Multidecadal Analysis of the Antarctic Dipole (ADP)

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Abstract:

Sea ice plays a major role in our world's rapidly evolving climate. Sea ice is important to our climate because it hinders exchanges between the ocean and atmosphere while also reflecting solar radiation back to space. The strongest sea ice teleconnection at the interannual time scale is between El Niño–Southern Oscillation (ENSO) events and a high latitude climate mode named the Antarctic Dipole (ADP). Due to drastic changes in the Antarctic climate system, an analysis of Antarctic Dipole variability is needed to advance our knowledge and understanding of the coupled climate system in southern high latitudes.

This study examines the life cycles of ENSO warm and cold events in the tropics and associated evolution of the ADP in high latitudes of the Southern Hemisphere. By investigating the Antarctic sea ice edge (SIE) and climate data, we will determine the current state the ADP. The ONI index was plotted from 1979-2019 in order to determine ENSO event years. Then a SIE monthly anomaly series (SIE') was generated and then an EOF analysis was applied to it. This data was then plotted for ENSO event years. The results of this study found no major change in the strength or frequency of ENSO events and that the ADP has remained relativity unchanged in contrast major large-scale changes occurring in Antarctic Sea Ice. This confirmation of the state of the ADP is important because as scientists continue to try to understand the impacts of the warming climate, understanding each facet of climate is increasingly vital.

Introduction

The world's climate is rapidly changing. Over the past 100 years average, global temperature have risen by 0.8 °C. (IPCC 2019). Although Earth's climate has fluctuated for millions of years (Jackson and Overpeck, 2000), the rate of warming over the last decade has been unprecedented (IPCC 2019). In the contiguous United States of America, the average temperature has increased by by 0.5 °C, and precipitation has increased by 5 to 10 percent (NOAA, 2016). In addition, to increasing temperatures and precipitation, the variance of temperature and precipitation is also growing. Furthermore, the frequency and severity extreme climate events is increasing (Konisky, 2017).

For most of the year, millions of square kilometers of the Southern Ocean are covered by sea ice with February typically the month of minimum ice coverage and September typically the month of maximum ice coverage. Sea ice is important to understand as it hinders exchanges between the ocean and atmosphere, reflects solar radiation back to space, and has numerous impacts on primary production and food chains in the Southern Ocean (Ainley et al., 2003; Parkinson, 2004). As an integral component of the climate system, the sea ice cover both affects and reflects changes in other climate components, making it especially interesting that the Antarctic sea ice cover has not experienced the dramatic decreases in sea ice cover over past decades compared to the Arctic sea ice cover (Parkinson and Cavalieri, 2008; Cavalieri and Parkinson, 2008).

The effects of global warming and climate change have been observed in both of the Earth's polar regions over the past several decades. The effects have been magnified in the last 10 years as show in the recorded sea ice extent and surface temperatures. (Parkinson, 2013) For example, in September 2012 Arctic sea ice extent set a new record low for the past 30 years, while Antarctic sea ice extent reached a record high for the same period, as reported by the National Snow and Ice Data Center (C.L. Parkinson et al, 2006). While September Arctic sea ice extent has slightly recovered since 2013, Antarctic sea ice extent continued to reach record highs until 2014, followed by a drop in 2016 and 2017. (Meehel et al 2019)

During the last two decades, the scientific understanding of Antarctic climate change has improved substantially. Steig et al. (2009) demonstrated that significant warming, previously thought confined to the Antarctic Peninsula, is much broader in geographical extent, extending to West Antarctica with primarily insignificant trends in East Antarctica. These results were later confirmed by O'Donnell et al. [2011], although with weaker warming across West Antarctica and more dramatic warming along the Antarctic Peninsula than suggested by Steig et al. [2009]. Both of these papers point to a major asymmetry in Antarctic climate change. The Antarctic Peninsula and West Antarctic regions show much more dramatic warming than in East Antarctica.

A large portion of the sea ice variability can be attributed to regional climate variability. (Yuan, 2008) Numerous studies suggest a strong link between the tropical El Niño-Southern Oscillation (ENSO) phenomenon and Antarctic sea ice variability [Simmonds and Jacka, 1995; White and Peterson, 1996; Harangozo, 2000; Yuan and Martinson, 2000, 2001; Rind et al., 2001; Kwok and Comiso, 2002; Martinson and Iannuzzi, 2003; Yuan 2018]. The strongest tropical-polar teleconnections in temperature and sea ice fields can be seen in the Antarctic Dipole mode (ADP) with anomalous areas centered in the northeastern Ross Gyre in the Pacific region. The ADP temperature anomalies present the largest ENSO affect outside of the tropical Pacific (Liu et al., 2002). It also represents the largest interannual variability in the Antarctic sea ice field. The changes in circulation in the South Pacific and Atlantic and stationary Rossby wave propagation associated with ENSO variability have been suggested as the main mechanisms for this tropical-polar teleconnection [Yuan, 2004]. However, the ADP has not been well studied in recent years. Additional data and better classification of this climate pattern will allow for a better understanding of the impact of ENSO variability on the sea ice extent in the Antarctic.

Gap

The knowledge on ADP was developed mostly in the early 2000's and there has not been much advancement in the recent decade. Since there is almost 20 more years of data available and the climate system in the Antarctic is under-going drastic changes in recent years, there is a need to revisit the tropical-polar teleconnection (Yuan, 2018). A re-visit of Antarctic Dipole variability is needed to advance our understanding of the coupled climate system in southern high latitudes.

Statement of Purpose

Research Question

How has the ADP evolved from 1979-2019 and how do its varying modes affect the Antarctic sea ice edge variability?

Hypothesis

H_0: ADP will be unchanged and there will be no variation in the teleconnection between the ENSO variability and Antarctic sea ice.

H_1: There will be long-term changes in the ADP in the western hemisphere due to the variation in El Niño Southern Oscillation (ENSO), which will be reflected in Antarctic SIE'.

Methods

Sea Ice Dataset

In this study, we combined 42 years of sea ice concentration data derived from brightness temperatures measured by the Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR) and the Spatial Sensor Microwave/Imagers (SSM/Is). SMMR data cover the period of January 1978–August 1987 with approximately 2-day time resolution, while SSM/I data from three spacecraft (F8, F11, and F13) cover August 1987– December 2019 at daily resolution. This combined dataset from SMMR–SSM/I data covers January 1978–December 2019. These data were provided as monthly ice concentration data in 25 km by 25 km grids.

Climate Dataset

To investigate teleconnections between Antarctic sea ice and global climate, we used data from the National Oceanic and Atmospheric Administration (NOAA). This data was the Oceanic Niño Index (ONI) from 1979-2019 which is used as the key indicator for monitoring El Niño and La Niña events. This Index is created through a 3-month running average of surface sea temperature in the east-central tropical Pacific between 120°-170°W also called the Niño 3.4 region.

Data Analysis:

The monthly mean sea ice edge (SIE) was defined as the outermost position of sea ice with an ice concentration of 15% in each degree of longitude. In austral summer, when 80% of the Antarctic sea ice fields have melted, the ice edge was chosen as the coastline latitude if no ice is present. (Yuan, 2008) The use of ice extent information only in the analysis also makes this study basically insensitive to ice concentration values which are known to be algorithm dependent. The SIE was then scaled so each degree of longitude contained one data value. We then created a SIE monthly anomaly series (SIE'). This series was created by subtracting out the monthly climatology of SIE for each day. This removes the seasonal cycle, leaving interannual and longer timescale variability. We then conducted an empirical orthogonal function (EOF) analysis on the SIE'. This analysis helps illustrate where the poles of the pattern are and better illustrates the standing wave patterns in the modes.

Then in order to determine during which years ENSO event occurred, we plotted the ONI against years. Then we look at year where the Index had value of greater than + 1.0 or less than -1.0. An ONI value of greater than +1.0 signified a El Niño event and an ONI value of less than -1.0 signified a La Niña event. Then the SIE' EOF analyzed data for El Niño and La Niña groups were then plotted separately on a longitude vs anomaly graph.

<u>Results</u>

The time series plot of ONI shows the strong/moderate El Niño and La Niña ENSO events that have occurred over the past 40 years. (Figure 1) This enables us to determine which years had El Niño events and which years had La Niña events.

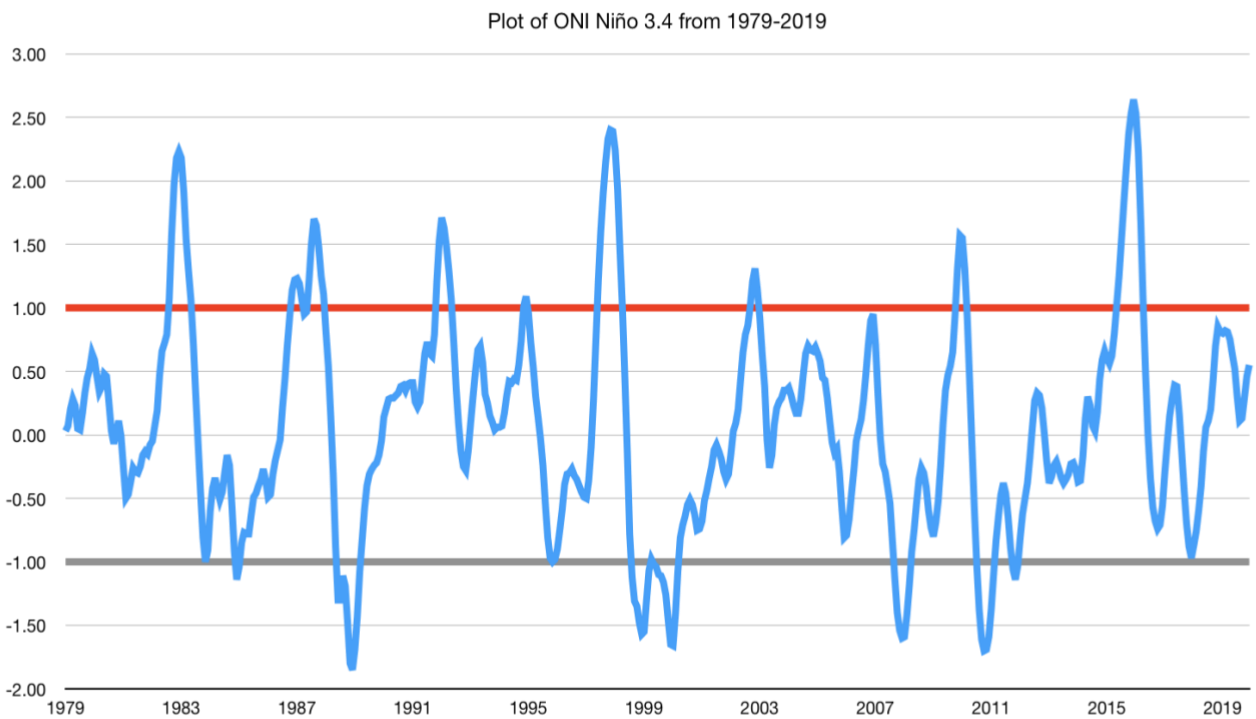

Figure 1: Graph of ONI time series from 1979-2019

The plot also enables us to understand how if at all the ENSO has changed over this 40-year time span. When comparing the first 20 years of the plot (1979-1999) to the second 20-year period (1999-2019), we can see that there has not been any significant change in El Niño or La Niña events or in their frequency. This means that ENSO as a whole has remained relativity unchanged since 1979. This means that when comparing SIE' in year before 1999 to year after 1999 any changes can be attributed to changes in the teleconnection and not in ENSO events. This is important because if there are changes that means that the method in which the teleconnection functions is changing due to the evolving climate.

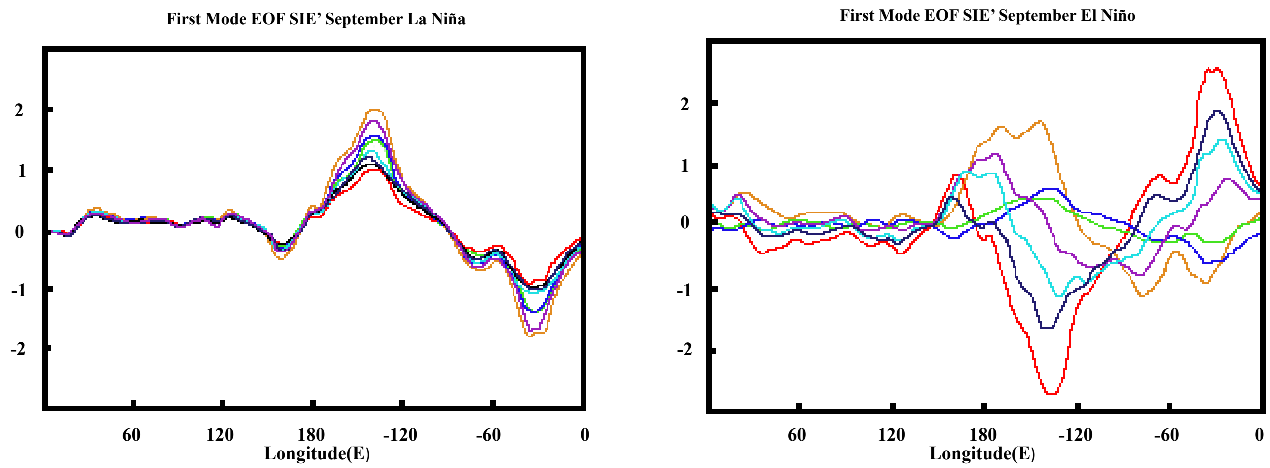

Figure 2: First EOF mode of September SIE' during El Niño(a) and La Niña events(b).

By analyzing the maximum SIE' after ENSO we can examine how SIE' responds to tropical forcing. (Figure 2) The SIE' that is in the dipole region responds to the ENSO teleconnection very regularly when compared to SIE' outside the region. It is also apparent SIE' is more influenced and consistent during La Niña event compared to El Niño events. The first EOF mode of SIE' demonstrates this relationship clearly. (Figure 2a)

Additionally, the plots show that the ADP has remained relativity unchanged since previous studies analyzed it with data from 1979-1999(Yuan, 2001). The EOF analyzed SIE' during ENSO events shows that there is no clear difference between the data before 1999 and after 1999, demonstrating the unchanged nature of the relationship despite the larger scale changes occurring in SIE. (Meehel et al 2019) As a result, this study remains consistent with previous studies that show that weather in the South Pacific and SIE do not react to warm event regularly. This difference is likely due to the way El Niño events form. (Harangozo, 2000).

Conclusions

Summary

In this study Antarctic sea ice extent was analyzed in order to understand the impact of the ENSO on its edge. First, ENSO events were analyzed in order to understand if there were changes in the phenomena. We found no major change in the strength or frequency of ENSO events. Then in order to study the predictability of the ADP, we compared SIE' during El Niño and La Niña years. We showed that the ADP has remained relativity unchanged in contrast major large-scale changes occurring in Antarctic Sea Ice, with significant decreases in sea ice in the Western Antarctic and equally significant increases in sea ice in the East. (Meehel et al 2019) As a result, we confirmed that the ADP remains significantly more predictable during La Niña events and does not respond well to El Niño events.

Limitations

This study broadly analyzed the impact the ENSO on Antarctic SIE. We focused solely on the ADP and the impact of the ENSO on the ADP. This means that this study can only reach broad conclusions and cannot specifically analyze how smaller changes in the ENSO impact the ADP and by extension Antarctic sea ice.

Future Research

To address the limitations of this study, future research could examine the ENSO in more depth, analyzing the impact of varying strength ENSO events on the ADP. In addition, future studies could analyze the connection between different ENSO regions and Antarctic SIE. Furthermore, the teleconnection was observed to be weaker during El Niño events. Examining this difference in closer detail may enable scientists to better connect the El Niño and ADP. This study did not examine the impact of other high latitude phenomena on the strength of this teleconnection.

Significance

This study provides evidence to support the conclusion that there have not been long-term changes in the ADP in the western hemisphere due to the variation in El Niño Southern Oscillation (ENSO). This unchanged state of the ADP can be seen in the relatively constant manner that SIE' reacted to La Niña event during the 40-year time-span. Current models have large errors and uncertainties in polar regions, and it is important to reduce these uncertainties since sea ice plays a key role in determining the climate. It is critical to better model polar regions to enable a better understanding of the impact of a warming climate.

In addition, better prediction of sea ice levels is important for understanding the future threats to animal and plant life. Many species rely on sea ice to survive and its decline could lead to their extinction. Thus, an improved understanding of Antarctic sea ice patterns is important to better comprehending how the Earth's climate functions and its impact on people.

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