Antarctica sea ice variability and southeast Indian Ocean SST: Possible relationship

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Relationships between the Antarctic sea ice variability and extrapolar climate variables especially the Indian Ocean SST have been explored and we have identified that the southeast Indian Ocean SST shows the most persistence relationship with Antarctic sea ice variability. The SST is the unique precursor for the Australian summer monsoon, Indian summer monsoon and ENSO phenomenon after the 1976-1977 regime shift and is also linked with recently discovered Indian Ocean Dipole event of subtropical Indian Ocean.

[Key words: Sea ice, southeast Indian Ocean, Antarctica, Southern Ocean, climate data, SST, sea ice edge]

1. Introduction

The cryosphere in the Southern Ocean is an active component in global climate and is influenced by many local, regional and remote climate fluctuations on the synoptic to geological time scales. The signature of teleconnection between Antarctic sea ice variability and climate has been a topic of research for a long time in modeling as well as observational studies1-4. White & Peterson2 discovered the Antarctic Circumpolar Wave (ACW) that propagates eastwards on the El Nino/Southern Oscillation (ENSO) time scales whereas Yuan & Martinson3, 5 found a quasi-stationary wave named as Antarctic Dipole (ADP) linked to the ENSO variability that also dominates the interannual variability of the sea ice field. Due to accumulation of sea ice data, connection of polar to tropical climate indices such as ENSO have been found statistically significant5, 6. In addition to ENSO, Antarctic sea ice is supposed to be linked to other climate indices such as tropical Indian Ocean sea surface temperature (SST), tropical land precipitation7, southeast Indian Ocean SST7 but these studies are at the primitive stage.

A number of modeling and observational studies suggest that tropical Indian Ocean SST anomalies can significantly affect Indian summer rainfall variability8-11. Some recent studies focus on the Southern Indian Ocean (SIO) SST variability and its relationship with Indian monsoon, Australian monsoon and African rainfall variability12-16. Southwest Indian Ocean, off Australia, may supposedly play major boundary forcing for Late Indian Summer Monsoon (LISM)12 and is also responsible for the transition of whole ENSO-monsoon system13. In addition, Mascarene High plays a major role in east Asian summer rainfall14. The southeast Indian Ocean and Mascarene high may be influenced by various physical processes.

Our knowledge in the Southern Hemisphere high latitudes and Antarctic is still in the infancy, largely due to few observations17 but in recent past, due to accumulation of data and improvement in statistical techniques the quality of data in high southern latitudes has improved. In the present work, we have tried to establish linear relationships between the sea ice variability and climate variables specially SST for the southeastern Indian Ocean and Mascarene region (Fig. 1).

2. Sea Ice and Climate Data

Satellite measurements of polar sea ice enables us for the variability study from seasonal to interannual time scales. In the present study we have used sea ice...
Sea Ice Edge (SIE) is defined as equator-most position of the 30% isopleth of ice concentration in each degree of longitude. The SIE monthly anomaly (SIE') was calculated by removing monthly climatology defined at each grid point in order to remove seasonal cycle.

To investigate the possible teleconnection between Antarctic sea ice and global climate the NOAA’s optimal interpolated version 2 SST (OISST) monthly fields for 23 years period (1982-2004) have been used. Monthly anomaly series was calculated by subtracting monthly mean climatology from the data. SIE' and SST anomaly series for the months of January-March (JFM), April-June (AMJ), July-September (JAS) and October-December (OND), respectively, are averaged to obtain seasonal-mean data and correlation between seasonal SIE' and seasonal Indian Ocean SST with a maximum lead-lag time scale of 3 years (12 season) has been calculated.

We defined some of the indices of three month mean SST anomalies extracted for SIO for the way which maximum correlation with SIE' is found and in shown in Fig. 1 (the reason of selecting these indices will be given in Results and Discussion section). The SIE' were correlated with the individual indices as well as combined ones.

3. Results and Discussion

The linear correlation between Antarctic sea ice edge variability and SST anomaly of Indian Ocean was calculated with a lead-lag time scale up to 3 years. The SST indices are constructed by averaging SST anomalies over the regions given in Fig. 1 depending on the consistent significant positive correlation on a lead-lag time scale of 3 years and the relative importance of the regions with respect to tropical atmosphere and monsoon. Since the Mascarene high is linked with the Antarctic Oscillation (AAO) and the East Asian monsoon rainfall14, 20, we have chosen Index A as the region covering some parts of the Mascarene high. Index B and C have been chosen because these regions show consistent significant positive correlation throughout the temporal lead–lag time scale up to 3 years. The reasons for selecting the south east Indian Ocean index (SEIOI) are due to its highly persistent nature and its effect on the northwestward translation of Mascarene high from austral to boreal summer12. This index has been a common unique SST precursor of various physical processes like ENSO, Indian summer monsoon, Australian summer monsoon after the regime shift13 of 1976-1977.

Index A is significantly correlated with sea ice variability with a lead as well as lag time scale of 6 seasons whereas Index B is positively correlated with ice leading seasons of 6 although the correlations are small and confined to the Ross and Bellingshausen/Amundsen Sea of Pacific Ocean (Fig. 2 A, B). Since the area for calculating index A covers the Mascarene high (MH) region which is positively correlated with AAO, these connections may be physically possible.
Fig. 2—The spatial pattern of correlation coefficients between seasonal sea ice edge anomaly and (A) Index A= [83°E - 88°E, 30°S - 36°S], (B) Index B= [92°E - 99°E, 39°S - 49°S], (C) Index C= [114°E - 116°E, 32°S - 37°S] and (D) SEIOI = [72°E - 122°E, 4°S - 26°S] with a maximum lead-lag of 3 years (correlation of 0.36, 0.26 and 0.17 is at 99.9%, 99% and 95% significant label respectively)

Fig. 3—The spatial pattern of correlation coefficients between seasonal sea ice edge anomaly and (A) Index A+C and (B) Index A + SEIOI with a maximum lead-lag of 3 years ((correlation of 0.36, 0.26 and 0.17 is at 99.9%, 99% and 95% significant label respectively)
The SST of the region over west of Australia (Index C) (Fig. 2C) and SEIOI (Fig. 2D) is correlated (99.9% confidence level) with SIE’ at the zero lag and the high correlation is maintained until a lead time of up to 8 seasons. This positive correlation is spread over entire Pacific Ocean including major sea ice variable regions such as Ross, Bellingshausen\ Amundsen seas.

The covariability of SST indices among themselves has been checked and the Index A is found to be independent with Index C and SEIOI. The Index A combined with either Index C or SEIOI were correlated with SIE’ (Fig. 3A, B respectively). The improvement in the correlation is negligible by adding the two indices, separately, which indicates that the correlation of these indices with SIE’ may be independent to different regions. It is difficult to comment on the cause-effect relationship on the basis of correlation analysis but due to highly coupled nature of ocean-atmosphere-cryosphere in the southern polar region\2\21\22 these relationships based on correlation may be physically possible.

There are many studies in last two decades relating to polar to tropical teleconnection and our knowledge of ENSO and Southern Hemisphere variability has been much advanced\3\5\6\23 in recent years. Two high latitude climate modes in Southern sub Polar region namely ACW and ADP mode were suggested to be linked to ENSO variability in tropics. ADP is a stationary wave in sea ice, SST and Surface Air Temperature (SAT) and it is linked to the ENSO variability\3\5 and ADP anomalies usually persists three to four seasons after the ENSO events mature in the tropics\6. One of the proposed mechanism of ADP-ENSO teleconnection is due to creation of persistent anomalous high (low) ENSO events which generates anomalous temperature and sea ice fields in the Pacific and South Atlantic simultaneously in opposite phase.

On the other hand it has been shown that SEIOI has a strong and significant evolution of whole Indo-Pacific system during the following one year period\13. The anomalous (cold) warm SEIOI in February – March is associated with strengthening of the MH due to surface wind forcing off west coast of Australia. The SEIOI was suggested to be the good predictor of ENSO after 1976-77 regime shift\13 so we could think that the SEIOI may also be linked physically with the Antarctic sea ice variability.

In view of these studies, the significant positive correlations of SEIOI and Index C with the SIE’ on the zero lag and its persistence on a lead lag time scale of up to 8 seasons seem realistic and physically possible. The correlations are small but are statistically significant up to the level of 99.9% from Student’s two tail test. The physical explanation of this connection may be important but it will be very early to propose any mechanism of this connectivity.

4. Conclusion

We have tried to identify the SST anomalies of the regions in Indian Ocean which show the persistent positive correlation with sea ice variability with a lead-lag time scale of up to 3 years. In our identification process, we have also considered the relative importance of the spatial domains of SIO which is paid attention by research community with respect to ENSO, monsoon, Asian summer monsoon, Australian monsoon connectivity in recent times. In this way we have identified four regions in SIO and defined the SST indices by area-averaging the SST anomalies over these regions. Index A and B show the positive correlation with SIE’ but the strength of their correlation is not large. The two indices named as Index C and SEIOI show maximum correlation with SIE’ up to a lead lag time scale of 8 seasons near Bellingshausen sea and some parts of Pacific Ocean. The strongest sea ice teleconnection was found with ENSO from earlier studies\3\5\6 and the SEIOI was supposed to be a better predictor of ENSO after 1976-77 regime shift\12\13. So the positive correlation of SIE’ with either Index C or SEIOI seems possible in view of previous studies. It has been also found that the correlation does not improve by adding independent SST indices of different regions. Thus, we can also argue that these correlations are regionally independent.

The studies relating to connectivity between Indian Ocean SST and Antarctic sea ice variability are in preliminary stage. Our next approach of this study will focus on identification of feasible physical mechanism (if any) behind this connection. In the recent years the relative importance of SIO in response to ENSO, Asian summer monsoon\12\13, South African rainfall\15, 16,24 and other tropical climate variables have been increasing. So our results may be considered as a robust precursor of polar to SIO although at an initial stage.

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