Towards a Seasonal Forecast in the Ross Sea

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1. Introduction

In a recent study (Yuan and Martinson, 2001), we found that the dominant interannual variance structure in the sea ice edge and surface air temperature fields is organized as a quasi-stationary (in space) wave which we call the “Antarctic Dipole” (ADP). It is characterized by an out-of-phase relationship between the ice and temperature anomalies in the central/eastern Pacific and Atlantic sectors of the Antarctic. The dipole consists of a strong standing mode and a weaker propagating motion within each basin's ice field. It has the same wavelength as the Antarctic Circumpolar Wave (ACW) and dominates the ACW variance. The dipole is clearly associated with tropical El Niño/Southern Oscillation (ENSO) events; it can be predicted with moderate skill using linear regression involving surface temperature two to four months ahead. The prediction performs better in extreme warm/cold years, and best in La Niña years. The Ross Sea is in the Pacific branch of the ADP. The climate variability in the Ross Sea is heavily influenced by the ADP oscillation. The linear regression prediction in Yuan and Martinson (2001) only shows the predictability of sea ice due to its links to the tropical climate variations. To build a more vigorous statistical model, we need to understand what causes anomalies in sea ice and surface temperature. The goal of this study is (1) to examine magnitudes of anomalies in sea ice and surface temperature during tropical warm and cold phases; and (2) to investigate atmospheric circulation in mid to high latitudes and meridional heat transports associated with the circulation. Monthly surface air temperature, meridional heat flux and meridional stream function of mass transport from National Centers for Environmental Prediction / National Center for Atmospheric Research (NCEP/NCAR) Reanalysis data were used in this study. Monthly sea ice concentrations were generated by the bootstrap algorithm from the National Aeronautics and Space Administration (NASA) microwave imager (Comiso et al., 1997). The sea ice edge was then derived from the monthly sea ice concentration.

2. Methods and Results

To determine the magnitudes of ENSO impact on Southern Ocean sea ice and surface temperature fields, we generated monthly composition maps of sea ice concentration, ice edge and surface air temperature for El Niño and La Niña scenarios in the Ross Sea Region. Based on the Niño 3.4 index, we selected five El Niño events in 1980, 1983, 1988, 1992, 1997 and four La Niña events in 1985, 1989, 1996 and 1999. The composite maps were generated starting from the maturing month of each ENSO event, January, through the following December. The differences between El Niño and La Niña scenarios show the maximum ENSO impacts on the sea ice concentration and temperature fields. The large ice concentration differences occur near ice edge. The austral winter months have the largest ENSO impacts on sea ice. The differences in ice concentration between the two states can reach 80% with more ice during the La Niña state in the Pacific. Figure 1 gives such an impact in May as an example. On the other hand, the large ENSO impact in surface air temperature extends further into the ice pack. The temperature differences are more profound from May to September, with a maximum in May (Fig. 2). The largest temperature difference reaches 10°C. These differences reflect the mean anomalies in the two climatological states. Anomalies in the monthly mean and at synoptic time scales could be even larger. Correlation between ENSO index Niño3 and meridional heat transports shows that heat was transported into the Ross Sea region during El Niño periods by both mean circulation and eddy activities (Fig. 3). This is consistent with less sea ice there during/after El Niño events. Moreover, the polarward heat transport is dominant by the mean circulation, which suggests that the mean circulation could be responsible for linking lower and high latitudes. Therefore, we plot the mean meridional mass transport stream function in the Ross Sea region from NCEP/NCAR Reanalysis data for the mean El Niño and mean La Niña state (Fig. 4). In this plot, the mean El Niño state is averaged from May (onset of an El Niño event in the tropics) to the following April (end of the event) and then averaged over five events in the last
twenty years. The mean La Niña state has been treated in the same way. The mean meridional circulation is dramatically different for two extreme states. During El Niño events, the Hadley Cell and Ferrel Cell are relatively equatorward, with an extensive poleward cell. Poleward mass transport (therefore heat transport) in the Ferrel Cell occurs from 45° to beyond 65°S. On the other hand, during La Niña events, the Hadley Cell and Ferrel Cell move southward 5 to 7 degrees of latitude with enhanced circulation compared to warm events. However, the polarward mass transport is quite weak beyond 60°S. These characteristic circulation patterns lead the large anomalies in sea ice and air temperature by a couple of seasons. Such a relationship provides an opportunity to build a seasonal forecast model for the area.

3. Relevance to RIME

These interannual variabilities in sea ice, air temperature and atmospheric circulation patterns are quite relevant to RIME for following reasons.

1. The magnitudes of interannual variability in the sea ice and surface temperature are large, and are comparable to fluctuations in monthly mean or even synoptic time scales.

2. The temperature simulation in the global climate model is very sensitive to sea ice concentration in polar regions. With wintertime ice concentration contrasts between +50% to −50%, the difference in temperature simulation can exceed 30°C (Parkinson et al. 2001). Therefore, interannual variations in ice concentration with magnitudes up to 40% likely affect regional forecast models significantly.

3. Variation of mean circulation in mid to high latitudes directly influences cyclone distributions in the polar/subpolar regions. In a modeling study, Rind et al. (2001) shows that ENSO-related anomalies in tropical sea-surface temperatures immediately invoke a meridional temperature gradient in the Pacific that alters the intensity of the Hadley Cell, manifested in a meridional shift of the subtropical jet (STJ). For warm events, the STJ moves equatorward in the Pacific, further from the source of available potential energy in the frigid Antarctic (agreeing well with observations in this study). This leads to a reduction in cyclogenesis and polar storm intensity.

4. The interannual variation of mean atmospheric circulation can also trigger regional atmosphere-ice coupling processes that affect storm distribution in the polar/subpolar regions. Such a case was found in 1996 when a wavenumber 3 pattern in the mean atmospheric circulation was coupled with sea ice distribution. The coupling processes provided favorable conditions for cyclogenesis in the open ocean near the sea ice extent maxima (Yuan et al., 1999).

References


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**Figure 3** Correlation between ENSO index Nino3 and total meridional heat fluxes due to mean circulation (top) and eddy activities (bottom).

**Figure 4** Mass transport stream function for meridional circulation in the Ross Sea region from 160E to 120W. The top panel (bottom panel) is the mean stream function averaged over five El Nino (four La Nina) events from May to following April. The stream function is from NCEP reanalysis.