Climate data for five Antarctic research stations

Resource C1

	Month of Year												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual mean
Amundsen-Scott (South Pole)													
(90°S: 2800 m)													
mean temperature (°C)	-28.1	-40.7	-54.1	-57.2	-58.0	-58.4	-59.5	-59.7	-59.3	-51.1	-38.4	-27.9	-49.4
mean windspeed (km/hr)													20.9
mean radiation (watts/m^2)													
total precipitation (mm)													<70
Vostok													
(78.5°S, 106.9°E: 3488 m)													
mean temperature (°C)	-32.1	-44.2	-57.9	-64.8	-65.8	-65.2	-66.7	-68.2	-66.2	-56.9	-43.2	-32.1	-55.3
mean windspeed (km/hr)													18.4
mean radiation (watts/m^2)													
total precipitation (mm)													
Mawson													
(67.6°S, 62.9°E: 16 m)													
mean temperature (°C)	0.8	-4.3	-10.2	-14.5	-16.5	-16.7	-17.8	-18.6	-17.5	-13.1	-5.7	-0.6	-11.2
mean windspeed (km/hr)	33.1	39.6	41.4	36.4	42.5	42.5	42.5	42.5	42.5	40.3	40.3	34.2	39.8
mean radiation (watts/m^2)													
total precipitation (mm)													
Rothera													
(67.5°S, 68.1°W: 16 m)													
mean temperature (°C)	1.0	0.1	-1.8	-4.3	-6.8	-9.9	-11.6	-11.5	-9.1	-6.1	-2.7	-0.2	-5.2
mean windspeed (km/hr)	18.0	19.4	12.0	22.2	22.2	20.7	21.9	25.4	25.7	24.8	23.5	19.3	21.3
mean radiation (watts/m^2)	191.8	138.6	62.5	19.5	2.9	-0.5	1.0	16.2	59.5	132.3	190.5	247.4	88.5
total precipitation (mm)													
Signy													
(60.7°S, 45.6°W: 16 m)													
mean temperature (°C)	1.1	1.2	0.2	-2.4	-5.6	-8.7	-10.2	-8.3	-5.2	-2.8	-1.1	0.0	-3.5
mean windspeed (km/hr)	12.6	14.0	15.3	14.1	13.5	13.1	13.3	14.6	16.1	16.0	15.3	12.1	14.2
mean radiation (watts/m^2)	147.2	104.3	58.8	31.8	13.2	7.5	12.4	35.6	79.1	134.8	169.0	178.9	81.1
total precipitation (mm)													405

BAS

Factors influencing Antarctic climate

Resource C2

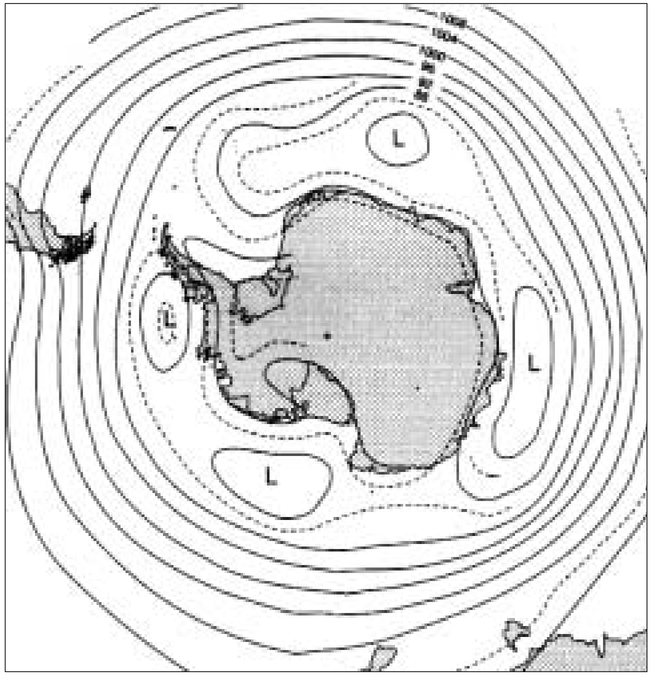
The climate of Antarctica is determined by a number of factors including its geographical location, topography and interaction with the high-latitude circulation of the southern hemisphere atmosphere and ocean.

The surface of the Antarctic continent receives less energy in solar radiation than it loses by infrared cooling. This is because the sun is low in the sky all year round and, for regions south of the Antarctic Circle, the sun does not rise above the horizon for part of the winter. Furthermore, the permanent snow and ice (which covers over 99% of the continent) and the sea ice (which covers up to 20 million km^2 of the surrounding oceans in late winter) both have a high albedo, reflecting up to 85% of the incident solar radiation. The net cooling of the polar regions has to be balanced by the transport of heat from lower latitudes by the atmosphere and ocean. In the southern hemisphere most of the atmospheric heat transported to Antarctica is carried by the north-south circulation of the atmosphere and by transient weather systems.

The East Antarctic ice sheet is a high plateau which reaches a maximum elevation of over 4000 m. Here persistent surface cooling generates a nearly permanent surface temperature inversion. The cold, dense air adjacent to the surface accelerates down the surface slope to form katabatic winds. Such winds are a characteristic feature of the Antarctic interior. Over the gentle slopes of the plateau, katabatic wind speeds rarely average more than 18 km/hr, but over the steeper coastal slopes the winds may accelerate and converge into coastal valleys, giving rise to high wind speeds. Averaged over the year, speeds can be as high as 70 km/hr, in a few areas where local topography funnels the wind. Around much of the Antarctic coast annual mean wind speeds are typically between 15 km/hr and 35 km/hr.

The outflow of cold air associated with the katabatic winds is restricted to the lowest few hundred metres of the atmosphere. Above the cold outflow, there is a compensating inflow of warmer air which gradually subsides into the katabatic layer. The katabatic winds generated over the Antarctic ice sheet exert considerable control over the regional atmospheric circulation and this influence extends well beyond the Antarctic continent itself.

The annual cycle of air temperature at stations in the interior of Antarctica is very different from that at coastal stations. At the coast, summer mean temperatures are around freezing and the coldest month is usually July or August. On the high plateau, temperatures are much lower as a result of both the high surface elevation and decreased solar heating at these latitudes. The most remarkable feature of the temperature records from the stations is the lack of any well-defined temperature minimum during the winter months.



Mean January (austral winter) surface pressure over Antarctica

Source: redrawn from Shwerdfeger, W. in Hansom, J. and Gordon, J. (1998) Antarctic Environments and Resources. Longman, Harlow

Precipitation over Antarctica mostly falls as snow, although rain may occur during the summer at any coastal location at low elevation. The highest precipitation occurs around the coasts, where weather systems moving in from lower latitudes cross the steep and high coastal slopes. Here annual precipitation totals can reach 300–400 mm water equivalent per year. Few weather systems penetrate inland onto the high plateau. The air here is very cold and dry, with correspondingly low precipitation. Much of the area of the East Antarctic plateau is a desert, with an annual precipitation of less than 50 mm water equivalent. A large proportion of the precipitation over the plateau occurs as a near-continuous fall of ice crystals from a clear sky – 'diamond dust'. The low precipitation is, however, able to maintain the continental ice sheet, over 3 km thick in many places, because melting and evaporation are negligible.

The weather systems responsible for transporting heat and moisture towards Antarctica have their origins in the mid-latitudes of the southern hemisphere. Large temperature gradients between the cold continent and the relatively warm ocean continually create low pressure areas over the ocean which travel east or south-east with the prevailing wind. The tracks of the low pressure areas result in a persistent circumpolar band of low pressure centred around 60–65°S. This is called the circumpolar trough (see diagram on this page). The continual succession of cyclonic storms makes the circumpolar trough region one of the cloudiest areas in the world, but the climate is relatively mild; surface air temperatures rarely fall below -10°C.

Investigating past climates

Resource C3

We now know that the last ice age was but one of many ice ages that the world has experienced in the last 20 million years.

Detailed records of climatic change have been deduced from the changing proportion of heavy to light atoms of oxygen and hydrogen in the water molecules of the sea and in the ice of the polar ice sheets. Isotope ratios are the key to our knowledge of past temperatures and climate. Their relationship with temperature is in part due to the tendency of heavier molecules to evaporate less rapidly than lighter molecules, and for heavier molecules to condense more readily from the vapour. As a result of this the colder the climate is the fewer heavy molecules are found in the snow of the ice sheets. The cyclical pattern of summer and winter can be seen clearly as ‘tree rings’ through ice cores, and long term changes in climate are also recorded.

The longest climate records based on the isotopic composition of sea water come from the sea floor itself, where oxygen atoms in the calcium carbonate in sea shells mirror the isotopic ratio in the sea at the time when the shells were growing. Scientific instruments called mass spectrometers are sensitive enough to be able to measure the isotopic ratio. Dating the shells is a scientific challenge. The climate cycles of the last million years are apparent in the sea bed and short warm spells and long ice ages reoccur. An ice age world has been the natural state of the planet for a long time – broken up by spells like the present when mankind developed.

The origin of the ice-age cycles lies in periodic changes in the Earth’s orbit and orientation. The orbit varies from nearly circular to an elliptical shape in a cycle 100,000 years long. During the cycle the distance between the Earth and Sun varies by as much as 11 million miles. The Earth also wobbles like a top in a 21,000 year cycle. Today the shape of the orbit places the Earth closest to the Sun in the northern hemisphere winter, and furthest away in the summer. The combination tends to make our northern winters mild and summers cool, and this favours ice sheet growth in the northern hemisphere. However 11,000 years ago the arrangement was just the opposite and it promoted the decay of the northern ice sheets. The tilt of the Earth also changes over a 41,000 year period. The predominant effect of all these periodic changes is to accentuate or diminish the contrasts between summer and winter.

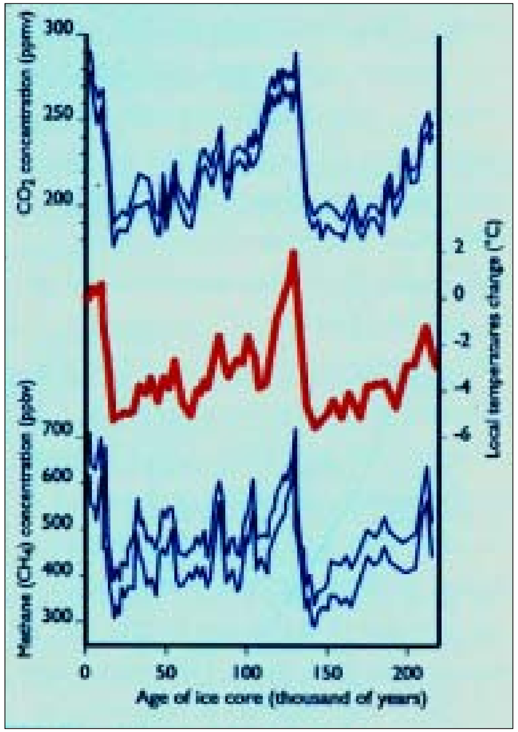
The best evidence for the astronomical theory of ice ages comes from the marine sediment record. The isotopic fluctuations found in sediment cores are indeed based on a superimposition of cycles of 21,000 years, 41,000 years and 100,000 years.

The broad picture of past global temperatures can be reproduced using computers to calculate the pattern of solar radiation through the past 500,000 years. Importantly, this type of analysis allows predictions to be made of the future. Soon the world temperature should fall. The world will face ice age conditions during most of the next 60,000 years, unless human activity has interrupted the natural climate cycle of our world.

Carbon dioxide and temperatures

The past is the key to the future. At Vostok station the oldest ice yet analysed for its climate record has been recovered. At a depth of over 2000 m, ice over 220,000 years old was found – ice deposited in the last but one ice age. When snow is transformed into ice, air becomes trapped in pores of the newly formed ice. So, in addition to discovering past air temperatures, changes in carbon dioxide (CO_2) and methane levels in the atmosphere can be determined. A comparison of CO_2 concentrations and temperature shows that their variations over time have been very closely coupled.

The warm interglacials have the highest levels of greenhouse gases (today and 120,000 years ago), while the coldest part of the last ice age (20,000 years ago) the lowest levels. The short warmer periods within the last ice age, called interstadials, were accompanied by higher levels of CO_2 and methane than in the preceding and following cooler climate. Today CO_2 levels are higher than at any time in the last 160,000 years, and a warmer future world seems inevitable.



DETR

Atmospheric temperature change relative to present and past atmospheric concentration of CO_2 and methane as measured in the Vostok ice core.

Surface air temperatures (°C) at Faraday/Vernadsky

Resource C4

Year	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962
Jan	0.1	0.9	1.2	0.2	0.1	-0.1	-1.0	0.9	-1.2	0.8	0.3	0.8	1.1	0.4	-1.4	0.2	1.8	0.2
Feb	0.8	0	1.7	-0.6	-1.5	-1.6	-0.4	0.3	-2.9	0	0.7	0.9	1.0	-0.7	-2.2	0.8	0.3	-0.5
Mar	-1.5	-0.1	0.5	-1.3	-3.6	-0.7	-0.1	-1.9	-4.7	-1.3	-1.3	0.5	0.2	-2.1	-1.8	-1.7	-0.7	-1.3
Apr	-4.4	-2.4	-1.8	-3.9	-8.2	-3.6	-0.5	-4.6	-12.0	-4.6	-2.0	-1.0	-1.2	-3.1	-13.9	-5.9	-2.0	-1.4
May	-4.9	-4.1	-5.1	-5.4	-11.2	-9.3	-3.9	-10.9	-13.8	-7.3	-4.3	-1.4	-3.7	-11.8	-13.8	-5.9	-4.7	-4.0
Jun	-9.6	-4.9	-11.6	-7.1	-13.9	-6.4	-7.0	-8.3	-14.6	-11.6	-7.8	-1.9	-12.3	-17.2	-9.3	-10.9	-7.9	-5.8
Jul	-12.8	-7.5	-5.8	-13.9	-12.1	-7.9	-11.2	-12.0	-15.0	-13.5	-5.9	-6.0	-14.1	-18.5	-20.1	-12.3	-10.6	-7.8
Aug	-10.2	-12.5	-9.7	-13.0	-13.8	-17.1	-8.3	-6.8	-9.7	-17.3	-7.1	-3.9	-13.9	-16.8	-13.0	-11.0	-13.7	-9.6
Sep	-10.4	-7.3	-9.8	-12.7	-9.4	-8.8	-13.4	-5.8	-8.0	-11.6	-6.7	-6.3	-4.9	-13.3	-10.9	-4.7	-8.5	-6.9
Oct	-7.4	-8.7	-5.5	-5.2	-5.4	-4.7	-5.3	-6.5	-6.3	-2.8	-3.4	-2.5	-7.6	-4.8	-5.2	-4.4	-5.8	-3.3
Nov	-4.4	-4.8	-2.4	-6.7	-4.3	-2.5	-1.7	-2.9	-2.7	-1.1	-3.8	-1.4	-1.0	-0.6	-4.8	-4.1	-3.4	-3.2
Dec	0.2	-1.0	-1.1	-0.8	0.4	-0.4	0.1	-1.1	0.2	0.2	-1.2	-0.8	-1.2	-1.7	-0.9	-1.1	-0.4	-0.5
Mean	-5.4	-4.4	-4.1	-5.9	-6.9	-5.3	-4.4	-5.0	-7.6	-5.8	-3.5	-1.9	-4.8	-7.5	-8.1	-5.1	-4.6	-3.7

Year	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Jan	0.2	0.6	0.4	0.3	-0.7	0.7	-0.1	-0.3	1.2	1.7	0.2	1.9	1.1	-0.1	1.6	-0.4	0.1	0
Feb	0.3	0.3	0.9	-0.5	-1.1	0.1	0.5	-0.1	0.9	1.6	1.0	2.1	1.4	0.8	0.7	-0.2	0.1	1.2
Mar	-2.1	-1.5	0.9	-0.6	-0.4	-1.1	-2.7	-1.5	0.2	0.4	-0.6	1.4	-0.2	-0.2	-0.8	-2.1	-0.5	-1.9
Apr	-4.5	-4.8	-3.1	-3.3	-1.2	-0.7	-3.9	-4.5	-1.4	-0.7	-3.3	-1.9	-1.4	-1.1	-0.4	-3.5	-2.0	-5.5
May	-3.7	-5.5	-2.9	-4.9	-6.2	-3.9	-7.3	-5.1	-4.6	-2.7	-4.5	-3.5	-4.0	-5.0	-4.0	-3.8	-7.4	-5.7
Jun	-6.7	-9.3	-6.0	-6.9	-6.5	-7.0	-11.3	-6.3	-2.7	-5.2	-7.4	-3.7	-7.2	-9.7	-5.6	-5.2	-8.9	-9.9
Jul	-8.9	-5.6	-11.5	-16.1	-7.4	-5.4	-13.3	-4.7	-4.3	-3.4	-9.1	-5.1	-9.2	-11.9	-17.6	-17.9	-9.2	-16.2
Aug	-15.9	-16.0	-13.3	-11.6	-9.5	-8.7	-8.1	-9.9	-4.8	-9.0	-5.7	-5.6	-8.2	-16.5	-10.7	-12.7	-9.7	-15.9
Sep	-11.1	-9.3	-6.2	-10.3	-8.9	-9.3	-4.9	-2.1	-4.6	-3.7	-7.3	-7.2	-5.0	-9.9	-13.6	-7.7	-7.3	-8.4
Oct	-8.3	-2.2	-8.3	-6.0	-7.1	-4.3	-7.3	-3.5	-1.9	-3.4	-3.7	-2.3	-3.4	-5.3	-8.5	-6.0	-5.4	-6.4
Nov	-2.4	-1.5	-2.0	-2.3	-3.0	-2.8	-2.4	-0.5	-1.0	-1.6	-1.7	-1.2	-3.8	-1.1	-1.8	-4.5	-2.2	-3.9
Dec	0.3	-0.1	-0.6	-0.6	-0.5	-0.2	0.3	0.4	-0.1	0.6	0.1	0.5	-0.1	-0.2	-0.4	-0.5	-0.4	-0.5
Mean	-5.2	-4.6	-4.3	-5.2	-4.4	-3.6	-5.0	-3.2	-1.9	-2.1	-3.5	-2.1	-3.3	-5.0	-5.1	-5.4	-4.4	-6.1

Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Jan	0.2	0.6	1.4	0.8	2.3	1.5	0.6	0.4	1.6	2.0	1.1	0.7	1.2	0.7	1.6	1.1	1.7	1.5
Feb	0.2	0.2	0.2	1.2	1.8	1.9	-0.1	0.8	2.3	2.3	0.8	-0.3	0.8	0.8	0.5	1.6	0.7	1.4
Mar	-0.3	0.1	-0.9	0.7	0.0	0.9	-1.2	-0.2	1.3	0.8	-0.9	-1.5	-1.1	-0.3	-0.8	0.5	-0.3	0.3
Apr	-2.4	-1.8	-2.0	-1.7	-0.4	-1.0	-2.6	-2.3	-2.5	-3.0	-2.2	-2.1	-1.9	-1.4	-1.3	-2.2	-2.0	0.1
May	-6.2	-2.4	-2.6	-3.4	-3.3	-5.7	-3.8	-3.2	-1.6	-3.6	-5.3	-6.9	-3.5	-3.3	-3.4	-2.4	-3.2	-3.1
Jun	-8.5	-4.0	-2.9	-6.0	-4.3	-4.3	-9.2	-4.1	-3.4	-4.4	-7.8	-11.1	-6.2	-4.7	-6.9	-3.9	-4.3	-1.1
Jul	-8.9	-11.4	-3.1	-6.4	-5.8	-7.7	-20.1	-5.5	-2.6	-3.5	-5.7	-10.3	-6.2	-12.2	-8.8	-5.8	-8.7	-2.7
Aug	-10.8	-8.8	-5.1	-5.5	-5.8	-10.5	-12.2	-9.9	-3.3	-7.4	-7.0	-8.5	-5.5	-7.0	-12.3	-7.8	-6.8	-3.9
Sep	-10.9	-9.4	-6.3	-3.5	-2.8	-11.6	-14.1	-4.6	-3.7	-6.2	-5.6	-6.6	-5.9	-8.5	-8.7	-2.5	-8.7	-6.1
Oct	-6.6	-7.6	-4.6	-5.9	-3.3	-6.0	-4.6	-2.4	-1.6	-4.3	-7.4	-3.8	-4.9	-9.5	-3.8	-3.8	-3.6	-3.3
Nov	-3.2	-3.2	-1.3	-1.8	-0.7	-3.5	-1.6	-1.1	-0.9	-3.5	-2.3	-1.8	-0.7	0.1	-2.6	-2.1	-2.2	-1.4
Dec	-0.7	0.8	-0.3	0.4	0	-0.9	0	-0.1	0.6	-0.6	-0.5	1.6	-0.8	0	-0.2	0.4	0.4	-0.1
Mean	-4.8	-3.9	-2.3	-2.6	-1.9	-3.9	-5.7	-2.7	-1.2	-2.6	-3.6	-4.2	-2.9	-3.8	-3.9	-2.2	-3.1	-1.5

Mean annual temperature (°C) at Amundsen-Scott station	
1957	-48.8
1958	-48.9
1959	-49.7
1960	-49.5
1961	-49.2
1962	-49.4
1963	-48.6
1964	-49.9
1965	-49.3
1966	-50.1
1967	-49.2
1968	-49.0
1969	-49.2
1970	-49.5
1971	-48.7
1972	-48.7
1973	-50.1
1974	-48.3
1975	-49.3
1976	-49.1
1977	-49.5
1978	-49.4
1979	-49.6
1980	-49.2
1981	-48.8
1982	-49.0
1983	-51.0
1984	-48.9
1985	-50.2
1986	-50.0
1987	-50.6
1988	-48.3
1989	-50.0
1990	-49.2
1991	-48.9

BAS

Predictions of future climatic change

Resource C5

Projections of future climate change are derived from the use of general circulation models (GCMs). These are sophisticated computer simulations that reproduce climate processes in the atmosphere and oceans in a simplified form.

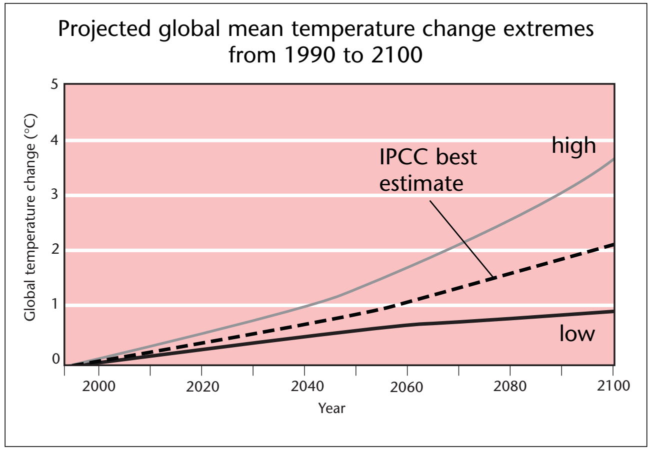
The models reproduce the meteorological and oceanographic processes in a world to which increasing effects of human activity are included, such as enhanced levels of green-house gases and dust (aerosols).

The models have to simplify the topography of the Earth's surface and find ways of describing climatically important, but small scale features, like individual thunderstorms, ocean boundary currents and tornados. There are still many uncertainties in the representation of climate processes in models, especially feedbacks associated with clouds, oceans, sea ice and vegetation.

The Intergovernmental Panel on Climate Change (IPCC) reported in 1995 that 'the balance of evidence suggests a discernible human influence on global climate' and that the climate would be expected to continue to change in the future.

The IPCC's best estimate predicted an increase in global mean surface temperature relative to 1990 of about 2°C by 2100. They also established a range of possibilities, with a rise of 1°C being the lowest and 3.5°C being the highest. These predictions can be seen in the attached graph. The IPCC also presented a global map, based on GCM results, of the pattern of surface temperature change (see below). These model simulations showed:

- general greater surface warming of the land than of the oceans in winter;
- a minimum warming around Antarctica and in the northern Atlantic which is associated with deep ocean mixing in those areas;
- maximum warming in high northern latitudes in late autumn and winter associated with reduced sea ice and snow cover;

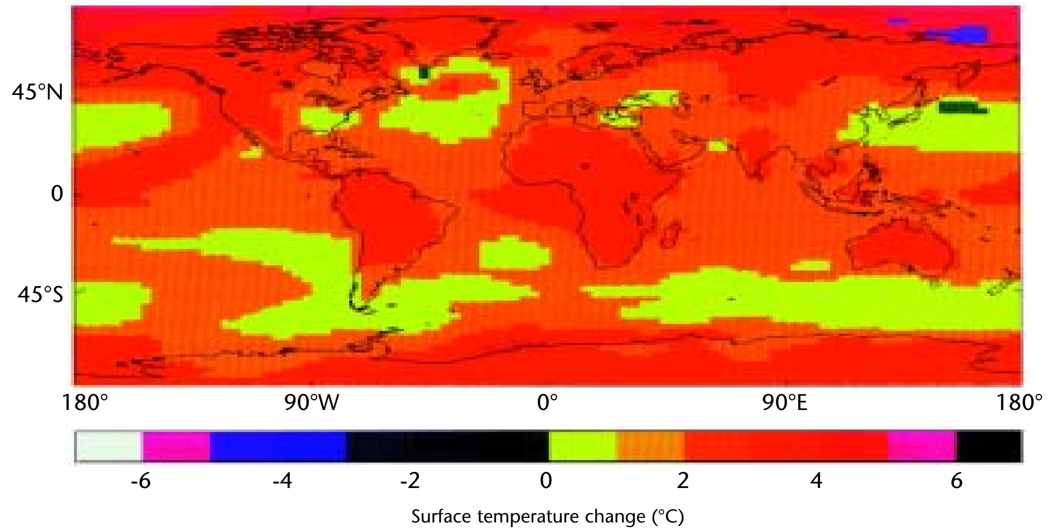


Projected global mean temperature change extremes from 1990 to 2100

- little warming over the Arctic in summer;
- little seasonal variation of the warming in low latitudes or over the Southern Ocean;
- a reduction in diurnal temperature range over land in most seasons and most regions;
- a more vigorous global hydrological cycle;
- increased precipitation in high latitudes in winter.

Regional changes could be expected to differ considerably from the global mean value. Even if greenhouse gas concentrations were stabilised by 2100, temperatures would continue to increase beyond then, because of the thermal inertia of the oceans.

The IPCC also suggested that there might be effects on oceanic circulation, especially in the North Atlantic – these are discussed in Resource ICE4. The possibility of increasing variability of the weather, with a tendency to more extreme events, such as floods, was also postulated. Although the scale and detailed nature of climatic changes are uncertain, there is little doubt that mean global surface temperatures will rise over the next 100 years. The potential effects of this on Antarctica are critical not only for the continent itself but also for the whole planet.



Map of the predicted pattern of surface temperature change projected by a GCM at the time of CO_2 doubling.

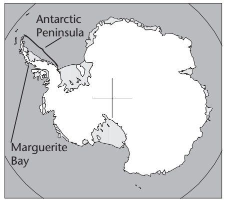
Source: Both map and graph are from IPCC (1996) Climate Change 1995. Cambridge University Press, Cambridge.

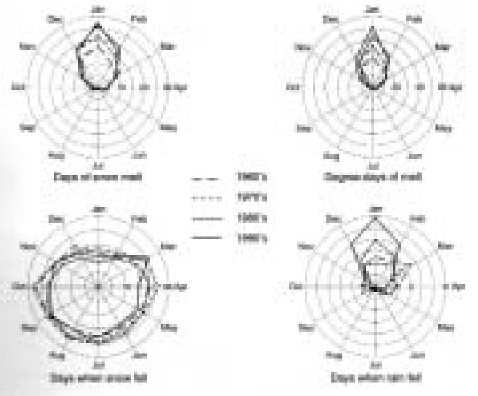
Changes in snow and ice cover in Marguerite Bay

Resource C6

Summary

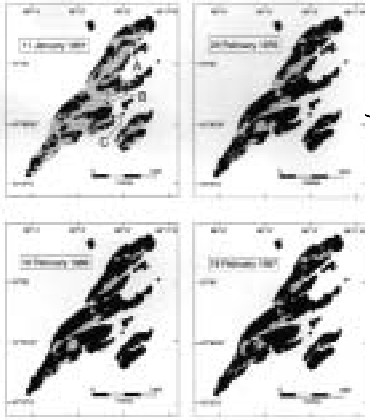
The production of maps from different generations of photographs and satellite images has revealed many changes in the extent of ice cover with time. Examples chosen from the Antarctic Peninsula region show that the most pervasive change is the consistent decline in the extent of small bodies of snow and ice. This paper shows how perennial snow or ice cover has decreased in the northern Marguerite Bay area, at a latitude of 68°S. The correlation of the change with elevation and with climate records from Adelaide and Rothera Research stations in the Antarctic Peninsula region is examined.





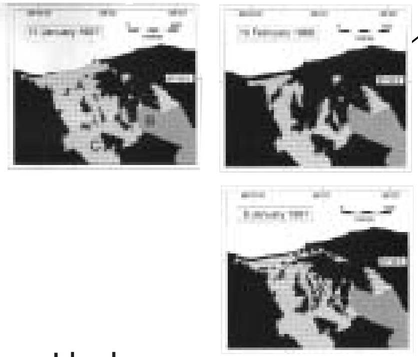
Climate data

- Meteorological records from Adelaide Research Station cover the period from 1 May 1962 to 1 January 1976, those from Rothera Research Station extend from 8 March 1976 to the present.
- For each decade we determined the mean number of days per month when the average temperature was above freezing, when snow fell and when rain fell.
- For days when the temperature was above freezing, we calculated the product of the temperature and number of days to obtain a parameter referred to as ‘positive degree days’.
- In broad terms, the number of days with melting conditions has increased, the number of positive degree days has increased, the number of days with snowfall has slightly decreased and the summer rainfall has increased.
- The increase in summer rainfall is especially significant because rain is a very efficient means of transferring heat into the snow or ice.



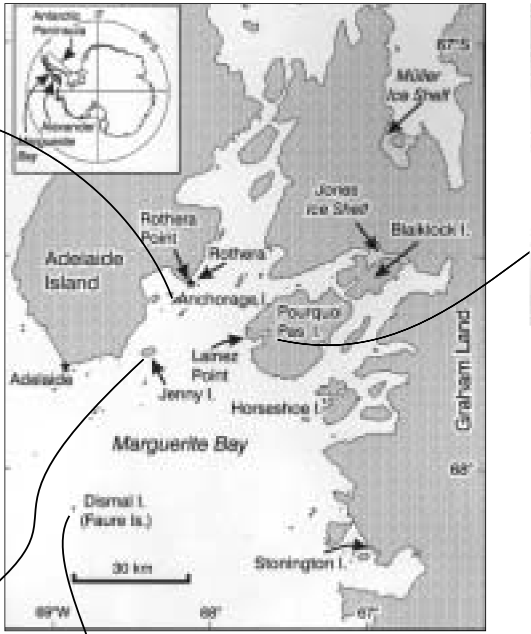
Anchorage Island

- Anchorage Island is a rocky, low-lying island 3 km long; its highest point is at 57 m asl.
- The total area of snow cover has decreased substantially from 1957 to the present. Snow or ice that filled inlets in 1957 has melted, allowing the sea to extend further into the island.



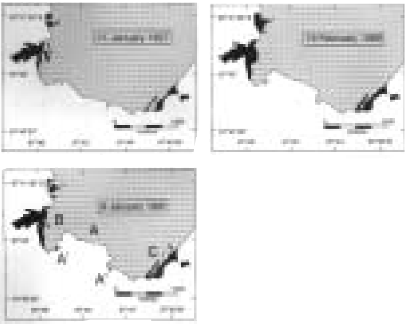
Jenny Island

- Jenny Island is a 3 km long island with rugged terrain rising to 569 m asl. There is a low-lying, north-facing central bowl.
- Comparison of photography from mid-January 1957 and mid-January 1991 shows a significant decrease in snow cover in the low-lying central area of the island at A.
- The terminus of the small glacier at B and the extent of ice-free ground at higher elevations (e.g. at C) have remained almost the same, indicating that changes in snow cover are linked to elevation. For this area of Jenny Island the threshold of snow melt appears to be at 175-200 m asl.



Dismal Island

- Dismal Island is the largest of the Faure Islands, a small archipelago of mainly ice-covered islands and skerries. Its maximum height is about 50 m asl.
- A marked increase in the extent of exposed rock took place between 1963 and 1974, followed by a continuing but lesser increase in subsequent years.
- New areas of exposed rock appeared in each season, and the sea has extended into inlets previously filled with snow or ice.
- The 1992 photographs were taken much earlier in the austral summer than previous ones, before the peak melting period. Even so, new areas of rock are visible, and many existing ones have grown larger.



Lainez Point

- Lainez Point is a low-lying rocky promontory on the south-west tip of Pourquoi Pas Island, rising to about 15 m asl.
- The principal change noted is the retreat of the small glacier in the centre of the map. It has retreated by approximately 500 m at A during the study period, remaining pinned on the newly exposed outcrops at A^{I} and A^{II}. The snow cover at Lainez Point B and at C has decreased from 1957.
- The 1957 and 1991 photo-sets for Lainez Point were acquired within two season-days of each other and show the changes discussed above. The 1989 data were acquired in mid-February, but show the same extent of exposed ground as the 1991 photography from mid-January. This suggests that for very low-lying areas like Lainez Point most of the seasonal melt has already taken place by mid-January.

Conclusions

We conclude that the evidence presented here shows that a significant reduction has taken place in the extent of small snow and ice bodies in the coastal area around northern Marguerite Bay.

The extent of the change is related to the elevation and to the extent of maritime influence. Sites at higher elevations and further from the open sea remain more or less the same.

The climate record at Rothera and Adelaide research stations shows increasing heat input during the melt season.

The reduction in snow area described indicates that in the study area the change in climatic parameters has caused mass-balance below 200 m above sea-level to change from either positive or in balance to negative.

The observations here are shown to be consistent with determinations of lapse rate and temperature change for this area.

The Antarctic climate

Worksheet 8

Antarctica is the coldest continent. At the Russian Vostok Station, the world record lowest surface air temperature of -89.2°C was recorded on 21 July 1983, and the annual mean temperature is an incredible -55°C. In this worksheet the Antarctic climate is explored by examining its spatial variation, change over geological time and possible change in the future.

A uniform climate?

Significant variations in climate exist between various locations in Antarctica. The climate and weather are influenced by a number of factors including latitude, altitude, the continental ice sheet, the Southern Ocean, and seasonal variations in sea ice cover. There are therefore major climatic differences between the continental interior and the coastal margins.

Task 1 Examine Resource C1 which shows climatic data for the following research stations:
Amundsen-Scott, Vostok, Mawson, Rothera and Signy.

- Locate them on the map of Antarctica shown in Resource N1. Draw a map of Antarctica using the one in Resource N1 as a base. Mark the stations on your map.
- At each marked station draw a climate graph showing monthly mean temperatures, as well as windspeed and solar radiation if the data are available. For each station also add its latitude and altitude, and annual mean precipitation if the data are available.
- Produce an annotation box which summarises the climate at each station in relation to the following factors: latitude, altitude, distance from the sea, proximity to ocean currents.

Reference to Resource C2 and Worksheet 12 on Marine Ecosystems should help you in this task.
Why is the South Pole not the coldest place?

Climate change over geological time

Antarctica has not always been so cold. The climate has varied from subtropical to freezing through a series of climatic changes over the past 100 million years.

At the time of the final break-up of Gondwana (see Resource G2 with Worksheet 6 on Geology), about 96 million years ago, Antarctica enjoyed a warm subtropical climate. By about 50 million years ago temperatures had begun to fall, but the climate was still able to support cool temperate rain forests, similar to those found in New Zealand today. The main reason for the cooling was the formation of deep-water circulation in the Southern Ocean around Antarctica. This occurred as the continent drifted away from South America and Australia. The climate of Antarctica continued to cool until 14 million years ago, by which time the East Antarctic ice sheet had grown to its present size. The West Antarctic ice sheet is younger, reaching its current size probably 5 million years ago. The Antarctic ice sheets have existed continuously for probably at least 3 million years.

Task 2 Read Resource C3 on investigating past climates.

- Summarise the techniques of dating ice and marine sediment cores as a series of bullet points.
- Explain the astronomical cycles of ice ages by drawing a table with three rows. In each row summarise the reasons for one of the three astronomical cycles (the cycles have periods of 21,000 years, 41,000 years and 100,000 years).

The role of ice cores in detecting climate change

Ice cores collected in Antarctica can give a very detailed picture of past climate during the last 200,000 years. This is because pockets of air trapped between snow crystals contain traces of past atmospheres. As ice is formed it traps the air. Careful chemical analysis of the air trapped in layers of the ice can reveal the composition of different atmospheric gases, such as CO_2 and methane.

BAS

Ice cores need careful handling to prevent contamination

Task 3 Look at the graph in Resource C3. This shows an analysis of the air trapped in a very deep ice core collected at Vostok station. Describe the relationship between local temperature, CO_2 and methane. If the start of ice ages is astronomically controlled, what role do you think CO_2 and methane might have in determining the expansion or reduction of the Antarctic ice sheet?

Current climate change

At a time when global temperatures are rising, it is important to know if temperatures are changing in Antarctica.

Task 4 Resource C4 shows monthly surface air temperature measurements from Faraday/Vernadsky station on the Antarctic Peninsula from 1945 to 1998.

- For each year calculate the mean temperature. Find the minimum and maximum temperatures for each month over the period 1945–98. You could also calculate the standard deviation of the mean annual temperatures and the standard deviation of the temperatures for each month.

➤

Task 4 ➤ *(continued)*

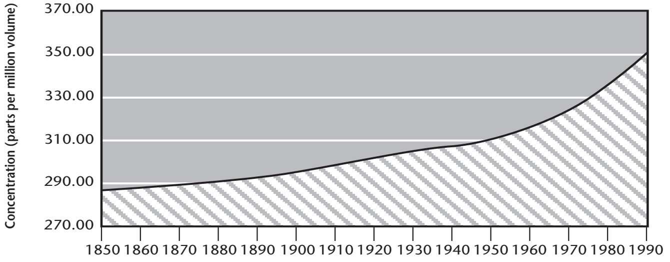
- Plot the mean annual temperatures. What do you notice about the variations from year to year? Explain how these variations make the determination of temperature trends difficult.
- Use regression analysis to find out if there has been a statistically significant change in temperature over 53 years at Faraday/Vernadsky.
- Plot the annual mean temperature data for Amundsen-Scott (South Pole) also shown in Resource C4. Has there been any significant change in temperature?
Why might the temperature trends at Amundsen-Scott be different to Faraday/Vernadsky?
- Climate data measured at Antarctic research stations, such as Vernadsky and Amundsen-Scott, is a very important input to computer climate models, which are being used to help forecast global climate change (see Resource C5).

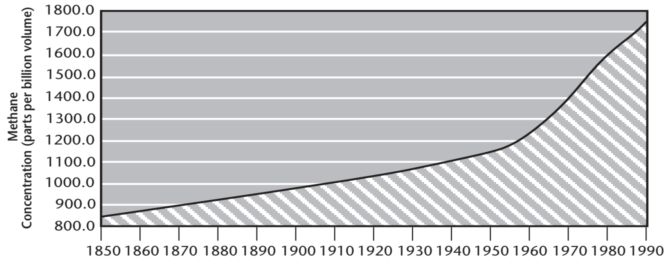
Another way of looking for evidence of climate change in Antarctica is to examine changes in snow and ice cover using remote sensing. Resource C6 is a recent paper by BAS scientists, which uses aerial photography to document changes in ice cover in the northern Marguerite Bay area, Antarctic Peninsula.

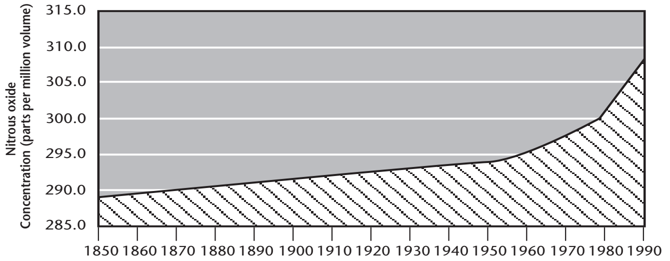
Task 5 Read Resource C6. How has the pattern of rainfall altered? How has the pattern of snowmelt changed? Describe possible relationships between rainfall and snowmelt. Comment on the changes in ice cover over the past 40 years. How accurate is the technique of aerial photography in assessing such changes? With reference to Resource C2 and Resource C6, suggest reasons why climate change in the Antarctic Peninsula may not be typical of climatic changes in Antarctica as a whole.
What overall conclusions can be drawn from the paper?

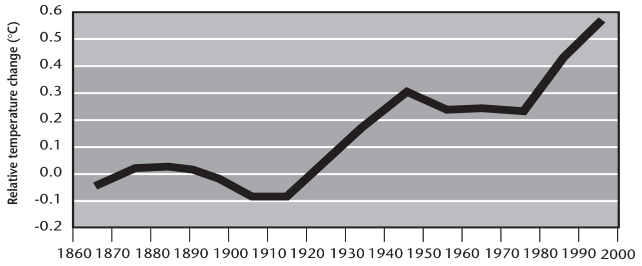
Global warming and greenhouse gases

During the last 150 years human use of natural resources, particularly fossil fuels, has led to the release of large amounts of greenhouse gases. The atmospheric concentrations of some of these gases are shown in the graphs in the centre of this page as well as a graph of changes in mean global, decadal average, temperatures.


Global CO_2 concentrations 1850–1990


Global methane concentrations 1850–1990


Global nitrous oxide concentrations 1850–1990


Change in global mean, decadal average, temperatures since 1860

Sources: Graphs 1–3, Climate Research Unit, Univ. of East Anglia. In: Warburton, P. (1995) Atmospheric Processes. Collins, London. Bottom graph: DETR.

Task 6 What do you notice about the relationships between the graphs? Explain how emissions of CO_2, methane and nitrous oxides from human activities may assist in global warming.

Future global temperature trends

Mean annual global temperatures have risen by 0.6°C since the mid-19th century. At present, greenhouse gas emissions continue to rise and a doubling of CO_2 concentrations by 2030 is thought possible. Computer climate models called general circulation models (GCMs), can predict how these emissions might affect the climate during the next 100 years.

Task 7 Read Resource C5 which examines the projections made by the general circulation models (GCMs).

- How will global mean temperatures change in the future according to the International Panel on Climate Change (IPCC)? What other effects might result?
- Resource C5 also describes how the GCMs predict the Antarctic climate might change. Summarise the likely effects on Antarctica as a bullet point list.
Explain why temperature increases are expected to be highest on the periphery of Antarctica.

Task 8 After reading this worksheet and its resources try to predict the effects on Antarctica if the climate warmed. For example, what will happen to the Antarctic ice sheet or the Southern Ocean? Write your predictions as a bullet-point list.
After doing this, work through Worksheet 7 and its Resources on Antarctic Ice and reconsider your ideas. Explain any differences.