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Comment on "Tropospheric response to stratospheric perturbations in a relatively simple general circulation model" by Lorenzo M. Polvani and Paul J. Kushner

Mark P. Baldwin

Northwest Research Associates, Bellevue, Washington, USA

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[1] *Polvani and Kushner* [2002] (hereinafter PK) examined the sensitivity of the tropospheric circulation to thermal perturbations in the stratosphere using a simplified dry general circulation model without planetary wave forcing. In their model the winter polar stratospheric lapse rate was adjusted to produce stratospheric conditions ranging from no polar vortex at high latitudes to a cold, strong polar vortex similar to that seen in the Southern Hemisphere. They found that for a sufficiently strong polar vortex, the subtropical jet in the upper troposphere shifted poleward by more than 10° and weakened slightly. For a sufficiently strong polar vortex the surface wind maximum strengthened and moved poleward. They also found that surface pressure over the polar cap was lower for strong polar vortex conditions, corresponding to a positive index of the model's leading mode of variability. Some models [*Shindell et al.*, 1999] predict that the stratospheric polar vortex will become stronger with increasing concentrations of greenhouse gases, and a stratosphere-induced shift in the position of tropospheric jet could cause large changes in surface climate. The purpose of this comment is to examine the observations for evidence of these tropospheric changes associated with strong and weak stratospheric polar vortex conditions.

[2] A direct comparison between the observations and PK's model results is complicated by two factors. First, the PK model was integrated to a steady state (~25 years) with no seasonal cycle. Second, by directly varying the stratospheric lapse rate they were able to obtain a range of vortex strengths larger than has been observed in either hemisphere during winter. Using observational data, the closest comparison is to form strong and weak vortex composites by averaging periods during Northern Hemisphere winter when the polar vortex was anomalously strong or weak. For this study I used daily NCEP/NCAR reanalysis data for 1958–2002 [*Kalnay et al.*, 1996].

[3] As an index of the strength of the stratospheric polar vortex I used the anomalous (deseasoned) zonally-averaged zonal-mean wind at 10 hPa, 60°N, which is highly correlated (0.96) with the Northern Annular Mode (NAM) index at 10 hPa [*Thompson et al.*, 2002]. Observational studies show that stratospheric perturbations (e. g., stratospheric warmings) typically last at least a month and on average affect the troposphere within approximately two weeks [*Baldwin and Dunkerton*, 1999, 2001]. Wintertime NAM anomalies at 10 hPa have an *e*-folding timescale of 15–20 days at 10 hPa [*Baldwin et al.*, 2003]. To define strong and weak vortex composites I used one-month (31 day) running means of the jet strength. The 31-day length of the running means is a compromise selected to obtain large composite differences between strong and weak vortex conditions while being long enough to include coupling to the troposphere. I then selected the ten 31-day periods that produced the weakest composite polar jet, and the ten 31-day periods that produced the strongest composite polar jet; I call these composites weak and strong vortex regimes. In principle, composites could be formed using early and late years in the data record. However, the trend is too small to produce large differences in the composites. The results shown below are not sensitive to the length of the running mean or the number of events in each composite.

[4] In Figure 1, the weak and strong vortex composites correspond to PK's modeled stratospheric lapse rate (K/km) of $\gamma \sim 0$(no polar vortex) and $\gamma \sim 2.5$ (as shown in Figure 1 of PK). The strong vortex composite in Figure 1 has a maximum jet speed of ~50 ms^{-1}, and does not match the ~70 ms^{-1} for PK's strongest vortex ($\gamma = 4$) that is similar to Southern Hemisphere winter.

[5] In the observations the strongest subtropical jet is found at 200 hPa and it is stronger for weak vortex conditions (Figure 1a). Figure 2 compares latitudinal profiles of the zonal-mean wind at 200 hPa and 1000 hPa. During strong vortex regimes the 200-hPa winds are stronger poleward of ~45°N and weaker equatorward of ~45°N. This behavior is consistent with Figure 1 in PK. However, PK also showed that the position of the subtropical jet (~300 hPa in their model) shifted poleward with a stronger stratospheric polar vortex. In the observations the difference in the jet position between the strong and weak vortex regimes was 1.3°, with slight equatorward movement during strong vortex regimes. (The latitudinal resolution in the NCEP data is coarse (2.5°), so I used cubic splines to interpolate the daily zonal-mean wind at 200 hPa every 0.01°.) This movement is statistically significant at the 95% level and is seen in composites formed using different averaging periods and numbers of events.

[6] The results at 1000 hPa (Figure 2b) are broadly consistent with the findings of PK. In the observations the average position of the strongest near-surface winds shifts

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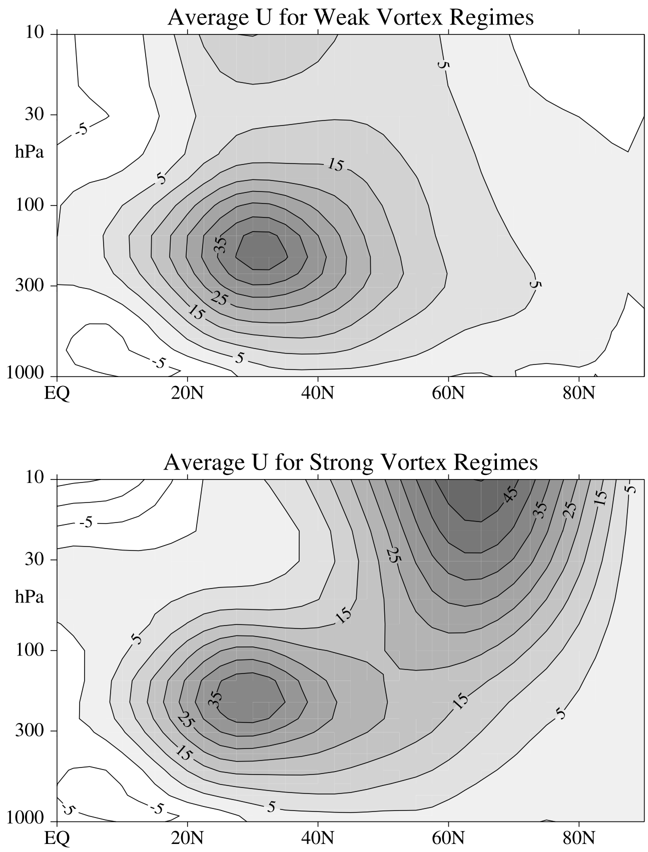

Figure 1. Zonally-averaged zonal wind (ms^{-1}) for weak vortex regimes (a) and strong vortex regimes (b).

markedly poleward (10–15°) for the strong vortex regime, but the strength of the maximum wind does not change appreciably. PK also found that the position of the maximum surface wind shifted poleward as the stratospheric polar vortex strengthened, but they found that the wind speed increased.

[7] The reason that the subtropical tropospheric jet position is relatively insensitive to changes in the strength of the stratospheric polar vortex can be understood by comparing the climatological jet position to the changes in zonal wind associated with annular mode anomalies. The strength of the tropospheric westerly winds is affected in a dipole pattern (Figures 1 and 2), consistent with the results of PK (their Figure 4). *Nigam* [1990] found that the leading empirical orthogonal function (EOF) of zonal wind is a dipole pattern, similar to the zonal wind pattern associated with the NAM at 1000 hPa (also called the Arctic Oscillation (AO)) [*Thompson and Wallace*, 1998, 2000]. The zonal wind in the troposphere tends to fluctuate in a dipole with a node near 45°N, and changes in the strength of the stratospheric polar vortex are closely associated with this dipole in zonal wind. A strong stratospheric polar vortex is associated with stronger high-latitude tropospheric winds, and weaker low-latitude winds. The largest change to the low-latitude 200-hPa wind is nearly coincident with the climatological jet. Thus, a stronger polar vortex is associated with a weakening of the jet, but only a small meridional displacement of the jet.

[8] I also tried the same methodology using Southern Hemisphere data. Analysis of Southern Hemisphere data is more difficult because the reliable data record is approximately half as long (beginning in 1979) and because the largest variations in the stratospheric vortex strength occur during spring, when the climatological average vortex strength is decreasing rapidly. I compared the anomalous subtropical jet position for the five strongest and weakest 31-day periods and found that the difference in the anomalous jet position between weak and strong vortex regimes was 3.4°, consistent with the Northern Hemisphere results. There is also no indication in the observations that the position of the Southern Hemisphere subtropical jet shifts poleward during midwinter, when the stratospheric jet is strongest.

[9] PK found that the average surface pressure over the polar cap was lower for strong vortex conditions. This is consistent with the observational results of *Baldwin and Dunkerton* [2001], who showed that the onset of strong and weak stratospheric vortex conditions tend to be followed by surface conditions resembling the positive and negative phases of the AO, respectively. The difference between the mean AO during strong and weak vortex regimes was 0.90σ (normalized by the daily standard deviation during DJF), consistent with both studies.

[10] In summary, I found that the observations were broadly consistent with the modeling results of PK. Stronger polar vortex conditions in the stratosphere correspond with a weakening of the subtropical jet at 200 hPa and

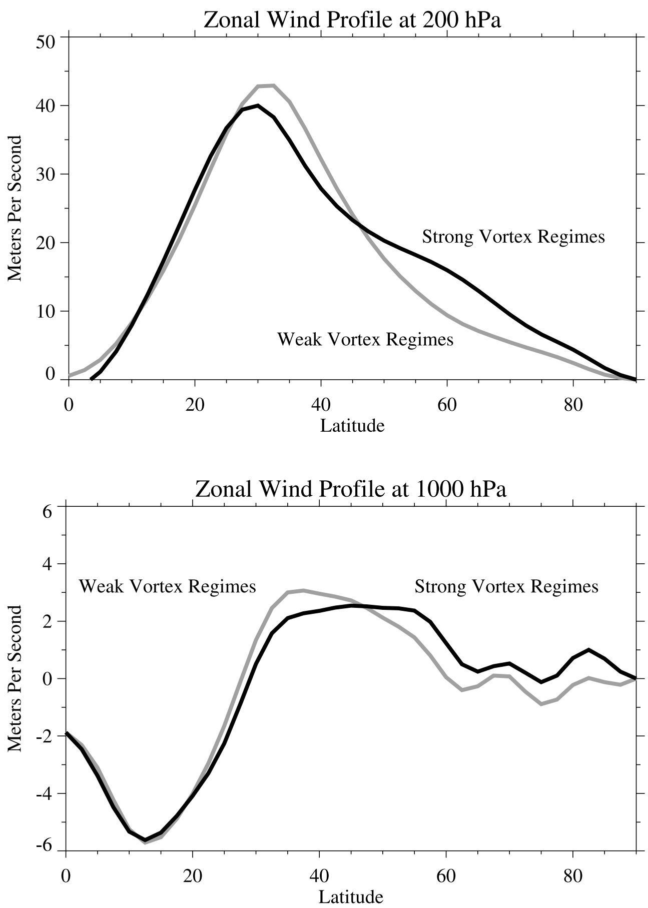

Figure 2. Profiles of zonal-mean zonal wind at 200 hPa (a) and 1000 hPa (b) for strong vortex regimes (black) and weak vortex regimes (gray).

stronger winds poleward of ~45°N. At the surface the observations support PK's result that the position of the maximum wind moves markedly poleward during strong vortex conditions. However, I found no evidence in the observations for poleward shift in the position of the subtropical jet during strong vortex conditions. This does not rule out the possibility that poleward shifts in the position of the subtropical jet could occur in the future if the stratospheric polar vortex becomes much stronger. All the observed changes in the troposphere are consistent with tropospheric annular mode anomalies of the same sign as the stratospheric annular mode anomalies.

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M. P. Baldwin, Northwest Research Associates, 14508 NE 20th Street, Bellevue, WA 98007-3713, USA. (mark@nwra.com)