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Interactive Comment

Interactive comment on "Trends and variability in stratospheric mixing: 1979–2005" *by* H. Garny et al.

Anonymous Referee #2

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This is a technically sound and well-organized paper that investigates long-term variability of fine-scale mixing in the lower stratosphere. The technique is simple and straightforward: It uses a measure of the separation of two parcel trajectories with time from initially adjacent starting points (Lyapunov exponents). Once time series of this quantity are constructed at all locations on a given isentropic surface, a multiple regression statistical model is used to estimate trends and other natural components of interannual variability on the 450K (15-17 km), 550K (˜ 22 km), and 650K (˜ 25 km) surfaces. The resulting regression coefficients are then discussed with respect to physical processes, especially the QBO, that influence planetary wave activity in both hemispheres.

Specific comments:

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(1) The only statistically significant and seasonally persistent trends occur at southern middle to high latitudes at the 450 K level. They are slightly positive (˜ 0.01 (day^{-1})/decade). The authors note that this trend is ‘‘consistent with an increase in winter-time wave 1 amplitudes at 60S over the same time period” (Bodeker et al., 2007). A positive trend in zonal wind occurs near 60S in October (Figure 14), which has been attributed to polar cooling associated with ozone depletion (Thompson and Solomon, 2002). The authors therefore suggest that the anthropogenic increase in zonal wind may be increasing the small-scale mixing at middle latitudes. This seems to be a reasonable hypothesis that could be investigated further.

(2) In general, one would expect that small-scale mixing would correlate with planetary wave activity as measured by E-P flux or eddy heat flux. Near 45N, some evidence for negative trends in January eddy heat flux at 100 hPa, implying a weakening Brewer-Dobson circulation, has been reported (e.g., Randel et al., 2002; Hood and Soukharev, JAS, 2005). These negative trends in the B-D circulation have been suggested to be a contributor to negative ozone trends at middle latitudes in that hemisphere. According to Figure 7 (center panel), there is a statistically significant negative trend in small-scale mixing during December and January near 40N. This result may therefore be consistent with the eddy heat flux analyses reported by the above authors.

(3) Although the Lyapunov exponent technique of measuring the rate of small-scale mixing is a useful tool, it should be emphasized that this parameter does not fully characterize planetary-scale or synoptic-scale wave activity. Specifically, it does not distinguish between anticyclonic poleward and cyclonic equatorward wave-breaking events, which commonly occur in the lower stratosphere (e.g., Peters and Waugh, JAS, 1996). The type of wave-breaking event that dominates depends on the meridional wind shear, which is modified if there is a trend in the polar vortex strength. Increased numbers of anticyclonic poleward events can produce increased numbers of dynamically forced ozone minima, including ‘‘mini-holes”, which also contribute to midlatitude ozone trends (Hood and Soukharev, JAS, 2005). So, more detailed studies are needed beyond that

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reported in the present manuscript in order to understand long-term changes in wave activity (as opposed to small-scale mixing) and their effects on ozone and other long-lived trace gases.

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