Southern Ocean Climate and Sea Ice Anomalies Associated with the Southern Oscillation

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ABSTRACT

The anomalies in the climate and sea ice cover of the Southern Ocean and their relationships with the Southern Oscillation (SO) are investigated using a 17-yr dataset from 1982 to 1998. The polar climate anomalies are correlated with the Southern Oscillation index (SOI) and the composites of these anomalies are examined under the positive (SOI > 0), neutral ($0 >$ SOI > -1), and negative (SOI < -1) phases of SOI. The climate dataset consists of sea level pressure, wind, surface air temperature, and sea surface temperature fields, while the sea ice dataset describes its extent, concentration, motion, and surface temperature. The analysis depicts, for the first time, the spatial variability in the relationship of the above variables with the SOI. The strongest correlation between the SOI and the polar climate anomalies are found in the Bellingshausen, Amundsen, and Ross Seas. The composite fields reveal anomalies that are organized in distinct large-scale spatial patterns with opposing polarities at the two extremes of SOI, and suggest oscillations that are closely linked to the SO. Within these sectors, positive (negative) phases of the SOI are generally associated with lower (higher) sea level pressure, cooler (warmer) surface air temperature, and cooler (warmer) sea surface temperature in these sectors. Associations between these climate anomalies and the behavior of the Antarctic sea ice cover are evident. Recent anomalies in the sea ice cover that are clearly associated with the SOI include the following: the record decrease in the sea ice extent in the Bellingshausen Sea from mid-1988 to early 1991; the relationship between Ross Sea SST and the ENSO signal, and reduced sea ice concentration in the Ross Sea; and the shortening of the ice season in the eastern Ross Sea, Amundsen Sea, far western Weddell Sea and lengthening of the ice season in the western Ross Sea, Bellinghausen Sea, and central Weddell Sea gyre during the period 1988–94. Four ENSO episodes over the last 17 years contributed to a negative mean in the SOI (-0.5). In each of these episodes, significant retreats in ice cover of the Bellingshausen and Amundsen Seas were observed showing a unique association of this region of the Antarctic with the Southern Oscillation.

1. Introduction

The Southern Oscillation (SO) refers to the seesaw in the surface pressure anomalies between the Indian Ocean–Australian region and the southeastern tropical Pacific on a seasonal and interannual timescale. The large-scale character of the SO in the Tropics and subtropics in the Southern Hemisphere is well known (Philander and Rasmusson 1985). The SO has a signature that extends to the mid- and high latitudes in the Southern Hemisphere in the winter and summer. The high-latitude signature of the SO has associated anomalies over the Antarctic sea ice cover. Understanding these links between the SO and Antarctic sea ice cover are important due to the sensitivity of sea ice to anomalies in climate forcing as sea ice interacts with the global climate over a broad range of spatial and temporal scales (Schlesinger and Mitchell 1985; Manabe et al. 1991). Sea ice albedo feedback involves changes in the climatological area of the ice cover and adjustments in the poleward heat transport by the atmosphere, in addition to changes in the thickness, albedo, and temperature of ice within the Antarctic ice pack. The ocean structure and circulation are affected during sea ice growth, as salt is rejected to the underlying ocean increasing its density and leading sometimes to deep ocean convection and bottom water formation. Equatorward transport of ice results in a net flux of freshwater and negative heat. Thus, anomalies in these polar processes have complex consequences in the global climate.

Many studies have analyzed the recent behavior of the Antarctic ice extent and have suggested connections between sea ice extent and the Southern Oscillation (Carleton 1988; Jacobs and Comiso 1993; Simmonds and Jacka 1995; Gloersen 1995; Ledley and Huang 1997; Jacobs and Comiso 1997; Watkins and Simmonds 2000). Using a 10-yr dataset (1985–94), White and Peterson (1996) found coupled anomalies that propagate eastward with the Antarctic Circumpolar Current during a period of 4–5 years (wavenumber 2) and taking 8–10 years to encircle Antarctica. It was suggested that this Antarctic Circumpolar Wave (ACW) is associated with ENSO-related activities in the equatorial Pacific, possibly through an atmospheric teleconnection with higher southern latitudes. Peterson and White (1998), in a case study, show ENSO can be a possible source of the interannual anomalies for sustaining the ACW in the western subtropical South Pacific. Parkinson (1998) also

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suggests that the lengthening/shortening sea ice season might be related to the variability of the ACW. Bonekamp et al. (1999) in an examination of the European Centre for Medium-Range Weather Forecasts (ECMWF) Atmospheric Reanalysis dataset from 1979 to 1994, however, did not find eastward propagating anomalies suggestive of an ACW prior to 1984. For that time period at least, a two-regime structure with and without the presence of ACW was indicated. Yuan and Martinson (2000) explored possible relationships between the record of Antarctic sea ice extent between 1978 and 1996 and global climate variability. Their analyses show a strong link of the sea ice edge anomalies in the Amundsen, Bellingshausen, and Weddell Seas to extrapolar climate. In a recent article, Venegas et al. (2001) found coupled oscillations in Antarctic sea ice and atmosphere in the South Pacific sector.

The objective of this study is to explore the spatial details in the teleconnections between SO and the anomalies in the Southern Ocean climate and in particular the anomalies of the Antarctic sea ice cover. Our approach is to analyze the linear correlation of the Southern Oscillation index (SOI) with the polar climate anomalies, and to examine the composites of these anomalies during three phases of the SOI that we define as $SOI > 0$, $0 > SOI > -1$, and $SOI < -1$, and henceforth will be referred to as the positive, neutral, and negative phases. The datasets used here span a 17-yr period from 1982 to 1998. Our study takes advantage of new data on ice motion and ice surface temperature derived from passive microwave imagery and the National Oceanic and Atmospheric Administration's (NOAA) Advanced Very High Resolution Radiometer (AVHRR) data. Rather than having to restrict our study area to the ice edge region, as was done previously (White and Peterson 1996), this dataset allows a more detailed examination of the spatial signatures of the climate and sea ice anomalies.

The paper is composed of five sections. Section 2 describes the climate and sea ice datasets used in our analysis. Section 3 presents the spatial pattern of correlation between the Southern Ocean climate anomalies and the SOI, and the composite patterns of the climate and sea ice anomalies associated with three phases of the SOI over 17 years. We discuss our results in the context of previous work in section 4. The paper is summarized in the last section.

5. Conclusions

The spatial signature of the climate and sea ice anomalies in the Southern Ocean associated with the Southern Oscillation are revealed in the correlation patterns and the composite fields. The correlation maps and lag-correlation plots show features of the spatial and temporal relationships between these anomalies and the index of Southern Oscillation, while the composite maps show the dominant spatial signature of the anomalies during the three phases of SOI. On a large scale, these anomalies are organized in coherent patterns and assume opposite polarities during the two extremes of SOI. Also, these anomalies covary with the Southern Oscillation and oscillate at approximately the same frequency. Association with ENSO-related activities in the equatorial Pacific is clearly indicated.

Overall, the climate anomalies in the Amundsen, Bellingshausen, and Weddell Sea sectors of the Antarctic polar ocean show the strongest link to the Southern Oscillation. Within these sectors, the climate anomalies show the highest correlation with the SOI and the composite patterns show the most intense and localized climate and sea ice anomalies associated with the extremes of SOI. Positive (negative) phases of the SOI are generally associated with lower (higher) sea level pressure, cooler (warmer) surface air temperature, and cooler (warmer) sea surface temperature in these sectors. Outside these sectors, the anomalies are not as distinct.

Linkages between the SOI, the climate anomalies, and the sea ice extent, concentration, motion, and ice surface temperature are also evident. The sea ice cover anomalies are located within the same sectors as those with the dominant climate anomalies. During the positive (negative) phase of SOI, positive (negative) anomalies of the SIE are located between 180° and 130°W in the Ross and Amundsen Seas, negative (positive) anomalies can be found between 100°W and 10°E in Bellingshausen and Weddell Seas, and, smaller positive (negative) anomalies are found in the sector between 10° and 50°E.

The physical mechanisms by which these polar processes are linked to the Southern Oscillation are complex and beyond the scope of this study. However, the identified relationships may be useful as diagnostic tools for climate models and for the eventual understanding of the underlying mechanisms of these associations. The composite fields presented can be used as an indicator of the general condition of the Antarctic ice cover during different phase of the Southern Oscillation as measured by the SOI. We have used these fields to explain, in a broad sense, the large-scale trends and anomalies (reported in recent literature) in the sea ice extent and the length of the ice seasons over the past 20 years. These composite fields are weighted by four strong ENSO episodes over the last 17 years. As a result, these warm events have probably weighted the sea ice and climate anomalies towards the patterns associated with the negative extremes of the SO index. Data of monthly anomalies of ice extent, ice area, and concentration in the Bellingshausen–Amundsen Sea sector (Fig. 9) show that the ice cover in the region is still declining while those in other regions appear to be increasing slightly. In fact, the mean trend of the Antarctic sea ice edge is close to zero over the period. Recession of the ice edge in the Bellingshausen–Amundsen Sea sector is compensated by expansion in the Weddell Sea and western Ross Sea sectors. Our analysis shows that spatially, the Pacific sector is different from other Antarctic regions in that it is influenced by climate anomalies with strong associations with the Southern Oscillation. The results suggest that the Bellingshausen–Amundsen Sea area is unique in its close association with the Southern Oscillation.