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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Climatology and trends in the forcing of the stratospheric zonal-mean flow" *by* E. Monier and B. C. Weare

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We appreciate the comments by the referee 1. We respond point by point to the comments.

Major points 1. The authors say in the abstract, "Ozone depletion causes a reduction in wave activity in high latitudes." I do not simply agree with it. The strong polar vortex corresponds to a baroclinically unstable situation, in which synoptic disturbances develop rapidly. Also, the strong westerly wind tends to excite topographically forced planetary waves. These must be compared with the mechanisms which suppress wave activity.

This sentence and the following one in the abstract will be replaced by the following:

Ozone depletion is well-known for strengthening the polar vortex through the thermal wind balance. However, the results of this work show that the SH polar vortex does not experience any significant long-term changes until the month of December, even though the intensification of the ozone hole occurs mainly between September and November. This study suggests that the decrease in planetary wave activity in November provides an important feedback to the zonal wind as it delays the breakdown of the polar vortex. In addition, the absence of strong eddy feedback before November is responsible for the lack of significant trends in the polar vortex in early spring.

2. Even though the residual tendency in zonal mean momentum equation is attributed considerably to gravity wave drag, it is still unknown whether the trend of the residual force comes from the trend of gravity wave drag. The trend of residual tendency estimated from the reanalysis during about twenty years is much smaller than the residual tendency itself. It may be contaminated from various sources of systematic errors in the data assimilation.

In the revised manuscript, we have attempted to address the uncertainty in the residual term and its attribution to a gravity wave drag by redoing the analysis based on a different re-analysis dataset, the NCEP re-analysis 2. We found several consistent features between the ERA40 residual term and that calculated using the NCEP re-analysis 2. In particular, the vertical profile and seasonality of both residual terms broadly agree outside of the polar region, although the ERA40 is noisier than the NCEP re-analysis 2 (see Fig. 1). The correlation analysis also shows a high (negative) correlation between the Coriolis term and the residual term (see Fig. 2 and Fig. 3 and response to major point 3).

We also redid the trend analysis of the various forcing terms based on the NCEP re-analyses 2 and added that analysis to the revised manuscript (see Fig 4.). There are clear similarities with the trend analysis based on the ERA-40 re-analysis: - the trend in du/dt and its seasonality are nearly identical; - the trends in the EP flux divergence and its seasonality agree well; - the trends in the Coriolis term and in the residual term

mirror each other well, especially when the trends in the EP flux divergence are small. Nonetheless, the signs of the trends in the Coriolis term and in the residual term do not agree well. As a result we have underlined the fact that while the trends in both terms mirror each other well in both re-analyses, there is a large uncertainty in the sign of the trends. As a result, we included a short discussion on the potential causes for the discrepancy in the trend analysis between the two datasets.

3. In Fig. 6, the authors concluded from the spatial correlation between the mean Coriolis force and the residual forcing that the gravity wave drag substantially drives the stratospheric B-D circulation. If the B-D circulation is noisier, the negative correlation is larger. In this case, the negative correlation does not indicate that the residual force is the driving force of B-D circulation.

The correlation analysis was redone using the NCEP re-analysis 2 (see Fig. 2 and Fig. 3), showing that the high spatial correlation between the Coriolis term and the residual term agree are nearly identical between the two independent re-analyses. This suggests that the contribution of noise or bias to the high (negative) correlation between the residual term and the Coriolis in the ERA40 re-analysis is small. This result strengthens the suggestion that gravity wave drag plays a considerable role in driving the Brewer-Dobson circulation, which is in agreement with previous studies that are cited in this manuscript.

Comments P11650.L12: It is unknown for me whether or not strengthening westerly winds actually causes a reduction in wave activity. (major point 1)

See response to major point 1.

P11650.L15: More discussions are necessary for identification of the trend in the gravity waves (major point 2)

See response to major point 2.

P.11656L19: Please briefly note the method of vertical average from 100hPa to 10

hPa. The air mass density should be considered in the average for conserving the budget.

The mass-weigthed averaging does not actually affect the results much since the vertical structure of the various terms is fairly homogenous with height.

P.11660L8: The latitudinal band of 30S-40N is asymmetric and seems to be somewhat wider to see the effects of equatorial waves. I would like to know the reason for this choice.

This a typo, the latitudinal band used in this analysis of the residual term in the tropics is really 10S-10N. This is corrected in the revised manuscript.

P.11663L11: In Fig. 6, the negative correlation between the Coriolis force and residual force does not indicate that the residual force mainly drives B-D circulation (see major 3).

See response to major point 3.

P.11664L5: Considering the smaller contribution of gravity waves to the driving B-Dcirculation in the SH, it seems to be natural that correlations with the residual forcing is different between the two hemispheres.

The correlation between the residual term and the Coriolis force are of similar magnitude in the SH, for both the ERA-40 and the NCEP re-analysis.

P.11666L2: In Fig. 8, please draw line indicators more clearly.

The line indicators are improved in the revised manuscript.

P.11670L5: Again, I would like to note that correlations with residual terms may be sensitive to the magnitude of noises. (major point 3)

Once again, the addition of the NCEP re-analysis to the revised manuscript provides more strength to the results highlighted in this paragraph.

P. 11671L2: More careful discussions are needed to conclude that the ozone depletion actually suppresses wave activity. (major point 1)

See response to major point 1.

P. 11672L24: It is really important to confirm conclusions obtained in the other reanalyses (major point 3)

We have adapted our conclusions to the results based on the NCEP re-analysis 2. In particular, we have pointed out that a consistent feature between the trend analysis using the ERA40 and the NCEP –reanalysis 2 is that the trends in the Coriolis term and in the residual term mirror each for most of the year. This suggests that long-term changes in gravity wave drag plays a significant role in driving long-term changes in the B-D circulation, which is in agreement with previous studies cited in the manuscript. Nonetheless, there is a large uncertainty as to the sign of the trend in both terms, as indicated by the lack of agreement between both re-analyses.

Interactive comment on Atmos. Chem. Phys. Discuss., 11, 11649, 2011.

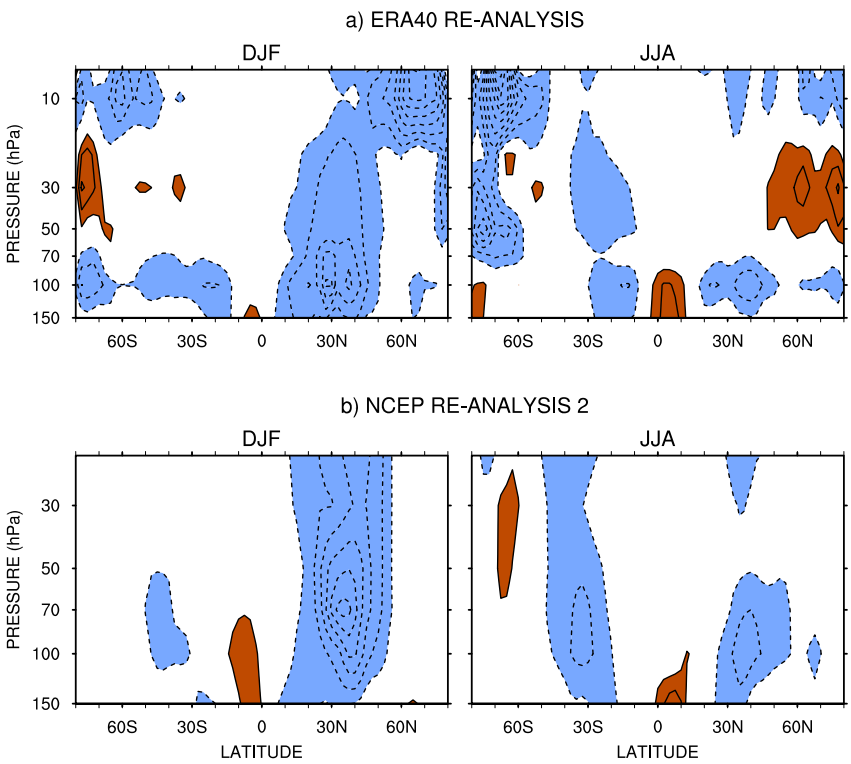

Fig. 1. Latitude-height cross-section of the residual term in the TEM momentum equation averaged of DJF and JJA for both ERA-40 re-analysis and NCEP re-analysis 2.

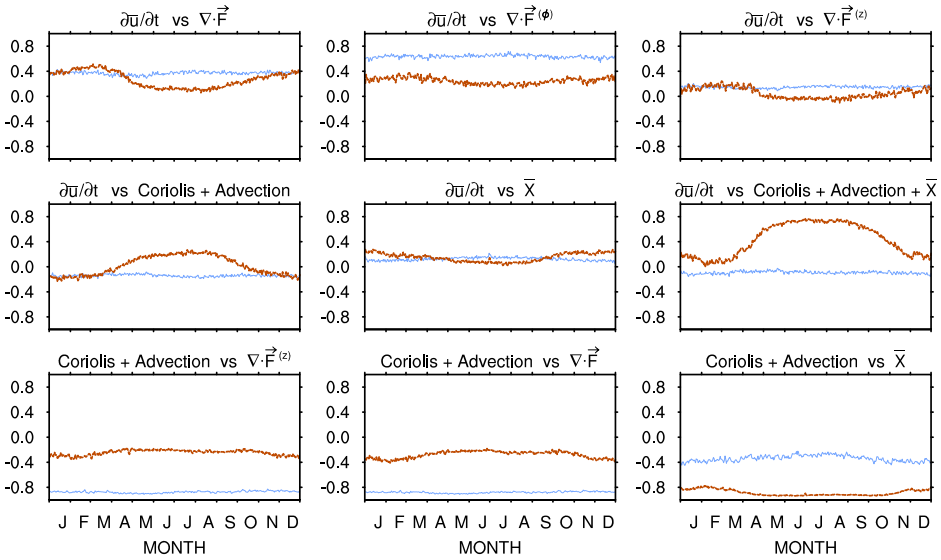

Fig. 2. Time variations of spatial correlations over the Northern Hemisphere in the troposphere (blue lines), and in the stratosphere (brown lines), for the ERA-40 re-analysis.

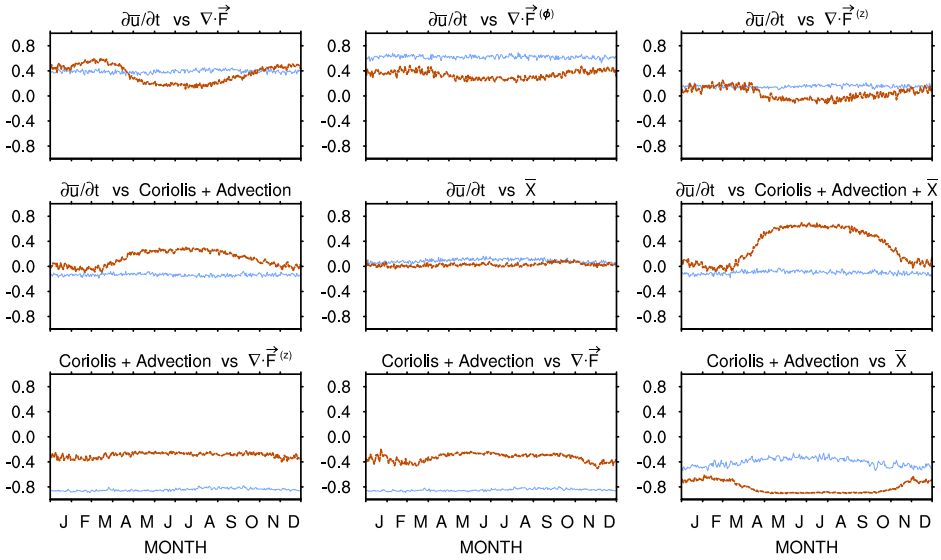

Fig. 3. Same as Fig. 3 but for the NCEP re-analysis 2.

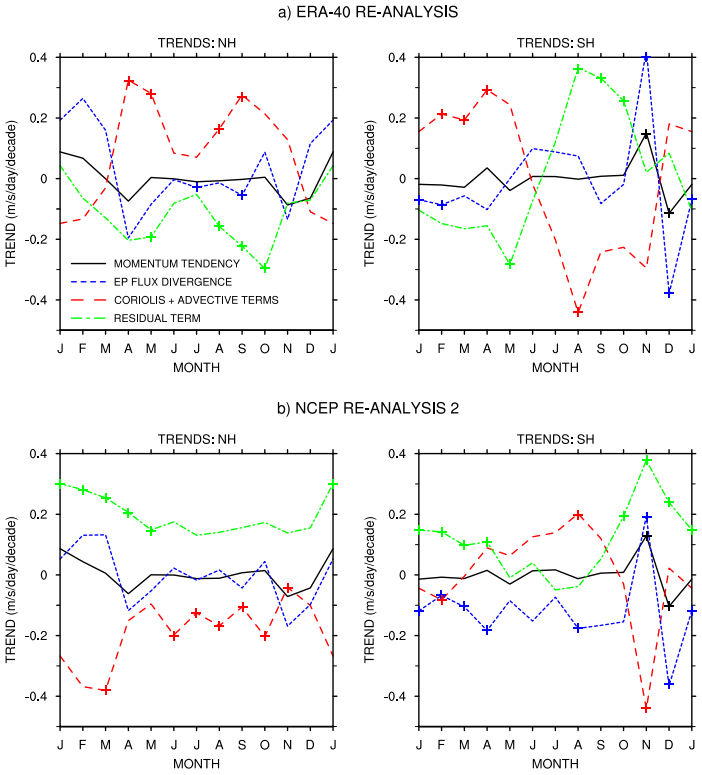

Fig. 4. Annual cycle of the trends in the momentum tendency and its forcing terms, for the (left) NH and the (right) SH, for both the ERA-40 re-analysis and the NCEP re-analysis 2.