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The Meteorology and Climatology of the Antarctic Plateau

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Abstract. This paper provides a brief introduction to the meteorological conditions and processes that are important on the Antarctic Plateau and considers the long term climatological means and variability of some of the main elements based on satellite and in-situ data. Sources of further data available on the World Wide Web are also given. For much more information on the subject the reader is referred to King and Turner (1997).

1. Broadscale circulation and weather systems

The atmospheric circulations of the Arctic and Antarctic are very different as a result of the contrasting land/sea distributions in the Northern and Southern Hemispheres. The Arctic consists largely of a frozen ocean, and the presence of the major mountain ranges of the Himalayas and the Rockies means that the troposheric flow is highly meridional with many weather systems reaching high latitudes and occasionally crossing the Arctic Ocean. On the other hand, the Southern Hemisphere has few large, high land masses so that the depressions move in a much more zonal track, only spiralling gradually towards the Antarctic coastal regions. The fact that the Antarctic consists of a large, high mass of ice centred close to the South Pole has a huge impact on the atmospheric circulation of the Southern Hemisphere. Depressions moving southwards from mid-latitudes tend to become slow-moving or start to track towards the east in the Antarctic coastal region as they come up against the steep orography of the Antarctic coastal region. There are therefore few active depressions over the Antarctic interior, although some depressions do penetrated to Dome C, South Pole or even Vostok when the mid-tropospheric flow is more meridional. This appears to happen as part of natural climate variability and can be detected by a sudden, rapid rise of temperature at the interior stations, the presence of cloud and occasionally moderate precipitation falling. A rapid rise of temperature at several stations on the plateau was documented by Sinclair (1981). During this event over 25-29 December 1978 the relatively high temperatures of 13.6°C (South Pole) and 15.7°C (Vostok) were recorded. A less extreme incursion of a front and complex area of low pressure over the interior of East Antarctica

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was examined by Pook and Cowled (1999). Depressions are more common over West Antarctica than East Antarctica because of the lower elevations.

2. Surface temperature

We have a relatively good knowledge of mean annual near-surface air temperatures across the Antarctic since the ice temperature at 10 m below the snow surface is a good approximation to this quantity and many short ice cores have been drilled across the continent during traverses. A map of mean temperature produced using these data is shown in Figure 1. The temperatures are closely correlated with elevation, and drop rapidly inland of the coast, with the lowest annual mean temperatures of less than -55°C being found at the highest locations of East Antarctica.

We have less information on seasonal mean temperatures since these cannot be determined from ice core data. Nevertheless, Vostok and Amundsen-Scott Station at the South Pole have operated for extended periods on the plateau and mean climatological data are summarised in Table 1. It can be seem from the standard deviations in Table 1 that the interannual variability of the annual and seasonal temperatures are small at both stations.

The annual cycle of surface temperature on the plateau is unlike that found in mid-latitudes, where the temperature gradually drops until mid-winter and then rises again at the same rate. Stations in the Antarctic interior experience a 'coreless' winter where temperatures drop rapidly at the start of winter and then remain relatively constant until there is a rapid rise of temperature at the end of winter as the sun returns. This temperature regime is experienced because of the rapid loss of heat that occurs in the dry atmosphere when the sun sets at the start of the winter, coupled with the isolation of the plateau from mild, maritime airmasses over the ocean.

3. Upper air temperatures

The lower part of the Antarctic troposphere is much more strongly stratified than the atmosphere in mid-latitudes. The troposphere is stably stratified throughout the year but the stability is strongest below 4 km during winter. A tropopause is very evident in the summer but becomes very indistinct in winter as the stratosphere cools rapidly.

A remarkable feature of the temperature conditions on the plateau is the very strong, low level temperature inversion (rise of temperature with increasing elevation). The inversion is strongest in winter when the temperature difference between the surface and several hundred meters above the surface can be more than 25°C (see Phillpot and Zillman, 1970). At Vostok the strength (depth) of the inversion varies from about 25°C (500 m) in July to 7°C (300 m) in January. The inversion is so strong because of the intense emission of infra-red radiation from the surface in the dry, cloud free conditions.

4. The surface wind field

The wind field of the Antarctic is one of the most marked characteristics of the continent with the persistent katabatic winds in parts of the coastal region being the most directionally constant on Earth. Models have allowed us to produce a good picture of near-surface winds over the continent and the winter season wind field from a recent high resolution model study (van Lipzig et al., submitted) is shown in Figure 2. The winds are strongest during the winter when the strong radiational cooling produces a large pool of cold air on the plateau to feed the katabatic wind system. It can be seen that strong katabatic winds are not found all around the coastal region, but are concentrated in the main glacial valleys, particularly around the coast of East Antarctica. Although the strongest winds are in the coastal region, strong downslope winds are still found over parts of the inte-

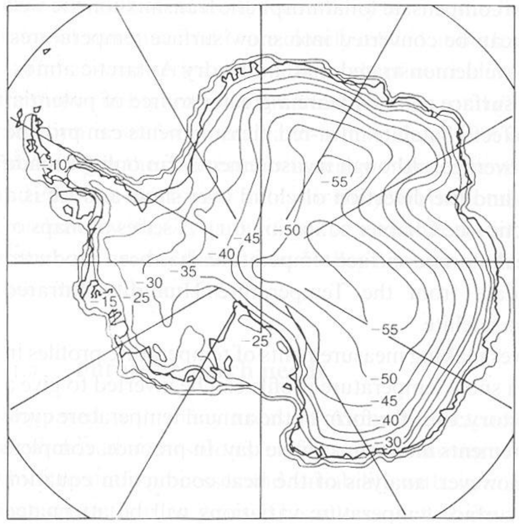

Fig. 1. Annual mean surface temperatures deduced from 10 m snow temperature measurements. From Connolley and Cattle (1987).

rior, such as the flow down onto the Amery Ice Shelf. The lightest winds are not surprisingly found over the highest parts of the interior along an arc running across East Antarctica. Mean annual and seasonal wind speeds for Vostok and South Pole are given in Table 2. It can be seen that South Pole has slightly stronger winds than Vostok in all seasons except summer, and in the annual means. The standard deviations for South pole are about double those of Vostok in most seasons indicating the fact that active weather systems play a greater role in dictating the weather at the station compared to Vostok.

5. Cloud

As far as optically dense cloud is concerned, mean cloud fractions decrease rapidly inland from the coast with increasing distance from the areas of open water and as the numbers of depressions decrease. Yet isolated areas of cloud can be observed on satellite imagery of the plateau. But the major feature of the interior is the thin veil of semi-transparent cirrus that can present. This can be very difficult for meteorological observers to detect, especially in winter and can result in the observer having to decide whether zero or ten tenths of cloud should be reported. The in-situ cloud observations from South Pole suggest that the mean cloud fraction is about 45%, with the most common types of cloud being cirrus (30%), altostratus (23%), nimbostratus (4%) and stratus (3%). Over the interior the observations suggest that most cloud is found in the spring and the least in winter, although the previously mentioned problems of detecting cloud during the winter may be a factor here. A detailed analysis of the cloud found over the Antarctic is presented in Warren et al. (1986).

6. Precipitation

The precipitation regimes of the coastal region and the interior are very different, with the edge of the continent receiving most precipitation from active depressions and the interior getting most of its accumulation from a gradual fall out of ice crystals known as 'diamond dust' or 'clear sky precipitation'. As can be seen in Figure 3, the largest accumulation is found over the

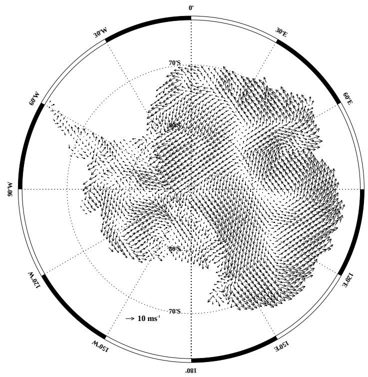

Fig. 2. The mean winter (June-August) vector wind field at 7 m for 1980-93 from the modelling study of van Lipzig et al. (submitted).

Antarctic Peninsula, which is located at relatively northerly latitudes and is affected by more depressions. Considering the rest of the Antarctic, the greatest amount of precipitation is found along the coast to the south of the Bellingshausen Sea. The mean annual accumulation decreases rapidly inland of the coast and over much of East Antarctica is less than 5 cm water equivalent. Hogan (1975) has estimated that Amundsen-Scott station receives less than 7 cm water equivalent of accumulation per year.

7. Climate variability and change

Inter-annual climate variability in the Antarctic coastal regions is larger than at lower latitudes because of feedback mechanisms related to the snow and sea ice cover. But in the interior the inter-annual variability of temperature and wind speed is rather small, as can be seen from Tables 1 and 2. The greatest climatic anomalies over the interior occur when maritime airmasses penetrate, which tends to occur when the planetary waves across the Southern Hemisphere are amplified. Such conditions occurred during the Austral summer of 2001-02, resulting in near record high temperatures at a number of stations (Turner et al., 2002). Vostok experienced anomalously warm temperatures over this period, with the mean surface temperatures for November 2001 to January 2002 being respectively 2.2, 1.4 and 3.2°C warmer than the long term means, the latter figure being 1.5 sd above average. In addition, on 11 January 2002 the station experienced a temperature of 16.5°C, which was within 3°C of the absolute maximum temperature ever recorded at the station. At Dome C the European Programme for Ice Coring in Antarctic (EPICA) was undertaking a season of drilling and experienced a number of periods of slight to moderate snowfall (E. Wolff, personal communication) more typical of a coastal site than an interior location that usually only receives clear sky precipitation. This resulted from the persistent high pressure to the south and southwest of Australia bringing maritime air masses into the interior of the continent on its western flank.

Climate change at the Antarctic stations is discussed in detail by Turner et al. (submitted). The in-situ temperature data suggests that Amundsen-Scott station has cooled at a statistically significant rate throughout the year over the period 1958-2000. However, Vostok data do not show any statistically significant tends over the year or in any season.

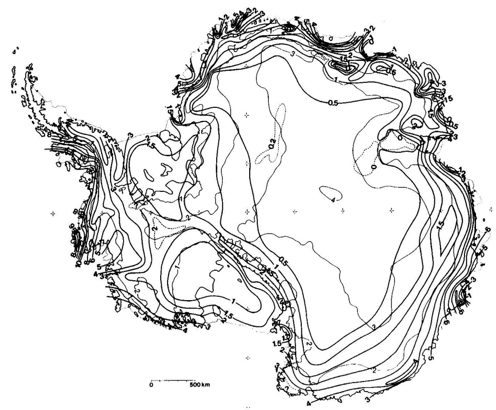

Fig. 3. Precipitation over the Antarctic estimated from ice core data. The units are cm water equivalent * 0.1. From Bromwich (1988).

Station	Annual	Autumn	Winter	Spring	Summer	Period
Vostok	-55.4 (0.8)	-63.0 (1.6)	-66.8 (2.2)	-55.5 (1.3)	-36.1 (1.0)	1958-2000
South Pole	-49.5 (0.6)	-56.6 (1.2)	-59.3 (1.6)	-49.7 (1.6)	-32.4 (1.4)	1958-2000

Table 1. Annual and seasonal mean near-surface temperatures (deg C) for the two stations with long records on the Plateau. The figures in parentheses are the standard deviations

Station	Annual	Autumn	Winter	Spring	Summer	Period
Vostok	10.1 (0.7)	10.8 (0.8)	10.5 (1.0)	10.3 (0.9)	9.1 (0.7)	1958- 2000
South Pole	10.6 (1.3)	11.0 (1.7)	11.8 (1.9)	11.1 (1.7)	8.4 (0.9)	1958- 2000

Table 2. Annual and seasonal mean near-surface wind speed (kts) for the two stations with long records on the Plateau. The figures in parentheses are the standard deviations.

8. Data sources

Monthly mean values of temperature, surface pressure and wind speed extending back to the 1950s for stations with long records can be found at the SCAR READER project web site at http://www.antarctica.ac.uk/met/READER/Data. Data for other stations with shorter records can be found at http://www.bas.ac.uk/met/metlog/. Current Antarctic observations can be found at the same location.

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