Changing climate in Antarctica

Increase in surface air temperature in Antarctica has been a subject of major concern in recent years, as it may destroy the existing ecosystem and exert varied adverse effects on mankind and vegetation. Atmospheric temperature depends on the amount of solar energy the earth receives and how much of this energy it retains through greenhouse gases (GHGs)[1,2]. As ground-based weather stations in Antarctica are few and far between, especially in the high-altitude interiors, and automated weather stations are also sparse, it is difficult to evaluate the changing climate across the entire continent. In addition, the harsh environment takes a toll on equipment, and long gaps of missing data interrupt the time series of some stations[3]. Although satellite-based temperature records provide a complete, continuous view of the continent from the early 1980s, they have their own limitations such as cloud interference and trends in skin temperatures. Moreover, using long-term data from different sensors is challenging because each sensor has its own limitations and may measure temperatures differently. Apart from this, if the sensors are not in orbit at the same time, simultaneous comparison of observations from different sensors is difficult. Scientists from NASA's Goddard Space Flight Center have observed from 26-year satellite record that the temperature increases are greater and more widespread in West Antarctica than in East Antarctica, where some areas show little change or even a cooling trend[3]. Mulvaney *et al.*[4] have observed that Antarctica is warming at one of its fastest rates and the most recent warming is faster than 99.7% of any other given 100-year period in the last 2000 years. They have observed that warming for several centuries has rendered ice shelves in the northeastern Antarctic Peninsula vulnerable to collapse and have suggested that continued warming is likely to cause ice-shelf instability to encroach farther southward along the Antarctic Peninsula. Chapman and Walsh[5] have observed that the climate of Antarctica does not exhibit any clear trend. Extensive study of climate change and its possible causes has been carried out in the Antarctic region. Almost all studies are in agreement that the temperature increases are greater and more widespread in West than in East Antarctica. However, as most of these studies involve long-term temperature trends measured over a continuous period of time varying between 26 and 2000 years, it may be possible that they have missed out on the finer aspects, which could provide a link to whether the recent rapid warming is natural or anthropogenic[6–8]. In light of this, the decadal temperature trend at 18 Antarctic stations has been examined over a period of 50 years and the possible association of this trend with that of solar activity, total ozone, CO_2 and ENSO has been explored as it may have a significant impact on the recent rapid warming.

Monthly mean surface temperature for 18 stations distributed over the entire Antarctic continent (Figure 1) has been obtained over a period of five decades from the Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, USA. Data prior to 2001 are based on READER (REference Antarctic Data for Environmental Research) project. These data are calculated from 6-hourly synoptic data[9]. Post-2000 data have been obtained from the American Meteorological Research Center (AMRC), USA. Long-term total ozone data for Halley station (75°35′S, 26°30′W) and Vernadsky station (65°15′S, 64°16′W) were obtained from Natural Environment Research Council–British Antarctic Survey, UK. Long-term daily CO_2 concentrations (ppmv) derived from flask air samples and *in situ* air measurements have been obtained from Scripps Institution of Oceanography, Scripps CO_2 Program, USA. The data have been averaged to yield monthly mean values for the south pole (90°S). Details of the data can be obtained from Keeling *et al.*[10,11]. Figure 6 representing the multivariate ENSO index has been taken from the website: http://www.esrl.noaa.gov/psd/enso/mei/index.html. The sunspot numbers have been downloaded from the website: http://solarscience.msfc.nasa.gov/SunspotCycle.shtml

The monthly mean temperature at each Antarctic station has been averaged on a yearly basis and the overall linear trends from 1960 to 2009 have been examined at these 18 stations over a period of 50 years. It is observed that 14 out of 18 Antarctic stations covered in this study indicate a warming trend, while four stations indicate a cooling trend (Table 1).

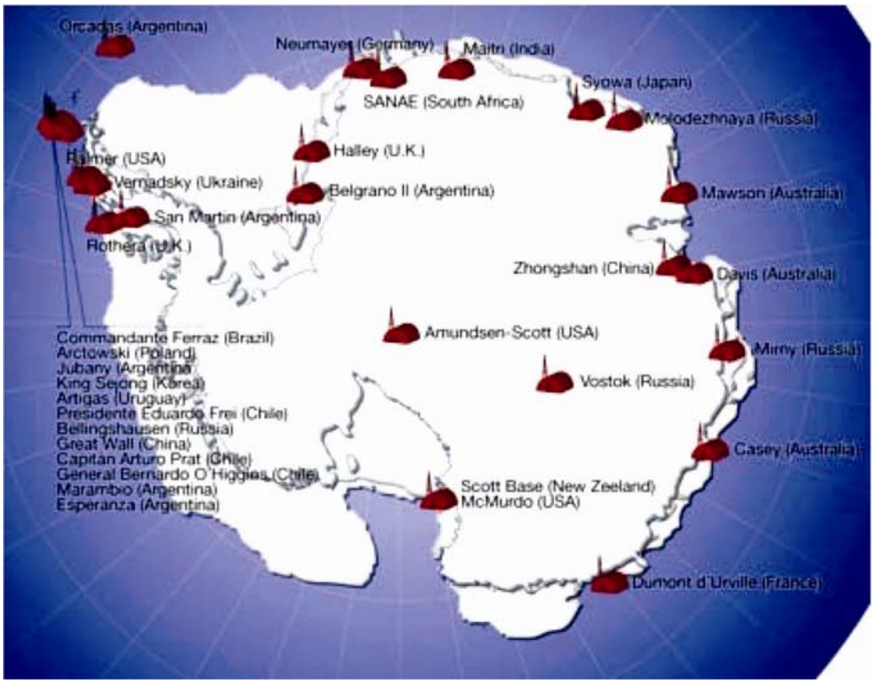

Figure 1. Major research stations in Antarctica. (Source: Ahlenius, H., International Polar Year educational posters, UNEP/GRID-Arendal, 2008; http://www.grida.no/polar/ipy/2843.aspx.).

Table 1. Overall yearly mean linear temperature trend at Antarctic stations from 1960 to 2009

Antarctic station	Overall trend from 1960 to 2009 (°C/decade)	
Amundsen-Scott (90°S, 0°E)	–0.008	
Novolazarevskaya station (70°46′S, 11°50′E)	0.189	
Syowa station (69°00′S, 39°35′E)	0.09	
Mawson (67°36′S, 62°52′E)	0.033	No. of stations showing a warming trend: 14/18
Davis station (68°35′S, 77°58′E)	0.109	
Mirny (66°33′S, 93°01′E)	0.141	
Vostok station (78°27′S, 106°52′E)	0.174	
Casey station (66°17′S, 110°32′E)	0.122	
Dumont d'Urville station (66°40′S, 140°00′E)	–0.033	
Scott Base station (77°51′S, 166°46′E)	0.130	
Neumayer station (70°39′S, 8°15′W)	–0.052	
Halley station (75°35′S, 26°30′W)	–0.155	No. of stations showing a cooling trend: 4/18
Orcadas station (60°45′S, 44°43′W)	0.20	
Marambio station (64°15′S, 56°39′W)	0.489	
Esperanza station (63°24′S, 57°7′W)	0.302	
Bellingshausen (62°12′S, 58°58′W)	0.203	
Vernadsky station (65°15′S, 64°16′W)	0.469	
Rothera station (67°34′S, 68°08′W)	0.361	

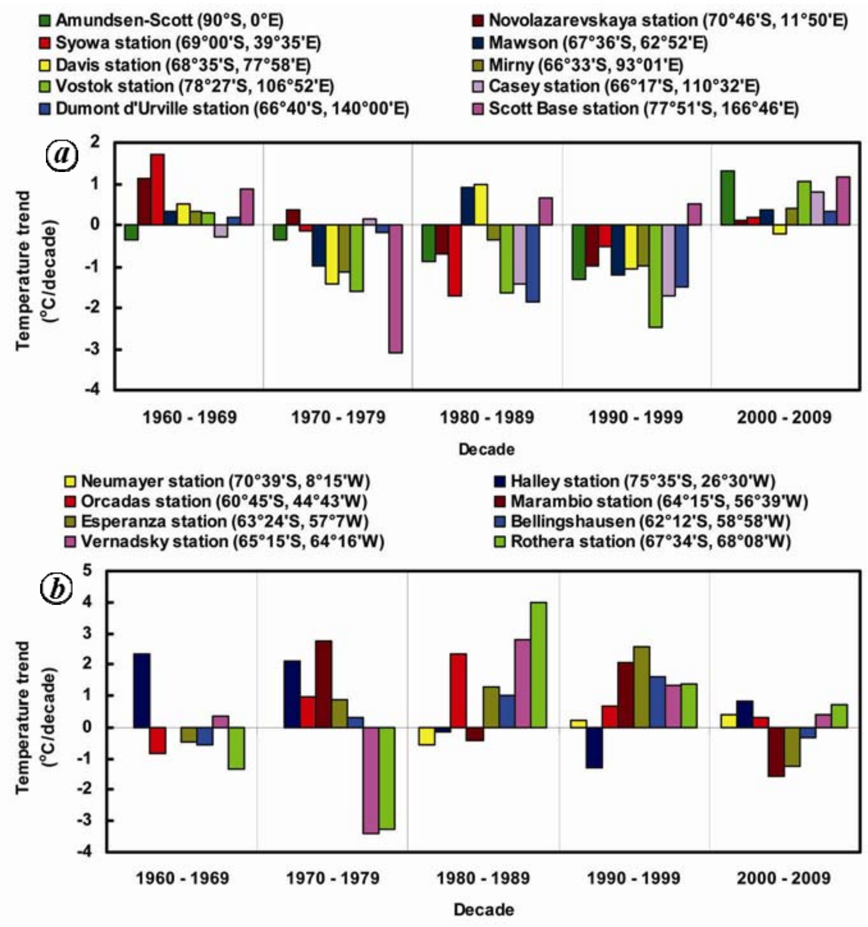

Figure 2. Decadal trend of temperature in (***a***) East Antarctica and (***b***) West Antarctica stations.

The warming trend is higher in West Antarctica than in East Antarctica, similar to that observed in the earlier studies. East Antarctica is comparatively cooler, because it has a higher elevation compared to West Antarctica. However, as the Antarctic climate is a mixture of countervailing signals from both natural and anthropogenic factors, this overall trend is not statistically significant for some stations distributed over the entire continent. Therefore, the entire dataset was further grouped into five decades (1960–1969; 1970–1979; 1980–1989; 1990–1999; 2000–2009) and the linear trend of yearly mean temperature was examined for different decades. The decadal temperature trend in East Antarctica (Figure 2) indicates that warming is relatively small but more widespread during the decades 1960–1969 and 2000–2009. The period from 1970 to 1999 indicates a widespread and significant cooling trend. The situation is exactly the opposite in West Antarctica (Figure 2), where warming is relatively large and more widespread during the decade 1970–1999. It is relatively small but widespread during 2000–2009. The period from 1960 to 1969 indicates a widespread cooling trend. During the period 1970–1979, Vernadsky and Rothera stations situated on the western coast of Antarctica show a sharp decreasing trend in temperature (–3.3°C/decade) compared to other nearby stations situated in the interior of the continent. This could be due to the strong effect of the southern westerlies, which comprise of a tight ring of winds encircling the Antarctic continent. Whenever these westerlies intensify due to higher stratospheric ozone depletion[12,13], Antarctica tends to cool as surface air pressure inside the ring decreases[14]. Since ozone depletion is strong but non-uniform over Antarctica[15], this strong cooling effect is also unique but

Table 2. Decadal climate change observed in East and West Antarctic stations

Decade	Number of stations in East Antarctica		Number of stations in West Antarctica	
	Warming	Cooling	Warming	Cooling
1960–1969	8	2	2	4
1970–1979	2	8	5	2
1980–1989	3	7	5	3
1990–1999	1	9	7	1
2000–2009	9	1	5	3

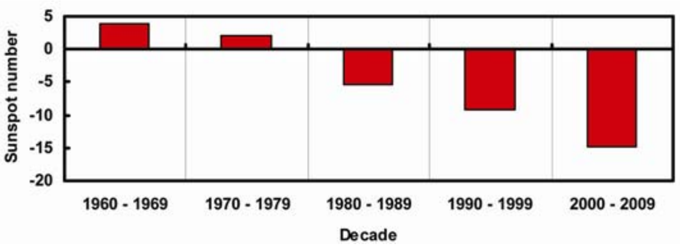

Figure 3. Decadal trend of solar activity.

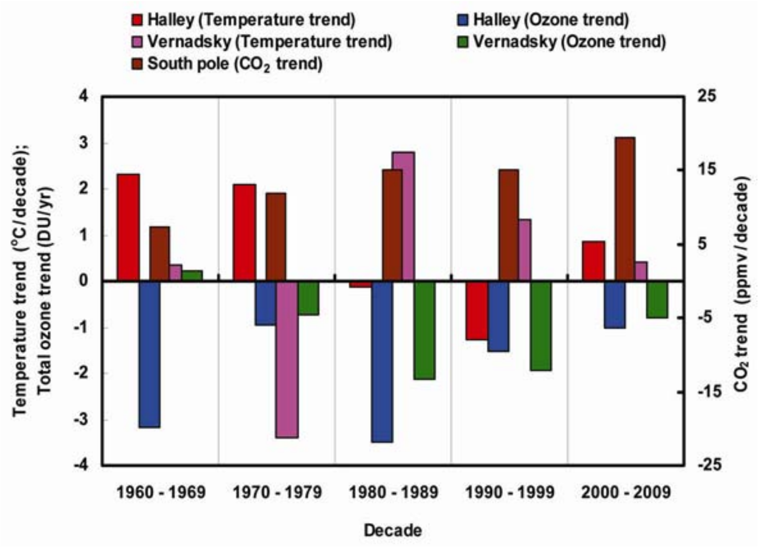

Figure 4. Comparison of decadal trend of temperature with decadal trend of CO_2 and yearly trend of total ozone.

not uniform over the entire continent. The results are summarized in Table 2. The possible association of the observed decadal temperature trend to that of solar activity (Figure 3), and total ozone and CO_2 (Figure 4) has been explored. As the output of solar UV radiation increases with increase in sunspot activity, the global temperature increases. Decreasing trend in total ozone (comprising of 90% stratospheric ozone) will result in an amplification of UV radiation reaching the ground, which is likely to induce a significant warming effect. Similarly, an increasing trend in CO_2 which is a prominent GHG is also likely to induce a significant warming effect. Long-term total ozone data could be obtained for only two West Antarctic stations, namely Halley and Vernadsky. Monthly mean CO_2 indicates an overall increasing trend of 1.173 ppmv/decade from 1960 to 2009. However, the decadal trend in temperature and CO_2 has a direct correlation at Halley station during the decades 1960–1979 and 2000–2009, and at Vernadsky station during the decades 1960–1969 and 1980–2009 as expected, and an inverse correlation during the remaining decades. This indicates that the warming trend in response to increasing concentration of CO_2 is weak in the Antarctic region. To evaluate the possible causes for the observed discrepancies, the association of decadal trend in temperature to the occurrence of El Niño/La Niña has been explored. The El Niño current arises, as the ocean and atmosphere interact, to balance the Earth's thermal energy. Normally, the waters of the eastern Pacific Ocean near South America are quite cool as a result of upwelling ocean currents. The tropospheric trade winds normally traverse from east to west in this region. However, in an El Niño period, the trade winds weaken, allowing the warmer waters of the western Pacific to migrate eastwards. This change in temperature of the sea-surface water causes large-scale shifts in the global circulation patterns in the troposphere and lower stratosphere. This oscillation is irregular, with a period of 4–7 years between episodes and typically lasts for 12–18 months. World map indicating the mixing of Atlantic, Pacific and Indian Oceans near the Antarctic continent is shown in Figure 5. Multivariate ENSO index (MEI) is a weighted average of the main ENSO features contained in the six variables: sea-level pressure, the east-west and north-south components of the surface wind, sea-surface temperature (SST), surface air temperature and total amount of cloudiness. When this index is negative, we have a La Niña (or ocean cooling), and when it is positive, we have an El Niño (or ocean warming). The stations in West Antarctica indicate a higher decadal warming trend during El Niño events as observed from Figure 6, while the stations in East Antarctica do not indicate any significant warming trend in response to El Niño. The increasing trend in temperature at Vernadsky station during 1960–1969 may be due to an increase in solar activity and increasing trend in CO_2 concentration. Decreasing trend in temperature during 1970–1979 may be due to the occurrence of La Niña events, whereas increasing trend in temperature during 1980–2009 may be due to an increase in CO_2 concentration and decrease in total ozone. The increasing trend in temperature at Halley station during 1960–1979 may be due to combined effects of an increase in solar activity, decrease in total ozone and increasing trend in CO_2 concentration. The decreasing trend in temperature during 1980–1999 may be due to a decrease

Figure 5. World map indicating the mixing of Atlantic, Pacific and Indian Oceans near the Antarctic continent. (Source: http://www.mapsofindia.com/worldmap/continents.html.)

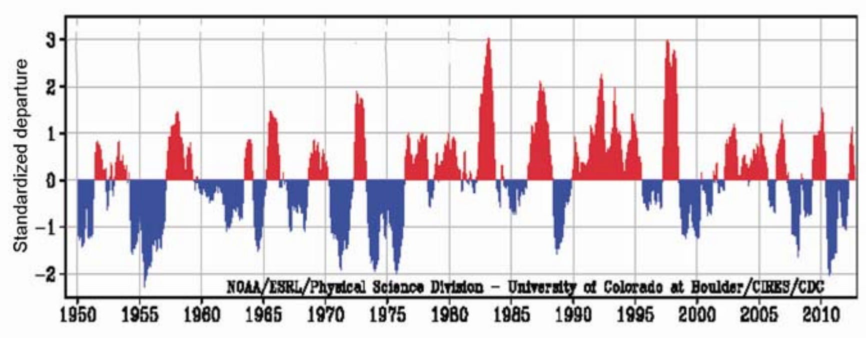

Figure 6. Multivariate ENSO index.

in solar activity, while increasing trend in temperature during 2000–2009 may be due to an increase in CO_2 concentration and decrease in total ozone. It may also be possible that due to simultaneous decrease in total ozone, increase in CO_2 concentration and occurrence of a large number of El Niño events the initial warm temperature might have caused higher precipitation, which in turn cooled Halley station resulting in a decreasing trend in temperature during the decades 1980–1999 (ref. 16). Another possibility could be that ozone loss might have caused the stratosphere above Halley station to cool, which in turn strengthened the polar vortex resulting in a more effective atmospheric barrier to the penetration of warmer air from the coastal areas[17].

It is concluded from this study that the climate of Antarctica has not changed monotonically in a single direction over these five decades and both natural factors (such as solar activity and ENSO) and anthropogenic factors (such as total ozone variability and GHG emissions) have contributed towards climate change in this continent. It is further observed that the warming trend in response to increasing concentration of CO_2 is weak in the Antarctic region.

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NANDITA D. GANGULY

Department of Physics,
St Xavier's College,
Ahmedabad 380 009, India
e-mail: ganguly.nandita@gmail.com

Remote sensing of moving objects

Traditionally, moving object characterization with remote sensors was done using RADAR systems, image sequences or videos[1,2], but, it is not always possible to acquire these datasets. However, recent developments in very high resolution (VHR) remote sensing sensors have opened a new opportunity in extracting moving object information using single-pass optical imagery. For this type of application, the challenges include: first, extracting target location in both multispectral (MS) and panchromatic (PAN) bands and second, exploiting the small time lag between the acquisition of MS and PAN bands created due to typical construction of line scanners. Several researchers have attempted to identify and estimate velocity of moving targets using single VHR optical images, for example, using 1 m resolution satellite and airborne images[3], Quickbird images[4,5] or IKONOS images[6]. Extraction of the target location becomes difficult with decreasing spatial resolution. The spatial resolution of MS bands in Quickbird and IKONOS is 2.4 and 4 m respectively, which is comparable with the dimension of small/medium (length less than 4 m) vehicles and is insufficient for inferring the shape of larger vehicles. Fusion of MS and PAN bands is not a solution in such cases because of the apparent mismatch in these bands for moving objects. This issue can be successfully addressed using finer resolution MS and PAN images having a finite time gap between acquisitions.

WorldView2 (WV2), launched in October 2009, provides 2 m spatial resolution, 8-band MS images and 0.5 m resolution PAN images, which is the highest spatial resolution among all commercially available satellites at present. Few studies have used single-pass WV2 images for moving target information extraction[7,8]. In this study, the potential of WV2 images for identifying and characterizing moving targets has been explored. Eight MS bands of WV2 system are arranged in two arrays (MS1 and MS2) of four MS bands each: MS1 consists of NIR1, Red, Green and Blue, and MS2 consists of Red Edge, Yellow, Coastal and NIR2. The focal plane layout of WV2 is shown in Figure 1.

The MS arrays are positioned on either side of the PAN array. Due to this hardware arrangement, the sequence of image collection in MS1, PAN and MS2 leads to a time lag of approximately 0.17 s between PAN and MS1/2 and 0.35 s between MS1 and MS2 (ref. 7). Besides this, hardware limitations have put further constraints on the Time Delay and Integration (TDI) settings of the MS bands: the following pairs, i.e. NIR1 and Red; Green and Blue; Red Edge and Yellow, and Coastal and NIR2 must have the same TDI (ref. 9), creating maximum time lag between NIR1 and NIR2 acquisition.

In most cases, inter-band time lag is not negligible for movement detection. However, for fast-moving objects like aircraft, due to this time lag a displacement is caused between object positions when viewed in different bands. Therefore, an aircraft visible in WV2 image, acquired on 19 February 2010 was selected as a moving object. The object in eight different bands is shown in

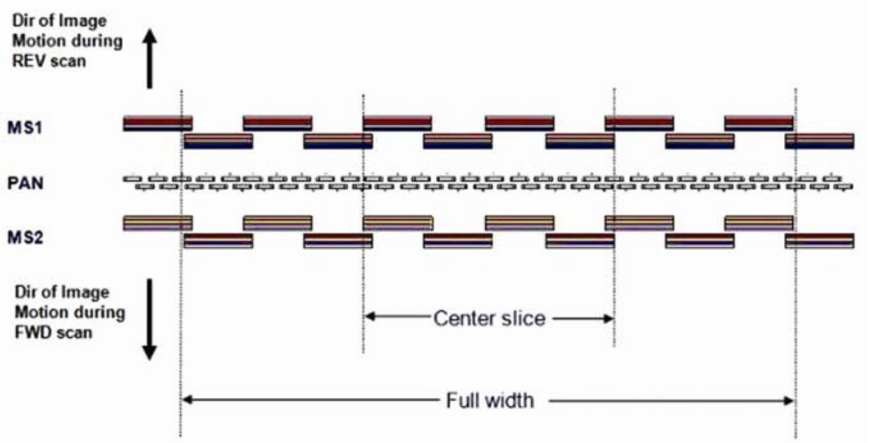

Figure 1. The focal plane layout of WorldView2 (source: DigitalGlobe[9]).