Ocean Science

Discussions

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Interactive comment on "A hybrid data assimilation method and its comparison with an Ensemble Optimal Interpolation scheme in conjunction with the numerical ocean model using altimetry data" *by* Konstantin Belyaev et al.

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Received and published: 21 August 2019

Authors response to interactive comment Referee #1 on "A hybrid data assimilation method and its comparison with an Ensemble Optimal Interpolation scheme in conjunction with the numerical ocean model using altimetry data" by Konstantin Belyaev et al.

The manuscript presents an application of a recently formulated method, the Generalized Kalman Filter (GKF), to the assimilation of altimeter data into an eddy per-

mitting model of the Atlantic Ocean. The results in terms of analysis and forecast error variance are compared against a simulation and an assimilation based on an Ensemble Optimal Interpolation method (EnOI). When evaluated with the assimilated altimeter data, GKF is shown to perform better for both metrics than the EnOI. The comparison is kept to the minimum and only the evolution of the globally averaged metrics and fields of one time instance are shown. The additionally impact on SST provides very little information except that GKF is able to produce larger changes in SST on eddy-scales than EnOI. Whether they go into the right direction is not possible to judge. Overall the amount of verification would be appropriate for an illustration in a paper that presents the method, which however has already been published. The presentation is very poor particularly due to the abundance of grammatical errors. I stopped to list the necessary changes on page two, since I felt that the manuscript would require too much extra work. The method remains obscure particularly because of deficiencies in the presentation. There are also problems in the application (potentially also in the formulation) of the method noted. Notably the application of the Birkhoff-Khinchin theorem on the drifts does not make sense to me as substantiated below. Additionally, the application of the EnOI seems to be problematic since it depends on two parameters whose effects have not been explored and their choices have neither been stated nor the selection criteria explained. One parameter, the scaling factor for the error covariance, seems to be incorrectly implemented, the other parameter, the error covariance of the observations, does not appear to be relevant in GKF, which hardly can be correct unless it is assumed to be zero there. The application of EnOI actually demonstrates that EnOI as almost a failure, not being able to adjust the SSS on eddy-scales. This is surprising since this method has been proven to work well with this model before in the Gulf of Mexico. I would expect that the analysis error could be almost arbitrarily reduced with decreasing observational error R, which means that the performance of GKF relative to EnOI can be adjusted by varying R in a way that desired result is obtained. This could be for instance be the one shown in the manuscript: EnOI reduces the analzsis error but less than GKF. Last, it remains

unclear in what way GKF is a hybrid method, since this term is only mentioned in the Title and the Abstract and no further motivation or explanation are given.

Re: The Authors are grateful to Referee for the useful comments, which helped us to improve substantially the paper. The paper was substantially revised to improve its style and grammar. Concerning the specific remarks, we can answer the following: 1. About the application of the Birgkoff-Khinchin theorem. We specially note that in our case when we consider quite a large domain, this theorem is applicable if the convergence is considered in an integral metric, for instance in L2 metric. 2. About the EnOI parameters α and R. In our paper we have specially noted in conclusions that the GKF scheme is governed by the same parameters. The problem of defining the best parameters for EnOI to adjust the data was not the goal of our study. However, both methods can be compared with respect to these parameters separately. 3. Concerning the failure of EnOI we have showen the opposite, the EnOI works and works correctly, as well as GKF. However, it was shown that the GKF has advanteges over the EnOI. May be it can be done working better, but it has not been our goal. Our goal was to compare both methods and it seems we did this correctly mathematically and methodologically. 4. Why GKF is a hybrid method. When we introduced GKF we have showen that GKF minimizes the given functional and therefore it can be considered as a variational method. At the same time, it uses the statistical approach since it deals the probability theory and methodology and thus it can be attributed to the stochastic methods (Belyaev et al., 2018).

P1 L14-15: How is the ability to assimilate data being judged? I guess by producing a result that this closer to the observation after assimilation. I suggest to connect the two parts into one and make clear relative to what state the analysis is "closer" L20: remove "a" from "A data assimilation" and "a great" L22 "the" in front of "Australian" and "American" L24 "altogether" instead of "at all" L25 remove "on how" L31 "Ghil et al (1991)" L34 "led" L35 remove "the" before "data L36 replace "the" before essential by "an" Re: We agree with all remarks and the text was revised according to them.

The changes are marked in red. P2 L1 replace "indicate" with "name" L2 add "the" in front of "Australian" and "American" L5 "economic" instead of "economy" L6 "medium" instead of "media" L7 add "the" before "used" L9 add "a" before "given" and change "with respect to" to "represented by" L12 replace "seeking" with "sought" and replace "in a" by "depending on" L13 research is uncountable and cannot be used with several replace "be found in (Marchuk" with " be found (e.g. Marchuk" L16 not clear what the sought field is in this context. It was the initial state in the previous paragraph but minimizing is variance would not make sense to me. Do you mean variance or variation, it the latter case it seems to be just the variational method. L17 I think it should be "the observed variables are the sum of the true signal, which the model is supposed to represent, and stochastic ...." L18 remove "the" before "known" L19 should be "Pendruff et al. (2002)" this is one of the modern development but not the only one. L20 sloppy formulation, should read "to the papers of Evensen (2009) and Xie et al (2010)" L22 I don't understand what that means. Change to "Van Leeuwen (2015)" and "Van Leeuwen (2011)", respectively L25 remove "the" before "hybrid and "both" and replace "are" with "have" L26 add "a" before "functional" L28 should be " found (e.g. Lorenc et. al., 2015; Tanajura et. al., 2013). We may also refer to Tanajura et. al. (2009)," L34 In the EnKF you have and ensemble of model runs but only one representation of the observations. Ensembles of observations are the same as just observations. L35 "As a consequence..." is this a problem or the goal of the method? In the latter case it should be formulated differently. l36 Not clear why it becomes better if no assimilation occurs. Better in the sense of what? Numerical forecast does not make sense to me because this might be ultimately happening but I don't see how this as a direct consequence. It could be better in the sense of obeying the dynamical equations L37-40 Minimum energy is characteristic for equilibrium states. For transitions I would apply conservation principles, e.g. those of mass or momentum. This would be equivalent to minimum energy change. Maybe this is meant here? Re: We agree with all remarks and the text was revised according to them. P3 L4-5 Please motivate why this method is used for comparison and not the EnKF as a more advanced method. Is this is more simi-

lar to the GKF? Re: We used EnOI for a comparison with GKF because we used the same logic to prepare the initial ensemble(s). Both EnOI and GKF use the previously prepared ensemble statistics to create the covariances but in case of GKF we use two ensembles in two sequential time-moment and EnOI uses one. In a case of EnKF we would need to create independent ensembles for each time moment, but for GKF we could do the same in two sequential time moments. L7 "data" instead of archive Re: We agree and the text was revised. L8 Strange formulation, the following is not about the possibility. Re: We agree and the text was revised.

l14 I don't get where the Fokker-Planck equation may play a role in this comparison. Eq. (3) eq (3) doesn't make sense from the dimensional point of view. The first () is a scalar, the second () is a vector of the model-dimension while the third () is a vector of observational dimension and Q a square matrix of observational dimensions. Re: Reference to the Fokker-Planck equation has been removed. Formula (3) is correct: σ is a scalar; Λ and C are both vectors (column), dim r$\times$1, where r is the model dimension; is a vector string, dim 1$\times$m, where m is dimension of observations; Q is a matrix, dim m$\times$m. Totally we have K is matrix with dimension r$\times$m.

P4 L6 I suggest to use "the model variables that are observed". "the observed variables" are understood as the observations. Re: We agree and the text was revised. l9 As the observational trend I would expect the difference Yn+1 - Yn rather than the difference between model and data Re: We agreed with this comment and rephrased the sentences. L10-11 should read "coincides". The operator for the "prolongation" needs to be speciÂňfied. Prolongation is as term that refers to time, while I have the impression that actually interpolation/extrapolation in (phase) space is more relevant here. Re: We agreed with this comment and rephrased the sentences. L11-12 I don't understand the ensemble average. This requires that something is obÂňserved in multiple ways which is rarely possible, except for if two satellite tracks cross. I think it should be made clear from the beginning that your ensemble is generated from several time instances before the assimilation step Re: We agreed and changed the text.

C5

L13 this Y needs a different symbol than the one above on line 10 because they have different dimensions. Also Yn+1 depends on Cn+1 while Cn+1 depends on Yn+1, so it is not clear how this could work Eq.5 Why is the formula for Cn+1 different here from line 10 ? Re: In this context Y is the observations, is the extrapolated observational vector on the entire space, is the anomaly of observed vector relative to vector C projected onto observational space. Actually, observations are divided into two parts: one part is related to trend C and the resudial part is related to innovation and assimilates. This distinguishes GKF method from EnOI where there is no trend and observations are assimilated as a whole. L32-33 "In the expanded form": If different forms for the equations exist this should be made clear from the beginning and transition operators defined. Re: In Eq. (6) the vector-column is multiplied by the vector-string and it defines the algorithm of calculation of the matrix Q. L37 you mean Eq. (5) Re: We agreed and changed the text. l36-37 I don't think this theorem applies for the cases that you have in mind. If the system is stationary there should be no trend. Eq. (5) provides an estimate of the tendency at a particular time. This is supposed to change with time. While Eq.(7) will change less and less with progressing time. For a constant tendency (that means slowly varying changes) (7) will even have a different sign because most of the Xai will soon be in the past relative to n. Re: This comment is correct if we consider the variability at each point independently. However, in our case we consider the state vector X on quite a large enough domain. Therefore, the positive trend at one point is compensated by the negative trend at another point (this is a reasonable suggestion). This means that the Birgkoff-Khinchin theorem is valid place if the convergence is considered in L2 metric (quadratic mean). P5 L9 The layers should have different but uniform densities. Re: We agreed and changed the text. L17 innovative use of language, but for normal people better remove relatively and just say "the temporal average ... has been removed" Re: We agreed and changed the text. L19 Previously..." If you did this you have to describe what has been done otherwise a suitable reference should be provided. Re: We used the data from AVISO and the phrase that the data have passed the quality control was removed from the text. L22-23 I don't understand

C6

what this has to do with parallelization. After parallelization you should be able to handle larger problems. And what does "reduced" mean - what has been done to reduce the size. Re: We agreed and changed the text. L25 why not say what they use? Re: We agreed and changed the text. L26-27 Particularly here you need to provide details of the scheme that was used to create the data for comparison. It is not even clear whether the respective results are discussed by Tanajura et al (2015) or elsewhere. Re: All details on how we provide data for comparison are described in 3.3. L33-34 "The high parallelization..." I don't understand what this means? Re: We agreed and changed the text.

P6 L3-4 no freshwater fluxes? Is there at least surface SSS relaxation? Re: We did not mention the freshwater flux conditions because it does not play any role in our research. Here we can say that the freshwater flux forms from rivers and precipitations. Rivers are climatological with annual cycle precipitations given from the reanalysis. Sea surface salinity has a relaxations which are formed from climatological data (ATLAS) and model computations.

L6 what does real mean. Are the without error. Re: real wind stress was taken from GFS without any changes.

L14 I don't understand how you get the number 50, do I need to know the time step for this? Re: Our previous results have shown that sample of 50 members is sufficient for statistically reasonable conclusions. It would be computationally expensive and unreasonable in this context, to extend substantially the sample's length. Eq.(8) in the ensemble OI the factor alpha also appears inside the () in front of H thereby acknowledging the fact that the variance over time typically is too large. L24 what are these considerations and how are the actual values for R and alpha? Why is there no error covariance matrix R necessary in GKF? Does it mean GKF uses zero error? Re: The factor alpha as well as matrix R are two empirical parameters for EnOI. The matrix Q in our method plays the same role as the matrix (HBHT + R) in EnOI. The only difference is that our scheme the matrix Q contains the anomaly relative to the previous model

state (already constructed analysis), while EnOI considers the anomalies relative to the average model state (matrix B). Therefore, the matrix Q can also be considered as Q=Q1+R, where R an empirically given variance. However, in our case, this pure empirical parameter can be compensated by the normalized factor sigma, (Eq. (3)) while in EnOI this is impossible. The same can be said for parameter alpha. The discussion about this issue has been already presented in Belyaev et al. (2018). In the EnOI scheme α was chosen 1 and R is diagonal matrix with values 0.01. All conditions which are necessary to apply GKF are discussed before (see Re in P4).

P7 Figure 1 which day is this and which model run? Re: Fig. 1 shows only an example the information of which we use. The HYCOM model and AVISO data set are shown together. The day when it was calculated is not specified. L15 better: initialized from the analysis at the past time n-1 Re: We agreed and changed the text. L16 simply: SLAa is the analysis at the time n Figure 2/3 what are the units on both axes? Are these days, which means the forecast period is one day? The forecast period should explicitly stated somewhere Re: We agreed and changed Figures 2,3.

P8 L5 How do the results depend on the heuristically defined values alpha and R in the EnOI? Can EnOI get closer to the data with a larger alpha and/or a smaller R, particuÂñlarly since R seems to be zero in GKF? Re: We did not specifically investigate how the result of EnOI application depends on α and R, because this is another problem, Because we used the same parameters in both EnOI and GKF. L14-15 My interpretation of Figs.2/3 is that the curves are displayed only until day 27 therefore I can not verify this based on Figure 2 and 3 Re: We agreed and changed Figures 2,3. Figure 4:please provide units and a colorbar the I can only read 0.3. Re: We agreed and changed Figures 4. P 11 L4-5 What is the argument here, the states are too different therefore B too large? Maybe the reason is the omission of alpha inside of the brackets of Eq. () or an inapÂñpropriate value for alpha. EnOI hardy improves the state in regions where the variability is large. Re: We did not state that B is too large. On the contrary we show that the EnOI method works in a right direction and really

assimilates data and decreases the error. In addition, We show that the GKF method does the same and a little bit better. We already said that the alpha and R parameters are the same in both methods. P13 l10 Why not the RMS differences instead of the mean bias, the mean bias across all moorings is not so interesting. Re: We used the mean bias but if we use the RMS metric there would be no difference in quality, only in quantity. But the mean bias demonstrate the differences between the methods more clearly. l 14-15 move or copy to the captions. Re: We agreed and changed caption to Figures 6.

P14 l1-6 This comparison is too superficial to be helpful since SST is only shown to demonÂňstrates only the existence of corrections on eddy-scales. Re: Fig for SST shows that GKF really corrects the model SST and makes it more dynamic. This confirms our previous results and those obtained by applying other DA schemes and does not contradict to observations. l9-10 I would have hoped that the study provides evidence rather than just asserting something. Re: We tried to prove our results not only mathematically and theoretically but also performing numerical experiments and comparing obtained results with observations.

Please also note the supplement to this comment:
https://www.ocean-sci-discuss.net/os-2019-56/os-2019-56-AC1-supplement.pdf