are not uncommon in the ocean, it is more common that they occur in eddy-rich areas, with enhanced likelihood of eddy-eddy interaction. An isolated eddy was chosen here to simplify the analysis, but we expect that the results presented here will aid the analysis of more complete eddy fields in future studies"

Concerning the sentence in the abstract: "Particles released close to the surfaces tend, in agreement with the observations, to accumulate around the edge of the eddy, whereas particles released at depth tend to distribute along the isopycnals." What we mean by "distribute along isopycnals" is that when particles are allowed to evolve freely at depth in the eddy they end up being deeper in the central part of the eddy and shallower in the peripheral part of the eddy, hence their distribution mimics that of the isopycnals (bowl-shape). Regarding distribution along isopycnals: To clarify this the sentences in the abstract has been changed to "Particles released close to the surfaces tend, in agreement with the observations, to accumulate around the edge of the eddy, whereas particles released at depth gradually become distributed along the isopycnals. After a month they are displaced several hundreds meters in the vertical with the deepest particles found close to the eddy center and the shallowest close to the edge. " Additionally, on page 198, L1 "gradually follow the isotherms" was changed to "gradually align along the isopycnals"

Regarding conclusion on aggregation mechanism: The following sentence has been added at the end of the Abstract: "The model results points towards a physical mecha-

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nism for aggregation at the surface, however biological processes cannot be ruled out using the current modeling tool."

On figure 6 the colour bar has been updated to go only to 10, there is still not much structure in the horizontal distribution after 30 days, so we have not altered the text.

Figure 7 has been changed, the colour scale now only goes to -60 and everything below -90 is white to emphasize the bowl-shape of the eddy at depth. Contour isoline for absolute velocity has been added, which makes it easier to locate the center of the eddy. As you point out the last sentence in the figure label is not correct. The figure label has been modified accordingly to "An example of the acoustic signature of an anticyclone recorded in the Lofoten basin during November 2009 while crossing the eddy from west to east. The edges of the eddy were crossed at about 23:30 and 3:00 and the center between 1:00 and1:30. The echogram shows mean volume backscattering strength (Sv, an indication of organism spatial density and hence of biomass). Higher Sv values indicate higher density. Black contour lines show absolute velocity in cm/s. Note the higher concentrations of biomass in the surface layer close to the edges (<50 meters around 23:30, 2:00, and 3:00) and the empty centre from the surface to 200 m depth." The large concentration at 300 meters actually occur close to, but slightly off the centre of the eddy, we have not released any particles there, we may do so in the future as is also suggested reviewer #1.

Interactive comment on Ocean Sci. Discuss., 9, 187, 2012.

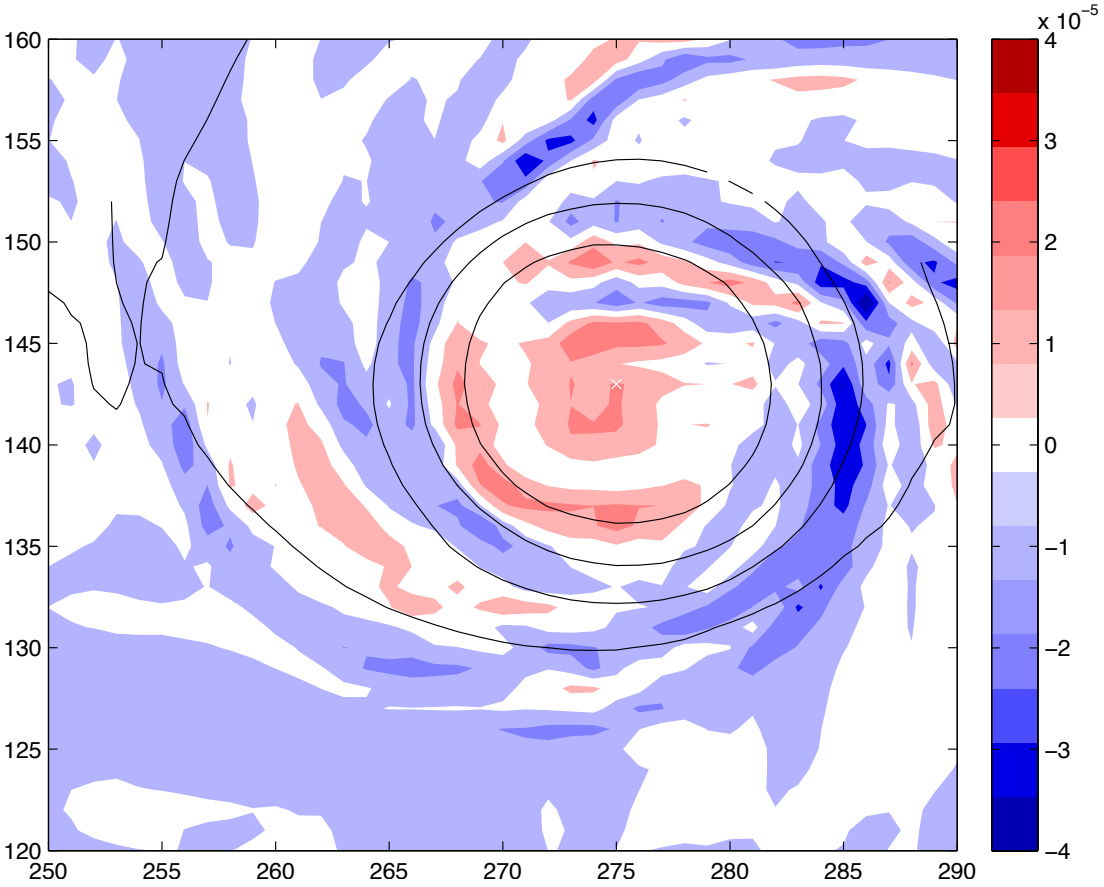

Fig. 1. Vertical velocity (m/s) in the eddy averaged over 20 days from the model layer 5 (16-21 meters). The eddy center has been co-located based on its density before the average was computed.

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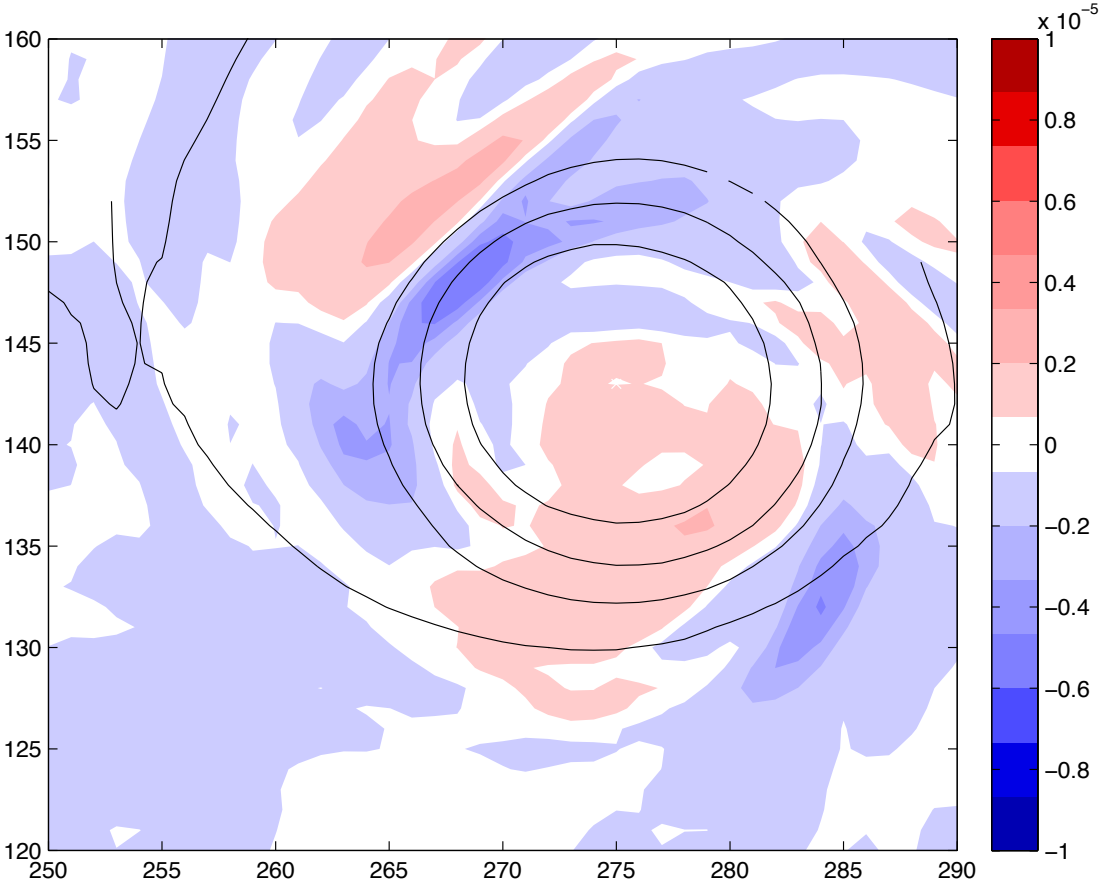

Fig. 2. Divergence (1/s) in the eddy averaged over 20 days from the model layer 5 (16-21 meters). The eddy has been co-located based on its density before the average was computed.

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