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Interactive comment on "Fall vortex ozone as a predictor of springtime total ozone at high northern latitudes" *by* S. R. Kawa et al.

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This paper reports a statistical correlation between total column ozone interannual variability at high northern latitudes in March and lower-to-mid stratospheric vortex ozone (10 to 40 hPa, equivalent latitudes > 70N) in the prior November. Several satellite data sets are employed to measure November lower stratospheric ozone in the vortex: POAM II, POAM III, and version 8 SBUV data, which is constructed using data from four different SBUV instruments. The SBUV data have poorer vertical resolution than the POAM data but extend over a period of 26 years (1979-2004) while the POAM data extend only from 1994 to 2004. Total ozone data from several different satellite instruments (Nimbus 7 TOMS, Meteor 3 TOMS, Earth Probe TOMS and NOAA 9 SBUV) are employed to measure March total ozone.

The importance of the observed correlation is that it may provide clues to the sources and predictability of dynamically induced changes in springtime total ozone in the Arctic. The latter has generally decreased since 1980, driven at least in part by anthropogenic halogen increases, but has exhibited more interannual variability of dynamical origin than has springtime ozone in the Antarctic (see their Fig. 1). In the Discussion section at the end of the paper, the authors first summarize current understanding of general dynamical and chemical processes influencing Arctic ozone in spring. In particular, it is emphasized that springtime Arctic ozone is largely determined by the rate of tropospheric wave forcing, which weakens the polar vortex and accelerates the mean meridional (Brewer-Dobson) circulation, transporting ozone poleward and downward in winter. They then consider sources of variability in the fall lower stratospheric vortex and emphasize that early-winter wave activity is likely to play an important role by influencing descent and mixing of ozone-rich air into the vortex. The authors note that other vortex properties in November (temperature, total ozone) do not correlate as well with March total ozone as does lower to middle stratospheric vortex ozone in November. Several possible mechanisms for explaining the observed correlation are then considered. First, the possibility that wave activity in November persists through the winter, thereby yielding more ozone in March was considered. However, no significant correlation between wave activity measures (e.g., 100 hPa eddy heat flux averaged over 40N to 75N in JFM) and the same quantity in November was found. They also investigated whether radiative cooling (which mainly drives descent in the vortex in November) correlates with November vortex ozone but the results were negative. Next, the authors note that several long-term model simulations do not show any significant correlation between November vortex ozone and March total ozone as found in the observations. Finally, they review several recent studies that may bear on the interpretation of the observed fall-spring correlations. In particular, they note that these correlations may be related to previous observational evidence that midwinter (JF) north polar temperatures are inversely correlated with upper stratospheric equatorial winds in the prior

September - October (Gray et al., 2001).

Below, some additional suggestions are first made with respect to the interpretation of the observed correlation between late fall vortex ozone and spring column ozone at high latitudes in the NH. Then, some minor criticisms and suggestions for improvement of the paper are made.

Following the authors' suggestion at the end of the paper, it is possible that the present correlation (between late fall vortex ozone and spring column ozone at high latitudes) is related to the correlative results of Gray et al. (2001). According to the Gray et al. paper (their Figure 7), significant negative correlations between JF NP temperatures and equatorial zonal winds are found not only in the upper stratosphere in Sept.-Oct. but are also found (with somewhat lower amplitudes) in the lower stratosphere in August through November. The correlation with lower stratospheric equatorial winds is the original Holton-Tan result that was suggested by them (Holton and Tan, 1980) to be caused by poleward deflection of planetary waves (weakening the winter vortex and increasing winter polar temperatures) during the easterly phase of the equatorial quasi-biennial wind oscillation. (It is now known that the Holton-Tan correlation is mainly present under solar minimum conditions; see Figure 8 of Gray et al.) If this latter interpretation is correct, then it may be suggested that a variant of the same mechanism could be primarily responsible for the late fall / spring polar ozone correlations reported here. The fact that the authors have not yet found any correlation between 40N to 75N averaged 100 hPa eddy heat flux (a measure of wave forcing) during JFM and that in November may not be sufficient to exclude this mechanism. First, the wave forcing field evolves significantly during the winter so that averages over constant latitude bands at a single pressure level may not correlate well between November and JFM even if changes in wave forcing in the fall are the main trigger for producing a weakening of the vortex in JFM. Second, the eddy heat flux at 100 hPa is only a measure of the wave forcing entering the stratosphere and does not account for wave refraction, absorption, and dissipation as waves propagate upward.

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Some further insight into how the upper stratospheric correlations of Gray et al. may relate to the results reported here, and also why model simulations do not reproduce the observed correlations, may be provided by the work of K. Kodera and colleagues. First, Kodera and Kuroda (2002) have used a simplified, quasi-geostrophic model of the residual circulation to show that, in general, the zonal mean winds near the stratopause evolve from a strong, radiatively controlled state during early winter (November - December) to a weak, dynamically perturbed state during late winter as planetary wave amplitudes become larger and radiative forcing decreases. The transition is characterized by a poleward shift of the lower mesospheric subtropical jet (LMSJ). During the middle winter, the stratopause circulation can either be in a strong polar night jet (positive Arctic Oscillation or AO) mode or in a weak (negative AO) mode, depending sensitively on the relative importance of radiative forcing and planetary wave forcing. Which mode is selected in a given winter can therefore be influenced significantly by weak external forcings such as the QBO, volcanic aerosol injections, and solar variability (see also Holton, 1994). Realistic speeds of the LMSJ are not reproduced by most general circulation models and these models are therefore not able to fully simulate interannual variability caused by weak external forcings (Kodera et al., 2003). Based on these results, it may be suggested that a possible next step in the analysis of the fall / spring vortex ozone correlations reported in this paper might be to search for correlations of the November vortex ozone with zonal winds near the stratopause at various latitudes and for various months during the fall. If a correlation is found for some months and latitudes, this could be an indication that interannual changes in wave forcing are influencing the development of the LMSJ and, hence, the selection of preferred internal modes in the polar winter stratosphere. With this information, it may be easier to identify the changes in wave forcing (as measured by EP flux divergence, for example) that are resulting in changes in November vortex ozone.

Specific suggestions / comments for the authors:

According to the way the paper is written, it appears that the authors expect readers to be fully familiar with earlier papers (Kawa et al., 2002; Newman et al., 1997, etc.). For example, the boundary of the vortex is not defined and the actual pressure levels (or potential temperature surfaces) that define lower to mid-stratosphere within the vortex are not actually stated. At the bottom of p. 159, we are referred to Fig. 3 of Kawa et al., 2002, to see an example cross section of the region that is used to define the vortex ozone data. The paper should stand on its own. So, basic definitions should be provided and jargon that assumes a detailed knowledge of earlier papers by the authors should be minimized.

In section 2.2, it should be emphasized that the SBUV instrument is not really able to resolve the ozone profile at pressure levels below about 30 hPa.

There is no description given in the paper of the March total ozone data that are employed in the analysis. As far as I can tell, the only mention of data sources for the total ozone data is a reference to Newman et al. (1997) in the caption to Figure 1. What satellite instruments are used? During 1995 and 1996, there are no TOMS data. What was used for these two years? Is this data set the Version 8 merged TOMS / SBUV total ozone record compiled by Stolarski et al. (http://code916.gsfc.nasa.gov/Data_services/merged/)? Or, is it a collection of TOMS and SBUV measurements from different instruments that has not been adjusted for intercalibration differences? At a minimum, a paragraph should be added to the paper describing the specific sources of the March total ozone data that were used.

In the text, it is stated that a 10 year record of POAM data and a 24 year time series of SBUV and March total ozone data are used in the analysis. However, in Figures 4 and 5, POAM data are plotted for an 11-year period (1994 - 2004) and SBUV and total ozone data are plotted for a 26-year period (1979 - 2004).

In the captions to Figures 4 and 5, "November" should be replaced with "the prior November".

In Figure 2, the left ordinate should have more labels (600, 700?). The units of the right

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ordinate should be specified either on the figure or in the caption.

In the abstract, the phrase "so that interannual variability in both quantities is largely driven by the later years" is not easy to understand. I suggest rewording this sentence. Also, the sentence beginning with "Variation in November ..." should be separated into two sentences.

References (excluding those given in the paper):

Holton, J. R., The quasi-biennial oscillation in the Earth's atmosphere and its links to longer period variability, in *The Solar Engine and Its Influence on Terrestrial Atmosphere and Climate*, NATO ASI Series, Vol. 125, E. Nesme-Ribes, ed., pp. 259-273, Springer-Verlag, Berlin, Heidelberg, 1994.

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