Response to Reviewers Comments (tc-2015-105)

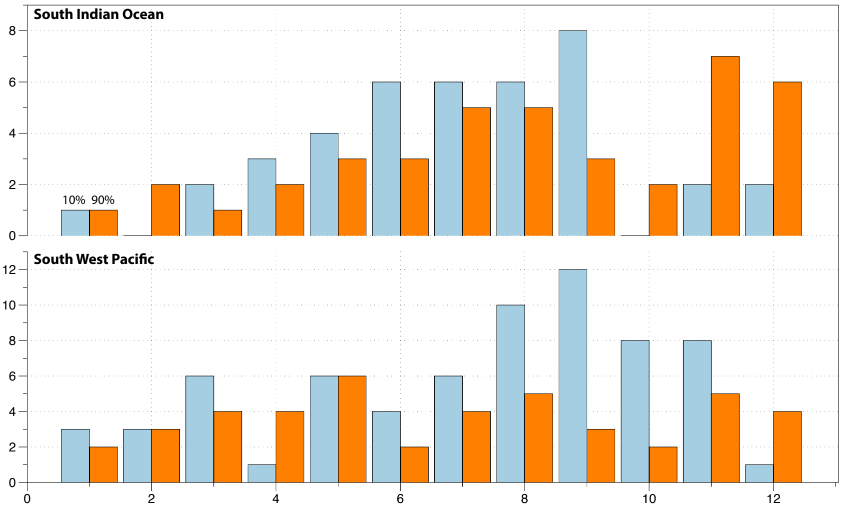
Reviewer 1: R. Fogt.

1. I think the paper could be strengthened significantly by adding a few lines and refer- ences to the joint role of ENSO and SAM on Antarctic climate, as outlined by L'Heuruex and Thompson (2006); Stammerjohn et al. (2008); Ding et al. (2012); and some of my work (Fogt and Bromwich 2006; Fogt et al. 2011). From your GPH composites in Figs. 7E and J, there is both a SAM structure as well as a PSA structure in the Pacific (also seen in Figs. 6E and J). I think a discussion of both of these modes and their interaction is needed on the discussion of potential tropical / ENSO variability on lines 4-25 on page 7.

We agree. We have added further details on SAM and PSA to the Introduction to help the subsequent discussion. Crucially, SAM is known to exhibit spatial and temporal asymmetry with a wave three pattern in the middle latitudes (Fogt et al., 2012) which is particularly pronounced in the Pacific (Steig et al., 2009), and has been linked to the tropics (e.g. Fan, 2007; Ding et al., 2012). Another postulated mode of variability is the Pacific–South American (PSA) pattern, a wave train of anomalies extending from New Zealand, off the coast of Marie Byrd Land (West Antarctica), and into the Weddell Sea/south Atlantic Ocean (Mo and Higgins, 1998) as a consequence of tropical forcing (Karoly, 1989). The relationship between low-latitude change and the mid to high-latitudes of the Southern Hemisphere remains contentious, however, with different observed seasonal teleconnections, such as central Pacific temperature changes in the austral winter (Ding et al., 2012), a linear relationship between ENSO and SAM in the austral summer (L'Heuruex and Thompson, 2006) and phasing of the different modes deciding the magnitude of the response (Stammerjohn et al., 2008). Importantly, the most positive phase of the SAM manifests itself at the surface most strongly during summer and autumn months (Thompson et al., 2011), while the PSA signal is primarily summer focused (Karoly, 1989). Here we observe wave three-like anomaly pressure patterns across the Southern Hemisphere all year round. With the further analysis suggested by the reviewer, we find the tropical Pacific plays a modulating role on the pressure anomalies (particularly during the spring and summer months) but is not the driver of all variability (see below).

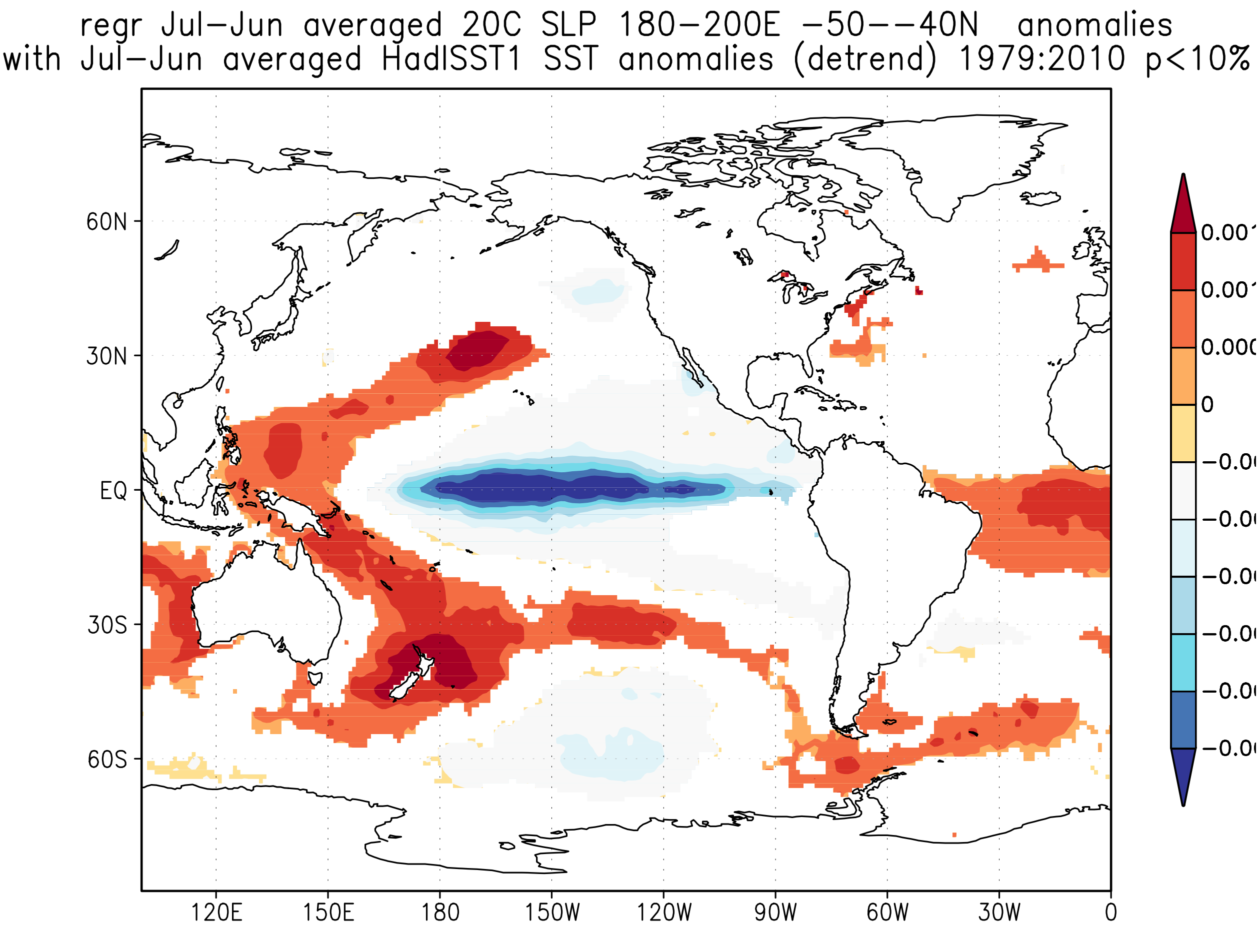
2. The discussion on increased ENSO variance and therefore a lowering of pressures in the SWP is misleading. Increased ENSO variance doesn't necessarily mean more El Ninos, and over the last 30 years, the SOI and Pacific SSTs have actually been trending towards a more La Nina-like state (consistent with the shift in the PDO). There are quite a few papers on this, but some of my work at least addresses this shift in austral spring (Clem and Fogt 2015, JGR). Notably, these trends towards increased La Nina events probably aren't significant anymore given the strong El Nino currently developing, but the way this is written makes it seem like the circulation in general is trending towards more El Ninos, and this isn't the case currently, at least not consistently.

The reviewer is correct. While ENSO variance is skewed towards El Niño events (e.g. An, 2004, *Geophysical Research Letters*) the increase in variance is not reporting a shift to more El Niños *per se*. We had not seen the paper by Clem and Fogt (2015) when we submitted the manuscript but this would add significantly to the discussion of the interaction of the different modes. Furthermore, there are several recent papers that demonstrate a trend towards a cooler tropical east Pacific and stronger Walker Cell circulation (e.g. Karnauskas et al., J of Climate, 2009; L'Heureux et al., 2013, Nature Climate Change; England et al., 2014, Nature Climat Change). We have undertaken further analysis of the pressure changes using the latest update of the 20th Century Reanalysis (20CRc). For the satellite era (post-1979) we find the pressure anomalies (10th and 90th percentiles) in the South Indian Ocean (SIO) and South West Pacific (SWP) are observed throughout the year but with a tendency towards September-February (see below).

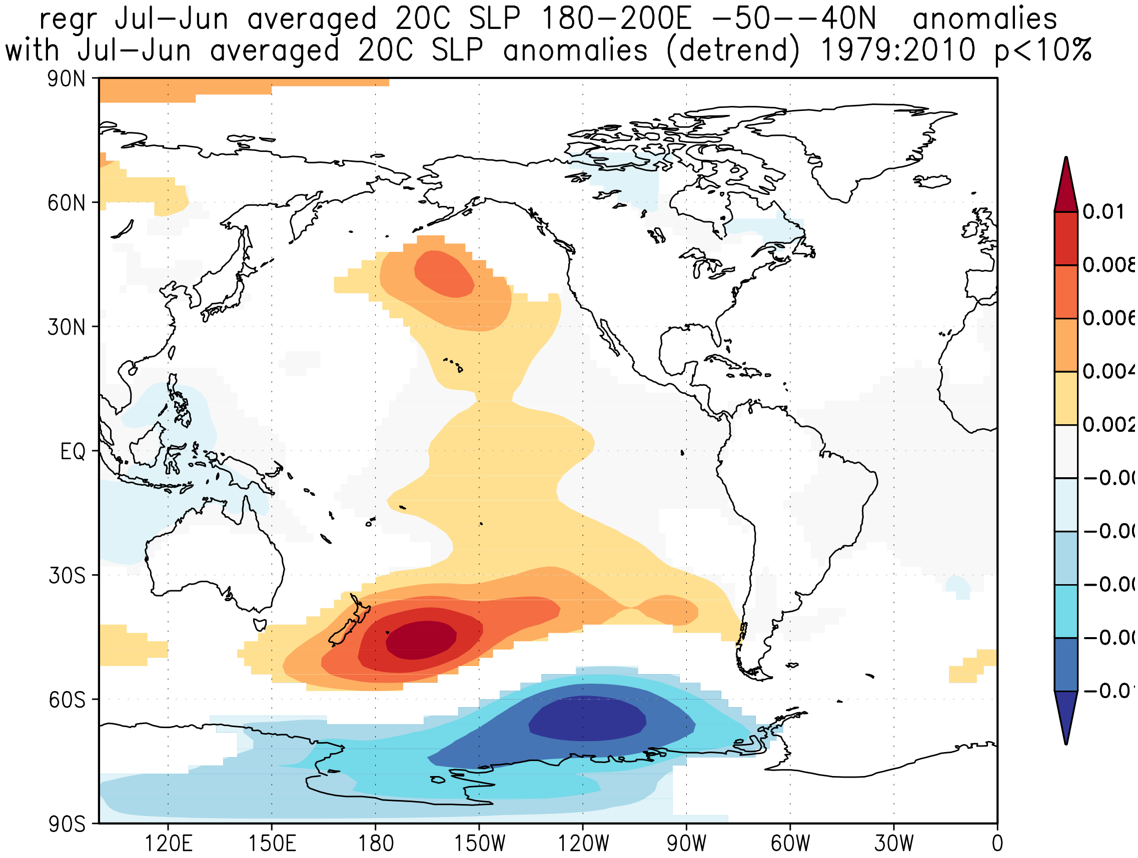


Thus, our data suggests whilst there is a tropical Pacific role in the east tropical Pacific (particularly with positive pressure anomalies - akin to a more La Niña-like state), this seems to have only a modulating effect.

There is an inverse relationship between SWP pressure and tropical SSTs (detrended and deseasonalised), with the upper panel below showing the regression across the Pacific and Atlantic SSTs (July-June): lower pressures in the SWP equate to warmer conditions in the central and east Pacific.



We also observe an opposing relationship between the southwest Pacific pressures and the West Antarctic (Marie Byrd Land) but see no response in Atlantic MSLP (low or mid-latitudes) (lower panel) - suggesting we are not observing a PSA pattern.



The long-term trend (post 1970) is towards lower pressure in the SWP and warmer temperatures over the Antarctic but importantly both appear to have levelled off in recent years (Figure 3 in the Discussion paper). Reflecting on the reviewers comments and our new analysis we propose that the shift to a stronger Walker Cell circulation (and stronger trade winds) may be offsetting the downward trend in the SWP and warming aloft Antarctica.

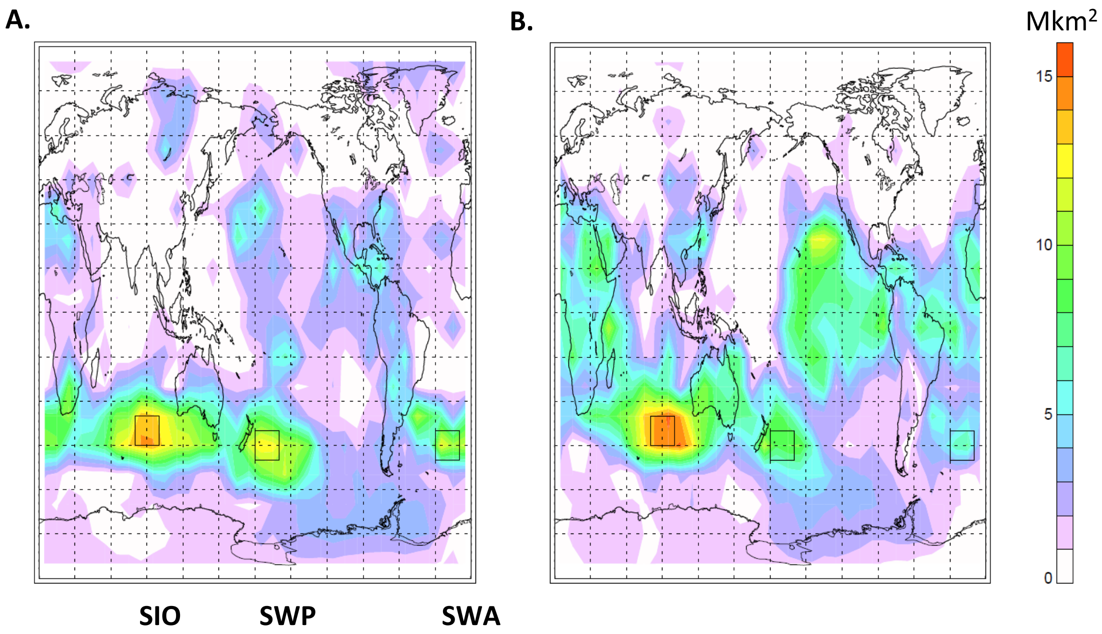
Minor comments:
1. Page 1, line 19: suggest changing 'has' to 'have' since I believe the subject is 'latitudes'.
Done.

2. Lines 27-28: I think this sentence about tropical and midlatitude pressure anomalies playing a larger role than hitherto believed is a bit strong, and should be worded more cautiously, more like 'this work adds to a growing body of literature confirming the important roles of tropical and midlatitude atmospheric circulation variability on Antarctic temperatures' or equivalent.
An excellent suggestion. We have changed the text accordingly.

3. Page 2, Line 28: The Ding et al. (2011) reference here talks only about the role of tropical Pacific SSTs, so using the words 'global SST' is not accurate.
Absolutely. The text has been changed.

4. Figure 4 (and supplementary figures): I wonder why the region for the SWP was chosen as it was, as there are stronger / larger areas a bit farther north and west towards NZ? I hardly can

imagine this changing the results much, but it just seems odd that the region chosen was not in the center of the darkest shading in Fig. 4.
We apologise for the mistake. The reviewer is absolutely correct. We have redone the figure and corrected all key figures/analyses (including those above). The revised figure showing the regression between deseasonalised and detrended SWP with MSLP and SST is given below.



5. Page 6, Line 11: Change ’Figure 7’ to ’Figure 8’
Done.

6. Page 6, Lines 27-28: suggest deleting the ’did not lead but’ on line 27 since this is repeated on line 28.
Done.

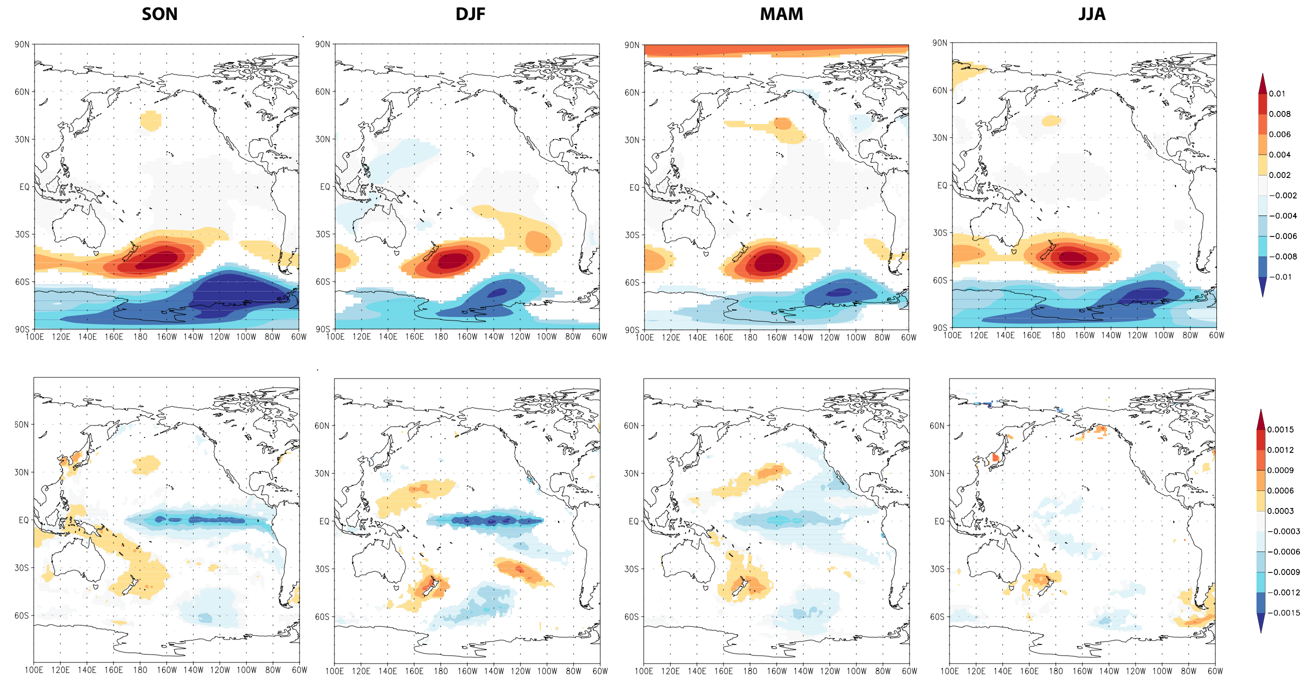
7. Page 7, lines 7-9: "Conversely, with increasing ENSO variance, the southwest Pacific pressure anomaly apparently weakens (Figure 4)." This is not at all clear from Fig. 4, since there’s no linkage on that figure from ENSO variance. You can infer this however from comparing the red and blue curves on Fig. 3, and I would agree that after 1940 as ENSO variance increases, the SWP pressure anomaly decreases. This however is not clear in earlier times, perhaps due to the uncertainty of the 20CR (but this may be constrained here somewhat due to records in New Zealand and Chatham Island starting before 1900). During 1870-1920 there is a clear increase in ENSO variance, but the SWP anomaly doesn’t decrease at this time. I think some comment on this needs to be made, and in general the statement on these lines needs to be better justified.

Thanks to the reviewers comments we now consider the tropical Pacific to play a modulating role (possibly though interaction with other modes of variability as raised by the reviewer) and as a result we would not anticipate a direct linear response. We have modified the text appropriately. Furthermore, we have investigated the New Zealand National Climate Database (CliFlo) for the Chatham Islands but unfortunately surface pressure data is only available from 1991, too short to further explore long-term trends. However, is is important to note that the 20th Century Reanalysis product is based on the observational data so any comparisons would not be truly independent.

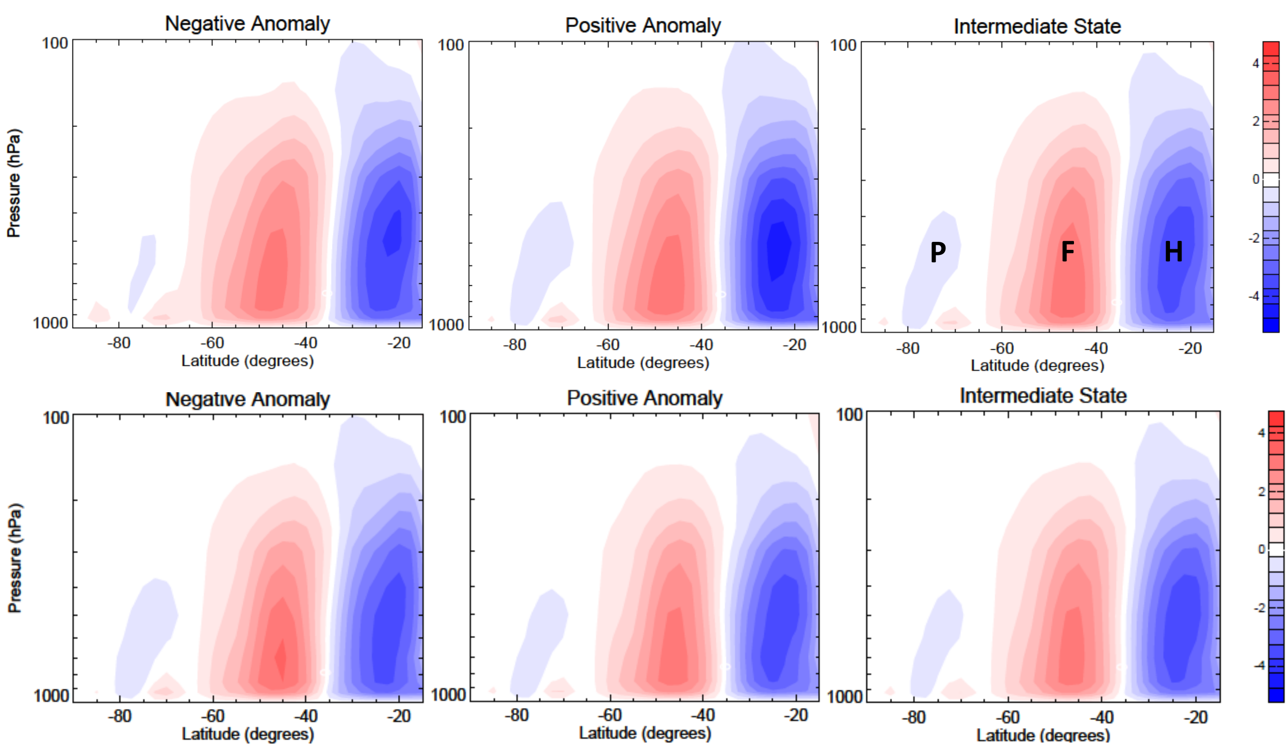
That said, other available datasets in New Zealand would have contributed to the reanalysis trends reported here.

8. Figure 10 needs to be made much bigger and clearer.

We agree completely. We have revised the figure to focus on the Pacific-basin only and pasted below a revised copy of the figure (based on the new SWP region defined above). Upper panels show seasonal relationship with MSLP and lower panels the relationship (with no time lag) with SSTs. Crucially, the opposing relationship between the SWP and MSLP over West Antarctica appears to be year round, suggesting a robust relationship, regardless of changes in the tropical Pacific.



We have also reanalysed the meridional mean mass streamfunction with the new SWP region (bottom panels; upper panel: SIO) and confirm a stronger Ferrel Cell, consistent with increasing poleward heat flux, providing a mechanism for warming over Antarctica.



Reviewer 2: Anonymous

1. I think the main omission by the authors is some calculations to clarify the capability of delta D in representing the local temperature and circulation variabilities. Most people reading this article will probably be more familiar with the SH climate, and are less likely to be experts in the ice core products (myself included) and so it is important that readers are pointed to some source of information about what delta D can tell us. I would be particularly worried about the seasonality of annual resolved delta D in representing the hemispheric circulation change in the SH high latitudes. These worries may be unfounded, but without a source of information about the limitation, I'm left wondering how good these isotope data are representing local climate variability.

This is a fair point. We have added further details regarding the application of stable isotopes in the ice core studies and how they relate to climate and broader synoptic conditions, including Jones et al., 2009, *The Holocene*. The important point here is the isotopic values obtained from our new ice core provide a measure of temperature at the inversion layer which can be related to an Antarctic-wide warming trend observed in the radiosonde observations.

2. There is a strong linear trend in the SLP or Z700 in the SH since 1979 in Era-I and NOAA-20th reanalysis data. It is worth testing whether the results in several figures are sensitive to this long term linear trend in the data.

There is a a major trend in the temperature and SLP data series from the 1970s. To satisfy ourselves that the correlation are robust we deseasonalised and detrended the correlations and regressions above.

3. A caveat ought to be added in the conclusions section that since Fig5 only looks at a simple coherence analysis of two time series there is still a question mark over the statistical significance and physical understanding of the results, and that further studies as new data and modeling become available should help to resolve this issue.

We completely agree and have added the appropriate text.