The seasonal cycle of stratosphere-troposphere coupling at southern high latitudes associated with the semi-annual oscillation in sea-level pressure

Thomas J. Bracegirdle, British Antarctic Survey, Cambridge, United Kingdom (tjbra@bas.ac.uk)

Introduction

The semi-annual oscillation (SAO) in sea-level pressure at high southern latitudes is the consequence of a twice-yearly contraction (and strengthening) and expansion (and weakening) of the storm track between 50°S and 65°S, with the contracted phases in spring and autumn (Fig. 1). In this study the extent to which inter-annual variability of the SAO is correlated with inter-annual variability in mid- to lower-stratospheric circulation at 60°S was determined using NCEP/NCAR Reanalysis 1 (NNR1) data (Kalnay et al., 1996) for the period 1979-2009.

A decadal-scale weakening of the SAO amplitude that occurred from the 1970s through the 1980s has been attributed to changes in the annual cycle of the tropospheric temperature difference between 50°S and 65°S (Meehl et al. 1998). Maxima in the annual cycle of this change in temperature difference, which occur in May and November, result in a flattening of the seasonal cycle of baroclinicity. The weaker SAO has persisted to at least 2005, but with large inter-annual variability (Taschetto et al. 2007).

The purpose of this study was to extend previous work on surface/tropospheric influences and determine the extent to which inter-annual variability of the SAO is coupled with stratospheric circulation variability. This is motivated by previous studies that show a significant influence of changes in the stratosphere on tropospheric circulation (e.g. Charlton et al. 2005; Simpson et al. 2009). The stratosphere is a pathway through which the SAO (and the tropospheric circulation more generally) may be influenced by factors such as El Nino - Southern Oscillation (ENSO) variability, solar variability and the quasi-biennial oscillation (Hurrell and van Loon 1994; Taschetto et al. 2007; Seppala et al. 2009; Haigh and Roscoe 2009).

The SAO

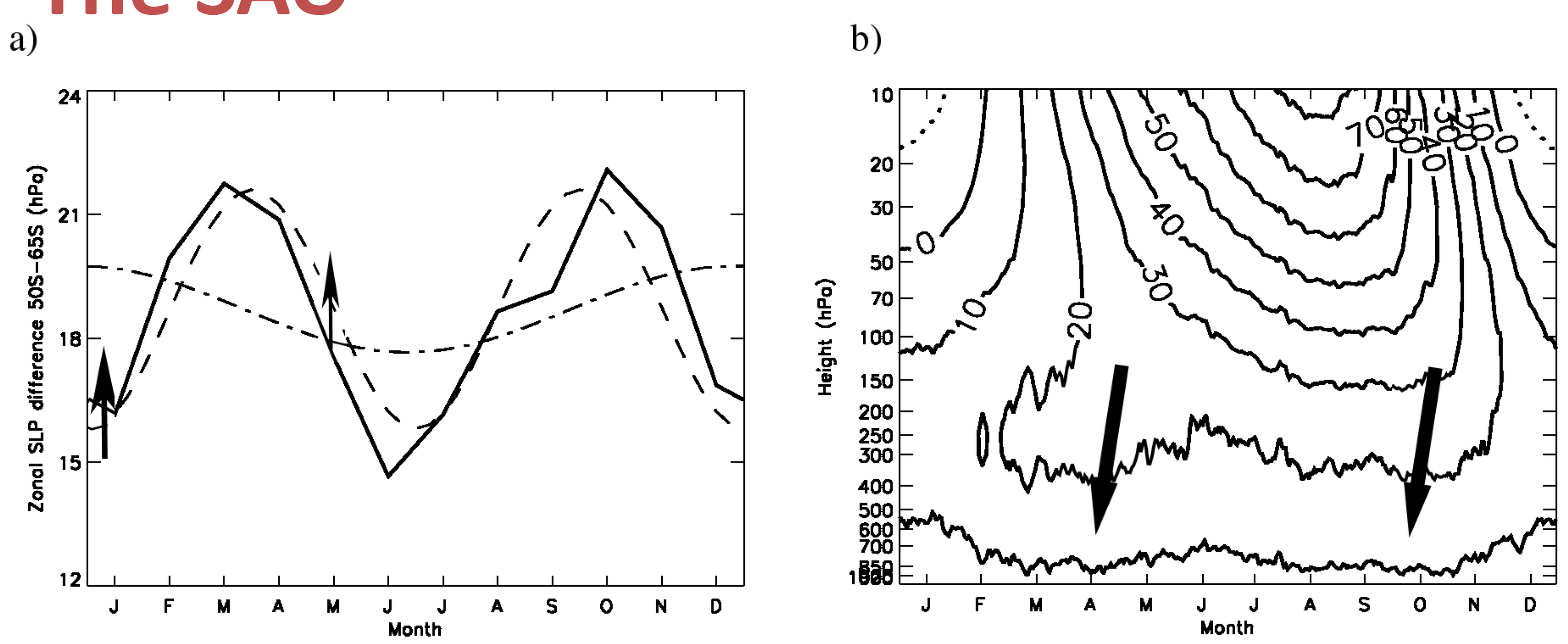


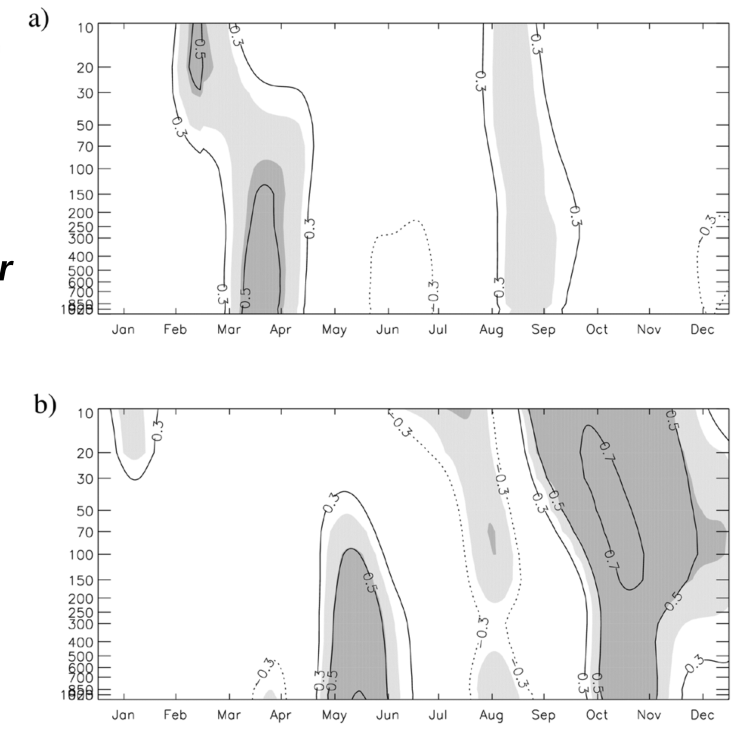
Fig. 1. monthly mean SAO index (zonal mean SLP difference between 50°S and 65°S) (solid line), its first harmonic (dashed-dotted line) and its second harmonic (dashed line). (b) multi-annual daily mean zonal mean zonal wind at 60°S (ms^{-1}). Tick lines on the horizontal axis in both panels indicate the middle of the month. The arrows in (a) indicate the months of maximum linear trends in the SAO index. The arrows in (b) indicate the approximate months of stronger winds associated with the SAO peaks. Plotted from the NNR1 dataset for the period 1979 through 2009.

Fig. 1a shows the annual cycle of the SAO index. In this study the second harmonic of the annual cycle defines both the amplitude and the phase (date of the first peak) of the SAO.

Results

- Fig. 2a shows that variability in the SAO amplitude is in general not significantly correlated with year-to-year variability of atmospheric circulation in most months. However, in the months of March and April significant correlations extend up to 10 hPa. There is a downward propagation of the correlations which takes approximately 1 month from 10 hPa to the surface.
- Correlations for year-to-year variability of the SAO phase are more extensive and stronger than for the amplitude (Fig. 2b). In the troposphere significant positive correlations occur in both May/June and October/November. A clear downward propagation of maximum correlations from 10 hPa occurs in October/November. The time scale for downward propagation from 10 hPa is approximately one month, similar to that seen for the amplitude correlations.

Fig. 2. Correlation of SAO amplitude (a) and phase (b) with year-to-year variations of the zonal mean zonal wind at 60°S for different months and vertical levels. The tick marks on the horizontal axis indicate the middle of the months. The contour interval is 0.2 and only contours for correlations of a magnitude of 0.3 or larger are drawn. The shading indicates significance at the 1% level (dark grey) and 5% level (light grey). The significance testing was conducted using a two-tailed Student's t test, which takes into account lag correlation, and the time series were all linearly detrended. The data used is smoothed daily NNR1 data using a 30-day low-pass filter. NNR1 data for the period 1979 through 2009 was used.



- Fig. 3 shows lag correlations based on time series of the SAO index in specific months (instead of the amplitude and phase of the second harmonic of the index) show more clearly the seasonal variations in vertical coupling between the SAO index and atmospheric circulation up to the mid stratosphere.
- The downward propagation of maximum correlations in autumn and spring noted in the amplitude and phase of the second harmonic (Fig. 2) are also evident here. The lack of a strong and significant downward propagation in most months is consistent with the findings of Graversen and Christiansen (2003).

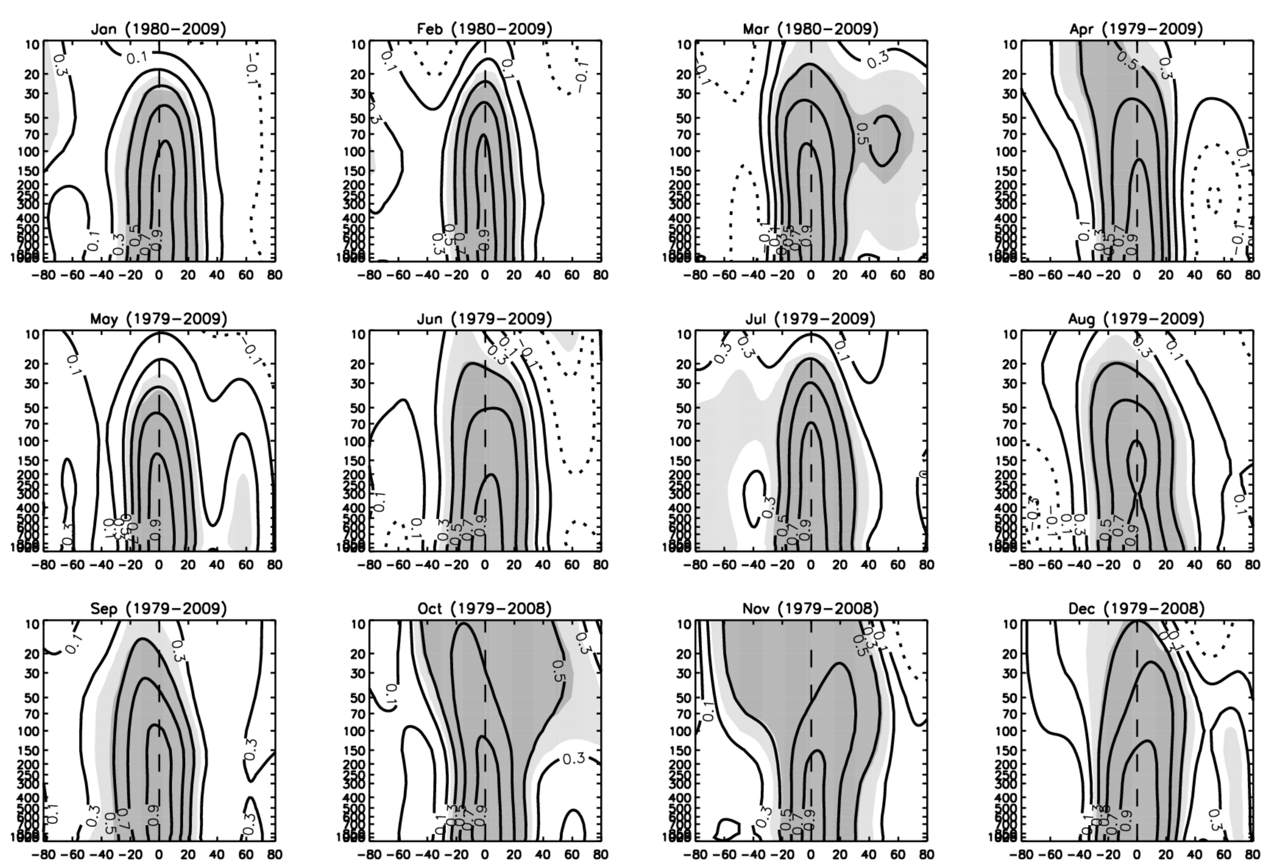
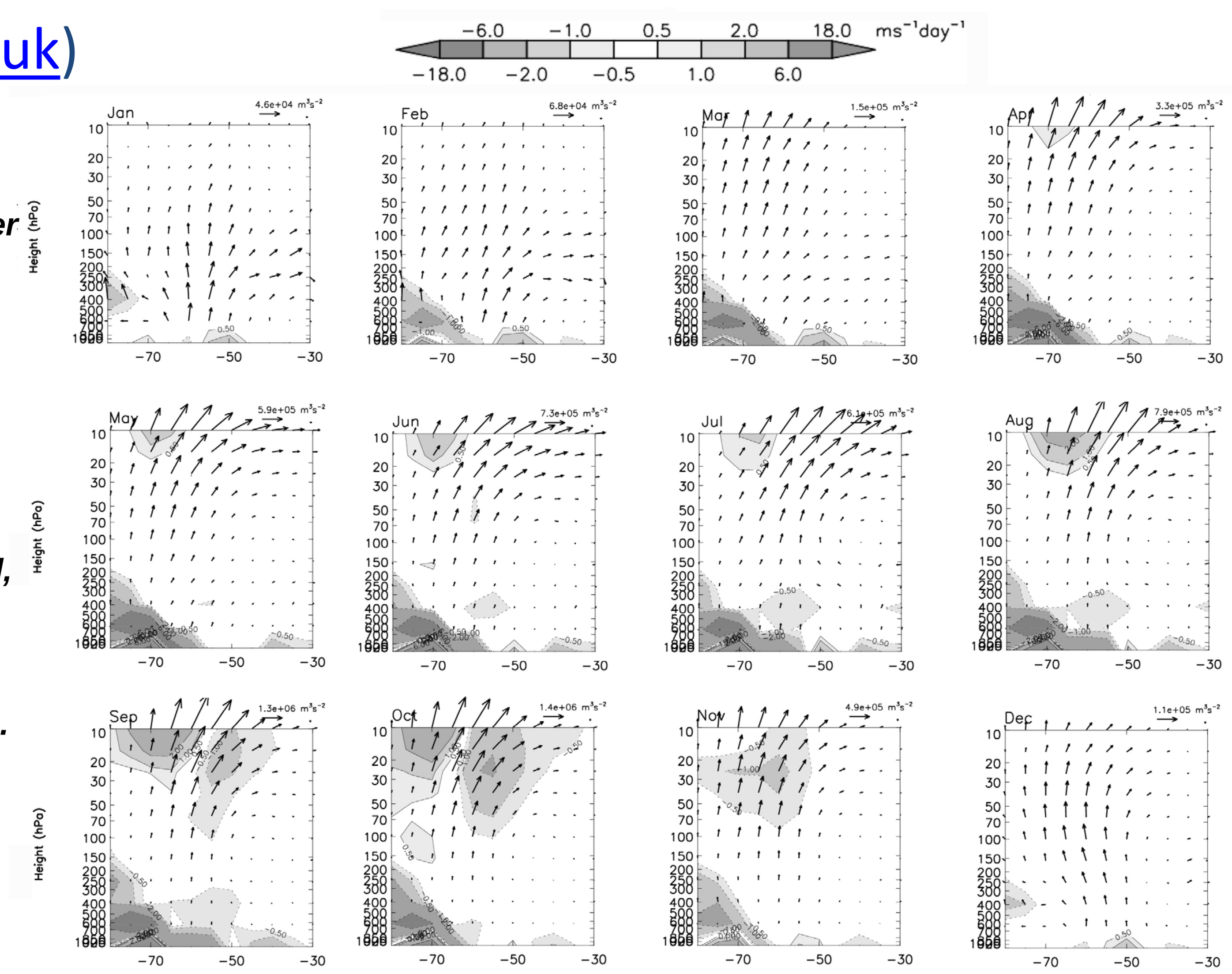


Fig. 3. Lag correlation between time series of the SAO index in individual months and zonal mean zonal wind on pressure levels at 60°S. Lags of between -80 and 80 days are shown. A large correlation at negative lags indicates zonal wind leading the SAO. The shading indicates significance as described in the caption for in Fig. 2. The data used is smoothed daily NNR1 data using a 30-day low-pass filter.

Fig. 4. Monthly mean wave-number 1 total Eliassen-Palm flux vectors and divergence contours. The magnitude of the plotted vectors ($\alpha F_y/\rho_0$, F_z/ρ_0) is shown in the top right of each panel, where α is 0.0063. Calculated from NNR1 for period 1979 through 2009.



To provide an overview of the propagation characteristics across the seasonal cycle, wave-mean flow diagnostics were computed for all months. Wave-number 1 dominates the propagation through the stratosphere at high southern latitudes (e.g. Hartmann et al. 1984; Shiotani et al. 1993), which is particularly strong in spring (September - November).

- The occurrence of significant of correlations up to 10 hPa for the SAO March and April (Fig. 2 and Fig. 3) cannot be explained by these wave-number 1 propagation characteristics alone.
- One possible mechanism for the correlations is resonance (Scott and Haynes, 2002) via phenomena such as wave reflection (Harnik and Lindzen, 2001).

Conclusions

- Year-to-year variability in the SAO amplitude is significantly correlated with mid-stratospheric (10 hPa) circulation variability in late summer/early autumn (February-March) and late winter/early spring (August-September).
- However, variability in the SAO phase is significantly correlated with mid-stratospheric circulation variability in spring (September-November).
- These maxima in significant correlations at 10 hPa propagate down to the surface in approximately one month.
- The early-autumn downward propagation of zonal wind correlations is a new finding, but the mechanism for its occurrence is not clear.
- It would be of interest to repeat the correlation analysis using one of the recently-released reanalyses: CFSR, ERA-Interim and MERRA.

References

Bracegirdle (in press) The seasonal cycle of stratosphere-troposphere coupling at southern high latitudes associated with the semi-annual oscillation in sea-level pressure. Climate Dynamics, doi: 10.1007/s00382-011-1014-4.
Charlton et al. (2005) The impact of the stratosphere on the troposphere during the southern hemisphere stratospheric sudden warming, September 2002. Quarterly Journal of the Royal Meteorological Society 131(609):2171-2188.
Graversen and Christiansen (2003) Downward propagation from the stratosphere to the troposphere: A comparison of the two hemispheres. Journal of Geophysical Research-Atmospheres 108(D24):4780.
Haigh and Roscoe (2009) The Final Warming Date of the Antarctic Polar Vortex and Influences on its Interannual Variability. Journal of Climate 22(22): 5809-5819. doi:10.1175/2009jcli2865.1
Harnik and Lindzen (2001) The effect of reflecting surfaces on the vertical structure and variability of stratospheric planetary waves. Journal of the Atmospheric Sciences 58(19):2872-2894.
Hartmann et al. (1984) Observations of Wave-Mean Flow Interaction in the Southern Hemisphere. Journal of the Atmospheric Sciences 41(3):351-362.
Hurrell and van Loon (1994) A modulation of the atmospheric annual cycle in the Southern Hemisphere. Tellus 46A:325-338.
Kalnay et al. (1996) The NCEP/NCAR 40-year reanalysis project. Bulletin of the American Meteorological Society 77:437-471.
Meehl et al. (1998) A modulation of the mechanism of the semiannual oscillation in the Southern Hemisphere. Tellus 50A(4): 442-450. doi:10.1034/j.1600-0870.1998.t01-3-00005.x
Randel (1988) The seasonal evolution of planerary waves in the southern hemisphere stratosphere and troposphere. Quarterly Journal of the Royal Meteorological Society 114(484):1385-1409.
Scott and Haynes (2002) The seasonal cycle of planetary waves in the winter stratosphere. Journal of the Atmospheric Sciences 59(4):803-822.
Seppala et al. (2009) Geomagnetic activity and polar surface air temperature variability. Journal of Geophysical Research-Space Physics 114: A10312. doi:10.1029/2008ja014029
Shiotani et al. (1993) Interannual variability of the stratospheric circulation in the southern hemisphere. Quarterly Journal of the Royal Meteorological Society 119(511):531-546.
Simpson et al. (2009) The Role of Eddies in Driving the Tropospheric Response to Stratospheric Heating Perturbations. Journal of the Atmospheric Sciences 66(5): 1347-1365. doi:10.1175/2008jas2758.1
Taschetto et al. (2007) Interannual variability associated with Semiannual Oscillation in southern high latitudes. Journal of Geophysical Research-Atmospheres 112(D2): D02106. doi:10.1029/2006jd007648