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Interactive comment on "Large decadal scale changes of polar ozone suggest solar influence" *by* B.-M. Sinnhuber et al.

Anonymous Referee #1

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In this paper, the authors report decadal variations of wintertime ozone in the middle stratosphere (800 K; 10 hPa) at several high-latitude ozonesonde stations over the 1991 to 2005 period. After adjusting the polar ozone data using a chemical transport model to account for observed changes in meteorological conditions, they find that the DJF residual ozone variations (measured minus model) correlate approximately with the 11-year solar cycle. However, they find the strongest correlation over the 14-year measurement period (R = 0.91) when energetic electron flux at geostationary orbit is used as the solar variability proxy rather than conventional indices such as the 10.7 cm radio flux (F10.7) and when negative residual ozone variations (model minus measured) are used. They therefore suggest that the observed correlation could be "evidence for a large-scale influence of energetic electron precipitation on stratospheric ozone." Using SBUV data, they then show evidence that the decadal variation of polar ozone near 10 hPa continues to be approximately in phase with the solar cycle over a 25-year period. Finally, using data from a single station (79N, 11E), they show that early winter (OND) polar ozone at 800 K correlates well with total polar ozone in March and with February mean planetary wave flux at 100 hPa averaged over middle latitudes. (The latter correlations had previously been demonstrated using satellite data in a paper by R. Kawa et al., Atmos. Chem. Phys., v. 5, p. 1655, 2005.) They therefore propose that energetic electron precipitation "could have a significant impact not only on polar stratospheric ozone and temperatures but also on climate."

In general, the data presented in this manuscript are worth presenting and do suggest an influence of the 11-year solar cycle on polar mid-stratospheric ozone in early winter. There may also be some secondary influence of the resulting ozone heating changes on circulation later in the winter, as suggested by the authors. However, as elaborated further below, the claim that energetic electron precipitation (EEP) is the primary source of this solar influence is not well-substantiated and the authors do not adequately consider the alternate possibility that the polar ozone signal is a secondary consequence of solar UV forcing of the stratosphere. Major revisions are therefore required before publication could be recommended.

(1) The primary evidence for an EEP influence is the high correlation (R = 0.91) shown in Figure 1c between negative residual ozone (model minus measured) and the > 2 MeV July to December electron flux at geostationary orbit (6 Re) over a 14-year period. However, as shown in Figure 1b, the electron flux at 6 Re correlates inversely with the solar cycle as measured by the 10.7 cm radio flux (F10.7), a good proxy for solar UV variations. This means that residual ozone (measured minus model) correlates positively with F10.7. Although the correlation may not be as high as found for the electron flux at 6 Re, it is probably high enough to be statistically significant. If so, then it would be difficult or impossible to distinguish between these two forcing mechanisms

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on the basis of statistical correlation analysis alone. The authors should calculate correlation coefficients against suitably averaged F10.7 and all other relevant indices (e.g., Ap index) to investigate in an unbiased manner whether other forcing mechanisms can actually be eliminated at the 95 per cent confidence level.

(2) Statistics aside, a major problem with applying the correlative result of Figure 1c to propose that EEP is the primary causal mechanism is that the electron flux at 6 Re is not an accurate measure of the precipitation flux into the polar atmosphere. As shown by Siskind et al. (GRL, v. 27, p. 329, 2002) and Randall et al. (JGR, v. 103, p. 28361, 1998), a much better measure of the precipitation flux (and the resulting effects on polar odd nitrogen and ozone) is the auroral Ap index. Siskind et al. specifically show that observed polar odd nitrogen interannual variations correlate well with the Ap index. The Ap index (see, e.g., http://www.ngdc.noaa.gov/stp/GEOMAG/kp_ap.shtml) correlates positively with the solar cycle rather than negatively as does the electron flux at 6 Re. Therefore, based on these previously published results, EEP should produce a variation of odd nitrogen that correlates positively with the solar cycle; the corresponding variation of ozone would correlate negatively with the solar cycle, opposite to that shown in Figure 1. Therefore, unless our understanding of precipitation-induced chemical effects on ozone in the polar stratosphere is flawed, it is unlikely that EEP can explain the decadal variation of polar ozone that is reported in this manuscript. The authors should provide a review of the Siskind et al. results (and other related work) in the manuscript. If they feel that EEP can nevertheless explain the results of Figure 1, then they should provide quantitative arguments for this proposal.

(3) There is an increasing quantity of evidence that solar UV-induced variations in the low-latitude upper stratosphere can indirectly perturb the polar stratosphere in winter. For example, Gray et al. (Q. J. R. Meteorol. Soc., v. 127, p. 1413; p. 1985, 2001) have shown using both model and data that January-February mean polar temperatures at 30 hPa are most sensitive to equatorial vertical zonal wind gradients near 50 km altitude in the previous September-October period. These zonal wind gradients

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are, in turn, directly influenced by solar UV variations through photochemically induced ozone changes, radiative heating changes, thermal wind changes, and resulting effects on the onset of the westerly semi-annual oscillation phase. Also, Kodera and Kuroda (JGR, v. 107, doi:10.1029/2002JD002224, 2002) argue that the stratopause circulation during the middle winter can either be in a strong polar night jet or in a weak polar night jet mode, depending sensitively on the relative importance of radiative and planetary wave forcing during early winter. Which mode is selected in a given winter can therefore be influenced significantly by weak external forcings such as the QBO and solar UV variability, both of which affect winds in the tropical upper stratosphere. Kodera et al. (GRL, v. 30, doi:10.1029/2002GL016124, 2003) also show that general circulation models are currently unable to accurately simulate realistic speeds for tropical winds near the winter stratopause and, therefore, these models are not yet able to fully simulate interannual variability caused by the solar cycle. Finally, Kuroda and Kodera (GRL, v. 32, doi:10.1029/2005GL022516, 2005) have recently reported evidence for a solar UV 11-year influence on the structure of the Southern Annular Mode, which includes positive feedback effects of ozone heating. While the details of the connection between solar UV induced effects in the tropical upper stratosphere in autumn and the wintertime polar lower stratosphere remain to be worked out, there is enough evidence for this connection that the authors should consider it in their manuscript. Is it possible, for example, that the autumn equatorial wind gradients identified by Gray et al. are also responsible (through wave-mean flow interactions, resulting influences on the occurrence of sudden warmings and the selection of preferred internal modes in the winter stratospheric circulation) for the DJF mid-stratospheric ozone variations reported in this manuscript? In their revision, the authors should consider this indirect UV mechanism on at least an equal footing with the EEP mechanism proposed in the current manuscript. Although the model employed by the authors accounts approximately for ozone changes caused by differing meteorological conditions, does it account fully for interannual ozone changes caused by changes in meridional ozone transport (associated with warming events, for example)? The latter ozone changes are most likely to be influenced by the solar UV flux.

Interactive comment on Atmos. Chem. Phys. Discuss., 5, 12103, 2005.