**Ocean Science
Discussions**

Interactive comment on "Ensemble smoother for optimizing tidal boundary conditions by assimilation of high-frequency radar surface currents – application to the German Bight" *by* A. Barth et al.

A. Barth et al.

a.barth@ulg.ac.be

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We would like to thank Michel Rixen for his very careful reading of his manuscript and constructive criticism. His comments contributed to the improved clarity of the revised manuscript. We agree generally with his comments and updated the manuscript accordingly.

Specific comments

- *The title could be modified to specifically mention the new "Ensemble perturbation smoother" technique. This is also suggested later in the text.*

  We agree with the reviewer and updated the title.

- *Abstract, line 1: ocean surface currents*

  ok, the manuscript is changed.

- *Abstract, line 16: perturbations on what?...to improve what? This can be a little bot more specific Clarify that the boundary boundary condition are perturbed and improved by the assimilation scheme.*

  We have added perturbations to the boundary conditions to improve them. Those points are clarified in the revised manuscript.

- *Page 2425, line 21: "we concentrate on the M2..." → for the sake of simplicity? Because this is the main tidal component? Please explain and say somewhere that you will also discuss the implications. This is a very specific detail of the study within this general purpose paragraph. I would suggest starting a new paragraph on this topic.*

  Yes, M2 is the main tidal component in the German Bight. Limiting only on M2 is done here for simplicity to test the proposed assimilation scheme. The structure on the text has been changed as suggested:

  As a first step for the assimilation of HF radar data, we concentrate for simplicity on the M2 tidal signal. Adding other tidal constituents would not add fundamentally any new complexity except that the model integration period would have to be substantially longer to resolve two constituents with a similar frequency as required by the Rayleigh criterion. In order to distinguish two periodic signals of

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frequency ν_1 and ν_2, the length of the time series has to be at least $(|\nu_1 - \nu_2|)^{(-1)}$ (Emery, 1998).

- *Page 2427, line 7, line 20 and eq (1): how is the SNR calculated? Does this have any impact on the $< u_r >$ given the temporal change in the current field within the CIT?*

  A figure was added to the manuscript showing on which part of the back-scatter spectrum the SNR ratio is calculated. The averaged radial component is computed as an average of individual current measurements during the CIT weighted by their corresponding SNR ratio.

- *Page 2428, line 25: please explain impact of sea state on Bragg scattering and/or provide reference*

  A reference to Gurgel at al., 1999 (Coastal Engineering) is added to the manuscript where this observation is discussed in more detail.

- *Page 2429, lines 3 and 24: "for simplicity'. So, what is the next step in order to gain accuracy? This could be discussed in the conclusions & perspectives*

  One can improve the assimilation in two different ways:

  – by assimilate the velocity components taking into account their covariance due to the merging of radial components
  – by assimilating directly radial currents

  The later approach is favored because the radial currents can also be assimilated where only one component is available.

- *Page 2429, line 14: "empirical" As these data are being assimilated, I would simply state "ocean tides', otherwise the wording sounds too much 'analytical'*

  "Empirical ocean tides" is the name of the product chosen by their authors (Savcenko and Bosch, 2008).

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- *Page 2430, line 2: GETM is probably a free-surface model (given the present study...), but it would be good to remind the reader about it.*

  Indeed, GETM is a free-surface model and the manuscript is updated.

- *Page 2430, line 6: does the North-Sea Baltic Sea model have tides? Or are the BC on GETM generated only through the perturbation eq 9-11? This becomes clear only at Page 2435, line 18*

  The North Sea-Baltic Sea model does have tides. The manuscript is updated to clarify this.

- *Page 2431: B does not need to be formed explicitly. But does B-1? Please complement*

  Indeed, B does not to be formed explicitly, only its inverse ($\mathbf{B}^{-1}$). Since the constraints use derivatives that are approximated as finite differences, the matrix $\mathbf{B}^{-1}$ is a sparse matrix. Only non-zero elements of this matrix are stored which allows for an efficient implementation.

- *Page 2431, line 24: re: Rayleigh. A reference or explanation would be useful. This limit is not always known under that name.*

  Reference and the formula was added.

- *Page 2432: dimensions of alpha and L?*

  alpha is adimensional and L is a length-scale. This information is now included in the manuscript.

- *Page 2432, line 2, 20: (and in general) open boundaries sometimes include the air-ocean interface (besides lateral ones). Maybe this should be clarified somewhere in the text*

  We clarified that we mean open sea boundaries.

- *Page 2432: t is usually used for time. I would recommend another symbol to avoid confusion*

  OK, we use l now.

- *Page 2432, eq 15-17: please explain what these equations are*

  The manuscript includes now that ε_ζ is the misfit of the shallow-water continuity equation and ε_u and ε_v are the misfits of the shallow-water momentum equations (with a linear bottom drag)

- *Page 2433, line 12 and page 2434, line 21: I would be more specific about what are all state variables includes in the x vector*

  Added to section "Application to data assimilation in the German Bight":

  The vector $\vec{x}$ is composed in the present implementation by the complex M2 tidal parameter of elevation ζ', zonal u' and meridional velocity v' defined over the whole model domain. In GETM version 1.6, tidal boundary condition are implemented such that only elevation at the boundary is used for the ensemble simulation.

- *Page 2433, line 20: I would provide more details on the construction of the H operator and maybe some other examples from the literature where this matrix is more than just an interpolator. The same goes for the model state vector, which is different from the usual 3D parameters of a dynamic ocean model.*

  The revised manuscript will provide more details about the definition of the observation operator and the model state vector and will include the following:

  In sequential data assimilation, the variables estimated by the assimilation are often the entire model state. However, different definitions can be more appropriate depending on the assimilation problem. Here we choose to include the forcing

fields, which is a common strategy in variational data assimilation (e.g. Hoteit et al., 2009). Assimilation can also be used to estimate model parameters for e.g. biological models (Spitz et al., 1998) or weights given to individual models in super-ensemble techniques (Rixen et al., 2009).

The definition of the observation operator depends equally on how the assimilation strategy is implemented. It can be a simple operator interpolating the model results at the location of the observations or a more complex transformation. For example, the observation operator can be an operator extracting the spectral information from the model to assimilate tomographic data (e.g. Rémy et al., 2002), an EOF projection to assimilate EOF amplitudes (e.g. Barth et al., 2006), or a complete radiance sub-model to assimilate radiance observations in a numerical weather model (e.g. Greenwald et al., 2002).

- *Page 2433, line 25: some references should be added here*

We cite Chen and Snyder (2007, MWR) for the use of the non-linear observation operator used in the analysis. The revised manuscript uses now $h(\cdot)$ instead of $\mathbf{H}$ to conform to the usual notation for a non-linear observation operator.

- *Page 2435, line 8 and 10: why 50, why 51: please explain*

We retained the 50-leading eigenvectors based on the distribution of the eigenvalues. Then, the smallest ensemble which spans the space of those 50 eigenvectors (around a given a first guess) is 51 following the method proposed by Pham, 2001.

- *Page 2435: "random": please specify the distribution*

The procedure is based on Gaussian-distributed random variables, but elements of the resulting random orthogonal matrix are not Gaussian-distributed. The exact procedure followed here is detailed in Pham, 2001 (referenced in the manuscript).

- *Page 2440, line 15: the importance of this point should be further emphasized, because of its dynamical implications*

  In the reviewed manuscript, this point was emphasized by showing its consequences:

  The method aims to derive the optimal perturbation and not the optimal state. Therefore, the final solution is obtained by rerunning the model. The analyzed model solution satisfies thus the model equations exactly. No spurious, transient motion such as gravity waves, are generated during the model run with this procedure as it is often the case in sequential assimilation schemes. All quantities which are conserved by a free-running model (taking the fluxes through boundaries of the domain into account) will also be conserved by the analyzed solution.

- *Fig 6-8: Line thickness should be increased. Could this be replaced by a S_{HF} by S_{EOT} calibration matrix?*

  Line thickness is increased. We prefer to use a graphical form because it is easier to interpret visually.

- *Are results sensitive to the length of assimilation period? What is the minimum length?*

  The minimum length should be at least one string tide/neap tide cycle. Otherwise the errors in the S2 tidal signal could lead to modification of the M2 boundary conditions. This would result in a high RMS error when the model currents are compared to the validation of surface currents.

Technical corrections

- *Page 2425, line 1: "a sometimes vigorous adjustment"*

- *Page 2425, line 21: "assimilation OF HF radar data"*

- *Page 2425, line 24: "to a realistic data assimilation case study"*

- *Page 2426, line 5: "Surface current observations were..."*

- *Page 2435, line 13: [N+1]*N*

- *Page 2437, line 17: RMS maps $<$of ...$>$*

- *Page 2438: "show a higher"*

- *Page 2439, line 9: "tide gauge station"*

- *Page 2439, line 14: remove "to us"*

- *Page 2440: two sentences starting with "Since"*

- *Page 2440, line 7: 'by assimilation OF HF radar..."*

- *Page 2442, line 21: "Alvera-Azcarate"*

  all these previous issues are corrected in the revised manuscript.

- *Page 2426, lines 12, 20: 5m vs 5.02m?*

  The system does indeed couple to 5.02 m long ocean waves. The radar measures the radial component of the surface current by analyzing the additional Doppler shift caused to the Bragg-resonant waves by the underlying current field.

- *Page 2426, line 12: "thus"? Is this a consequence of the preceding wording?*

  Yes. Due to the decrease in orbital motion of these waves, they couple to ocean currents down to about 0.5 m below the sea surface. As a result the radar provides surface currents averaged over the top 0.5 m of the water column.

- *Page 2426, line 12: "surface current" I would suggest explaining at this stage the need of at least 2 RADARS to get the 2 components of velocity*

  This information is already included in the manuscript (two last paragraphs of this section).

- *Page 2435, line 14: "to the <identity> vector"*

  The manuscript was clarified and this vector is now referred as "the column vector with all $N + 1$ elements equal to one".

- *Page 2435, line 26 and page 2437, line 8: 60 days from which date?*

  The 60 are counted from 1 September 1991. The manuscript is updated.

- *Page 2436, line 17: "representative" or "representation" or "representativity". I've seen it all in the literature...*

  The manuscript now uses "representation error" which seems to be the most common form in the literature (altought all three are used indeed).

- *Page 2440, line 22: "unassimilated". Which could also be worded as "validation HF radar velocities"*

  We use now the expression "HF radar velocities set aside for validation".

- *References: number at the end of every reference?*

  Those numbers were added by the EGU staff during type-settings. They represent the page number where articles where cited.

- *Table 1: RMS units?*

  ok, they are added now to the table.

- *Fig 2: crosses are not obvious*

  Crosses are now red.

- *Fig 5 and others: I would add a contour of the HF radar coverage*

  We agree. A contour line was added to figure 5 and 9 to show the HF radar coverage.

- *Fig 10 caption: left and right should probably be swapped*

  yes (the manuscript is updated).

Interactive comment on Ocean Sci. Discuss., 6, 2423, 2009.