6.2 TRANSIENT EDDY FORCING OF THE SOUTHERN HEMISPHERE ANNULAR MODE VARIABILITY: RESULTS FROM NCEP-DOE REANALYSIS AND A QUASI-LINEAR MODEL

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1. INTRODUCTION

The principal mode of atmospheric circulation variability in the Southern Hemisphere (SH) has a predominantly zonally-symmetric structure, characterised by a meridional seesaw of the zonal winds between 40°and 60°S. The vertical variation of the circulation anomalies associated with this mode (known as the Southern annular mode; SAM, hereafter) is equivalent barotropic. The temporal evolution is dominated by low-frequency fluctuations (with periods greater than 50 days) and is largely irregular (e.g., Limpasuvan and Hartmann 2000).

Previous studies (e.g., Lorenz and Hartmann 2001) have suggested that the synoptic-scale eddies play an important role in forcing the SAM variability, and that the interactions between these eddies and the zonal wind anomalies provide a positive feedback that helps the SAM persist in its extreme phases. Here, we have used NCEP-DOE Reanalysis (Kistler et al. 2001) and a two-layer quasi-linear model to investigate some further aspects of the eddy-zonal flow interactions associated with the SAM variability.

2. DATA AND MODEL

The basic dataset used in this work comprises the zonal and meridional winds and temperature at 300 hPa, extracted from NCEP–DOE Reanalysis 2 (hereafter, NCEP2). The dataset covers a period of 22 years (1979-2000). First, the daily anomalies were obtained by removing a fitted straight line and the first three harmonics of the annual cycle from the data at each grid point. The high-frequency and medium-frequency anomalies were then obtained by applying two band-pass filters that retain 2-8 day and 8-30 day fluctuations, respectively. The zonally-averaged E-P flux divergences calculated from these high-frequency and medium-frequency anomalies represent the forcings of the zonal-mean flow by the respective type of eddies. Various time-domain and spectral statistical techniques were used to analyze the anomalous variation of the SAM (defined here as the first EOF of the zonally-averaged zonal wind) and the eddy forcings, with a particular focus on their interrelationship.

A two-layer, quasi-geostrophic, quasi-linear model on the sphere was also used to model the circulation variability associated with the SAM. The circulation variability in the model arises from the interactions between the eddies and the zonal-mean flow in the presence of mechanical and thermal dissipations. Long numerical integrations of the model with realistic values of the dissipation and other model parameters were carried out, and outputs were saved for a period equal to the period of NCEP2. The model solutions were analyzed using the same statistical techniques as used for NCEP2.

3. RESULTS

Fig. 1 shows the first EOF of the zonally-averaged zonal wind and of the transient eddy forcings (TEFs) due to high- and medium-frequency eddies, as calculated from NCEP2 and the quasi-linear model. As mentioned above, EOF1 of the zonally-averaged zonal wind ([u]) has a meridional structure showing opposing variations of [u]-anomalies at 40°S and 60°S. It can be seen that the simple quasi-linear model also captures the structure of EOF1 of [u] rather

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well. Further, in both NCEP2 and the model, the meridional structure of EOF1 of the high-frequency TEF (HFTEF) closely resembles that of EOF1([u]), although the resemblance is not as good in the case of the medium-frequency TEF (MFTEF).

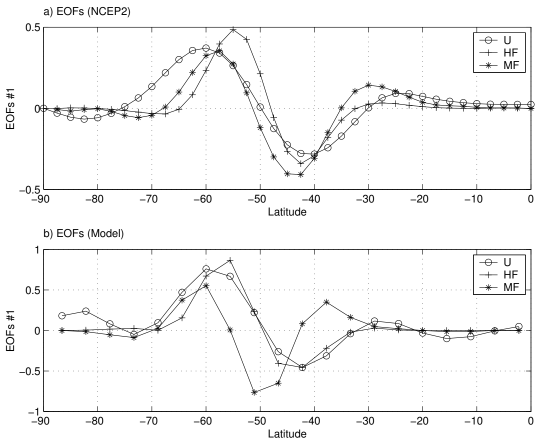

Figure 1: First EOFs of the zonally-averaged zonal winds, the high-frequency TEF, and the medium-frequency TEF. a) NCEP2 and b) Quasi-linear model.

The cross-correlation functions calculated for PC1([u]) and PC1(HFTEF) and for PC1([u]) and PC1(MFTEF) are shown in Fig. 2. The cross-correlation profiles are suggestive of the existence of feedback mechanisms between the zonal flow and the eddies. As was noticed by previous investigators (Robinson 1996; Lorenz and Hartmann 2001), there is a positive feedback between the anomalous variations of [u] and HFTEF, indicated by the presence of nonzero correlations at large positive lags. It should be noted, however, that the mere presence of nonzero correlations at lags other than zero does not provide conclusive evidence that a positive feedback exists. This is because the nonzero lag-correlations may well be due to the lagged autocorrelations of either or both of the time series. However, experiments with nonlinear primitive equation models (Robinson 1996) and simple statistical models (Lorenz and Hartmann 2001) show that such a positive feedback between PC1([u]) and PC1(HFTEF) does indeed exist. In addition to this positive feedback, Fig. 2 also shows the evidence of a weak but statistically significant *oscillatory* feedback between [u] and MFTEF. Again, these results concerning the positive and oscillatory feedbacks are well simulated by the simple quasi-linear model.

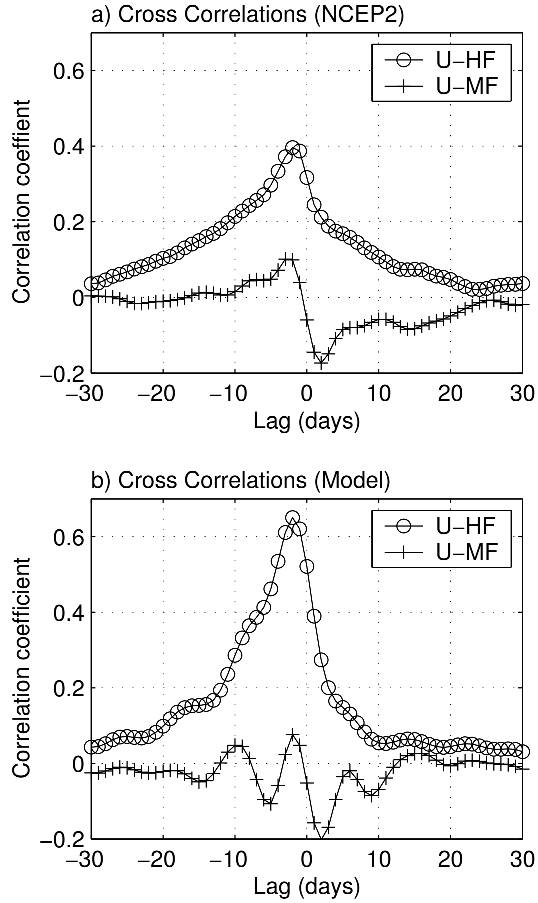

Figure 2: Cross-correlation functions for PC 1 of [u] and PC 1 of high-frequency TEF (circles), and PC 1 of [u] and PC 1 of medium-frequency TEF (crosses): a) NCEP2 and b) Quasi-linear model. Correlation coefficients with magnitude larger than 0.07 are significant at 95% level. In all cases, PC 1 of [u] leads at positive lags.

The above mentioned oscillatory feedback, if present, would enhance the variance of PC1([u]) in a frequency-band removed from the zero frequency. That this is indeed the case can be seen from Fig. 3, which shows the power spectrum of PC1([u]) and the coherence spectra between PC1([u]) and PC1(HFTEF) and between PC1([u]) and PC1(MFTEF). As before, results derived from both NCEP2 and the quasi-linear model are shown. The PC1([u]) power spectrum (Fig. 3a) shows increased power with respect to a best-fit red-noise spectrum (dashed curve) at an intermediate frequency range (5–20 days). This frequency range approximately corresponds to the frequencies at which the coherences between PC1([u]) and PC1(MFTEF) are

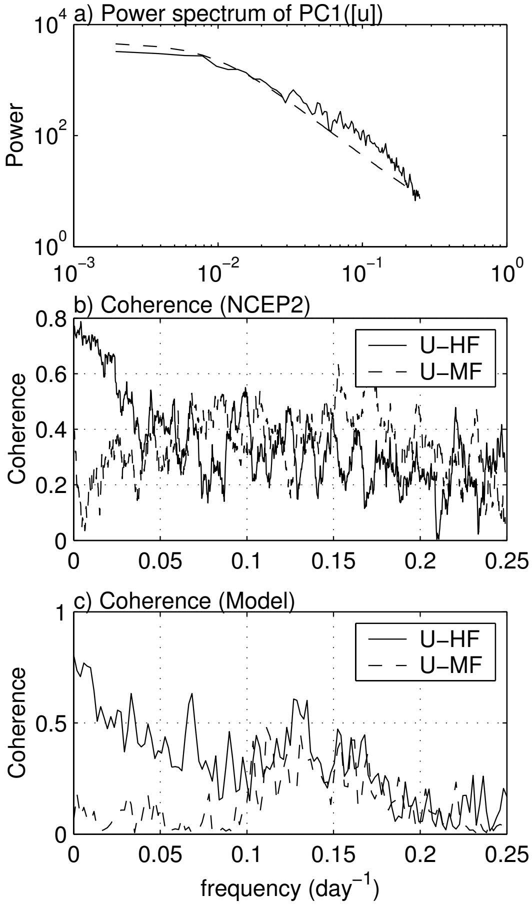

Figure 3: a) Power spectrum of PC 1 of [u] from NCEP2, b) Coherence spectra of PC 1 of [u] and PC 1 of high-frequency TEF (solid), and of PC 1 of [u] and PC 1 of medium-frequency TEF (dashed) from NCEP2, and c) as in b) but for the quasi-linear model.

largest (Figs. 3b,c, dashed curves), suggesting that the enhanced variance of PC1([u]) at the intermediate frequencies is a result of the above mentioned oscillatory feedback between PC1([u]) and PC1(MFTEF). In contrast, the coherent variations of PC1([u]) and PC1(HFTEF) take place at the lowest frequencies, consistent with the presence of a positive feedback. A comparison between the results derived from NCEP2 and the quasi-linear model clearly shows that the quasi-linear model has done rather well in simulating the second-moment spectral statistics derived from NCEP2.

The lagged-composites of the HFTEF during

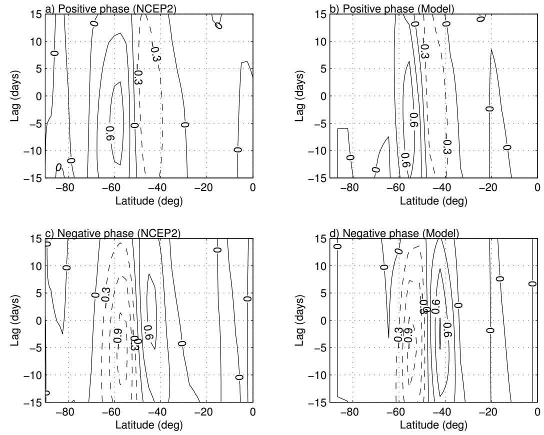

Figure 4: Lag-composites of high-frequency TEF anomalies with respect to PC 1 of [u]: a) positive phase, NCEP2, b) positive phase, quasi-linear model, c) negative phase, NCEP2, and d) negative phase, quasi-linear model. Both timeseries were filtered with a 50-day low-pass filter, and standardized before compositing.

the extreme phases of PC1([u]) are shown in Fig. 4 as a function of latitude. Results from both NCEP2 and the model show that the HFTEF anomalies at high latitudes precede PC1([u]) by about 5 days, whereas at lower-middle latitudes the corresponding time-lag is smaller. This suggests that the zonal-wind anomalies at both the high and lower-middle latitudes are predominantly forced by the HFTEF anomalies at the high latitudes, with the HFTEF anomalies at lower-middle latitudes assuming a secondary role.

4. REFERENCES

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