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An Eddy-Feedback Model for Propagating Annular Modes

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Some types of extreme events in the extratropics are often associated with anomalous jet behaviors. A well-known example is the annular mode, wherein its variation e.g., the meandering in the north-south direction of the jet, disrupts the normal eastward migration of troughs and ridges. Since the seminal works of Lorenz and Hartmann, the annular mode has been mostly analyzed based on single EOF mode. However, a recent study showed that the first and second leading EOFs are strongly correlated at long lags and are manifestations of a single oscillatory decaying-mode. This means that the first and second leading EOF modes interact and exert feedbacks on each other. The purpose of this study is to develop an eddy-feedback model for the extratropical low-frequency variability that includes these cross-EOF feedbacks to better isolate the eddy momentum/heat flux changes with time- and/or zonal-mean flow. Our results show that, in the presence of the poleward-propagation regime, the first and second leading EOF modes interact and exert positive feedbacks at lags ~10 (~20) days about ~0.07 (~0.16) day^{-1} in the reanalysis (idealized GCM). This feedback is often ignored in the previous studies, and in fact, the magnitude is nearly double the feedback exerted by the single EOF mode. We found that this apparent positive eddy feedback is a result of the effect of jet pulsation (strengthening and weakening) in zonal flow variability (z_2) on the eddy momentum flux due to the meandering in the north-south direction of the jet (m_1). A finite-amplitude eddy-mean flow interaction diagnostic has been performed to demonstrate the dynamics governing the positive feedback in the propagating regime of the annular modes. It is shown that the poleward propagation is caused by an orchestrated combination of equatorward propagation of wave activity (baroclinic process), nonlinear wave breaking (barotropic processes), and radiative relaxation. The latter two processes follow the first one, and as such, the meridional propagation of Rossby wave activity (likely generated by an enhanced baroclinic wave source at a low level) is the central mechanism. Finally, our model calculations suggest the rule of thumb that the propagating annular modes (i.e., when EOF1 and EOF2 together represent quasi-periodic poleward propagation of zonal-mean flow anomalies) exist if the ratio of the fractional variance and decorrelation time-scale of EOF2 to that of EOF1 exceeds 0.5 or the two leading PCs showing maximum correlations at larger lags. These criteria can be used to assess the predictability of preferred modes of extratropical circulation in GCMs. The present study advances and potentially transforms the state of our understanding of the low-frequency variability of the extratropical circulation.