J003-002 Room: C513 Time: May 28 14:00-14:15

Chaotic mixing and transport barriers in stratospheric polar vortex

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Chaotic mixing processes and transport barriers around the wintertime stratospheric polar vortex are investigated with an idealized barotropic model. A barotropically unstable jet is forced in order to obtain a fluctuating polar vortex. A flow with quasi-periodic time dependence and an aperiodic flow with similar behavior are investigated using several Lagrangian methods.

A typical chaotic mixing process is observed in the quasi-periodic flow, resulting in effective mixing inside and outside of the polar vortex. The mixing regions are on the critical latitudes of several planetary waves that grow through barotropic instability. Poincare sections give accurate locations of chaotic mixing regions, and transport barriers are identified as the edges of invariant torus regimes. In addition to the transport barriers associated with strong potential vorticity gradients, another type of transport barrier exists, which is not related to the steep potential vorticity gradient.

Chaotic mixing is dominant also in the aperiodic flow. Comparing with the quasi-periodic flow, an aperiodic flow with the same wave energy has a higher average Lyapunov exponent. This arises because the area involved in chaotic zones increases. The evolution of the correlation function is also more typical of a chaotic zone. Isolated regions are found near the center of the polar vortex, which can be explained by the invariant tori in the Poincare sections of the quasi-periodic flow.

Next, interannual variations of the flow field and large-scale horizontal transport and mixing inside the wintertime polar vortex of the Southern Hemisphere upper stratosphere are investigated using isentropic winds obtained from UKMO assimilated data for nine years of 1992-2000. We focused on the midwinter, July, when the polar vortex is not much distorted, although eastward-propagating wave called the 4-day wave is observed in some years in the polar region. Finite-time Lyapunov exponents are computed and contour advections are done to examine stirring and mixing in the polar region.

When the 4-day wave has a large amplitude, effective mixing through stretching and folding process is seen inside the polar vortex. Finite-time Lyapunov exponents are sometimes as large as the midlatitudes, and the material contours of small areas grow exponentially in time on the poleward side of 70S. Such mixing properties are not uniform inside the vortex.

When the wave is not clearly seen, on the other hand, wind fields are close to a solid body rotation around the pole and mixing is very small; Lyapunov exponents are small and the material contours grow linearly in time by the stretching due to the meridional shear of the polar night jet.

Such interannual variability of the strength of the mixing is correlated with the variability of the perturbation amplitude of potential vorticity in the polar region.