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Interactive comment on "A 24-variable low-order coupled ocean–atmosphere model: OA-QG-WS v2" *by* S. Vannitsem and L. De Cruz

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Dear Dr Trevisan

Thank you very much for your comments on our manuscript. Please find a detailed response to your specific comments below.

1. You are right. More information should be added concerning the results obtained with previous low-order coupled ocean models. This further highlights the similarities between the present work and the previous ones, with a marked difference with the results of Nese and Dutton (1993) and much more similarities with the work of van Veen (2003). In the former, the activation of the dynamics within the ocean leads to an increase of predictability. This feature contrasts with our results but could probably be

associated with the way the heat is transported in the ocean basin and then transferred toward the atmosphere in their model.

In the work of van Veen, the ocean plays a "passive" role when the atmosphere is in a chaotic regime, while it plays more active role in setting up the (coupled) dynamics when close to the periodic windows of the atmospheric model. This aspect is in agreement with our results, indicating that in a fully chaotic regime, the presence of the ocean is not increasing in a substantial way the amplitude of the Lyapunov exponents, but plays a more important role close to the periodic windows of the system as illustrated in Figure 6 of the manuscript. Figures 1 and 2 show the temporal evolution of the solution A2 for two different values of δ and for a value of θ^*, illustrating the crucial role played by the coupling close to the onset of chaos.

Both models (Nese and Dutton,1993, and van Veen, 2003) are quite different in their conception and it is therefore difficult to conclude why their results are different, and at the same time it is difficult to compare with our results which are only based on a mechanical coupling between the two model components. The introduction of a thermodynamic equation would be necessary to clarify this point and will be the subject of a future extension. This aspect will be discussed in more details in paragraph 5, Section 3.2, by adding,

"Their results are most probably associated with the way heat is transported in the ocean basin and then transferred toward the atmosphere in their model, a feature not present in our model."

and at the end of paragraph 4, page 16:

"Interestingly, the results confirm the tendency already reported in van Veen (2003), indicating that the presence of the ocean has a stronger influence on the dynamics of the atmosphere when close to periodic windows."

We will also add more information on the results of the two previous works (Nese and

Dutton, and van Veen) in the introduction (3rd paragraph):

"The coupled model developed by Nese and Dutton (1993) was used to evaluate the impact of the ocean transport on the predictability of the coupled system. They have found that when the ocean dynamics is activated, an increase of predictability is realized."

And also :

"In this model, a systematic bifurcation analysis has been undertaken and compared with the bifurcation structure of the atmosphere only. In particular it was shown that the ocean plays an important role close to the bifurcation points of the model, but much less in the chaotic regime. In the latter case the ocean integrates the rapid fluctuations of the atmosphere in a quite passive manner without providing a strong feedback toward the atmosphere".

2. Indeed the values of the Lyapunov exponents obtained in the present work are different to the ones found in Trevisan et al (2001). The main reason is the difference of parameter settings chosen (but which were fixed in the range suggested by previous authors, Charney and Straus, 1980; and Reinhold and Pierrehumbert, 1982), in particular the aspect ratio of the domain. Moreover there is no orography in the present version, contrarily to the previous work of Reinhold and Pierrehumbert (1982).

To try to understand the properties of the increase of Lyapunov instability as a function of the coupling parameter, we have computed the mean absolute amplitude of these vectors along the different modes of the coupled system. Figure 3 displays the result for the first (backward) Lyapunov vector corresponding to the dominant Lyapunov exponent. The ten first points correspond to the barotropic atmospheric variables, the ten next ones to the baroclinic variables and the last four to the ocean variables. Clearly the projections along the atmospheric variables do not change as a function of the coupling δ, but well the projection along the ocean variables. A similar picture is found for the other backward Lyapunov vectors. This suggests that the increase of Lyapunov

instability is mainly associated with an increase of the projection of the Lyapunov vectors along the ocean variables, and not the baroclinic instability within the atmosphere. This aspect is worth investigating further in the future by investigating the properties of the characteristic vectors (also called covariant vectors) of the system which are (non-orthogonal) intrinsic directions of instability (e.g. Legras and Vautard, 1995). This figure and the comments on that feature will be introduced at the end of section 3.

3. Concerning the link between the local Lyapunov exponents and the ocean variables, there is no clear relation as illustrated in Figure 4, in which the local Lyapunov exponents corresponding to the first Lyapunov vector are plotted as a function of the second ocean variable (similar pictures are found for the other variables). A link is only visible between these local quantities and the dominant modes of the atmosphere, ψ_1 and θ_1. As in the previous point, a better characterization of the instability properties of the flow and their link with the underlying variables would be worth analyzing based on the characteristic vectors.

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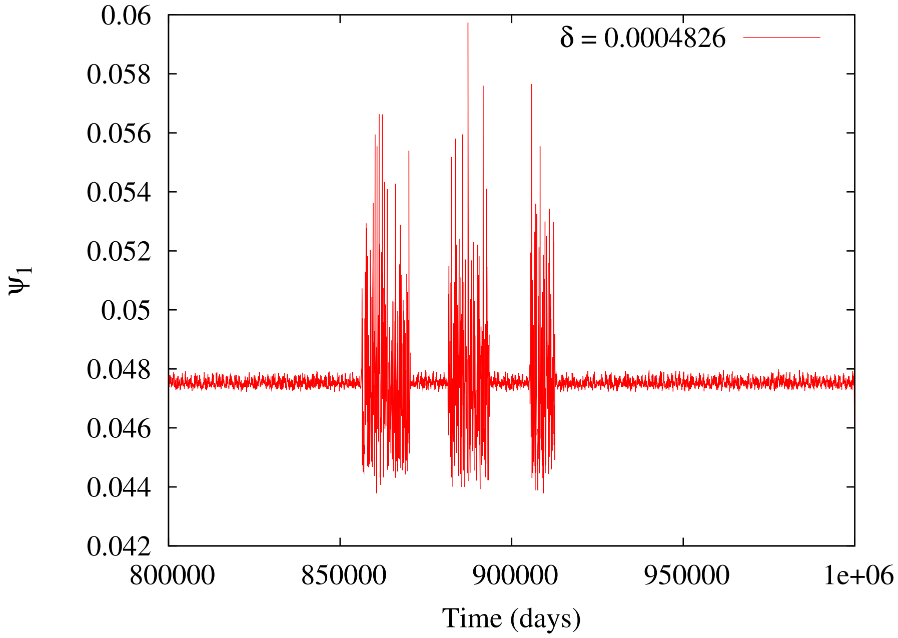

Fig. 1. Trajectories of the first mode of the barotropic streamfunction field for $\delta=0.0004826$ and $\theta^*=0.10$.

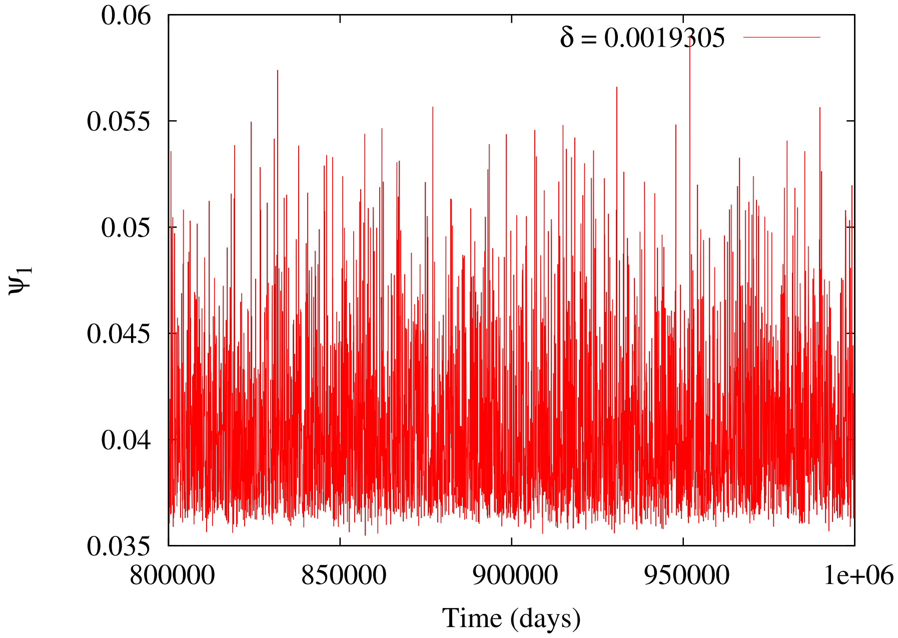

Fig. 2. Trajectories of the first mode of the barotropic streamfunction field for $\delta=0.0019305$ and $\theta^*=0.10$

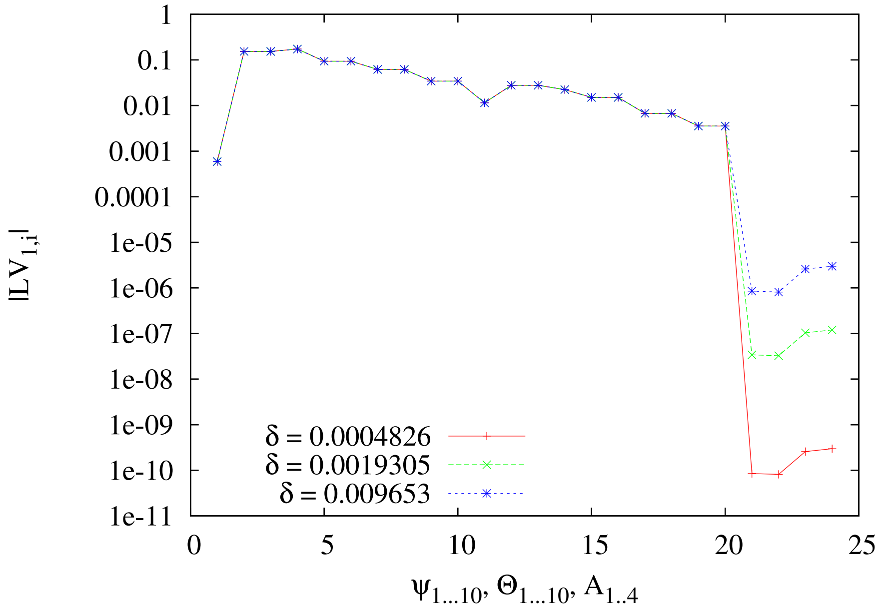

Fig. 3. Mean absolute amplitude of the first (backward) Lyapunov vector along the variables of the system for $\delta=0.0019305$ and θ*=0.14.

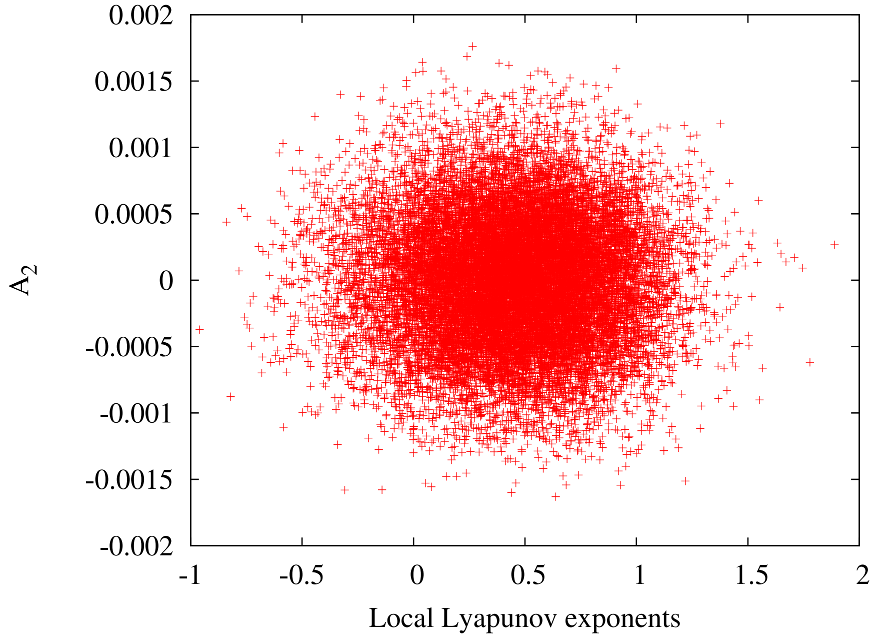

Fig. 4. 2-D representation of the variable A2 as a function of the local Lyapunov exponents as obtained with the parameters of Fig. 1 of the manuscript ($\delta=0.0019305$ and θ*=0.14).