Low-frequency variability of the winter polar vortex in a simple model of the seasonally evolving stratosphere

Luke Hatfield, R. K. Scott

School of Mathematics and Statistics, University of St Andrews, UK

We investigate persistent low-frequency variability in the stratospheric winter polar vortex in a rotating spherical shallow-water model under the action of topographic wave-forcing and radiative cooling to a simple time-varying equilibrium state representative of the seasonal cycle in solar heating. A weak, linear drag with a frictional timescale much longer than the timescales of the model's other dynamical and radiative processes is applied to the tropics to mitigate the unconstrained growth of tropical easterlies that otherwise occurs in this system due to the persistent deposition of angular momentum at lower latitudes. Control of these easterlies allows the model to be run in a statistically stationary state over sufficiently long timescales to allow robust quantification of low-frequency variability. Of particular interest is the distribution of quiescent and disturbed winters, in which the winter vortex is alternately close to radiative equilibrium, with low planetary wave amplitude, or else strongly disturbed by the wave forcing and held far from radiative equilibrium. A range of modes of variability is obtained, dependent on the topographic forcing amplitude, with a typically quiescent winter vortex at low forcing amplitude and a typically disturbed vortex at higher amplitude. At both of these extremes there is little year-to-year variation of the vortex state. For a range of intermediate forcing amplitudes, the vortex may transition between quiescent and disturbed states from one winter to the next with persistent, low-frequency variability. To investigate the extent to which the low-frequency variability found here may be explained in terms of the low-latitude flywheel mechanism suggested by Scott and Haynes (1998), we conduct additional experiments in which the tropical linear drag has a greater or narrower latitudinal extent, and find that drag imposed over a sufficiently wide region (approximately 20 degrees from the equator) does indeed suppress the variability. An alternative method to control the tropical easterlies is proposed via the construction of a radiative equilibrium height profile which relaxes the mean flow in the tropics to a westerly regime. Similar variability is found, suggesting it is robust to the details of the model configuration, but this method proves less effective at consistently controlling the build-up of tropical easterlies. Finally, we investigate the interplay between the internal low-frequency variability of the winter vortex and a simple representation of the tropical quasi-biennial oscillation.

Key words: polar vortex, low-frequency variability, shallow water, seasonal cycle, quasi-biennial oscillation