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A global mass circulation paradigm for the annular mode variability

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The Northern Hemisphere cold season circulation anomalies are diagnosed in a semi-Lagrangian ?-PVLAT coordinate by following contours of the daily potential vorticity (PV) field on isentropic (?) surfaces using the NCEP/NCAR reanalysis II dataset from 1979 to 2003. It is found that circulation anomalies propagate poleward and downward simultaneously in the stratosphere and equatorward in the extratropical troposphere. On average, it takes about 40 days for warm anomalies and 70 days for cold anomalies to travel from the equator to the pole. The beginning of the equatorward propagation of the tropospheric temperature anomalies coincides with the arrival of the poleward and downward propagating temperature anomalies of the opposite sign over the polar stratosphere. Accompanied with warm (cold) anomalies is a successive levelling (steepening) of isentropic surfaces propagating poleward and downward. The zonal wind anomalies follow the poleward and downward propagating temperature anomalies of the opposite sign. A global mass circulation paradigm is proposed to qualitatively explain the simultaneous meridional and downward propagation of circulation anomalies that appears responsible for the annular mode variability. The meridional propagation of circulation anomalies can be viewed as an intensity variation of the zonally averaged isentropic mass circulation. When the mass circulation is weaker, the isentropic surfaces in the extratropical stratosphere (troposphere) are steeply (gently) sloped, corresponding to the positive phase of the annular mode. The cold air mass is effectively imprisoned within the polar cap when the mass circulation is weaker, responsible for warm surface temperature anomalies prevailing in the extratropics. Meantime, the weaker mass circulation also implies a temporary reduction of air mass supply over the polar cap, leading to a negative surface pressure anomaly. The warm anomalies brought by the stronger mass circulation cause a lowering of isentropic surfaces in the polar stratosphere, resulting in more gently sloped

isentropic surfaces in the extratropical stratosphere. This corresponds to the negative phase of the annular mode in which the meridional temperature gradient in the extratropical stratosphere is weaker accompanied with a weakened polar jet and a falling of the tropopause. The stronger warm air branch of the mass circulation aloft requires a strengthening of the compensating equatorward advancement of the surface air mass, causing massive cold air outbreaks in the extratropics. The more air mass aloft brought by the stronger mass circulation contributes to a rising of the surface pressure over the polar cap till the surface cold air moves out. This explains why the surface pressure anomalies in high latitudes are positive during the negative phase of the annular mode. The well-known apparent downward propagation of geopotential height and zonal wind anomalies into the troposphere from the stratosphere in the polar region can be explained as the local dynamic PV response to the arrival of the simultaneous poleward/downward propagating heating anomalies in the polar stratosphere and the compensating equatorward propagating tropospheric heating anomalies of the opposite sign, rather than suggesting the stratospheric origin of the anomalies. The apparent equivalent barotropic structure of the annular mode mainly results from the dynamic response to the heating anomaly that has an opposite polarity between the stratosphere and lower troposphere.