

Interactive comment on “Impact of Optimal Observational Time Window on Coupled Data Assimilation: Simulation with a Simple Climate Model” by Yuxin Zhao et al.

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Dear O. Martinez Alvarado,

A few tel-conferences of all co-authors have been held to discuss yours comments. All authors converge to the point that all the comments are very important and useful for authors to improve the quality of this manuscript (MS). Therefore, all comments of yours have been fully addressed in the revision.

Now we will reply to each comment point by point as following:

1 It would be useful to have more background information on the CDA strategy studied in the paper. In particular I was wondering why the observational data should be

C1

assumed at the assimilation time when 4DVar would avoid that problem. It was only in Section 4 that 4DVar was mentioned as an alternative.

RE: As Line 10-16 of Page 2, we have added some background information on the CDA strategy in the introduction part of the revised manuscript. A 4-dimensional variation (4D-Var) scheme implements state estimation through minimizing a distance measure between the model and observations defined on all individual observational times within an OTW. Thus the minimized distance reflects the averaged effect in the OTW. As in Hunt et al. (2004), we expand the EnKF to include a time window in which the observations are treated as the exact assimilation times, even though their times are different in the window. Namely, we just assume that all the collected data sample the “truth” variation at the assimilation time and will be sequentially assimilated with their original error scales. Thus in this study the observational data included in the OTWs should be assumed at the assimilation time while 4DVar can relax that problem. Thanks.

2 P2, L20-22: The two questions posed are circular in the sense that the answer to the first would depend on the effects of varying the OTW on the quality of CDA and the answer to the second depends on the existence of an optimal OTW. I would suggest the following rearrangement: ‘1) What is the impact of varying OTWs for each coupled component within the coupled model framework on the quality of CDF for climate estimation and prediction initialization? 2) Based on this impact, Is there an optimal OTW so that assimilation fitting has maximum observational information, but minimum variability distortion?’ The point is subtle, but it might be worth doing for clarity.

RE: Thank you very much for your generous comment and we fully agree with that. We have corrected that as Line 27-29 of Page 2 in the revised manuscript.

3 Equation (1): Should there be a dot over eta? Is the dot over C6 correct?

RE: Fixed. Thanks.

C2

4 It is not necessary to describe the Runge-Kutta method in Section 2.1.

RE: As Line 3-4 of Page 5, we have deleted the discussion and equation of the Runge-Kutta method. Thanks.

5 P5, L3: What is 'localization and imbalance'?

RE: Because of the sampling error from a finite ensemble size, the ensemble-evaluated background variance is usually underestimated, and spurious correlations exist between a state variable and remote observations. To remove the long-distance spurious correlations and increase the reliability of ensemble-evaluated background covariance, the localization technique was introduced into ensemble-based filters. Given a biased CGCMs and the atmospheric and oceanic observing system (also including the land and sea ice), maintaining a balanced and coherent climate estimation is of critical importance for producing accurate climate analysis and prediction initialization. Given the assimilation model bias of warmer atmosphere and colder ocean, the atmospheric-only (oceanic only) data constraint produces an overcooling (overwarming) ocean through the atmosphere-ocean interaction will create imbalanced and incoherent oceanic (atmospheric) states estimation contrast to the observational model. The imbalanced atmosphere-to-ocean flux tends to decrease the assimilation quality and produce different climate features and variability from the real world. But this one-diamond conceptual coupled model is too simple to simulate the complex physics such as the imbalance between different components and have no need to apply the localization scheme and consider the imbalance.

6 P5, L26: Please define Y_k , or is it the same as $Y_{k,t}$.

RE: In this study the y_k , or is it the same as $y_{k,t}$, as Line 24 of Page 5. Thanks.

7 P7, L3-5: Move this paragraph to the end of section 2.2. I was actually wondering whether twenty cases were sufficient to compute statistics.

RE: This simple conceptual coupled model is same as that used in Zhang et al. 2012

C3

(A study of enhance parameter correction with coupled data assimilation for climate estimation and prediction using a simple coupled model). In that study, based on the trade-off between cost and assimilation quality, after a series of sensitivity tests on ensemble sizes of 10, 20, 50 and 100, no significant difference on assimilation quality is found when the ensemble size is greater than 20. Thus we chose the ensemble size of 20 in this study. And in order to avoid causing confusion, we correct that as Line 28-29 of Page 7 of the revised manuscript. Thanks.

8 P7, L30: How are model years defined?

RE: A model year is defined as 10 non-dimensional time units, as Line 24 of Page 6. Thanks.

9 P8, L9-11: What do you mean by the strong nonlinearity and smoothness of the Runge-Kutta method? Can you elaborate on this point? Perhaps a different method would be more appropriate to obtain the solution of system (1).

RE: Usually the Leap-frog method and Runge-Kutta method will be used as the time difference time scheme to obtain the solution of the climate models. In the paper named "Mitigation of coupled model biases induced by dynamical core misfitting through parameter optimization: simulation with a simple pycnocline prediction model", Fig.3 showed the power spectra of this simple coupled model's states derived by the Leap-frog and RK4 time difference scheme. We can see that the characteristic variability time scale of each coupled components obtained by both methods is a little larger than that set in Eq. (3) and varies for different time difference time scheme selected. The main idea of this study just illustrates that a closely relationship between the length of optimal OTWs and the corresponding characteristic variability time scales exists, which is independent from the time difference scheme we selected in this study. Owing to the simplicity and directness, we choose the RK4 as the time difference scheme used in this study. But its strongly nonlinearity and smoothness of the Runge-Kutta method will smooth the solution of the time series of the solutions, the characteristic variability time

C4

scale will be extended and larger than that set originally. Thanks.

10 P8, L22: It is not clear why the spread should be small. Please explain this point.

RE: In this study each assimilation experiment will be repeated for 20 times starting from 20 different ensemble initial conditions. The mean value and uncertainty (standard deviation) of the 20 cases will be evaluated. Here the spread just represents the standard deviation of the 20 cases. Thus the spread will be smallest when using the optimal OTW, as Line 17-19 of Page 9. Thanks.

11 P8, L28: What is 'convexity with respect to OCN-OTWs'?

RE: Sorry for this mistake and confusion. And the "convexity" has been replaced by "sensitive variation" which just represents the variation of the Omega-RMSE curves is sensitive with respect to the OTWs. As Line 25 in Page 9 of the revised manuscript we have corrected. Thanks.

12 P11, L1: Which one is the curve of X2-RMSE in the OCN-OTW space? The figure (Fig. 9b) only shows one set of lines as a function of OCN-OTW and it corresponds to omega-RMSE.

RE: In this study the curve of X2-RMSE in the OCN-OTW space is not shown and the reason has been added as Line 25- 27 in Page 9 in the revised manuscript. Thanks.

13 P11, L12-17: The information in these lines is a repetition from the previous paragraphs. They can be deleted.

RE: Corrected. Thanks.

14 P12, L3-8: The discussion about the influence of the coupling term in the optimal OTWs is interesting, but it is hard to see what the implications for the real world or for a realistic CDA system are. Please, also discuss these points.

RE: As we have shown that changing that changing coupling strength (controlled by the coupling coefficients C1 and C2 in this case) between the atmosphere and upper

C5

ocean may have some influence on the characteristic variability time scales of coupled media, so as on the optimal OTWs. On the one hand these experiments can further illustrate the idea that a close relationship between the length of the optimal OTW and the corresponding characteristic variability time scale exists. On the other hand, for a realistic CDA system, the coupling physics could be very complicate and affected by many factors. The results of this simple model give the insights that we can only consider the factors which have obvious influence on the characteristic variability time scales when determining the length of the optimal OTWs for a realistic CDA system. And the factors which will have litter influence on the characteristic variability time scales can be just ignored. Through this way the process of determining the optimal OTWs for the realistic CDA system will be greatly simplified and make it possible to apply the method of using the optimal OTWs to the realistic CDA system. As Line 22-28 of Page 13 and Line 20-23 of Page 14, we have added some discussion on these points. Thanks.

15 Figure 5: What does the blue shading under the lower bound mean?

RE: As Line 8-9 of Page 10 and Line 3-4 of Page 20 of the revised manuscript, the blue shading below the ensemble spread represents the range of the uncertainty of state estimation in each assimilation experiments. Thanks.

16 Figure 10c is not discussed and therefore could be dismissed.

RE: From panel c) we can clearly see that the time series of the Omega also obviously varies with changing C2, which also corresponds to the results shown in panel b) in Figure 10. Thus we think that panel c) is also necessary and reserve it. Thanks.

17 Figures 11a and specially Fig. 11b, which only shows a horizontal line, are not needed as they can be simply described in the text.

RE: We fully agree with this comment and in the revised manuscript the panel a) and b) of the Figure 11 have been deleted. Thanks.

C6

Technical corrections: P1, L21-23: Some of the main results are given in these lines. However, the sentence is written in a very confusing style. I would encourage the authors to rewrite it to make the abstract, and the paper, more accessible.

RE: This sentence has been rewritten, as Line 21-22 of Page 1. Thanks.

P1, L30: Delete 'the' between 'by' and 'coupled'. P1, L32: Add 'to sub-grid processes' after 'approximation'. P2, L11: Delete 'in each medium here' and add 'for each medium' after '(OTW)'. P2, L20: Delete 'exist' between 'not' and 'an' and add 'exists' after 'OTW'. P2, L21: Expand 'What's' to 'What is'. P3, L25: Change 'frequent' to 'frequency'. P4, L7: Delete 'Namely'. P5, L6: Either change 'In the words of Zhang (2011a)' to 'Following Zhang (2011a)' or clearly indicate the quote from that paper using quotation marks. P6, L15: Change 'including' to 'included'. P6, L19 and L20: Change 'integrates' to 'is integrated' P6, L24: Delete 'etc.' or perhaps change it to 'and other parameters'. P7, L4: Change 'will obtain' to 'was obtained'. P7, L11: Omega and w are two different letters. Figure 3 presents the power spectrum of what? P8, L23: Change 'keeps' to 'is kept'. P9, L26 and L27: Change 'including' to 'included'. P10, L15: Delete 'gained'. P10, L11: I think where it says 'only limits' should say 'is limited'. Caption to Fig. 9: Change 'panels' to 'panel'.

RE: Corrected. Thanks.

P2, L24: Change 'identify' to 'identifies'. Also, the end of the sentence, after 'medium' is not clear. Please, rewrite.

RE: Corrected. (The sentence has been corrected as Line 30-31 of Page 2 in the revised manuscript). Thanks

P4, L8: Define TU.

RE: As Line 9-11 Of Page 4, TU is the time unit. And in this study 1TU equals 100 time steps. Thanks.

P4, L12: I think the sentence is incomplete. What does 'C2' does in contrast?

C7

RE: In this study C1 denotes the upper slab oceanic forcing on the atmosphere while C2 in contrast. Here 'C2 in contrast' just represents that C2 denotes the atmospheric forcing on the upper slab oceanic, as Line 19 of Page 4. Thanks

P4, L16-17: As it is written, the sentence starting with 'Where' and ending with 'scale' makes no sense. Please, rewrite.

RE: This sentence has been rewritten as Line 24-26 of Page 4 in the revised manuscript. Thanks.

P4, L21: Do you mean 'In summary' rather than 'Summarily'?

RE: Yes. Corrected. Thanks.

P4, L24: The method's name is Runge-Kutta not Runger-Kutta. Since it is not used in the text the acronym RK4 is not necessary.

RE: In the revised manuscript we have corrected as 'Runge-Kutta' and deleted the acronym RK4. Thanks.

P4, L25: Change notation as 'k0-k3' looks like 'k0 minus k3'.

RE: According to a reviewer's generous comment, we have deleted the discussion about the RK4. Thanks.

P5, L14: The sentence does not make sense. Please rewrite.

RE: This sentence has been rewritten as Line 18-22 of Page 5 of the revised manuscript. Thanks.

P7, L28: The sentence is incomplete. Figure 3 presents the power spectrum of what?

RE: Corrected as Line 26 of Page 8 of the revised manuscript. Thanks.

Figure 10: The value of C1 in the legend is constant and therefore it is not needed there.

C8

RE: We have deleted the C1 in the legend in Figure 10. Thanks.

Thank you very much again for your generous help and comments! We hope that the revised manuscript meets your requirement.

Sincerely yours, Shaoqing Zhang and Co-author

Please also note the supplement to this comment:

<http://www.nonlin-processes-geophys-discuss.net/npg-2016-68/npg-2016-68-AC2-supplement.pdf>

Interactive comment on Nonlin. Processes Geophys. Discuss., doi:10.5194/npg-2016-68, 2017.