

Comments on 'Spatial structure of ultra-low frequency variability of the flow in a simple atmospheric circulation model' by I. N. James and P. M. James (October 1992, 118, 1211–1233.)

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#### SUMMARY

James and James (1992) examine internally generated interannual variability in a multi-level primitive-equation model. The authors claim that the variability in the global mean relative angular velocity is associated with fluctuations in the mid-latitude zonally-averaged zonal winds. We question this relationship, and present results from an aqua-planet GCM which indicate that, instead, the global mean relative angular velocity is primarily related to changes in the tropical zonally-averaged zonal winds. Furthermore, we also question whether the 'ultra-low-frequency variability' examined by James and James is not simply just 'climate noise'.

#### 1. INTRODUCTION

James and James (1992) (JJ hereafter) investigated the interesting problem of whether processes internal to the atmosphere can generate large-amplitude interannual variability. This is an important problem given the recent concern regarding the detection of global warming. They show that large-amplitude interannual changes to the wind and temperature fields may occur with fixed external forcing in their model, and their results imply that when examining interannual variability it may be important to consider internally generated processes in addition to those extensively studied such as carbon dioxide doubling or variations in the sea surface temperature.

Numerical experiments carried out by JJ with a multi-level primitive-equation model revealed decadal variability in both the global-mean relative angular velocity and the principal components of the first EOF (EOF1) of the zonally-averaged zonal wind. The temporal properties of the global-mean relative angular velocity were examined by calculating the time-power spectrum of the coefficient of the gravest zonal-mean spherical harmonic, denoted  $\zeta(1,0)$ , averaged over pressure. This analysis indicated that the variance increases with period and has its largest amplitudes on decadal timescales (Fig. 3(b) of JJ). The power spectrum of the principal components of EOF1 also was shown to exhibit a red-noise spectrum with greatest amplitudes on decadal timescales (Fig. 6(a) of JJ). The power spectra for the principal components of the next several EOFs were either white or weakly red. Because of the similarity in the shape of power spectra for the  $\zeta(1,0)$  time series and the principal components of EOF1, JJ concluded that "most of the unexpected ultra-low frequency variability which was noted in the previous section is associated with the large-scale structure described by EOF1" (note that the ultra-low frequency variability of the 'previous section' refers to that variability found for the  $\zeta(1,0)$  time series).

In this note, we question the validity of the relationship between the global mean relative angular velocity and EOF1 claimed by JJ, and also argue that the ultra-low-frequency variability observed by JJ is not 'unexpected' but is consistent with expectations from the concept of 'climate noise'.

#### 2. RESULTS AND DISCUSSION

We have re-examined some of JJ's findings using data from a Geophysical Fluid Dynamics Laboratory (GFDL) rhomboidal-30, nine-level, aqua-planet, general circulation model (GCM). The model was run for the equivalent of 2025 days with solstitial solar forcing and zonally-homogeneous sea surface temperatures that are symmetric about the equator. The first two EOFs of the zonally-averaged zonal wind, using pentad averages, are shown in Fig. 1. As expected from the symmetry of the model's forcing, these EOFs are very similar when reflected at the equator. The variance of the first two EOFs—EOF1 and EOF2—are 22% and 17%, respectively. We supposed that if this GCM were run for a longer period of time, then the cross-equatorial symmetry would improve. The structure of these two EOFs resembles that of the first of JJ's EOFs (see their Fig. 4(a)). The power spectra of the principal components of EOF1 and EOF2 are shown in Figs.

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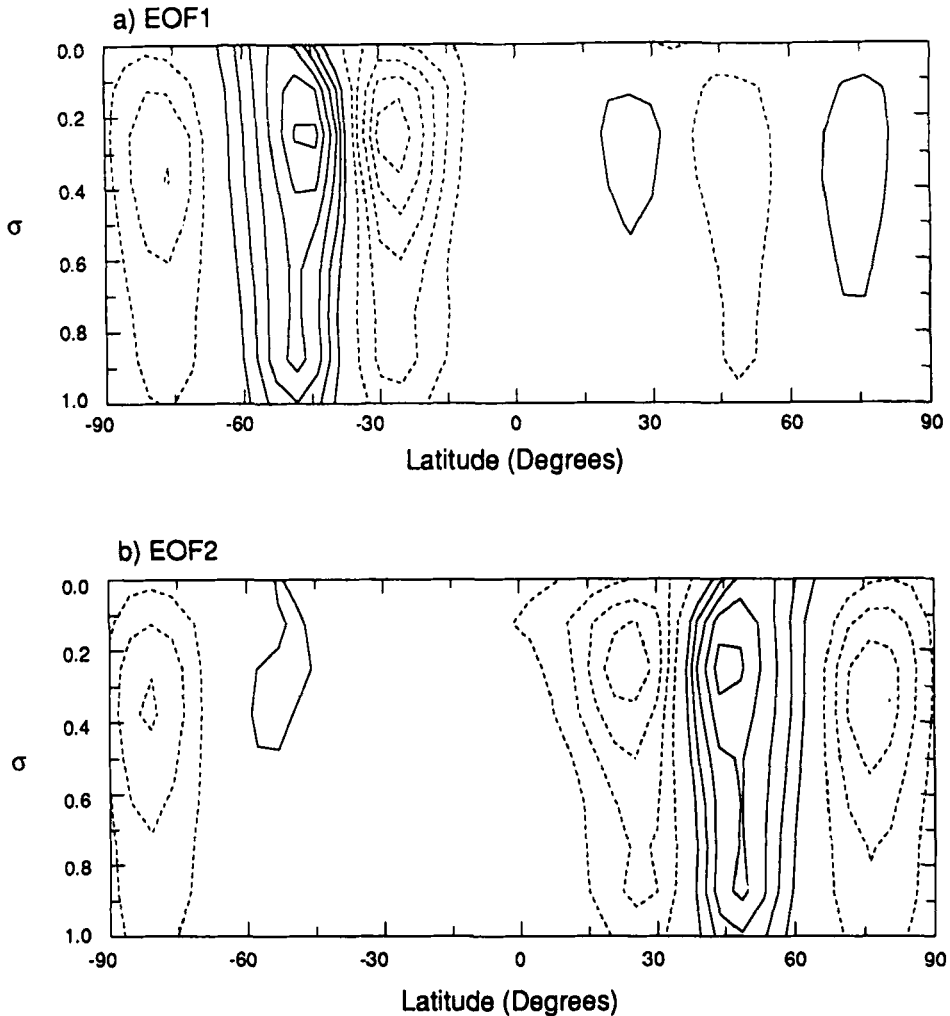


Figure 1. The meridional cross-sections: (a) EOF1; (b) EOF2. Contour interval is 0.03. Solid contours are positive and dashed contours negative.

2(b) and 2(c). These spectra were smoothed four times with a  $1/2/1$  filter. In both cases, a red-noise spectrum without statistically significant peaks is obtained.

The properties of these EOFs can be seen by adding and subtracting EOF1 from the time-mean zonally-averaged zonal wind (Fig. 3). The amplitude of EOF1 is chosen to correspond to the average value of the 10% most positive and most negative principal components. The primary role of EOF1, and similarly of EOF2, is to displace the jet meridionally. When the principal component is positive this displacement is poleward, and when it is negative the displacement is equatorward. Similar meridional displacements of mid-latitude jets have been found from observations, e.g. Trenberth (1979), Kidson (1986, 1988), Lau *et al.* (1989), and in numerical models, e.g. Robinson (1991), Yu and Hartmann (1993).

We next examine whether these two EOFs account for the variability in the global mean relative angular velocity, as postulated by JJ. Following JJ, we use the GCM's  $\zeta(1,0)$  to measure the global mean relative angular velocity. As with the principal components of EOF1 and EOF2,  $\zeta(1,0)$  exhibits a red-noise spectrum (Fig. 2(a)), though with an apparently statistically significant

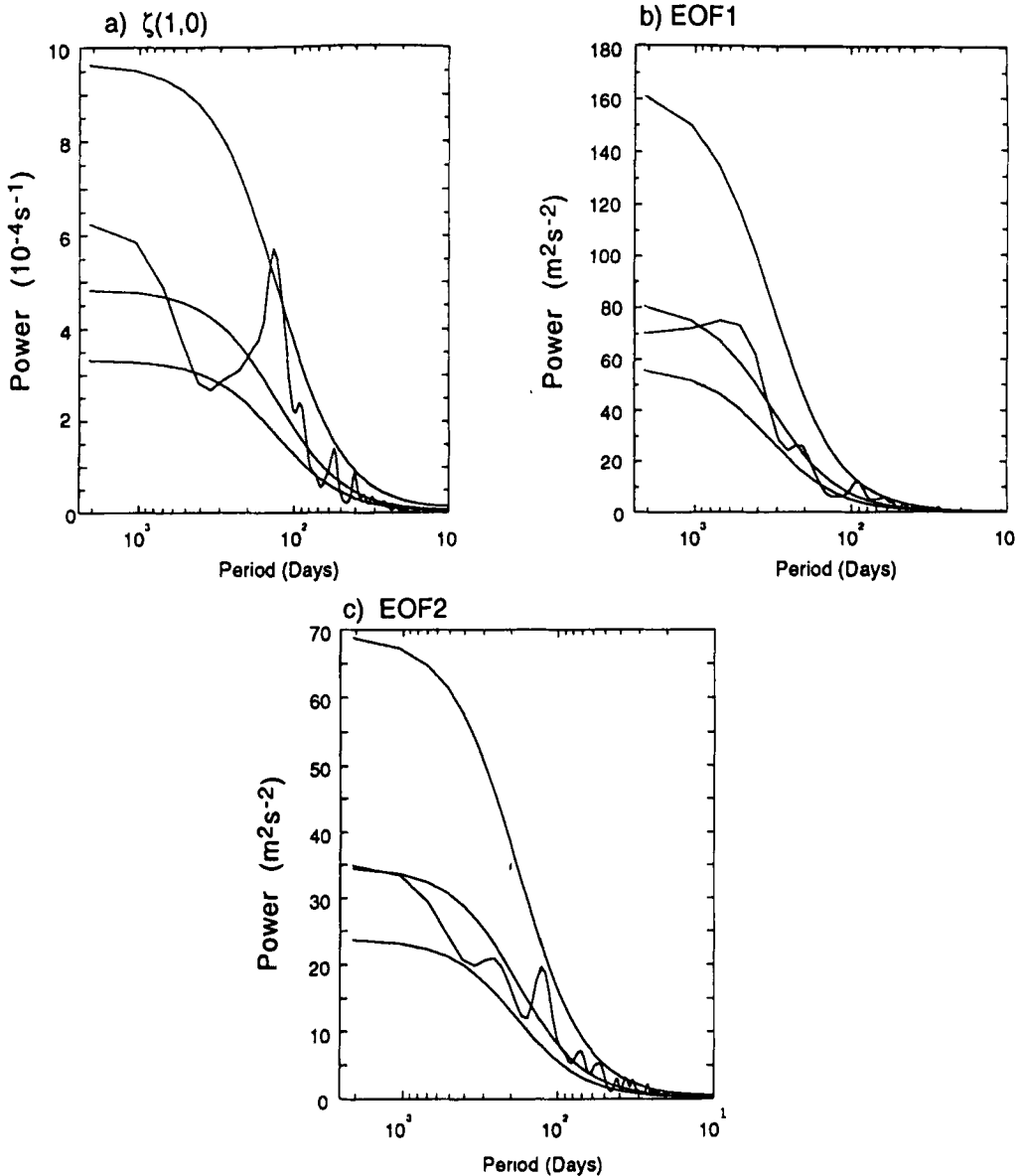


Figure 2. Power spectra: (a) the  $\zeta(1,0)$  time series; (b) the principal components of EOF1; (c) the principal components of EOF2. These power spectra are compared with their red-noise spectrum and corresponding 5% and 95% significance levels.

peak at 120 days. The correlations of the GCMs  $\zeta(1,0)$  time series with the zonally-averaged zonal wind at all latitudes and sigma levels are shown in Fig. 4(a). Most of the variability in  $\zeta(1,0)$  is associated with fluctuations of the zonally-averaged zonal winds in the *tropics*—not in the mid latitudes as stated by JJ. Furthermore, linear correlations between the  $\zeta(1,0)$  time series and the principal components of the first two EOFs give values of  $-0.35$  and  $-0.51$ , respectively, indicating that EOF1 and EOF2 contribute towards only 12% and 26%, respectively, of the variance of the global mean relative angular velocity.

The relationship between the global mean absolute angular momentum (GAAM), the global mean relative angular velocity,  $\zeta(1,0)$ , and the zonally-averaged zonal wind field is also examined.

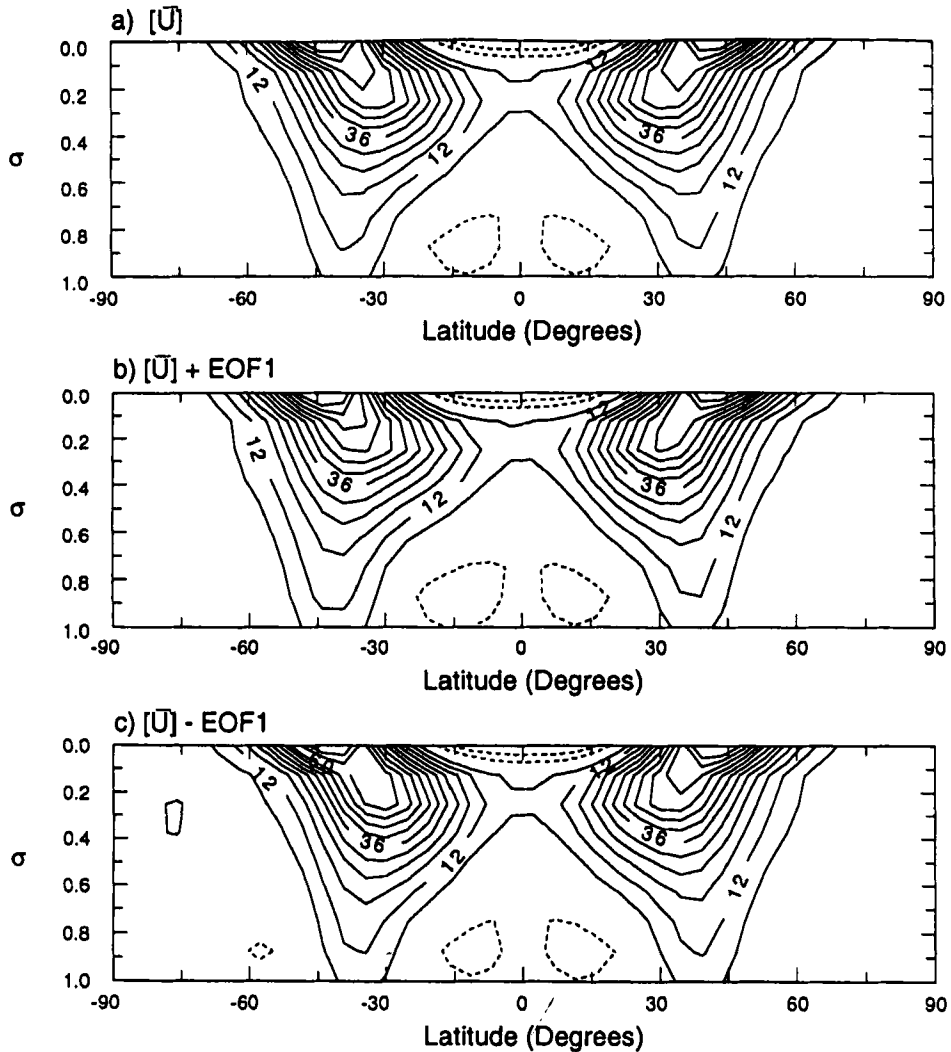


Figure 3. The meridional cross-sections: (a) the time mean, zonally-averaged, zonal wind  $[\bar{u}]$ ; (b) the sum of  $[\bar{u}]$  and the 10% most positive EOF1; (c) the sum of  $[\bar{u}]$  and the 10% most negative EOF1. The method for choosing the amplitude of EOF1 is described in the text. Solid lines are positive and dashed lines negative. Contour interval is 6.

The linear correlation between the GAAM and  $\zeta(1,0)$  time series is 0.81. In a model in which the lower boundary is isobaric, variations in GAAM would be exactly proportional to the pressure-weighted average of  $\zeta(1,0)$ . The linear correlations between the GAAM time series and the principal components of the first two EOFs is  $-0.11$  and  $-0.26$ . Furthermore, large linear correlations between GAAM and the zonally-averaged zonal winds are concentrated in the tropics (Fig. 4(b)), as in the case of  $\zeta(1,0)$ . Thus, the relationship between the EOFs and GAAM is even weaker than that for  $\zeta(1,0)$ . Such behaviour is consistent with both observational studies, such as those by Benedict and Haney (1988), Lau *et al.* (1989), and the numerical modelling study of Robinson (1993), which show that most variability in the global angular momentum arises from fluctuations in the tropical zonally-averaged zonal winds.

According to JJ, the stated relationship between the principal components of the first EOF and  $\zeta(1,0)$  is based on similarities in the shape of their power spectra. Using an aqua-planet GCM, however, we have shown that there is only a slight relationship between these quantities, even

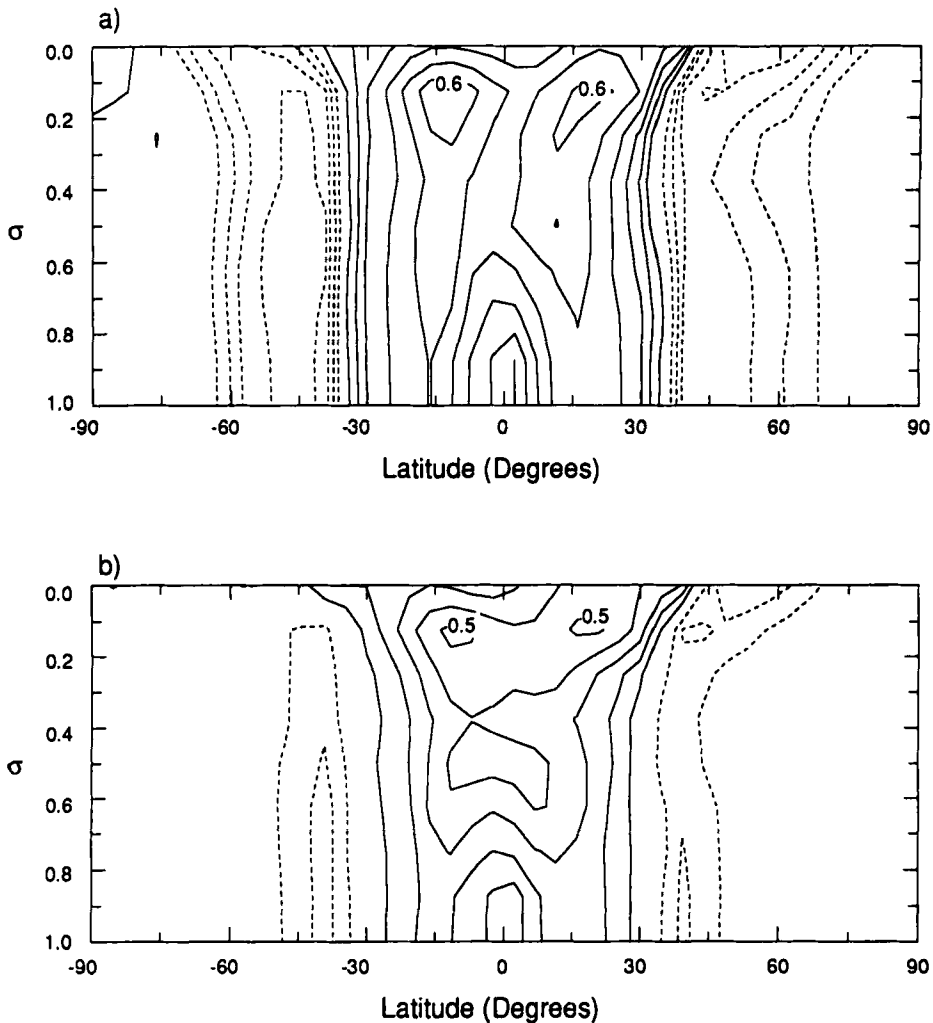


Figure 4. The linear correlation of the zonally-averaged zonal wind time series at all points: (a) with the  $\zeta(1,0)$  time series; (b) with the GAAM times series. Solid lines are positive and dashed lines negative. Contour interval is 0.1.

though they both exhibit red-noise spectra. Since JJ did not calculate the linear correlation between  $\zeta(1,0)$  and the zonally-averaged zonal winds, or the linear correlation between  $\zeta(1,0)$  and the principal components of their EOF1, they have not demonstrated that there is a close relationship between these two quantities.

While it is, in principle, possible that the variations in GAAM in JJ's model are dynamically different from those in the aqua-planet GCM, this is not likely. Very similar zonal wind correlations with GAAM have been obtained in the present aqua-planet GCM, in another GCM with coarser resolution but with a seasonal cycle and realistic orography (Feldstein, personal communication), and in a simple global two-level model (Robinson 1993). The model used by JJ is effectively bracketed in complexity between the present GCM and Robinson's two-level model. Furthermore, there are good dynamical reasons why fluctuations in GAAM should be dominated by upper-level tropical winds. Firstly, in middle latitudes any zonally-averaged eddy torques on the atmosphere will be largely balanced by Coriolis torques on the mean meridional circulation. Only in the tropics will the dominant response be an acceleration of the zonal wind. Secondly, as pointed out by

Robinson (1993), wind anomalies in the tropics are not removed effectively by thermal dissipation, because near the equator the thermal wind constraint is very weak. Thus upper-level tropical zonal winds have a long 'memory', which is reflected in their contribution to the red spectra of  $\zeta(1,0)$  and GAAM.

JJ suggests that the ultra-low-frequency variability in their model "is a result of the inherently chaotic nature of the flow in an atmospheric model", implying that there are important nonlinear dynamical processes occurring on decadal timescales. Indeed, their power spectra for  $\zeta(1,0)$  and the principal components of their EOF1 both show peaks on decadal timescales. JJ concede, however, that none of these peaks is statistically significant, and both power spectra can be fitted by a red-noise spectrum. Furthermore, a quick smoothing by eye of JJ's Figs. 3(b) and 6(a) suggests that these power spectra are white for periods greater than one or two years. This shape for both power spectra suggests the possibility that the ultra-low-frequency variability may be just 'climate noise' or 'natural variability', such as was studied by Leith (1973) and Madden (1976, 1981). Stated differently, the variance on the timescale of the ultra-low-frequency variability, which is equivalent to the variance of a corresponding long time average of the data, may be due to statistical sampling associated with the model's high-frequency daily weather fluctuations, effectively integrated over time by components of the system that are weakly dissipated. Variability of time averages on all timescales, including that associated with ultra-low-frequency variability, is inevitable when dealing with long time averages of essentially unpredictable weather systems.

To provide an example of ultra-low-frequency variability due to climate noise, we examined the variability in GAAM in the data from a 100-year run of a rhomboidal-15 GFDL GCM. This model includes an annual cycle with continents, specified climatological sea surface temperatures, a full radiation package with predicated clouds, and a moist convective adjustment. For the following calculations, the annual cycle has been removed. The power spectrum for the GAAM time series (not shown) has a red-noise spectrum with no statistically significant spectral peaks on timescales greater than one year. To examine whether climate noise can account for the power on timescales greater than one year, we follow the procedure outlined by Dole (1986) by calculating the statistic  $\chi^2 = Ns_T^2/v_T^2$ , where  $N = 100$  is the number of years in the time series,  $s_T^2$  is the variance of the annual-averaged GAAM, and  $v_T^2$  is the theoretical variance of the annual averages of a time series modelled by a first-order Markov process. For the calculation of  $v_T^2$  we use the lag-one autocorrelation of the pentad principal component time series (Madden 1981). Note that the lag-one autocorrelation is a measure of the 'memory' of the system. We specify a null hypothesis that  $s_T^2$  is not greater than  $v_T^2$  and then examine the statistical significance of  $\chi^2$ . For  $N-1 = 99$  degrees of freedom, the critical value of  $\chi^2$  at the 95% significance level is 123.0 for a one-sided test. However, the calculated value of  $\chi^2$  is 83.5. Thus, we cannot reject the null hypothesis, and interpret the ultra-low-frequency variability of the GAAM as arising from climate noise.

In summary, although JJ do show that large-amplitude, internally-generated, ultra-low-frequency variability does occur in their model, there are two important properties of this variability that the authors have not dealt with convincingly. These are, as stated above, whether the variability in the global mean relative angular velocity is strongly associated with the mid-latitude zonally-averaged zonal winds, as represented by their EOF1, and whether the ultra-low-frequency variability is no more than climate noise.

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