

High resolution climate reconstructions of recent warming using instrumental and ice core records from coastal Antarctica

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सार – एंटार्कटिक सतही तापमानों के वही पर लिए गए प्रेक्षणत्मक रिकार्ड अपेक्षाकृत अपर्याप्त हैं। इस प्रकार शताब्दी और दशकीय समय मानों पर गत जलवायु परिवर्तन को पुनःस्थापित करने के लिए प्रोक्सी आधारित हिम कोर का अध्ययन करना थोड़ा कठिन है इस अध्ययन में एंटार्कटिक जलवायु परिवर्तन के हाल ही के साक्ष्यों की रिपोर्ट और इनके भूमंडलीय संपर्कों के साथ-साथ पूर्वी एंटार्कटिक के ज्ञानिग माउड लैंड से प्राप्त की गई उपकरणों और प्रोक्सी रिकार्डों की समीक्षा की गई है। इस क्षेत्र में सबसे बड़ा (1961 से) और मौसम का निरंतर लिए गए रिकार्ड वाला नोवोलाजरेवस्कया (नोवो) केन्द्र के मासिक माध्य वायु तापमान रिकार्डों से 0.25 डिग्री से. / दशक की दर पर उल्लेखनीय रूप से उष्ण प्रवृत्ति का पता चला है। इस उष्णता के स्थानिक और कालिक सामंजस्य को समझने के लिए ज्ञानिग माउड लैंड क्षेत्र के तटीय भाग से सही दिनांकित हिम कोरों का निर्धारण किया गया है। सभी प्रोक्सी रिकार्डों से +0.12 डिग्री से. / दशक तक बढ़ी हुई उष्णता का पता चलता है। इस क्षेत्र से दो उच्च विभेदन वाले हिम कोरों (आई.एन.डी.-25/बी.5 और आई.एन.डी.-22/बी.4) से स्थिर आक्सीजन और हाइड्रोजन आइसोटॉप प्रोक्सी रिकार्डों के हाल ही के निर्धारण द्वारा इसका समर्थन किया गया है। इन रिकार्डों में आई.एन.डी.-25/बी.5 ने गत 100 वर्षों (1905 से 2005) के लिए अल्ट्रा उच्च विभेदन वाले आँकड़ें उपलब्ध कराए हैं और आई.एन.डी.-22/बी.4 कोर में एंटार्कटिक परिवर्तन के गत लगभग 470 वर्षों (1530 से 2002) के आँकड़ें उपलब्ध हैं। इन हिम रिकार्डों ने दक्षिणी वलयाकार पद्धति (एस.ए.एम.) और एल निनो दक्षिणी दोलन (ई.न.एस.ओ.) जैसी उष्णकटिबंधी और मध्य अक्षांशीय जलवायु पद्धतियों सहित इनके संपर्कों के साथ-साथ एंटार्कटिक जलवायु प्रणाली पर सौर-प्रबल के प्रभाव की पूरी जानकारी उपलब्ध कराई है। इन रिकार्डों का उपयोग करते हुए परिकल्पित सतह वायु तापमानों से गत कई दशकों (लगभग 0.4 डिग्री से./दशक) में अत्यधिक रूप से संवाधित उष्णता सहित 0.06–0.1 डिग्री से./दशक द्वारा भी उष्णता का पता चला है। इस बात की पुष्टि हुई है कि ज्ञानिग माउडलैंड के तटीय क्षेत्र वास्तव में उष्ण होते हैं और यह प्रवृत्ति हाल ही के दशकों में स्पष्ट रूप से बढ़ी है।

ABSTRACT. In-situ observational record of Antarctic surface temperatures is rather sparse. Proxy based ice core studies are thus critical for reconstructing the past climate change on centennial and decadal time scales. The present study review the available instrumental and proxy records from the Dronning Maud Land region of East Antarctica as well as report recent evidences of Antarctic climate change and its global linkages. The monthly mean air temperature records of the Novolazarevskaya (Novo) station, which is the longest (since 1961) and continuous meteorological record in this region, revealed a significant warming trend at a rate of 0.25 °C / decade. To understand the spatial and temporal consistency of this warming, well-dated ice cores from the coastal Dronning Maud Land region were assessed. All proxy records consistently suggest an enhanced warming up to +0.12 °C / decade. This is further supported by a recent assessment of stable oxygen and hydrogen isotope proxy records from two high resolution ice cores (IND-25/B5 and IND-22/B4) from this region. Among these records, the IND-25/B5 provided ultra-high-resolution data for the past 100 years (1905-2005) and the IND-22/B4 core represented the past ~470 years (1530-2002) of Antarctic change. These ice records provided insights on the influence of solar forcing on Antarctic climate system as well as its linkages with the tropical and mid-latitude climatic modes like the Southern Annular Mode (SAM) and El Niño Southern Oscillation (ENSO). The calculated surface air temperatures using these records showed a warming by 0.06-0.1 °C / decade, with greatly enhanced warming during the past several decades (~0.4 °C / decade). It is confirmed that the coastal areas of Dronning Maud Land are indeed warming and the trend is apparently enhancing in the recent decades.

Key words – Warming, Ice core, Stable isotope, Dronning Maud Land, Antarctica.

1. Introduction

In Antarctica, the *in-situ* observational record of Antarctic climate parameters is rather sparse and initiated

mainly since the International Geophysical Year (IGY - 1957/58). These limited instrumental records indicate that Antarctica has undergone significant temperature changes in recent decades (Turner *et al.*,

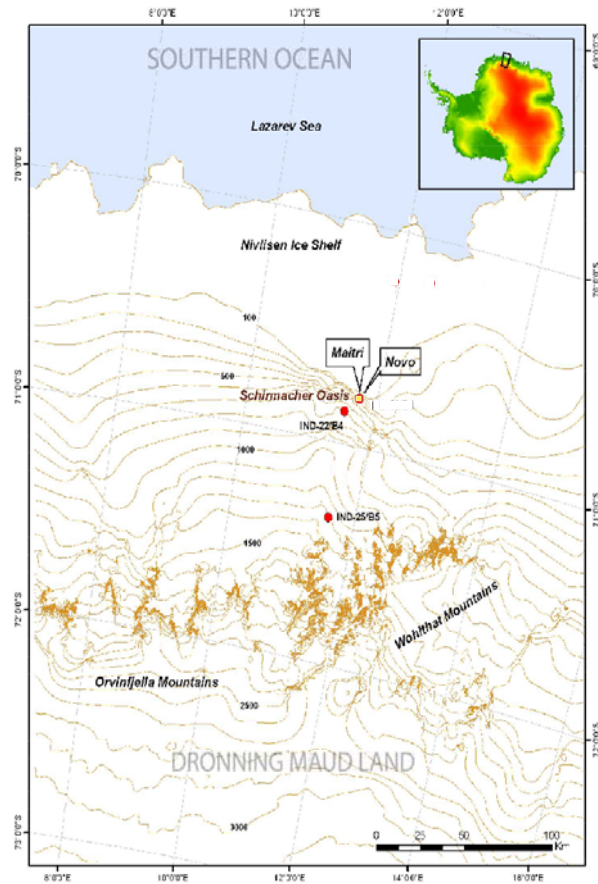


Fig. 1. Study area with locations of Novolazarevskaya (Novo) meteorological station as well as ice core sites of IND-22/B4 and IND-25/B5

2005). Accordingly, the largest annual warming trends are found on the western and northern parts of the Antarctic Peninsula (e.g., + 0.56 °C per decade at Faraday/Vernadsky station). Many records in East Antarctica do not show any significant trend and the Amundsen-Scott Station at South Pole even reveal a slight cooling of -0.05 °C per decade (Turner *et al.*, 2005 & 2009). However, the spatial and temporal complexity of Antarctic climate necessitates the analysis of long-term climate data all over the Antarctica. Study of ice core records offer one of the most direct and accurate method to study the Antarctic climate change beyond the instrumental limits (Schneider *et al.*, 2006; Mayewski *et al.*, 2009). Proxy records of ice cores from polar regions present continuous and highly resolved long-term records of reliable information on major climatic parameters. Among the various proxy records, the stable isotope ratios of oxygen ($\delta^{18}\text{O}$) and hydrogen (δD) offer the most critical information on the past changes in temperature. Since the heavy isotopes in precipitation decrease with the

temperature of condensation, stable isotope ratios in ice cores provide reliable information on past temperature (Dansgaard, 1964).

Antarctic ice core studies have revolutionized our view of the climate variability as well as become a cornerstone of climate change detection and attribution studies (Mayewski *et al.*, 2009). For example, they provided the first clear evidence that abrupt climate changes have occurred in the past, and they have shown that greenhouse gases and climate have been tightly linked over the last ~800,000 years (Jouzel *et al.*, 2007). Isotope records of ice cores have also provided insight into the tropical-polar teleconnections (Isaksson and Karlén 1994; Schneider *et al.* 2006). A network of high-resolution ice core records with annually resolved proxy records that focus on the past few centuries are most fundamental for the study of recent climate change in Antarctica (Mayewski *et al.*, 2005). A crucial component of such studies is the assessment of local/regional records and its incorporation to the large schemes of Antarctic climate change. One of the important regions that have attracted researchers in East Antarctica is the Dronning Maud Land (Queen Maud Land) that is directly inland to the major upwelling zones of the global thermohaline circulation. The present study reviews the available long-term meteorological (~50 years) and ice core isotope proxy records (>100 years) along with recent high quality ice core proxy records from the coastal Dronning Maud Land (DML). The review provides an improved understanding on the climatic and environmental variability in this part of Antarctica during the past few centuries.

2. Data and methodology

The data discussed in this study are the annual temperature record of the Novolazarevskaya (Novo) station as well as the stable isotope proxy data of ice core records from the coastal Dronning Maud Land (DML). Although there are a few meteorological stations in DML region like Novo (Russia), Syowa (Japan), Maitri (India), Neumayer (Germany) that have meteorological records for the past several years, only the Novo data are the longest (started in 1961) and continuous in this region that are ideally placed to understand the multi-decadal climate change as well as the calibration with the ice core proxy records. The temporal records of some of the key meteorological parameters at this station is considered to be the most representative records for the coastal Dronning Maud Land as well as one of the key records of the continental-wide Antarctic instrumental database as part of the SCAR (Scientific Committee on Antarctic Research) Reference Antarctic Data for Environmental Research (READER) project (Turner *et al.*, 2005). The Novo data as reported in the READER database

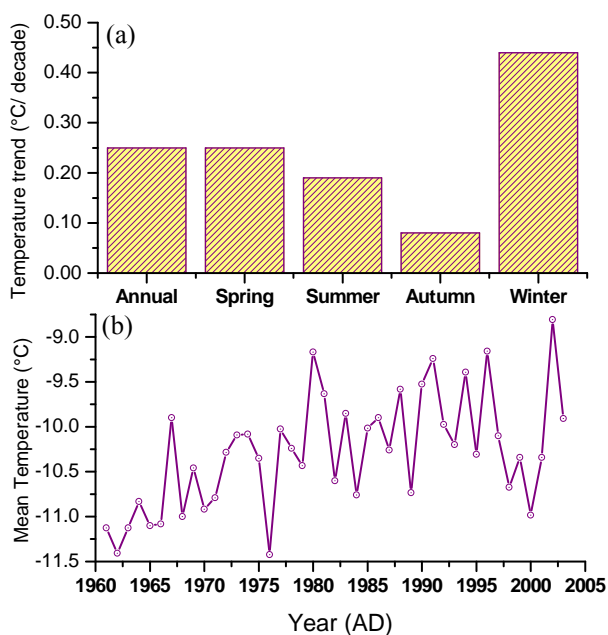


Fig. 2(a&b). (a) Annual mean near-surface temperature at Novolazarevskaya station and (b) The annual and seasonal near-surface temperature trends at Novolazarevskaya station for 1961-2000 (Turner *et al.*, 2005)

(<http://www.antarctica.ac.uk/met/READER/>) consists of monthly mean near-surface and upper air temperature, mean sea level pressure, near-surface and upper air wind speed, and heights of standard pressure surfaces (Turner *et al.*, 2005). For the present purpose, we have used only the annual near-surface temperatures and the computed trends.

The proxy climate data used in this study come from two ice core records from the coastal DML region (Fig. 1). Among these records, one core (IND-22/B4, length: 62 m) was collected near the Tallaksenvarden nunatak (location: 70° 51.3' S & 11° 32.2' E) during the 22nd Indian Scientific Expedition to Antarctica (ISEA) and represent a low altitude site (elevation: 680 m) with moderate snow accumulation (up to ~170 kg m⁻² a⁻¹) (Thamban *et al.*, 2006). The second core (IND-25/B5; length: 65 m) was collected during the 25th ISEA near the Humboldt Mountains (location: 71° 20' S & 11° 35' E), representing higher altitude (elevation: 1300 m) and very high accumulation (accumulation rate: up to 528 kg m⁻² a⁻¹) site (Naik *et al.*, 2010 a). Proxy data used here are stable isotope ratios of oxygen ($\delta^{18}\text{O}$) and hydrogen (δD) that are extensively used as the most reliable proxies for the past reconstruction of temperature and moisture sources. The details on sample processing, methodology

and analytical precision are described elsewhere (Naik *et al.*, 2010a; Laluraj *et al.*, 2011; Thamban *et al.*, 2011). The age constraints for the IND-22/B4, achieved by volcanic markers and stable isotope records, provided a record for the past 4 years (Thamban *et al.*, 2006). Chronological control for the IND-25/B5 ice core was based on multiple and complimentary methods: (i) atomic bomb (Tritium) markers; (ii) annual layer counting using stable isotope records; and (iii) volcanic time markers; The exceptionally rigorous and reliable age constraints for this core provided an ultra-high-resolution proxy record for the last 100 years (1905-2005), with a sampling frequency equivalent to the monthly time resolution (Naik *et al.*, 2010 a & b).

3. Results and discussion

3.1. Climate variability in Dronning Maud Land – instrumental and proxy records

The monthly mean near-surface and upper air temperature study using the Novo data revealed a significant warming trend over the period of 1962-2000 at a rate of + 0.25 °C / decade (Turner *et al.*, 2005). The estimated seasonal surface temperature trends (1962-2000) as part of the above study at Novo were: Spring +0.25 ± 0.41; Summer + 0.19 ± 0.34; Autumn + 0.08 ± 0.4; Winter + 0.44 ± 0.66 °C / decade [Fig. 2(a)]. Obviously, the warming trend on annual basis seems to be influenced by a predominantly warming trend during the winter. There exist significant interannual and decadal variability within the long-term warming trend [Fig. 2(b)]. The changing nature of the temperature trends over recent decades is further demonstrated by the overlapping 30 year trends in the annual mean surface temperatures that revealed that the warming was significantly greater during the 1961-90 period (+0.41 ± 0.38) compared with 1971-2000 (+0.10 ± 0.41) (Turner *et al.*, 2005). The study also revealed that the Novo data revealed a remarkable record in the East Antarctica that showed statistically consistent warming trend. Such a finding also calls for a substantiation of the instrumental data for longer time periods using reliable proxy based climate records.

Proxy climate records having at least annual time resolution from the broad area of Dronning Maud Land (DML) are limited (Isaksson *et al.*, 1996 & 1999; Graf *et al.*, 2002; Kaczmarek *et al.*, 2004; Divine *et al.*, 2009; Naik *et al.*, 2010 a & b). Within the western Dronning Maud Land (DML), shallow firn/ice cores were studied representing the coastal and inland regions (Isaksson *et al.*, 1996). One of the cores (length – 30 m) was obtained at about 200 km from the coast at 700 m asl and covers the period 1932-1991. The other core (length – 20 m) was retrieved about 500 km from the coast at 2900 m asl and

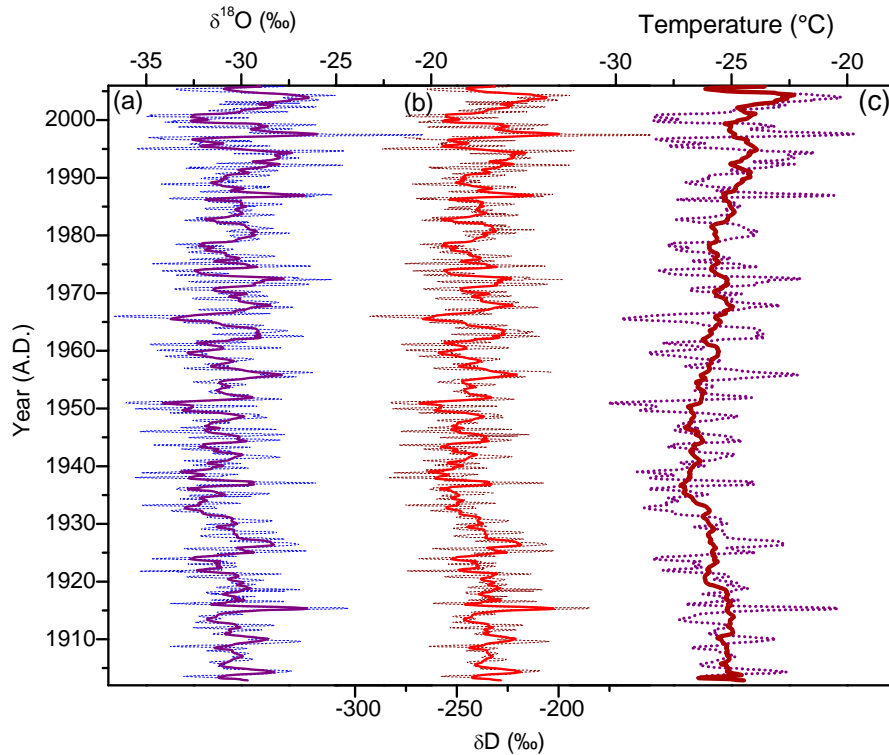


Fig. 3. Proxy climate records of IND-25/B5 core: a) $\delta^{18}\text{O}$ record with annual smoothing; b) δD record with annual smoothing; c) Mean surface air temperature (SAT) estimated using $\delta^{18}\text{O}$ data with a decadal smoothing showing an enhanced warming trend since 1930s (thick line)

covers the period 1865-1991. The recent accumulation increase that has been reported from several areas of the Antarctic continent is not present in either of these records. Instead, the records suggest a significant decrease in accumulation, with the strongest trend from about 1975. The stable isotope records from both the coastal and the high-altitude sites suggest positive temperature trends. The surface air temperature derived from the oxygen isotope records of the coastal core suggest an increase of about 1.8°C since the early 1930s, and this increase in the high-altitude is about 0.8°C since 1865 (Isaksson *et al.*, 1996). However, it is possible that the temperature reconstructions at this region using $\delta^{18}\text{O}$ records are partly influenced by the changes in moisture sources.

The European Project for Ice Coring in Antarctica (EPICA) focussed mainly on the deep ice core records that span the past climate of 740,000 years with decadal time resolution using deep ice core from the polar plateau of the DML. Additionally, the project collected several shallow (<50 m) firn/ ice cores that provided annual records from the past 200 years and few of them up to the past 2000 years (Graf *et al.*, 2002). In spite of the large

variability, the stacked composite stable isotope derived temperature records suggest an increased warming during the 20th century, which occurred almost entirely during the decades 1910-40 (Graf *et al.*, 2002). Further, the records indicate that recent warming in the northern hemisphere observed since 1978, are not found in these inland proxy records.

A 100 m long ice core retrieved from the eastern part of Fimbulisen ice shelf in the coastal DML extended till 1737 AD, with a mean long-term accumulation rate of $0.29 \text{ m a}^{-1} \text{ w.e}$ (Kaczmarek *et al.*, 2004). A significant (95%) negative trend in the 20th century (from ~1920) found in the accumulation record is in agreement with other coastal ice cores from this region. Measurements of melt layers in this core revealed that fewer melting features are visible at depths corresponding to approximately 1890-1930 AD and the number of ice melt layers increased again after 1930 AD (Kaczmarek *et al.*, 2006). The increase in melting frequency around ~1930 AD corresponds to the beginning of a decreasing trend in accumulation and an increasing warming trend reflected in oxygen isotope record.

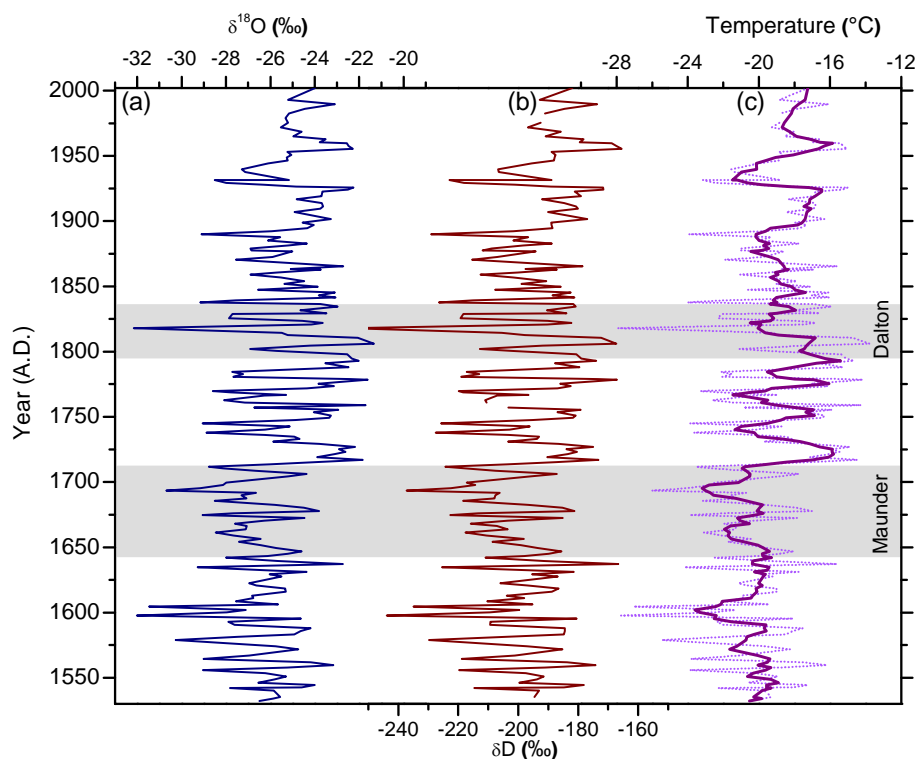


Fig. 4. Proxy climate records of IND-22/B4 core: a). $\delta^{18}\text{O}$ profile; b). δD profile; c). Mean surface air temperature (SAT) profile along with the long term warming trend (thick line); The shaded intervals are periods of the well known solar events (Maunder and Dalton Minima)

Detailed proxy studies on the above core as well as some selected shorter ice cores from DML region were also used to examine the role of the tropical ENSO in the temporal variability of $\delta^{18}\text{O}$ in annual accumulation of coastal Antarctica (Divine *et al.*, 2009). Records reveal that on typical ENSO timescales of 2-6 years, the strength of the teleconnection varies in time, being stronger for years with generally negative phase of the Southern Annular Mode (SAM). On a bi-decadal scale, positive isotope anomalies are associated with oceanic warming and a westward sea surface temperature gradient in the equatorial Pacific. The data reveals that the multi-decadal positive trend in the annual mean $\delta^{18}\text{O}$ values from the analyzed cores are indicative of the atmospheric warming that begun in this part of the DML already in the 1910s (Divine *et al.*, 2009). The trend in $\delta^{18}\text{O}$ record, quantified in terms of long-term surface air temperature (SAT) changes, is consistent with the instrumental data from the Novo station.

3.2. Recent high-resolution ice core proxy data from coastal Dronning Maud Land

Considering the significant spatial variability within the Antarctica and limited nature of the available climate

proxy records in coastal Antarctica, researchers from National centre for Antarctic and Ocean Research (NCAOR) and Geological Survey of India (GSI) have undertaken a project to retrieve and study ice cores from coastal Dronning Maud Land (Fig. 1). The studies substantiated the importance of ice cores for reconstructing Antarctic climate change beyond the instrumental period (Nijampurkar *et al.*, 2002; Thamban *et al.*, 2006; Naik *et al.*, 2010 a & b; Laluraj *et al.*, 2011; Thamban *et al.*, 2011). The dedicated facility for ice core research established at NCAOR is the first of its kind in India and has sophisticated facilities for the storage, archival, processing and analysis of ice cores. The Indian initiatives also contribute to the International Trans Antarctic Scientific Expedition (ITASE) programme of SCAR. These high-resolution (seasonal to annual) ice core studies revealed the utility of ice records to reconstruct the natural environmental processes like the global volcanic eruptions, microbial environments, as well as the polar and extra-tropical climatic teleconnections during the past hundreds of years.

Two ice cores detailed here have shown considerable variations of $\delta^{18}\text{O}$ and δD profiles in both IND-25/B5 and IND-22/B4 cores on an interannual to decadal scale,

supporting changes in surface air temperature and circulation changes in the coastal DML region (Figs. 3 & 4). Comparison of the temperature proxy records ($\delta^{18}\text{O}$ and δD) of the high accumulation core (IND-25/B5) with the available long-term (~50 years) meteorological data of Novo station in coastal DML revealed a positive correlation. The close similarity between the 'Novo' summer temperature record and the corresponding periods in IND-25/B5 $\delta^{18}\text{O}$ record suggest that the $\delta^{18}\text{O}$ record could be utilised for deducing the general surface air temperature (SAT) for this region. Additionally, this core also provides an opportunity to study the linkages between the polar and tropical climatic modes.

The tropospheric circulation in Antarctica is considered to be driven primarily by the Southern Annular mode (SAM) and El Niño Southern Oscillation (ENSO) on an interannual to decadal timescale (Thompson and Wallace, 2000). Over the last 50 years, the SAM has shifted more into its positive phase with decreases of surface pressure over the Antarctic and corresponding increases at mid-latitudes (Marshall, 2003). The positive trend in the SAM seems to have resulted in a strengthening of the circumpolar westerlies and contributed to the spatial variability in Antarctic temperature change (Kwok and Comiso, 2002). Most importantly, ENSO is also known to affect the SAM in a highly non-linear way. The SAM and ENSO forcings can combine, partially offset or even enhance their influence on each other and the Southern Hemisphere as a whole (Fogt and Bromwich, 2006).

A study based on instrumental data from Halley station as well as the IND-25/B5 proxy record from coastal DML revealed that the key factor affecting the regional SAM-temperature relationship is the relative magnitude of two climatological low pressure centres to the west and east of the area, which determines the source region of air masses advected into the locality (Marshall *et al.*, 2011). Relationships between the surface air temperature, SAM and ENSO in the study region were evaluated using the annual $\delta^{18}\text{O}$ record of IND-25/B5, the reconstructed SOI (Southern Oscillation Index) as well as the SAM indices. Comparison of the IND-25/B5 ice core $\delta^{18}\text{O}$ record with the reconstructed index of SAM for the period 1905 to 2005 depicted slight negative correlation, suggesting that higher polarity of SAM corresponds to lower temperatures in the region and vice versa (Naik *et al.*, 2010 b). The analysis showed that for the period wherein the $\delta^{18}\text{O}$ and SAM relationship was insignificant or positive (1918-1927; 1938-1947 and 1989-2005), the relationships between the SOI and SAM are also in-phase (Naik *et al.*, 2010 b). This indicates that during warm ENSO events, positive $\delta^{18}\text{O}$ anomalies exist in the study site and *vice versa*. Further, the above periods (1918-

1927; 1938-1947 and 1989-2005) incorporate several El Niño and La Niña years. When the years of El Niño and La Niña events are omitted from the records, the relationship between the filtered $\delta^{18}\text{O}$ and SAM data became statistically significant, suggesting that ENSO events weakens the SAM-temperature relationship (Naik *et al.*, 2010 b). Above study demonstrated that during the past century, the combined influence of ENSO-SAM modes have controlled the temporal changes in $\delta^{18}\text{O}$ values at the core site.

Stable isotope profiles of IND 22/B4 revealed that the $\delta^{18}\text{O}$ and δD values were significantly more negative during 1550- 1715 AD coeval with the "Little Ice Age" (LIA), suggesting cooler temperatures during this period (Thamban *et al.*, 2011). The stable isotope records of IND 22/B4 suggest that relatively depleted $\delta^{18}\text{O}$ and δD are synchronous with periods of reduced solar activity like the Dalton Minimum (~1790-1830 AD) and Maunder Minimum (~1640-1710 AD), indicating relatively lower air temperatures during these periods (Fig. 4). Earlier studies have already suggested that solar forcing possibly influenced the Antarctic climate system (Bard *et al.*, 2000). The solar modulation of the southern hemisphere climate system is suggested to be through the dynamical coupling between the troposphere and stratosphere during the late spring/winter (Kuroda *et al.* 2007). Accordingly, enhanced solar activity would enhance the ultraviolet and ozone production that would lead to stronger troposphere-stratosphere coupling through a strong interaction between the planetary waves and radiation. Our study in association with multiple ice records from Antarctica as well as the proxy records of solar variability suggest an inherent influence of solar forcing on the Antarctic climate change in the past.

The oxygen isotopic composition of polar snow provides a valuable temperature proxy since a strong spatial relationship exists between average local surface air temperature (SAT) and isotopic composition of local precipitation (Dansgaard, 1964). While the relation between $\delta^{18}\text{O}$ and temperature are not completely known at the study region, using data from central DML from Masson-Delmotte *et al.* (2008), the spatial $\delta^{18}\text{O}$ -T slope was estimated to be 1.31% / °C (Naik *et al.*, 2010 b). Applying this $\delta^{18}\text{O}$ -T spatial slope to the $\delta^{18}\text{O}$ profiles of IND-25/B5, the surface temperatures were estimated to be between -33.7 and -12.4°C (Fig. 3). The SAT record of IND-25/B5 exhibited high amplitude oscillations, with an average warming of 1°C for the entire century (1905-2005) with a trend of 0.1°C / decade. This is comparable to the estimated warming over the West Antarctica (0.1°C / 10 years) for the last 50 years (Steig *et al.*, 2009). The IND-25/B5 SAT record also revealed greatly enhanced warming trend since 1930s, with a warming of

~0.4°C/10 years (Fig. 3). As discussed in earlier session, the instrumental record of the nearby Novo station also revealed a warming for the last ~50 years with similar temperature trend as found in the IND-25/B5 ice core. These records are further supported by another coastal ice core from coastal DML, which estimates a positive trend of the order of 0.12%/decade for a similar time period (Divine *et al.*, 2009).

The reconstructed $\delta^{18}\text{O}$ -derived SAT record of IND-22/B4 also demonstrates an inter-annual to decadal variability with a long-term positive trend (Thamban *et al.*, 2011). The SAT record using the $\delta^{18}\text{O}$ -T relationship as defined earlier showed that during the last ~470 years, the temperature fluctuated between -27.9 and -13.8°C at the core site (Fig. 4). The estimated warming at this site is ~2.7°C for the past 470 years, with a positive trend of 0.6°C per century. Although this is lower than at the IND-25/B5 site, it may be noted that the relatively longer time period as well as the coarser sampling resolution at IND-22/B4 site may introduce increased uncertainty in the SAT estimation. However, it is significant that both the records confirm that the region has indeed warmed during the past few centuries. Considering the inherent inconsistencies of the instrumental and proxy records as well as taking into consideration of the spatial heterogeneity, it is not surprising to see the variability among the various records. These records while confirming the instrumental record of warming trend at Novo station advocate that the generalised picture of a warming trend in West Antarctica and a unchanged (or even cooling trend) in East Antarctica (*e.g.*, Chapman and Walsh, 2007; Steig *et al.* 2009) needs to be confirmed. Considering such spatial and temporal variability of Antarctic climate, it is crucial to synthesize a continental-wide temperature reconstruction for the past few centuries using a combined network of instrumental and ice core based proxy records.

4. Conclusion

Analysis of the Novolazarevskaya instrumental record (since 1961) from coastal Dronning Maud Land revealed that the region has undergone a substantial changes during the recent decades, with a significant warming at a rate of 0.25 °C / decade. In order to understand the spatial and temporal consistency of these findings, stable isotope proxy records of well-dated ice cores from the coastal Dronning Maud Land region of East Antarctica were assessed. These records provided insights on the influence of solar forcing on Antarctic climate system as well as its linkages with the tropical and mid-latitude climatic modes like the Southern Annular Mode (SAM) and El Niño Southern Oscillation (ENSO).

The calculated surface air temperatures using these records showed a warming by 0.06-0.1 °C / decade, with greatly enhanced warming during the past several decades (~0.4 °C / decade). It is proposed that the coastal areas of Dronning Maud Land are warming, and the trend is apparently enhancing in the recent decades.

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