Sensitivity of the vertical coupling of Northern wintertime annular modes to anomalous high-latitude surface heating

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Throughout the atmospheric column, the first mode of variability in anomalies of wintertime geopotential height (and other parameters) is associated with an annular variation. These modes describe, in the positive phase, an intensification of the polar vortex, increased mid-latitude westerly winds, poleward migration of the baroclinic storm tracks and decreased polar temperatures. While it is generally considered that these are equivalent barotropic features, it is unclear how variations in the stratosphere and troposphere interact. This interaction is explored using results from the NCAR Community Climate Model (version 3.6.6) configured to a resolution of T31L26 using the "standard" boundary data (control simulation). To quantify the vertical coupling of the annular variations in the Northern Hemisphere, principal component (PC) analysis is performed on pressure surfaces independently throughout the atmospheric column for 10 years of twice daily wintertime (DJF) geopotential height anomalies. For each year, the temporal series of the firest mode (PC1) at some level of interest (say, 500 hPa) is correlated with PC1 found at all other levels. The resulting correlation mapping is presented in Figure 1 as a function of temporal lag. The Figure may be interpreted such that a disturbance in the PC at the level of interest propagates through the atmospheric column. At some lag-time, the initial disturbance has no influence on the atmospheric state, and correlations become trivial. This analysis is not inconsistent with the fluctuation dissipation theory described by Leith (1975) and applied by North et al. (1993). To provide a complementary view of the troposphere-stratosphere coupling, the Figure includes also the lag correlation based on the 50 hPa PC1 to assess the downward influence variations in the stratospheric vortex exert on the troposphere. To gauge the sensitivity of this coupling, an anomaly model experiment is performed: all Arctic sea ice is replaced by open water at 271.4K in the surface specification. A substantial additional heat source is thereby introduced at the surface via longwave radiative heating and sensible heat flux. With no sea ice, warmer lower tropospheric temperatures at the pole reduce the synoptic wave activity, and subsequently the wave forcing of the stratosphere (Noone et al., 2003).

In the control simulation the vertical coupling is substantial in the troposphere and stratosphere, although the two are largely decoupled in the mean. Large interannual variation indicates that in some years the vertical coupling is stronger while in other years there is no coherent association between the variations the stratosphere and the troposphere. This result is consistent with observational data sets and other correlative studies (e. g., Zhou et al., 2002). In the stratosphere there is evidence for a long time scale (50 days) downward modulation of disturbances in the control simulation, which is mostly absent in the no-ice experiment result. The vertical coupling across the tropopause is increased in the absence of sea ice, and reflects increased zonal symmetry in the tropospheric variations. In the control simulation, the correlations suggest tropospheric variations precede stratospheric variations by around 15 days. The signal of a tropospheric-precursor is more clearly evident in the no-ice experiment. Conversely, evidence for downward propagation of stratospheric signals over 15 days in the control is absent in the experiment. Instead there is greater persistence of stratospheric variations without sea ice. This is symptomatic of a less well formed

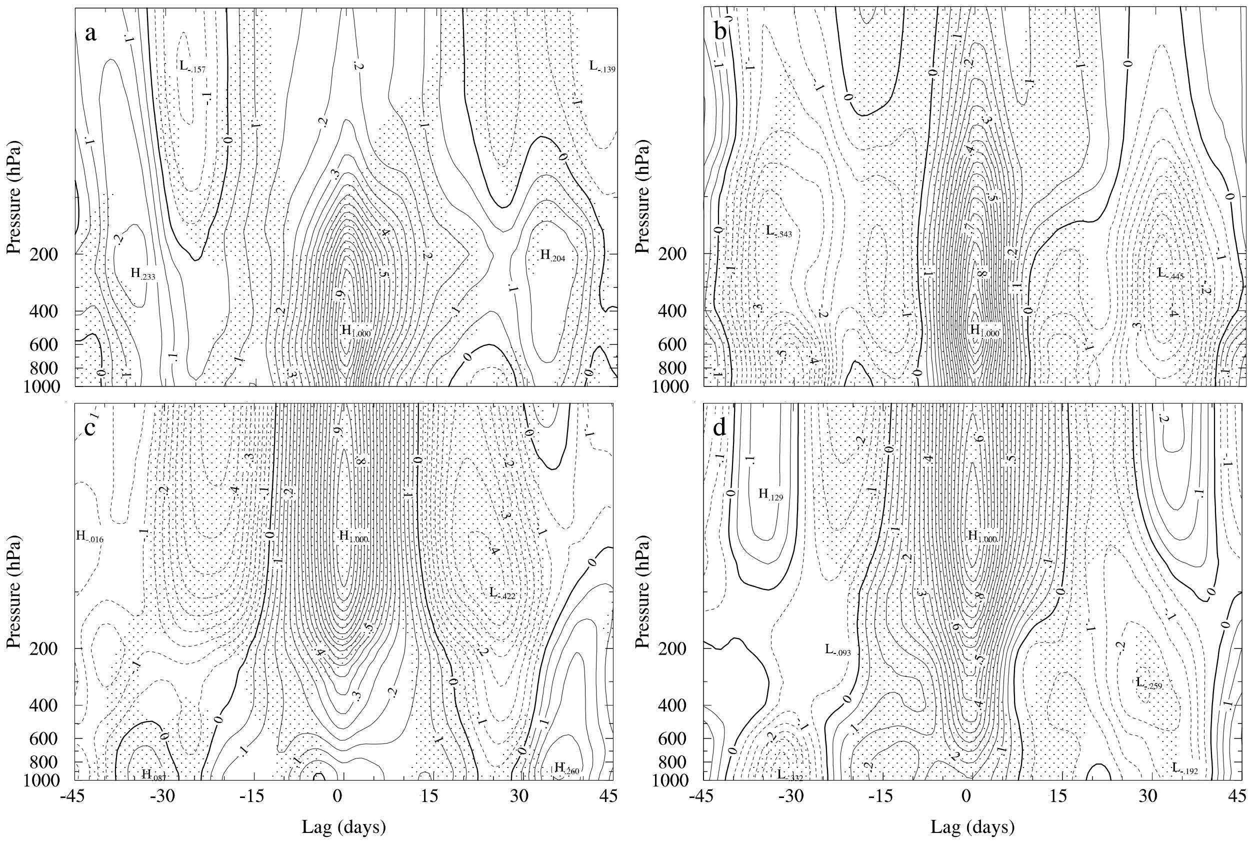

Figure 1: Lag correlation between PC1 at (a and b) 500 hPa and (c and d) 50 hPa and PC1 computed at other levels for (a and d) control and (b and d) no sea ice experiment. Contour interval is 0.05. Stippling indicates where the interannual variation in the correlation coefficient is less than 0.3

vortex and of a system that has less dependence on strong wave-mean interactions, as is associated with "preconditioned" stratospheric flow (Smith, 1992). Indeed this result suggests that with no sea ice, the winter circulation contrasts less distinctively with summer circulation. Specifically, the magnitude of the dynamic feedback between the location and strength of the tropospheric jet, and the generation of eddies and wave pumping that modulates the annular variations (as emphasized in many recent studies of annular modes), can be influenced by the conditions of the lower atmosphere.

References

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