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Interactive comment on "Implications of model error for numerical climate prediction" *by* O. Martínez-Alvarado

Anonymous Referee #2

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The paper investigates if solutions of numerical climate models lie on the projection of the actual climate attractor in the model's phase space. The study compares model errors between perfect and imperfect models when using perfect or imperfect initial conditions for Lorenz '63 and snapshots of atmosphere models and observations. The results are correct. However, I feel the conclusions are already well known and I do not see the scientific result that goes beyond existing work of studies of model biases in data assimilation. The use of a toy model (Lorenz '63) is a perfectly valid approach, but the possibility to perform a decent statistical analysis with long model simulations is not exploited.

To my understanding there is scientific consensus that:

- Weather and climate models show systematic biases. This implies a different attractor for the model and the real world.
- If data assimilation is used, the model is initialized close to the state of the climate system but it will fall back into it's model state after a short period of time. While a perfect model would not show biases in climate runs (at all forecast times), state-of-the-art models do.
- The correlation of the model state with initial conditions will reduce with time and become tiny for long term simulations (if the mean state is subtracted).

The results of this paper state (see abstract):

- "It is shown that the imperfect model's orbit and the system's orbit are essentially different, purely due to model error and not to sensitivity to initial conditions."
- "Furthermore, if a model is a perfect model, then the attractor, reconstructed by sampling a collection of initialized model orbits (forecast orbits), will be invariant to forecast lead time."

I do not see much of a difference.

The one result which I found to be really interesting/surprising is given on page 138: The perfect model with imperfect initial conditions undergoes a short period in which the distance to the full system is decreasing. However, I can not recommend the publication of the paper in it's current form.

Major comments:

- In the introduction it is not stated what is actually investigated within the paper. Just saying: "The objective of this contribution is to show the implications of the second assumption for long-term integrations of a "simple" dynamical system in three-dimensional phase space" is not enough to give the reader any idea about the content of the paper.
- The use of a toy model such as Lorenz '63 should allow the use of sufficient statistics. However, the statistics for Figure 1, 2 and 3 are not sufficient. The quantity that should be considered in Figure 1 is the PDF of a simulation much longer than the presented simulation for the two attractors. I am sure that the results in Fig. 2(b) will change if the attractor is calculated for a longer time since more trajectories run away from the standard loop. The plot is therefore not very meaningful. Fig. 2(b) should be changed into a comparison to the PDF. Showing four instances of orbits from initial conditions in Figure 2(a) and (c) is good for visualization, but not sufficient to draw any meaningful conclusions (e.g. consider mean and variance of the distance against time for a large number of starting points). More statistics is needed! It should easy to turn the zigzag lines in Figure (3) into smooth lines if longer simulations are considered. And this will be totally necessary if conclusions are drawn from these plots. For example: With the given zigzag plots I do not believe the following sentence: p. 138 l. 10: "The two imperfect models show a short period of very fast divergence from the prototype system's orbit followed by a plateau and a second period of fast divergence." I believe the plateau is caused by insufficient statistics.
- Figure 4: I have seen similar plots in talks about data assimilation in atmosphere and ocean for several quantities and several time-scales (without the horizontal lines). It is well known that models fall back into their own attractor if data assimilation is stopped. I do not see why this result and the conclusions (p. 139 ll 26-29) are new!

- p. 140 ll.1-8: As outlined in the introduction, we know that short term forecasts can be used to evaluate models for long term predictions. We also know that models will fall back into the model state when data-assimilation is stopped. What is new?
- p. 143 ll. 1-12: "The fact that no member in the ensemble is close to the actual behavior of the system might be due to the same effect: in this particular event, an ensemble around accurate initial conditions generates an ensemble forecast with every member tending towards the model's attractor and away from the true future state of the system". This might be true. But it might also be true that the spread in the ensemble is simply not tuned correctly and fails to reproduce the model error. I do not believe this conclusion on the basis of only one forecast. This is a chaotic system: One occasion does not tell much.
- p. 144 l. 9-12: Please state clearly what this framework is. I believe you mean the conclusions in p. 140 ll.1-8 ???

Minor comments:

- Acronyms are used throughout the paper that can be avoided. E.g.: p. 142 l. 4: no explanation for 2-PVU; Fig 2: IC can only be understood in combination with the text; Fig. 4: l.u. is hard to understand when looking at the Figure only; p. 152: PV
- p. 132 l. 24: I guess it would be sufficient if the model attractor is very close to the system's attractor.
- p. 134 l. 17 and p. 143 l. 14 and p. 144 l.9: I find the introduction of the word "prototype system" rather confusing. Especially in the conclusion: "...in the prototype system/imperfect model combination based..." is not at all helpful.

- p. 136 l. 16: It is Figure 1.
- p. 137 l. 15: Lorenz ’93 -> Lorenz ’63
- p. 140 l. 24: (T + 0d) -> T + 0d
- Figure 1: Please increase the size of the black dots, choose a different color than the nearly invisible gray and thicker lines, and use the same color in (a) and (c). The explanation of (b) is cryptic.
- Figure 2: I would suggest to remove the lines for the interquartile range. The label of the y-axis is not useful and should be replaced.