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Comment on "On the presence of annular variability in an aquaplanet model" by Masahiro Watanabe

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[1] In the work of *Watanabe* [2005] (hereinafter referred to as W05), the results of an 'aquaplanet' simulation are compared to similar experiments performed by *Cash et al.* [2002] (hereinafter referred to as CKV02). The purpose of both sets of experiments is to investigate what role, if any, zonally-symmetric modes of variability (so-called annular modes) play in explaining the low-frequency variability of the models. The conclusion of W05 is that both zonally-symmetric and zonally-asymmetric modes of variability exist in the model. W05 cites this as support for the interpretation by *Robinson* [2004] that the annular mode in an aquaplanet model (and, by extension, in nature) is a fundamental dynamical mode, and that the zonally asymmetric appearance of annular mode events is the result of a superposition of annular-mode variations with independent zonally asymmetric variations. This is in contrast to the conclusion of CKV02 (which was further developed in *Cash et al.* [2005] (hereinafter referred to as CKV05)), namely that the zonally-symmetric structure identified in their model by empirical orthogonal function (EOF) analysis was in fact a statistical representation of a distribution of zonally asymmetric structures.

[2] However, it is by no means clear that the conclusions of W05 are supported by their results. Below, we make the case that the results of W05 are similar in most respects to those of CKV02 and CKV05, and that the original interpretation of CKV02 still holds. We will also show that the results of W05 are heavily dependent on the structure of several unrotated EOFs, which recent work by *Vallis et al.* [2004], *Gerber and Vallis* [2005], as well as various previous studies [e.g., *Richman*, 1986; *Barnston and Livezey*, 1987] have shown to be prone to precisely the type of amalgamation of structures hypothesized in the CKV papers.

[3] We first note that the results presented in W05 are generally consistent with those presented in CKV02 and CKV05. Namely,

[4] 1. The leading EOF of the 10-day low-pass filtered zonal mean and zonally varying surface pressure in the aquaplanet models resembles the Northern Annular Mode (NAM) and Southern Annular Mode (SAM) identified by Thompson and Wallace and others (compare W05, Figure 1a with CKV02, Figure 4c; W05, Figure 1b with CKV05, Figures 5a–5c).

[5] 2. One-point correlation maps of the 10-day low-pass filtered data do not recover the zonally symmetric structure of the leading EOF (compare W05, Figures 2a–2c with CKV02, Figures 9a–9d; W05, Figures 2d–2f with CKV05, Figures 10a–10d).

[6] 3. The leading EOF becomes more zonally localized as the asymmetry of the boundary conditions increases (compare W05, Figures 1 and 3 with CKV05, Figure 5).

[7] 4. High-frequency eddy forcing plays a crucial role in the dynamics of the events (compare W05, Figure 4 with CKV05, Figure 12).

[8] Given the similarity of the results, the primary difference between W05 and the CKV studies thus lies in the interpretation of those results. To separate the influence of non-annular variability from any annular variability that might be present in the model, W05 focuses on the upper tropospheric stream function. When an EOF analysis is performed on this field, the leading EOFs are, in fact, distinctly non-annular. What W05 describes as the "annular mode" does not appear until the 3rd EOF. W05 cites this as supporting evidence that the "annular mode can be identified distinctly from the quasi-stationary waves." However, it is generally accepted that physical interpretation of unrotated EOFs past the first is suspect at best [see *Barnston and Livezey*, 1987, and references therein]. Given the fact that the 3rd EOF is constrained to be orthogonal to the first two EOFs, it is unclear what physical significance can be ascribed to it in W05. By definition, its shape is at least in part purely a function of the EOF analysis.

[9] This concern about the physical significance of the "annular" mode in the zonally symmetric model is heightened by the large, zonally-localized departures from zonal symmetry. Given that the model has zonally symmetric boundary conditions its variability must be uniformly distributed in longitude, barring some deviations introduced by the finite length of the integration. However, the "annular" pattern in the zonally symmetric case in W05 shows large deviations from zonal symmetry, with well-defined centers of action. Given the similar location in latitude and zonal extent of these centers to the centers shown in the first two EOFs (W05, Figures 3a–3b), it seems a more plausible hypothesis that this 3rd EOF represents a residual of the slowly propagating waves identified by the first two EOFs, rather than a dynamical structure in its own right. In any case, it seems unwise to ascribe much dynamical significance to it.

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[10] In the zonally asymmetric model presented in W05, Figures 3d–3f, the wavenumber-5 disturbances no longer make up the two leading EOFs, and the leading EOF resembles the ones found in CKV05. It should be noted, however, that this pattern is not particularly annular. There is a weak polar center with little zonal symmetry, the midlatitude center has zero amplitude for $\sim 60^\circ$ longitude and over the colder SSTs the amplitude of the EOF is twice that of the rest of the domain. Finally, let us make the point that a zonally symmetric EOF does *not* necessarily imply that there is a dynamically significant mode of variability, even if the zonally symmetric EOF is the first one, and is well separated from the ensuing EOFs. Indeed, a zonally symmetric leading EOF is expected to emerge whenever the statistics of the underlying flow have little zonal structure, as was explicitly shown by *Gerber and Vallis* [2005]. The zonal symmetry of the annular mode thus reflects the zonal symmetry of the boundary conditions and forcing of the flow.

[11] Of course, such statistical arguments do not preclude there being a real, dynamically significant, zonally symmetric mode of variability. However, neither can such arguments – or the presence of zonally symmetric EOFs – be used to support the notion of such a mode. The question is not so much whether there is an "annular" mode – if this is defined as being the first zonally symmetric EOF - but whether such a structure represents a dynamical mode of the model.

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