Reply
or
Interannual Southern Hemispheric Atmospheric Variability in the NCEP reanalysis between 1980 and 2002

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Climate Variability in the Southern Hemisphere is receiving increasing attention due to both the large greenhouse gas forced response that many climate model exhibit in polar regions (IPCC, 2002), and observed recent trends in the Southern Annular Mode (SAM) index (Thompson and Solomon, 2002; Thompson et. al, 2001). Hall and Visbeck (2002) described regional impacts of the SAM in a coarse resolution coupled climate model. The overwhelming dominance of this mode in the model's oceanic, sea ice and atmospheric interannual to decadal variability led us to the hypothesis that most of the interannual climate variability of the real world would also be associated with the SAM. This statement was contested in a recent commentary by a White (this issue) who claims that the Antarctic Circumpolar Wave

(ACW) is the dominant mode of interannual climate variability in the southern hemisphere. He presented supporting evidence from an analysis of the sea level pressure anomaly data obtained from the NCEP-NCAR atmospheric reanalysis.

Modes of southern hemisphere atmospheric variability are often identified in terms of the first few empirical orthogonal functions (EOFs) of pressure or geopotential height data (Kidson, 1988; 1999; Mo, 2000; Renwick, 2002). Most studies have used 500-hPa height anomalies, with fewer studies using pressure levels closer to the surface (850 hPa). However, the choice of level makes little difference due to the equivalent barotropic nature of month to month atmospheric variability (e.g. Thompson and Wallace (2000)). Mo (2000) computed the first three EOF patterns of 500 hPa height data and discussed the principal component time series for the whole lengths of the NCEP-NCAR reanalysis period (1949-1998). White (this issue), however, restricted his analysis to the period between 1982 and 2001, perhaps becuase he doubts the accuracy of the first 20 years of NCEP data. To facilitate direct comparison to White's results, we computed EOFs of the area-weighted monthly height anomalies of the 850 hPa pressure surface for nearly the same time period (1980-2002). However, we employ a standard rather than complex EOF analysis technique. Complex EOF analysis is often used to identify propagating anomalies (arising, for example, from coupled ocean-atmosphere interactions). It typically combines two standard EOF modes into one complex mode. There is therefore a direct correspondence between our standard EOF patterns and White's complex EOF patterns, as we discuss below.

Figure (1 a-c) shows the first three standard EOF patterns normalized to unit spatial variance. In agreement with most previous studies we find that the southern annular mode

(SAM) is represented by the first EOF and accounts for $\sim$20% of the total variance followed by two modes which each account for $\sim$ 10% of the variance. The second and third modes both show maximum amplitude in the Pacific and have often been associated with a propagating wave train within the Pacific - South American Sector. They have been referred to as the PSA teleconnection pattern (Ghil and Mo, 1991; Karoly 1989; Kiladis and Mo 1998; Kidson 1999; Yuan and Martinson, 2000). We refer to them as PSA-1 and PSA-2.

All of the power of White's first complex EOF is contained in the 180^o phase, which closely resembles our SAM pattern. Our SAM principal component time series (Figure 1d) is also very similar both to White's and that of Gong and Wang (1999). We use the standard SAM definition, where a positive index indicates a stronger than normal pressure gradient between the subpolar low and subtropical high regions (Thompson and Wallace, 2000). However, White has chosen a phase reference which resulted in a negative polarity compared to this definition, so that his SAM time series appears anti-correlated to ours.

Our PSA-1 and PSA-2 patterns correspond to White's second complex EOF at 180^o and 270^o phase respectively. Both modes show a weak relationship with ENSO (fig 1, e-f). The monthly (annual June-May season) zero lag correlation between the PSA-1 index and sea surface temperature anomalies in the Nino3 region is 0.2 (0.5), and slightly higher for the PSA-2 index with 0.3 (0.6). White refers to the combined, possibly propagating, PSA pattern as the Antarctic Circumpolar Wave (ACW). Visual inspection suggests that his ACW time series is close to our PSA-1 (EOF 2) principal component with opposite polarity. However, one can not be sure since he used a phase demodulation technique to obtain a real time series from the complex principal component time sequence that was not fully explained.

The power spectra of the three time series (Figure 2) was computed based on four 5.3 year long overlapping segments and shows spectral shapes that are consistent with an autoregressive red noise process. The dotted lines are the maximum and minimum values from a large number of randomly generated time series of the same length, energy and lag one persistence as the SAM time series. In contrast to White's results our spectral analysis shows that the SAM dominates the PSA variance for almost all frequencies. In particular we find no significant reduction in SAM energy for low frequencies. The difference between the SAM and PSA spectra is only barely significant for each spectral band, which should be of no surprise given the short time series at hand. However, since the SAM energy is consistently larger by a factor two than both of the PSA modes it is very unlikely that the overall dominance of the SAM will change once longer reliable time series are available. This result calls into question most of the summary statements made by White that might have been based on a peculiarity in his spectral estimate.

Finally, we compute the monthly variance associated with the SAM (see also Gong and Wang, 1999) and that of the combined PSA-1 and PSA-2 modes (Figure 3 a, b). Both modes contribute significantly to the variability of the 850 hPa pressure surface in different parts of the southern hemisphere. SAM seems to dominate the pressure changes in the vicinity of the Antarctic continent and thus is largely influencing the strength of the circumpolar winds as suggested in Hall and Visbeck (2002). The combined PSA modes, however, contribute mostly to pressure changes in the Pacific sector between 50^o and 65^oS and thus can influence the departures from the zonal atmospheric circulation. For example the PSA-2 mode has been associated with an ENSO forced dipolar surface air temperature and sea ice response between the Atlantic and Pacific sectors (Yuan and Martinson, 2000).

On the basis of our diagnostic of the NCEP-NCAR reanalysis data we maintain that the SAM is the dominant mode of atmospheric pressure variability on ALL time scales at least out to 5 years. Neither White nor we have presented any new evidence for the respective impacts that the SAM or PSA might have on observed interannual variability of the ocean circulation or properties. Thus we see no reason to depart from our working hypothesis as presented in Hall and Visbeck (2002) that changes in the circumpolar zonal winds associated with the SAM will dominate the interannual ocean variability.

Figure Captions

Figure 1: The first three EOF modes of monthly area-weighted 850 hPa pressure surface height anomalies (a-c). The data were reduced by sampling every 3rd point in the zonal direction (7.5 degrees) between 82^oS and 30^oS and then normalized by cosine of latitude prior to the decomposition in order to ensure a more equal area representation. The cosine latitude factor was multiplied back to the pattern prior to display. The principal component of the three EOFs (SAM, PSA-1 and PSA-2, d-f) are given in geopotential meter. The principal component time series PSA-1 and PSA-2 (e and f) are shown together with scaled Nino3 SST anomalies (yellow) for reference to ENSO.

Figure 2: Spectral estimates based on four 5.3 year long segments of the SAM, PSA-1 and PSA-2 principal components. The dotted lines are the envelope of spectral estimates based on a large number of random times series with the same energy and length as the SAM time series and a lag one autocorrelation of 0.25. The lag one autocorrelation of the SAM

and PSA time series varied between 0.15 and 0.3. Thus the dotted line are also a reasonable estimate for the uncertainty in the PSA spectra but would have to be vertically shifted to match the mean energy level of the PSA spectra.

Figure 3: Fraction of local monthly 850 hPa height variance associated with the SAM (a) and the combined PSA-1 and PSA-2 modes (b) between 1980 and 2002.

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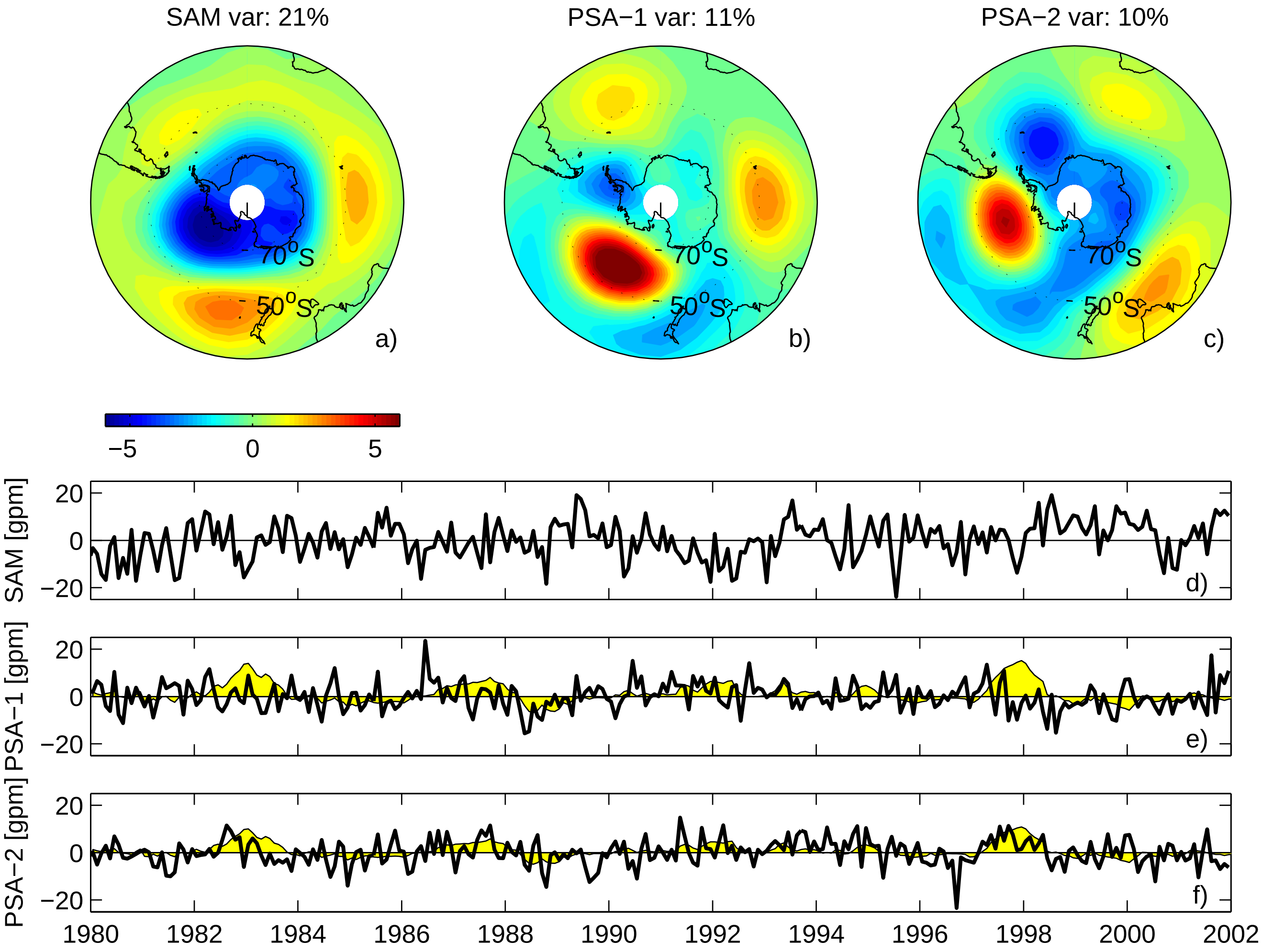
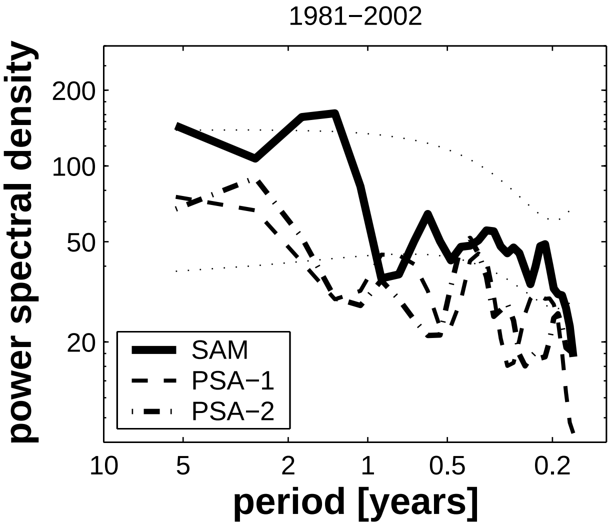
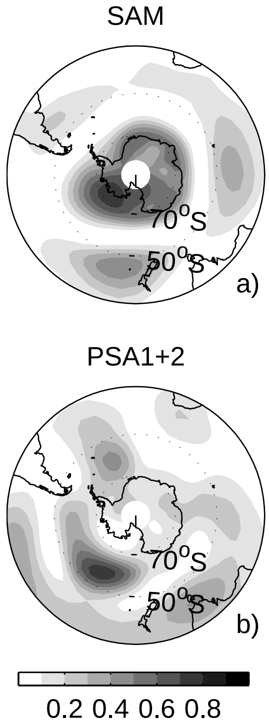

SAM var: 21%
PSA−1 var: 11%
PSA−2 var: 10%
70°S
50°S
a)
b)
c)
−5
0
5
SAM [gpm]
PSA−1 [gpm]
PSA−2 [gpm]
20
0
−20
d)
e)
f)
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002


1981−2002
power spectral density
200
100
50
20
10
5
2
1
0.5
0.2
period [years]
SAM
PSA−1
PSA−2


SAM
70°S
50°S
a)
PSA1+2
70°S
50°S
b)
0.2 0.4 0.6 0.8