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Interactive comment on "Brief communication: Changing mid-twentieth century Antarctic sea ice variability linked to tropical forcing" *by* Chris S. M. Turney et al.

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Anonymous Referee #1.

General comments: The precise goal of this manuscript is not clear. In particular it is not clear what are the time scales of interest to the author. The title says that there is a link between tropical forcing and Antarctic sea ice variability. In the introduction and in the conclusion multi-decadal to centenial variability seem to be the interest because trends of sea ice extent over multiple decades are discussed. On the other hand most of the manuscript seem to be about inter-annual variability using seasonally averaged detrended ERA-interim surface pressure and HadSST Nino3.4 to show linear correlation between different regions. The physics of short and long time scales is not the same for example Ferreira et al. 2015 show that the same wind anomaly produces opposite effect on sea ice extent at short and long time scales. Therefore my recommendation is that the authors make clear what they are trying to show and align their demonstration accordingly. If the focus is the inter-annual variability of sea ice then the conclusions cannot be used to explain the multi-decadal trend observed during the satellite period. If the focus is on the multi-decadal trend of sea ice extend then a detrended Nino3.4 index doesn't seem to be a good index to use because the time scale of El-Nino is 2 to 7 years. Maybe the Interdecadal Pacific Oscillation would be a better index (see Meehl et al. 2015).

>We do agree the introduction requires some clarification given the range of timescales and the potential opposing mechanisms operating across the region. The complex nature of the processes is summarised by Ferreira et al who describe the surface expression of relatively warm deep water after some 20–25 years of enhanced westerly airflow, overriding the chilling effect of surface waters associated with enhanced northward Ekman drift. Importantly, the potential contribution of sub-surface melting described by Bintanja et al. suggests that sub-surface melting may be further contributing to sea ice expansion off the George V coast, delaying the surface expression of warmer waters postulated by Ferreira et al. Whilst we cannot definitively resolve these issues our study aims to provide a long-term perspective from the mid-nineteenth century assuming the short-term Ekman processes dominate. We have therefore reframed the Introduction to make this more explicit. Whilst we sympathise with the referee's comment regarding multidecadal variability, our recent work on climate changes in the southwest Pacific (Turney et al., 2017, Climate of the Past) suggests that interannual variability is the most significant periodicity over the past 140 years.

Specific comments: Whatever the time scale chosen by the authors for this work, the choice to correlate first Nino3.4 to SWP and then SWP to sea ice extent is not sufficient. If the hypothesis is that there is a relation between the tropical Pacific and sea ice then these two variables should be correlated directly.

>The reviewer is correct and we have now undertaken direct correlations. Our analyses have refined the timing and processes involved. From more detailed study we find the highest correlation between the region of marked sea ice expansion off the George V coast and tropical Pacific is centred on during the late spring-early summer during the periodin October-December (rather than September-November as we originally reported). The table below summarises the correlations for both Nino 3.4 and Nino 3 (using HadISST) using detrended and deseasonalised data, taking year-on-year differences (p values in parentheses; significant values p<0.1 are marked by *).

Nino 3 September-November 0.12 (0.47) October-December 0.31 (0.06)* November-January 0.31 (0.05)* December-February 0.18 (0.27)

Nino 3.4 September-November 0.14 (0.42) October-December 0.30 (0.07)* November-January 0.28 (0.09)* December-February 0.15 (0.39)

>Regardless of the parameter used, central tropical sea surface temperatures appear to have a direct relationship with sea ice off George V Land coast, through modulating the pressure anomaly in the southwest Pacific. As a result, the figures have been revised to incorporate the October-December period, although the overall pattern of responses is broadly the same as September-November used in the previous submission. For instance, the revised Figure 2 is attached (with modified caption below). Our analyses support an increasing body of literature that the central tropical Pacific modulates atmospheric circulation across large parts of the high latitudes and plays a direct role on sea ice off the George V coast across October-December (e.g. Wilson et al., 2014). Our work is supported by further analyses described below that suggests this teleconnection is indeed via Rossby wave penetration of the high latitudes.

>Figure 2: (a) Spatial correlation between deseasonalised and detrended HadISST Nino 3.4 region sea surface temperatures (SSTs) and mean sea level pressure (October-December) derived from ERA-Interim (Dee et al., 2011) (1979-2016). Note,

the schematic black arrowheads show the Rossby wave train that extends over the southwest Pacific (SWP; 50ËŽ-60ËŽS, 160-180ËŽE) into the Amundsen Sea (AS; 65ËŽ-55ËŽS, 95-135ËŽW). (b-d) Spatial correlations between SWP pressure anomaly, and zonal (b) and meridional (c) wind stress at 10 m, and sea ice concentration (National Snow and Ice Data Center; https://nsidc.org/data) (d). Hatched areas denote significant at 95% confidence level.

To investigate the relation between equatorial Pacific and sea ice I would strongly recommend to use a climate model without data assimilation in which the temperature is changed in the equatorial Pacific and the response is analysed. Using a climate model in which surface temperature is assimilated and showing that the behaviour is qualitatively similar to geopotential height from reanalysis and satellite observations of sea ice extent seems useless.

>We appreciate the referee's comments but this really does depend on what you are trying to test. We have now clarified the Introduction so that we describe the need to develop long-term records that extend beyond the satellite era (post-1979). Here we wished to explore whether a climate model forced by observations matches the changes in sea ice inferred from the recently reported climate reconstruction from the subantarctic southwest Pacific (Turney et al., 2017, Climate of the Past). We hope this sounds alright.

The abstract says the results of this manuscript provide new insight in Antarctic ocean circulation but this is not the case. There is no discussion about ocean circulation in the manuscript.

>We have clarified the text to make it clear we are referring to Ekman processes. We apologise for the confusion.

Details: Fig.2a: The unit of "yr-1" is not very readable, maybe % per decade would be clearer

>This is a fair point. Referee #2 also raised this issue but for all figures. We have increased the font size as requested.

Anonymous Referee #2 The paper presents the result on the connection between tropical atmospheric circulation mode and sea ice variability in Antarctica. This is a relevant topic in the framework of the understanding of present day and past climatic change, and deserves great interest in the scientific community. The paper is well organized and synthetically reports the obtained result, it deserve the publication on The Cryosphere journal with few technical revisions.

>We thank the reviewer for his or her highly supportive comments and especially the comment that the paper deserves to be published.

Specific comments At the end of the introduction some sentences regarding what the paper want to demonstrate are necessary.

>This point was also raised by Referee #1, and we have proceeded to add further details on the purpose of the study at the end of the Introduction as described above.

Figures legend are sometime too small, please increase the character size.

>This is a fair point. We have increased the character size for all figures as requested.

Referee T. O'Kane.

The role of stationary Rossby waves in connecting tropical variability to the South Pacific and the Pacific South American pattern has been loosely applied in many studies, often without sufficient regard for the seasonally dependent barriers to stationary Rossby wave propagation of the type identified by Ambrizzi et al. (1995) and more recently reexamined by Li et al. (2015). In particular, it is well known from ray tracing theory that, coincident with the establishment of the subtropical jet in during the austral spring through winter, Rossby wave propagation from the tropics to the midlatitudes in the South Pacific is largely blocked by the establishment of a reflecting surface poleward of the subtropical jet east of 60E and west of 120W (Ambrizzi et al. 1995; Ambrizzi and Hoskins 1997, Li et al. 2015). This surface occurs where the total wavenumber is imaginary due to a negative meridional gradient of vorticity (see Fig. 11 Li et al 2015). This barrier represents a major problem for studies that invoke the excitation of equivalent barotropic Rossby wave trains propagating from the tropics into the extratropics, initiated by diabatic heating anomalies in the tropical equatorial Pacific during the austral autumn, winter, and or spring, as an explanation for the establishment of the PSA pattern.

A recent study of Rossby wave sources and Southern Hemisphere mid-tropospheric variability by O'Kane et al (2016) find that local Rossby wave sources within the jet are far more important to the PSA development and variability than those due to tropical convection. They apply advanced nonstationary nonparametric methods for timeseries analysis capable of isolating causal relationships rather than simple correlations. Their work raises serious questions to the validity of WKB theory in an atmosphere that is inherently unstable. Consistent with dynamical mode theory (Frederiksen & Frederiksen 1993), O'Kane et al 2017 apply more standard methods to show that the PSA is a multiscale nonlinear dynamical mode with the major percentage of PSA variability occurs on time scales from synoptic to intraseasonal, is largely independent of persistent coherent tropical processes, and manifests via internal waveguide instabilities and dynamics. The small fraction of the total variability with a tropical signal arises entirely due to modulation of the SH midlatitude jets, via the zonal component of the thermal wind. The recent study by Irving and Simmonds (2016), while confirming that the PSA pattern does indeed have a strong influence on observed warming over the Antarctic Peninsula during the austral autumn, shows only a very weak relationship between PSA variability and ENSO. Rather than correlations (not causal), and in light of recent studies questioning the mechanisms leading to the PSA, direct calculation of Rossby wave source, wave activity flux and upper level divergence, as was done in the aforementioned studies of O'Kane et al 2015 and 2017, should be undertaken by the authors to clarify the role of tropical sources and to test their assertions.

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>We appreciate the insightful comments of referee O'Kane regarding recent studies of Rossby waves, including his own studies with others. A major challenge for understanding recent trends in sea ice is the limited amount of pre-satellite data, with the concomitant small number of studies that extend backward to the pre-satellite era. Whilst Irving and Simmonds (2017) suggest a weak relationship between the PSA and Nino 3.4, the relationship is highly dependent on the tropical region investigated (Turney et al., 2017, Climate of the Past). Crucially, O'Kane et al. (2016) suggest that mid-latitude variability is an important contributor to Rossby wave propagation. Our study builds on this work but shows the increasing tropical variability is imposing increasing variability across the mid to high latitudes (most notably in the southwest Pacific as described here), reinforcing the propagation of Rossby waves, but that local factors most probably also contribute. The reviewer makes an excellent point that the paper could be enhanced with a more complete description of the physical mechanism. It was remiss of us to not include direct analysis to support our mechanism, rather relying on published work on this issue; for instance, inn our recent paper on the propagation of Rossby waves across the mid to high latitudes (Turney et al., 2017, CoP), we report amongst other analyses the vertical velocity for Nino 3 at 300 hPa that is consistent with a Rossby-wave pattern. In response to O'Kane, we have now generated something similar for Niño 3.4, and this looks equally promising and could be included in the paper as supplementary figures to meet the reviewer's suggestion. The resulting figure (detrended and deseasonalised) is shown below. Because of the limited number of figures allowed in the main text, we assume this would need to be put within Supplementary Materials. We have therefore attached here as a Supplement file.

We have added the following at the end of the Results and Discussion section: 'In this paper, we address the question of whether interannual changes in tropical sea surface temperatures might play a role in sea ice conditions. We recognize that a more complete answer could be given with a high-quality, consistent, centuries-long data set. However, although efforts are being made to use proxy data to reconstruct changes prior to the onset of satellite observations (e.g., Becagli et al., 2008; Küttel et

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al., 2012; Abram et al., 2013; Porter et al.,2016) none of these is yet at a high level of maturity.' Importantly, the inferred changes in zonal wind stress along the East Antarctic coastline has recently been shown to have far-reaching consequences (Spence et al., 2017). Our inferred changes in southwest Pacific atmospheric pressure during the mid-twentieth is consistent with a regional SAM-like expression next to the East Antarctic. Potentially important, the reconstructed and modelled changes in winds reported here may extend their impact via coastal-trapped barotropic Kelvin waves. Specifically, Spence et al. (2017) report how wind-induced Kelvin waves can have far-reaching consequences on the sensitivity of the marine-based West Antarctic Ice Sheet and sea level rise. Our new results from the southwest Pacific are consistent with the Spence et al. study and provides an important contribution to the growing body of work that changes over the East Antarctic can have global impact(s).

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Please also note the supplement to this comment:
https://www.the-cryosphere-discuss.net/tc-2017-51/tc-2017-51-AC1-supplement.pdf

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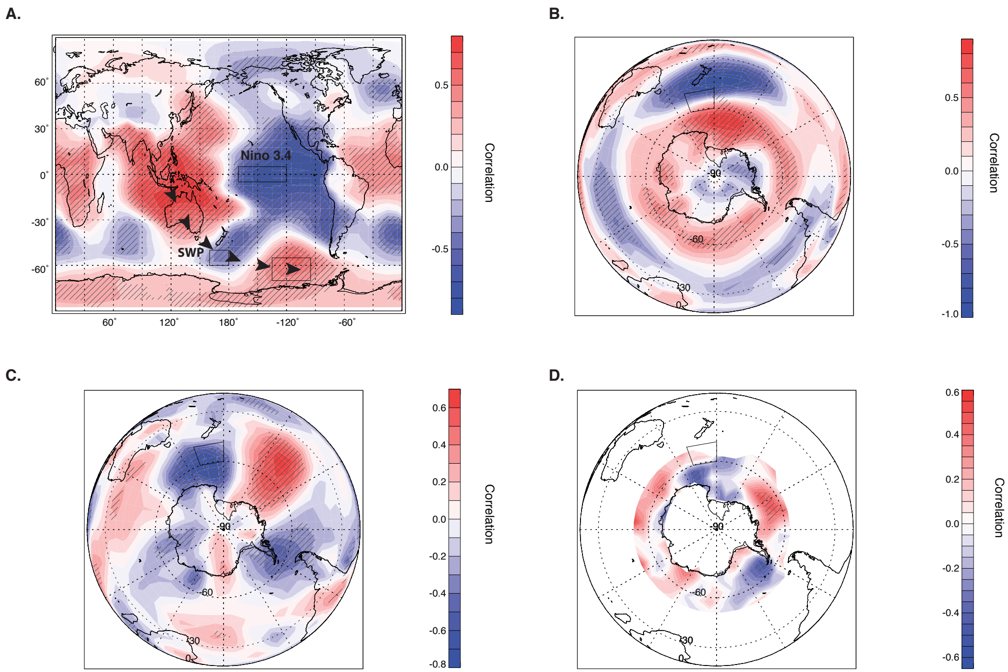

Fig. 1. Figure 2