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Inter-annual variations observed in spring and summer Antarctic sea ice extent in recent decade

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सार – समुद्री हिम का बढ़ना और उसमें कमी आना एक जटिल प्रक्रिया है और इस संबंध में समुद्री तथा वायुमंलीय परिसंचरण में यह महत्वपूर्ण जानकारी देता है। एंटार्कटिक में समुद्री हिम की विविधता दक्षिणी महासागर की मौलिक उत्पादकता को उल्लेखनीय रूप से प्रभावित करती है और इस प्रकार ध्रुवीय परिस्थितिक तंत्र में प्रजातियों की कार्य प्रणाली और जीविका को नकारात्मक रूप से प्रभावित करती है। हाल ही के दिनों में समुद्री हिम की विविधता की जानकारी आर्कटिक क्षेत्र के लिए पूर्ण रूप से विकसित नहीं थी। इस शोध पत्र में क्विक स्केट स्केट्रोमीटर आँकड़ों से प्राप्त किए गए नवम्बर और फरवरी महीनों के लिए 1 × 1 डिग्री के स्तर पर एंटार्कटिक में मासिक प्रभंजन समुद्री हिम आवरण में देखे गए अंतर–वार्षिक (1999–2009) प्रवृत्तियाँ को मुख्य रूप से केन्द्रित किया गया है। भारत के ओश्यिनसेट–2 उपग्रह से प्राप्त किए ओस्केट स्केट्रोमीटर आँकड़ों का उपयोग नवम्बर 2009 और फरवरी 2010 के माह में देखे गए समुद्री हिम विस्तार (एस.आई.ई.) के लिए तथा जलवायविक अधिकतम (1979–2002) समुद्री हिम विस्तार (सी.एम.एस.आई.ई.) से इनके विवेचन का निर्धारण करने के लिए किया गया है। एस.आई.ई. और सी.एम.एस आई.ई. के मध्य अत्यधिक मात्रा में भिन्नाताएँ देखी गई हैं तथापि इस प्रवृत्ति के परिणामों से पता चलता है कि ये समुद्री हिम आवरण में उच्च अन्तः वार्षिक भिन्नताओं के कारण होते हैं। इन प्रवृत्तियों के स्थानिक वितरण से पश्चिमी प्रशांत महासागर के पाकेटो, रोस समुद्र, अमंडसेन और बेलिंगशाउसेन सागर (ए.बी.एस.), वेडले सागर और हिन्द महासागर के दक्षिणी क्षेत्र में सकारात्मक और नकारात्मक प्रवृत्तियों की विद्यमानता का पता चलता है। फरवरी के आउस्ट्रल ग्रीष्मकालीन माह में देखे गए एस.एस.टी. में प्रेक्षित दीर्घ अवधि प्रवृत्तियों (1982–2009) के साथ समुद्री हिम प्रवृत्तियों की तुलना की गई है। इस अध्ययन से रोस सागर के आस–पास देखी गई वृहत् मान शीतलन प्रवत्ति से और ए.बी.एस. सेक्टर में उष्ण प्रवत्ति से अच्छे परिणाम प्राप्त हुए हैं।

ABSTRACT. The growth and decay of sea ice are complex processes and have important feedback onto the oceanic and atmospheric circulation. In the Antarctic, sea ice variability significantly affects the primary productivity in the Southern Ocean and thereby negatively influences the performance and survival of species in polar ecosystem. In present days, the awareness on the sea ice variability in the Antarctic is not as matured as it is for the Arctic region. The present paper focuses on the inter-annual trends (1999-2009) observed in the monthly fractional sea ice cover in the Antarctic at 1 × 1 degree level, for the November and February months, derived from QuikSCAT scatterometer data. OSCAT scatterometer data from India's Oceansat-2 satellite were used to asses the sea ice extent (SIE) observed in the month of November 2009 and February 2010 and its deviation from climatic maximum (1979-2002) sea ice extent (CMSIE). Large differences were observed between SIE and CMSIE, however, trend results show that it is due to the high inter-annual variability in sea ice cover. Spatial distribution of trends show the existence of positive and negative trends in the parts of Western Pacific Ocean, Ross Sea, Amundsen and Bellingshausen Seas (ABS), Weddell Sea and Indian ocean sector of southern ocean. Sea ice trends are compared with long-term SST trends (1982-2009) observed in the austral summer month of February. Large-scale cooling trend observed around Ross Sea and warming trend in ABS sector are the distinct outcome of the study.

Key words – Antarctic, Sea ice trends, SST trends, Scatterometer.

1. Introduction

The Polar sea ice cover feature of the Earth's cryosphere is showing the highest degree of season-to-season variability. The formation and melting of sea ice play significant role in the polar climate. Zhang (2007) discussed that an increase in surface air temperature and downward longwave radiation results in an increase in the upper-ocean temperature and a decrease in sea ice growth. This leads to a decrease in brine rejection from ice into the

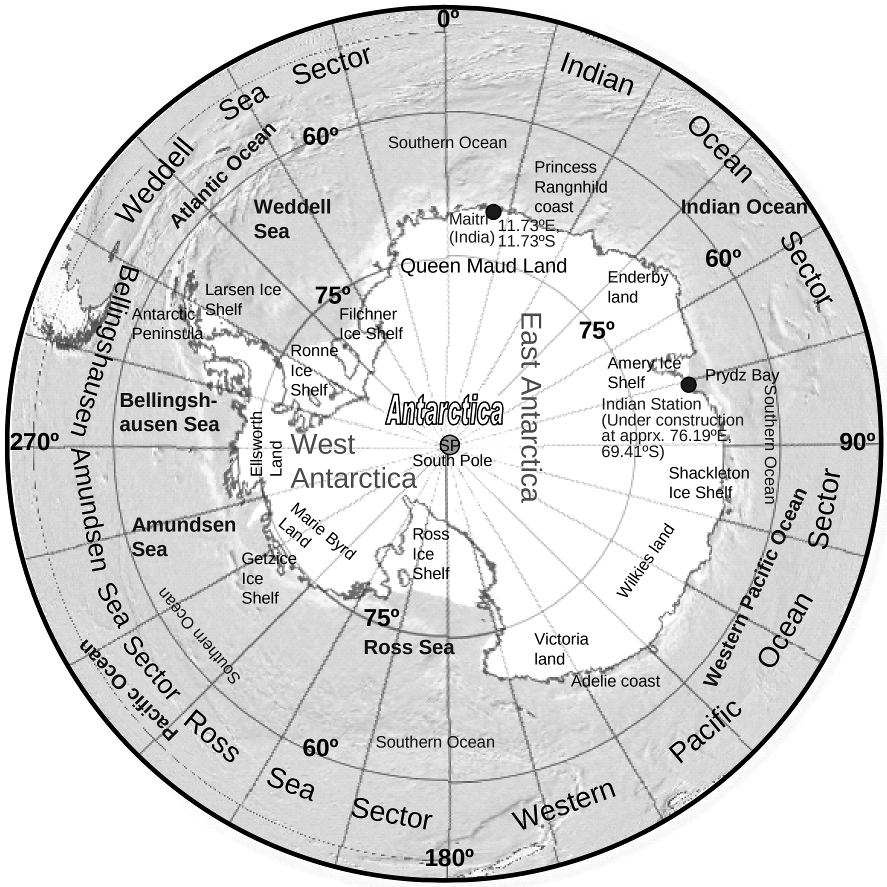
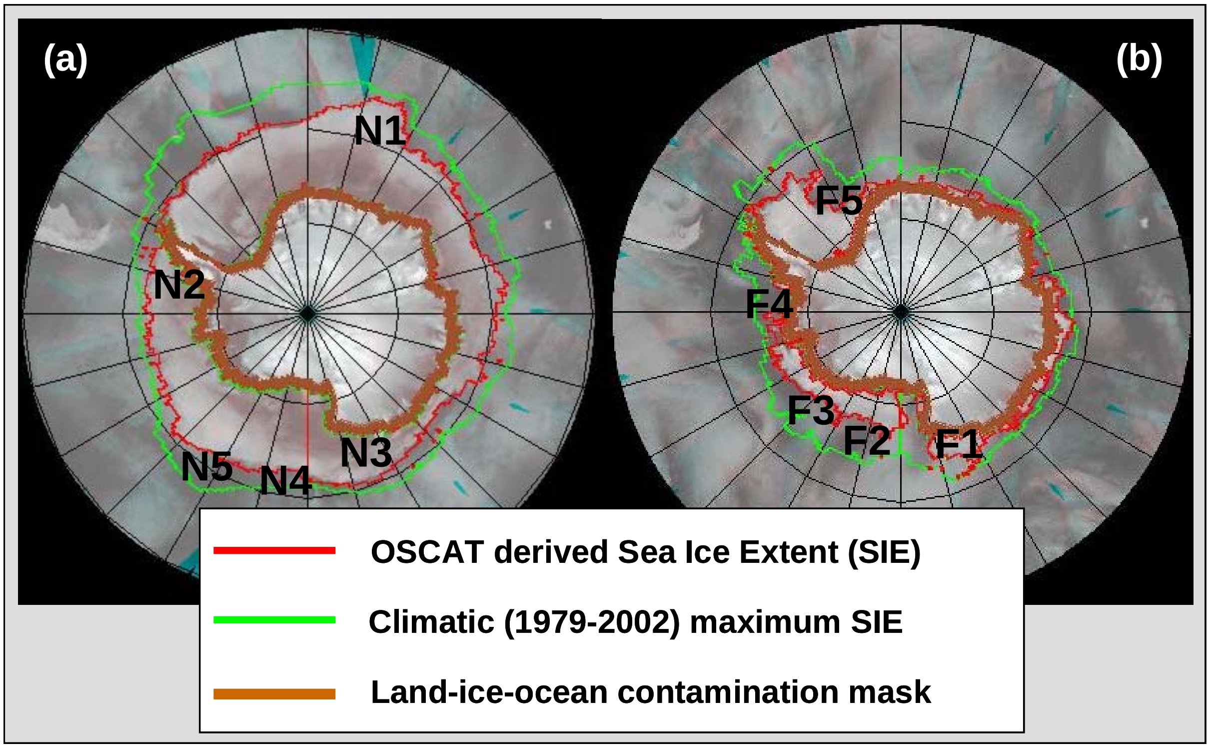


Fig. 1. Location map of the Antarctic

ocean. The reduction in salt rejection, upper-ocean density and enhanced thermohaline stratification tend to suppress convective overturning, leading to a decrease in the upward ocean heat transport and the ocean heat flux available to melt sea ice (Zhang 2007).

The polar regions are expected to provide early signals of a climate change primarily because of the ''ice-albedo feedback'' which is associated with changes in absorption of solar energy due to changes in the area covered by the highly reflective sea ice (Comiso and Nishio, 2008). Modern climate over the Antarctic and the Southern Ocean results from the interplay of the ice sheet, ocean, sea ice, and atmosphere and their response to past and present climate forcing (Mayewski *et al*. 2009). Sea ice also has strong influences on key demographic parameters through its impact on food web processes, on the distribution and abundance of food supply, and on the nature and extent of breeding and feeding habitats (Jenouvrier *et al*., 2005).

A distinct asymmetry between the Northern and the Southern Hemisphere sea ice trends have been observed during the end of the twentieth century. While in the Northern Hemisphere the sea ice exhibits a large decrease there is no significant trend in the sea-ice extent of the Southern Hemisphere (Lefebvre and Goosse, 2007). However, recent reports suggest that in the recent trends are slight positive at the Antarctic level (Cavalieri et al., 1997; Zwally *et al*., 2002; Vyas *et al.* 2003) but varies from one sector to another sector (Liu et al., 2004; Oza *et al.* 2010).



Figs. 2(a&b). Sea ice extent overlaid on the OSCAT data (a) November 2009 spring month and (b) February 2010, a summer month. Regions marked by N1 to N5 and F1 to F5 are for easy referencing for other figures

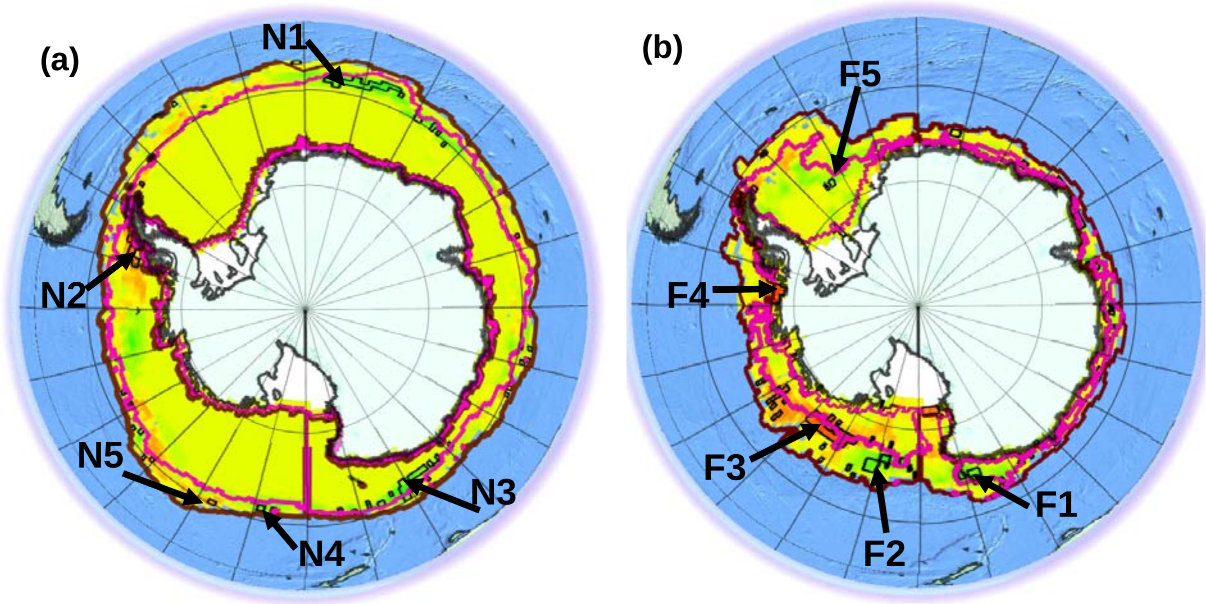
This emphasizes that, as a sensitive indicator of global climate change, a detailed understanding of nature and causes of spatio-temporal variability in the Antarctic sea ice is necessary. Present paper addresses the recent sea ice trends observed at 1 × 1 degree level and its linkage with the trends observed in the Sea Surface Temperature (SST).

2. Materials and methodology

Monthly Climatic maximum sea ice extent (CMSIE) data were obtained from the website (http://www.nsidc.org) of National Snow and Ice Data Centre (NSIDC). To assess the present day deviation of sea ice extent from climatic maximum in the spring-summer period of November 2009 and December 2010, data from the OSCAT scatterometer onboard Oceansat-2 satellite, launched by India in September 2009, were utilized. OSCAT is 13.515 GHz (Ku-band) active microwave dual-pencil-beam conically scanning scatterometer with the outer beam vertically (VV) polarized, and the inner beam horizontally (HH) polarized. OSCAT has a swath of 1800 km with a repeat cycle of 29 orbits in 2 days. Because of the nature of polar orbiting satellites, sensor covers almost entire polar region in a day.

Daily Gridded (Level-3S) Sigma-0 composite product (0.5 degree resolution) from the OS2 was used. The 10-year data from the QuikSCAT Ku-band scatterometer is available from August 1999 to November 2009 at BYU (http://scp.byu.edu) site and same was used to derive the monthly sea ice trends. The sea ice cover was identified using the Spatio-temporal coherence technique discussed by Oza *et al.* (2011). Linear trends in the SST for the summer month of February was derived using the NCEP/NCAR reanalysis SST data for the period from 1982-2009. Climatological maximum monthly sea-ice extent data (Stroeve and Meier, 1999) was obtained from the website (www.nsidc.org) of National Snow and Ice Data Center (NSIDC).

Sea ice area at 1° × 1° grid level was computed using known trigonometric formulas considering Earth to be a sphere of specified radius (Oza *et al.*, 2010). Linear least-square regression was employed to derive the grid-level



Figs. 3(a&b). Sea ice trends (1999-2009) derived from QuikSCAT data at 1 × 1 degree level for the month of (a) November and (b) February. Regions marked by N1 to N5 and F1 to F5 are for easy referencing for other figures

sea ice trends. The linear fit derived using data from 1999 to 2009 between 0% to 100% sea ice fractions suggests that, during extrapolation care should be taken to saturate the extrapolated value at 100% and cutoff at 0%, if extrapolated value is lower than 0%.

A location map of the Antarctic is shown in Fig. 1, which can be utilized to identify the name of the sectors and Seas to identify the locations in the subsequent figures of the sea ice and SST trends.

3. Results and discussion

For the comparison of sea-ice edges, the sea ice cover was transformed into vector layer using raster-to-vector utility of ENVI Image processing software. These vectors were overlaid on the RGB composite [Figs. 2(a&b)] made from H-V-V combination. Here H means H-polarization Sigma-0 and V indicates V-polarization Sigma-0 images. This RGB composite shows the different texture of sea ice from the ocean and Land ice of the Antarctic. Sea ice extent derived from the OSCAT data and climatic maximum sea ice extent are also shown in the figure. Sea ice follows a typical seasonal pattern from growth to decay. Growth of sea ice starts from the re-freezing of sea water with the start of winter dark period and decay starts from the beginning of sunny summer period in the polar regions. The period of November 2009 to February 2010 is the spring-summer melting period in the southern hemisphere.

The change in sea ice cover observed by the OSCAT data during melting period in the Antarctic is shown in Figs. 2(a&b). The significant decay of sea ice cover from November to February due to melting, which is a typical pattern of the Antarctic, is visible. It is also observed that the difference from the climatic maximum (1979-2002) sea ice extent is higher in the western side of the Antarctic as compared to that observed in the eastern side in both the months. However, deviation between these two edges, in the Ross and Amundsen and Bellingshausen Seas (ABS) sectors, is much larger in the month of February (denoted by N4 and N5) compared to that observed in the month of November (denoted by F2 and F3). Minimum sea ice cover has been identified in the month of February (austral summer period) in the Indian Ocean (IO) sector in comparison to other sectors. Large scale differences are seen between the observed sea ice cover in both the months from the maximum SIE observed in respective months.

Sea ice trends (1999-2009) derived from QuikSCAT scatterometer data are shown in Figs. 3(a&b) for the months of November [Fig. 3(a)] and February [Fig. 3(b)]. OSCAT derived sea ice extent and climatic maximum sea ice extent for the respective months are also shown in figure.

It is seen that in all the sectors and in both the months sea ice trends are extending up to the climatic maximum (1979-2002) sea ice extent. This indicates that

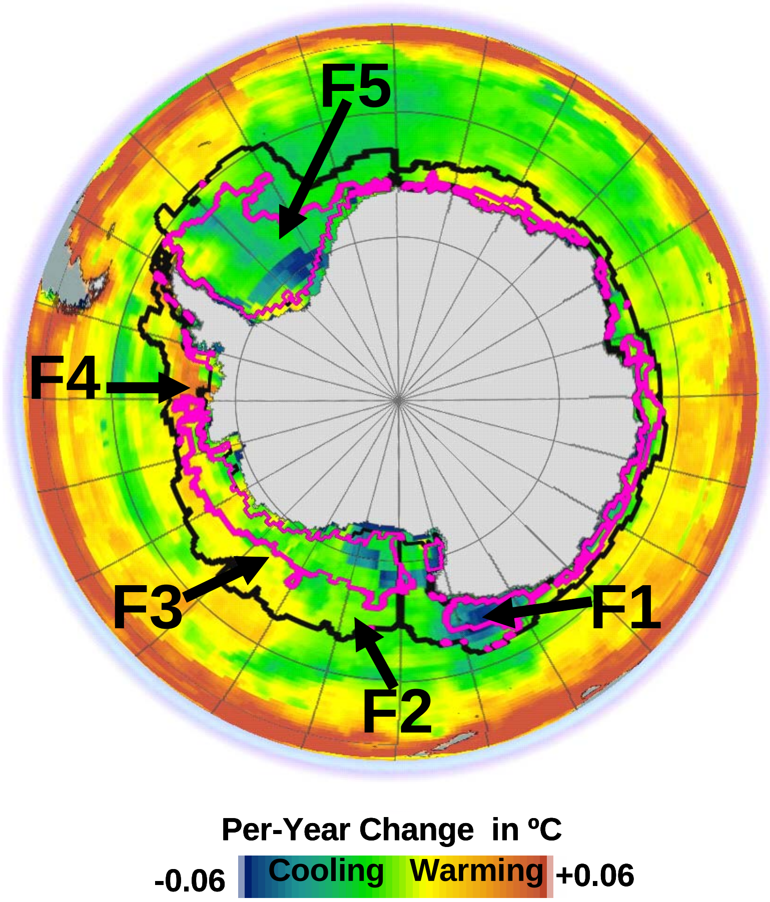


Fig. 4. Spatial distribution of Sea Surface Temperature (SST) trends (1982-2009) derived from NCEP/NCAR reanalysis data for the month of February. Regions marked by N1 to N5 and F1 to F5 are for easy referencing for other figures

sea ice cover must be fluctuating at the marines from year-to-year and deviates from the climatic maximum as seen in Figs. 2(a&b). This confirms that large-scale reduction in sea ice cover has not been observed in the Antarctic in contrast to significant declining summer sea-ice trends reported in the Arctic. Stammerjohn *et al*. (2008) specified that annually the average of the sea ice extent in the Antarctic reaches its most equator ward position, but does not remain there as long.

Spatial distribution of the sea ice trends show that the distinct variation in trends from one location to another location is observed in the Antarctic. A positive trend of about +8% to +11% observed, in the month of November, around N1 (IO sector) and N3 in Western Pacific Ocean (WPO) sector. A dipole like phenomena of positive and negative sea ice trends in Ross sector is a distinct pattern. Ocean area adjoining the WPO sector is showing the positive sea ice trends, whereas area nearer to ABS sector is showing negative trend. Statistically significant positive trend observed in this sector is around +7% to +8% in November (N4), and +6% to +12% percent in February (F2). For other area around N4 and F4 similar kind of statistically weak trends are observed.

Liu *et al.* (2004) have reported positive trend of about 15.8% per decade in autumn, 6.7% per decade in winter and 13.6 % in spring, that gives the overall positive trend of about +9.6% per decade in the central Pacific Ocean around RoSs Sea. It is clear from their analysis that seasonal trends are stronger than the annual average trend, because the seasonal anomalies will be averaged out in the annual trends. Similarly, these seasonal trends may be further intensified if computed for a specific month of the season. This could be the reason for the much stronger trend (+6% to +12% per year) obtained for the specific

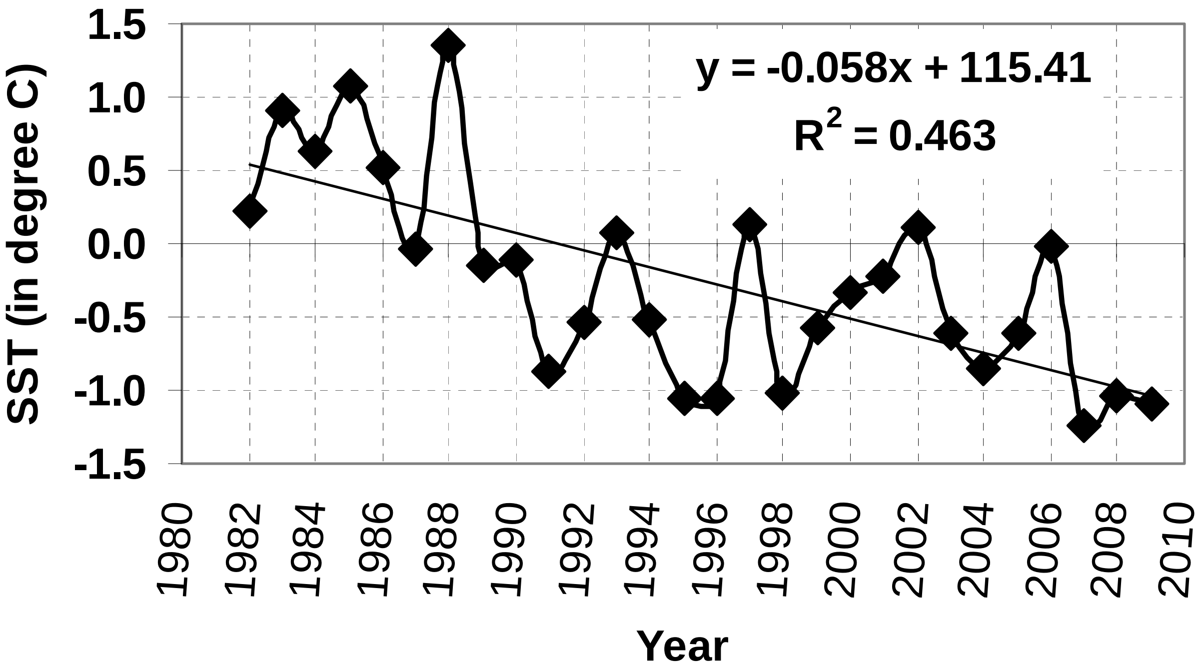


Fig. 5. Year-wise SST profile of February month (1982-2009) for the region marked by F1 in Fig

February month in contrast to the average seasonal trends observed by Liu et al (2004), who obtained around +15% per decade and +4.2% annual trend obtained by Comiso and Nishio (2008).

Statistically significant negative trends observed in the Ross sector are in the range of -8% to -12% percent in November (N5) as well as in February (F3). In ABS sector negative sea ice trends are observed in both the months and more prominent in the austral summer period of February. Area in these sectors nearer to Antarctic Peninsula is showing statistically significant negative trends of –(8-11) percent in November (N2) and of about –8% to -13% percent in February (F4). For this region, near to Antarctic Peninsula, Comiso and Nishio (2008) have reported a negative trend of about -5.7% per decade. Liu *et al.* (2004) have obtained the maximum negative trend -14.3% percent per decade arising from the trends in summer (-29%), autumn (-18.1%) and spring (-7.5%). The negative sea ice trend has also an effect on the Antarctic habitats. Decreasing sea ice can have harmful effects on penguins, since it leads to a decrease in the availability of food resource such as krill and therefore to a decline in populations growth and reproduction (ASOC, 2008).

The results obtained in the present analysis further confirm that the sea ice trends in specific months, such as November or February, are much stronger than the seasonal (spring-summer) or annual average trends obtained by other researchers.

An important outcome of the study is the positive trend observed near the Adelie Coast in the WPO sector, adjoining to Ross Sector. These positive trends of about +8% to +11% persist during months of November (N3) to February (F1). Increasing sea ice trend at the end of austral summer in the month of February in this region (F1) is a distinct pattern. Significant cooling trend (1982-2009) of SST is observed around F1 (Fig. 4). In large area of Weddell and Indian Ocean sectors cooling trend of SST is also observed. The significant positive trend seen in the Figs. 3(a&b) in Weddell Sea (F5) during February is consistent with the cooling trend of SST (Fig. 4). The influence of cooling trend in SST could have impact on the winter sea ice trends in the Indian Ocean sector that needs further investigation.

Majority of area in the Ross sector and WPO sector nearer to Ross sector are also showing cooling trend in SST. Around F1, near the Adelie Coast, statistically significant cooling trend of -0.06° C per year is seen.

Fig. 5 shows the SST profile for February month for the period from 1982 to 2009 for the site F1. Highest SST observed in 1988 is 1.38 ºC and lowest observed of about -1.24 °C in 2007. Significant decline in SST is observed during 1988 to 1991. During the period from 1992 to 2006 it remains within the range of (-0.5) ± 0.5 °C. Observed SST is below -1 ºC from 2007 onwards.

Fig. 4 also shows the dominant negative trend (warming) in the ABS sector and statistically significant trend of around +0.03 °C per year (*i.e.* +0.3 °C per decade) is observed around F4 nearer to the Antarctic Peninsula. This warming trend of SST is in consistent with the negative trend of sea ice observed around F4. Lefebvre and Goosse (2007) discussed that small changes in sea-ice concentration are expected in regions, where the temperature is well under the melting point for most of the year, since the risen temperature will still remain on a low level. In contrast to that, regions where temperatures are slightly below the melting point will be affected the most.

The warmer and colder oceanic and atmospheric conditions are linked with the Southern Annular Mode (SAM) and El Niño and Southern Oscillation (ENSO) events. One of the primary features of an ENSO event is the strengthening of the polar front jet in the south Pacific during La Nina events (Stammerjohn *et al*., 2008). This leads to more storms, warmer condition and less sea ice in the southern Bellinghausen and western Weddell Seas but colder conditions and more sea ice in the Amundsen and Ross Seas. This effect strengthens due to a positive trend in the covariance between positive SAM and La Nina events and the opposite scenario applies to El Nino events (Stammerjohn *et al*., 2008).

4. Conclusions

The paper describes the inter-annual variability and spatial distribution of trends (1999-2009) observed in the Antarctic sea ice cover derived from OSCAT and QuikSCAT scatterometers for the November (spring) and February (summer) months. It is observed from the analysis that the deviation in year-to-year annual maximum sea ice extent is very high and no permanent shrinkage of sea ice extent has been observed during the last decade at the Antarctic level.

However, location specific statistically significant trends have been observed during both the study months. Strong positive sea ice trend in the Ross sector and negative in ABS sectors were observed, that confirms the continuation of similar trend observed during 1979-1998 by other researchers. Positive trend observed in the Indian Ocean sector during November is a distinct pattern.

Cooling trend of SST in the sea-ice region showing positive trend and warming of SST in the region showing of negative sea ice trends confirms the linkage between sea ice processes with the oceanic processes.

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