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Geoscientific Model Development
Discussions
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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

S. Vannitsem and L. De Cruz

stephane.vannitsem@oma.be

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Thank you very much for your constructive comments. Please find below the response to your specific comments.

1. WS means "Wind Stress". It is clarified in the last paragraph of page 4.

2. Yes indeed the evolution of the time averages is computed with different initial conditions in phase space. We agree with you that the convergence is not yet completed and we have modified the text according to your recommendation. Paragraph 2 page 13 now reads:

"The temporal variations of these mean values are illustrated in Fig. 3, for θ^*=0.077 and 0.14 starting from two different initial conditions. The convergence is very slow due to

the long term natural variability of the ocean embedded in this system. The presence of different attractors cannot be confirmed or excluded at this stage, due to the blurring of the large natural variability of the system. This analysis would need even longer model integrations, with a higher order numerical scheme in order to better control the numerical error as suggested by the anonymous referee."

We have tested another scheme and we have obtained a different evolution of the mean as illustrated in Figure 1 (embedded 8th order Runge-Kutta Prince-Dormand method with adaptive step size and 9th order error estimate). But the convergence is not completed in this case either. Longer integrations would also be needed.

3. One important feature of the coupled model is the presence of a set of very small amplitude Lyapunov exponents. As you mentioned it is hard to distinguish between the different exponents close to 0 in Figure 5a. In fact for small values of the thermal forcing parameter, θ^*, the solution are stationary stable solutions with very small amplitude (negative) Lyapunov exponents. When it is increased, periodic and quasi-periodic (2-torus) solutions appear up to 0.065. 2-torus solutions are also appearing between 0.087 and 0.095 for the parameters explored. The small amplitude exponents are associated with the presence of the ocean whose response time scale is long.

Thank you very much for pointing out the theorem of Newhouse, Ruelle and Takens. Indeed there are only one or two exponents very close to 0 in the periodic and quasi-periodic regimes. We address this point in more details in Section 3.2, end of page 14:

"For values of θ^* smaller than 0.055, stable steady states are found with a set of four negative Lyapunov exponents of very small amplitude (e.g. for θ^*=0.02, σ_1=-0.00128, σ_2=-0.00128, σ_3=-0.00133, σ_4=-0.00133 day^{-1}) and the next ones with amplitudes 1000 times larger. At θ^*=0.055, a periodic solution emerges with a first exponent equal to σ_1=-1.1 10^{-8} day^{-1}. For larger values up to θ^*=0.065, quasi-periodic solutions (2-torus) appear, as well as for parameter values between 0.087 and 0.095. Between

0.065 and 0.087, chaotic solutions separated by periodic windows are prevailing. Beyond 0.095, the dynamics become chaotic and no periodic solutions were found for the parameter range explored."

4. Thank you very much for drawing our attention toward these references. Indeed these will certainly be useful in our future investigations. We will also add a sentence at the end of the aforementioned paragraph as " A detailed analysis of the transitions from quasi-periodic motions to chaotic behaviors will be investigated in the future as in recent works (Broer et al, 2011; Sterk et al, 2010; among others)."

Minor points:

1. We have added a table with the list of parameters.

2. Thank you for pointing out this confusion. We have added a sentence at the end of Section 2.2.

All the other corrections have been made.

Interactive comment on Geosci. Model Dev. Discuss., 6, 6569, 2013.

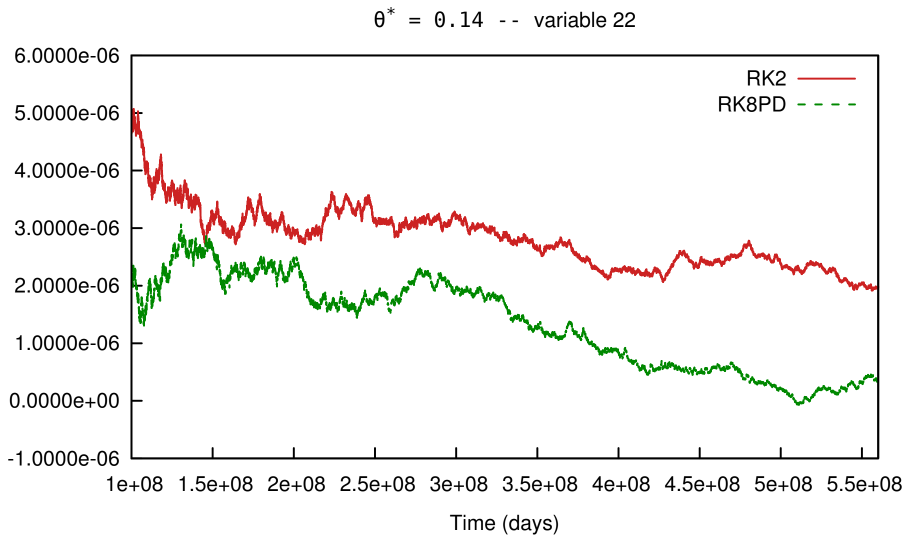

Fig. 1. Evolution of the temporal average for A2 with two different numerical schemes. The green one corresponds to an embedded 8th order Runge-Kutta Prince-Dormand method with adaptive step size