**Anonymous Referee #2**

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Over the last decade or so many studies have proposed mechanisms by which processes in other parts of the globe can influence ENSO variability. The hypothesis discussed here is novel and interesting: can fast oceanographic processes (e.g. barotropic waves) driven by (stochastic) atmospheric variability influence ENSO? Furthermore can the Southern Hemisphere SLP variability result in decadal variability in ENSO.

To address the first question the author mainly references previous work he has done (Stepanov 2009a&b, Oceanology) or studies by Ivchenko et al (2004, 2006). Little additional hard evidence is presented here for the number of complex processes needed to accomplish this connection other than correlations of SLP measures and ENSO over a fairly short record ~20 years, which is subsequently divided into two ten year periods.

1) While the description of the processes connecting the Southern Hemisphere to the tropics is lengthy but with many ambiguities:

a) The author uses large-scale measures in difference in SLP between latitude bands but then appears to argue for the importance of SLP variability right at the Drake passage. Changes in the flow of the ACC at the Drake passage is supposedly a key measure of the pressure forcing but itself appears to have little relationship to the ENSO variability (see Fig. 4).

**The paper does not deal with changes in the flow of the ACC at the Drake Passage (that is not key factor for ENSO). According to Stepanov and Hughes 2006, there is a mass exchange between the Southern Ocean and Pacific basins both at short and long periods that is due to the balance of wind stress by form stress (a pressure difference across topographic obstacles) in Drake Passage. Though there is a weak but statistically significant negative correlation between SAM-index (that characterizes the strength of the wind over the ACC and strength of the ACC current itself) and the basin total mass variability associated with the meridional flux near 40$^o$S, which can be seen from the above-mentioned figure. The "large-scale measures in difference in SLP between latitude bands" is chosen to characterise air jet instability over the region near Drake Passage.**

b) Are the critical pressure anomalies due to the wind driven flow against the west coast of South America. If so how do they reach the equator?

The author just indicates that it is similar to the mechanism described by Ivchenko and due to barotropic Rossby waves. What are the path(s) for the waves and wave energy to reach the equator?

Do the Rossby waves mainly propagate westward in the open ocean and then travel equatorward as coastally trapped Kelvin waves along the Australian coast (as suggested by studies by Ivchenko et al. of salinity forced anomalies near Antarctica)?

**The text was modified to extend the description (the paths have been shown on Fig.1 of Blaker et al 2006): Blaker et al 2006 show that the energy from the anomaly in the Weddell Sea arrives at the western Pacific boundary via two ocean wave mechanisms. Barotropic Rossby waves transmit the signal directly across the Pacific Ocean (waveguide pattern of which was confirmed later by observations by Close and Naveira Garabato (2012)). Barotropic Kelvin waves follow the Antarctic coastline and form waves which propagate along the ridge systems that extend away from the Southern Ocean. These waves propagate along topographic ridges which provide a connection between Antarctica and the land masses in the southern hemisphere. The paper analyses the impact of the air jet instability over the region near Drake Passage on ENSO, which is characterised by a difference in SLP between two latitude bands rather by pressure anomalies due to the wind driven flow against the west coast of South America.**

How does the barotropic signal influence the baroclinic structure on the equator? Based on Fig. 5 (presented in a previous study) are the equatorial anomalies at depth (50-200 m), which appear to be less than 0.3°C, of sufficient amplitude to influence ENSO? Temperature anomalies at depth associated with ENSO are often an order of magnitude larger than this.

**Since after the appearance of temperature anomalies in the tropics the subsequent interaction between the atmosphere and ocean in the model tropics was excluded (due to fixing temperature and salinity fields at the ocean surface in these numerical experiments), the development of surface and subsurface (within Ekman layer) anomalies was limited, nevertheless the zonal model temperature difference (~1°C) in the tropical Pacific (which characterizes the thermocline slope here) is comparable with observation. The proper changes in the text have been made.**

c) Given that the connection between the SH SLP and ENSO is very novel (and far from most conventional thinking), can it be better supported? For example can the location of the pressure anomalies be tied to the wind forcing (wind stress curl and or wind-drive flow impinging on topography) in both location and time and then the resulting ocean anomalies tracked toward the equator using sea surface height data from satellites or output from ocean reanalyses? The following studies have used SSH from satellites to investigate barotropic Rossby waves.

Andres, M., Y.-O. Kwon, and J. Yang (2011), Observations of the Kuroshio's barotropic and baroclinic responses to basin-wide wind forcing, J. Geophys. Res., 116, C04011, doi:10.1029/2010JC006863.

Farrar, J. Thomas, 2011: Barotropic Rossby Waves Radiating from Tropical Instability Waves in the Pacific Ocean. J. Phys. Oceanogr., 41, 1160–1181.

Perhaps the satellite topography data is of sufficient temporal resolution (10 days) to examine some aspects of the propagating signal.

**Author does completely agree with this comment, but this issue is beyond of the paper scope. The tracking of SSH anomalies from observations tied to the wind forcing (or some others) in the Southern Ocean can be special issue for further study (e.g. see Close and Naveira Garabato (2012)). In this paper author wished only to underline the importance of variability of the balance of wind stress by form stress impacting a mass exchange between the Southern Ocean and Pacific basins that can lead to the change of thermocline slope in the tropics, which was demonstrated by previous studies (Stepanov and Hughes (2006), Stepanov 2009a&b, Ivchenko et al (2004, 2006) and Blaker et al 2006). The proper changes in the text have been made.**

2) Most of the new results presented here assume that the SH wind forcing is the main mechanism for generating decadal differences in ENSO and then uses differences in correlations or in the variability of the Southern Hemisphere atmosphere to support his idea. However, there are several major issues with this approach:

a) Climate time series include multiple signals and randomly generated variability. Thus two time series will exhibit periods of stronger and weaker correlations by chance, especially when examining interannual variability over short periods. So differences in the correlations between a measure of ENSO and SH SLP variability between two ten year periods is to be expected and no way confirm the former is differentially driving the latter. Once can perform significance tests to determine if the differences in correlations between periods are significant, e.g. see

Gershunov, A., N. Schneider, and T. Barnett, 2001: Low frequency modulation of ENSO-Indian Monsoon rainfall relationship: Signal or noise? J. Climate, 14, 2486–2492.

However, the difference values reported here between two ten-year periods are not likely to be significant.

**Thank you very much for this comment. Author does completely agree with this comment and the text was modified:**

**The correlation coefficient between NINO3.4 index and $\Delta p$ time series for 1989-2011 period is about 0.6 ($\Delta p$ leads 4 months) and slightly varies for 1989-1999 (0.65) and 2000-2011 (~0.5) periods (all the correlations presented by the paper are statistically significant with a probability of 95%, which was determined through the effective number of degrees of freedom following Bretherton et al. (1999)).**

**Similar correlation analysis with NINO3.4 and 5-month running average SOI index shows that the negative correlation coefficient between these time series with lag of 4 months (SOI index leads the NINO3.4) is decreased from 0.5 (for 1989-1999 period) to 0.3 (for 2000-2011 period, note that for 2000-2008 period the correlation is lower: -0.2) yielding the value of the correlation coefficient of about -0.4 for whole 1989-2011 period. It is worth noting that SOI and NINO3.4 indexes vary in phase rather than SOI index leading the NINO3.4: the maximal correlation between SOI and NINO3.4 indexes is obtained for zero lag: it is equaled to about -0.7 and -0.6 for 1989-1999 and 2000-2011 periods respectively, while the correlation coefficients between these time series when either SOI leads or lags NINO are less (~-0.4).**

**Though the differences between the above correlation values for two ten-year periods are not statistically significant, but that suggests that the variability over the Southern Ocean recently contributed more to the processes of ENSO development than process in the tropics.**

b) the paper switches between measures of ENSO and of SH SLP variability. Sometimes Nino 4 is used some times Nino 3.4. Sometimes the southern Annular mode is used, sometimes a difference in SLP between two points. Switching of indices, (to get more favorable results) takes a way credibility of the findings.

**Using the Southern Annular Mode and “a difference in SLP between two points” for characteristic of wind variability over the ACC and air jet instability over the region, respectively, is justified. In introduction it was supposed that NINO4 describes a primary source of some factor forcing the maximal development of non-canonical ENSO events, which is due to ocean impact (NINO4 is the region where changes of sea-**

**surface temperature lead to total values around 27.5°C, which is thought to be an important threshold in producing rainfall in the tropics during ENSO). Therefore model ocean characteristics obtained by Stepanov (2009a) have been compared with NINO4. However analysing SLP field, variability of which reflects joint effect of the interaction between the ocean and atmosphere, assumes using NINO index, incorporating similar impact. Therefore further we will compare new characteristics found with NINO3.4: it is the region that has large ENSO variability, and that is close to NINO4 region where changes in local sea-surface temperature are important for shifting the large region of rainfall typically located in the far western Pacific (though the comparison results are similar for NINO4 too). The proper changes in the text have been made.**

c) It is unclear why the correlation between the Southern Oscillation (tropical SLP) and NINO SST is an indication of changing influence of remote locations, including the SH on ENSO. The author assumed that even though there wasn't a large difference in the SH SLP variability between the 1990s and the 2000s but based on the variability in to the SO and NINO indices between these periods indicates that processes near Antarctica still impacted the tropical Pacific Ocean with the same efficacy. There appears to be a huge leap in logic here and an assumption that the only factor influencing ENSO variability is the mechanism proposed here.

**The text has been modified (see also comments below and answer for comment 2a).**

d) The author finds that maximum correlation between the SLP variability during July-September (SH winter/spring) leads the ENSO variability (which peaks in December) by 4 months. While this could provide evidence for SH variability driving ENSO other factors could come into play. Key among these is the evolution of ENSO and the atmospheric teleconnections associated with tropical SST anomalies. While ENSO peaks in boreal winter (Nov-Jan) SST anomalies are already well established in the tropical Pacific by boreal summer (July). Multiple studies have shown that the Southern Hemisphere atmosphere responds to these tropical SST anomalies both in Austral winter (JJA) and the following austral summer (DJF). For example see:

Karoly, David J., 1989: Southern Hemisphere Circulation Features Associated with El Niño-Southern Oscillation Events. J. Climate, 2, 1239–1252.

Qinghua Ding, Eric J. Steig, David S. Battisti, John M. Wallace. (2012) Influence of the Tropics on the Southern Annular Mode. Journal of Climate 25:18, 6330-6348

Ryan L. Fogt, David H. Bromwich. (2006) Decadal Variability of the ENSO Teleconnection to the High-Latitude South Pacific Governed by Coupling with the Southern Annular Mode. Journal of Climate 19:6, 979-997

Michelle L. L’Heureux, David W. J. Thompson. (2006) Observed Relationships between the El Niño–Southern Oscillation and the Extratropical Zonal-Mean Circulation. Journal of Climate 19:2, 276-287

In addition ENSO influences both SAM and the dipole pattern in SST near the tip of South America, the two leading patterns of variability in the Southern Hemisphere and the ones focused on here. Thus the correlation between SH SLP and ENSO may actually be dominated by the rapid atmospheric teleconnections that occur in response to topical Pacific SSTs in austral winter (JJA, and the subsequent increase in the ENSO signal through austral spring and into winter <DJF>due to process within the tropical Pacific) rather than by wind-driven ocean process in the SH causing the lag between SH SLP and tropical SSTs.

**It is absolutely true for conventional ENSO events (though SST anomalies can appear in the tropical Pacific before July, but not all anomalies lead to the development of ENSO events). However, the paper attempts to find some plausible explanation for the change in ENSO characteristics in the 2000s when frequent occurrences of the SST anomalies centered in the central equatorial Pacific is observed. Since the robust predictability of conventional tropical predictors for ENSO has changed in the 2000s, therefore the paper attempts to show that the impact of the Southern Ocean on the tropics (where variability of SLP almost did not change) can prevail during warm periods. However, if a strong cold ENSO event occurs during warm periods (e.g., 2007-2008), so it leads to charged conditions of the recharge/discharge ENSO oscillator and, as a result, the atmospheric variability in the tropical Pacific is increased again that increases the impact of the tropical interactions on ENSO. This fact explains why the correlation between the SOI and NINO are less during warm periods than before 2000s, but the difference is below statistically significant level. It is shown that a principal component characterising strength of meridional shear of zonal wind over the Southern ocean can be good predictor for ENSO during warm periods about 8 months early (in ~April), i.e. this event is coincident with the time of ENSO onset and likely it is due to changes in the**

**global meridional atmospheric circulation (see introduction). The proper changes in the text have been made.**

Other comments/suggestions:

1) Figures:

a) several of the figures, including figures 1, 2a&b, 3, are well known and don't really contribute to the main points of the paper.

**Two figures were removed. Presentations to different audiences demonstrated that results presented on Fig. 2 are surprising for them; therefore this figure was not removed.**

b) Figures 4 and 5 have appeared in the literature before (the former has appeared twice) although in a difficult to obtain journal.

**Similar figures really have been published before, but these new figures are not identical to previous ones.**

c) some of the figures are very small and difficult to see.

**It looks this problem is due to format provided by Ocean Science since all figures on A4 format are clear to read and they look very good.**

2) Some generalizations are made about ENSO that are over statements or not completely true. For example, on page 954 lines 15-30. It is argued that Nino 4 responds to the primary forcing while the Nino 3 variability lags and is amplified by its proximity to land. In terms of SST, ENSO events can evolve where NINO4 leads NINO3 but also the reverse occurs events occur where NINO3 SSTs lead Nino 4 (e.g. see the classic paper by Rasmusson and Carpenter 1982, Mon. Wea Rev.). The author states that NINO 3 SSTs are amplified by land sea interactions, but Nino 3 is still thousands of kilometers from South America and its probably more due to ocean process then the proximity to land that cause larger amplitude SST anomalies in NINO3.

**The text was modified:**

**Oscillator model paradigm for ENSO (e.g., Suarez and Schopf 1988; Battisti and Hirst 1989; Weisberg and Wang 1997; Jin (1997)) is now widely accepted. This paradigm assumes eastward propagating Kelvin waves as the main factors that provide the negative feedback that brings about the phase change. However it means that sometimes eastward propagating Kelvin wave can also trigger the development of ENSO rather oppose the growth of its developing. The comparison of the time series of the NINO3 (SST averaged in area of 5°N-5°S; 150°W-90°W) and NINO4 (SST averaged**

**in area of 5°N-5°S; 160°E-150°W) indexes (www.cpc.ncep.noaa. gov/data/indices), as a measure of the departure from normal sea surface temperature in the east and central Pacific Ocean respectively (not shown), demonstrates that both indexes are varied in phase, but the amplitudes of the variability are different: the amplitude of NINO3 index can be up to 2 times larger (before 2000) than NINO4. It is reasonable to think that NINO4 describes a primary source of some factor forcing the onset of ENSO events, while NINO3 is a combination effect of the primary source and changes due to the beginning of ENSO onset in the central Pacific, i.e. the subsequent interaction between the atmosphere and ocean in the tropics (a cross-correlation analysis presented by Ashok et al. (2007) confirms that the variability of NINO4 index leads NINO3). It is likely that the subsequent changes in the Walker circulation cell can significantly amplify ENSO development in this region located close to land. Therefore when the development of conventional ENSO (characterized by NINO3) prevails, a westward migration of the eastern equatorial Pacific SST anomaly pattern from the South American coast into the central equatorial Pacific is observed. While in the central Pacific, NINO4 signal can be attributed only to the "ocean" impact.**