Climate of the Antarctic Ice Sheet

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Department of Earth and Space Sciences

PCC Summer Institute 2016
Fig. 1—Average heights of the continents [after Koszta, 1933]

ICE ON PLANET EARTH

ANTARCTICA

N. AMERICA

S. AMERICA

AFRICA

ASIA

AUSTRALIA

EUROPE

AVERAGE HEIGHT (km)

AREA \( \times 10^6 \text{ km}^2 \)

2.5

2.0

1.5

1.0

0.5

0

50

40

30

20

10
Fig. 1. The Antarctic continent. Contour lines only for 2,000, 3,000 and 4,000 m elevation. Full circles = meteorological stations in operation in the winter of 1968. Open circles = stations in operation for two years or more at any time, but not in 1968. Station numbers refer to Table I.
Topics

Surface temperature
Surface energy budget
Clouds
Snowfall
Stratosphere: temperature and clouds
Wind and drifting snow
Man’s First Winter at the South Pole
Cold Fiercer Than Men Had Ever Faced, Ceaseless Winds, a 6-Month Night—Yet 18 Pioneers of Science Survived, and Thrived
By Paul A. Siple, Ph.D., D.Sc.
Scientific Leader, Amundsen-Scott IGY South Pole Station

South Pole Station established December 1956
Paul Siple 1957

South Pole Station
established December 1956

February 1960
Paul Siple’s lecture at Purdue
Из помещения метеостанции выносить только в случае пожара!

КНИГА УЧЕТА
Метеоданные
ст. Восток

Объем 100 листов
Артикул 2802р
Преднал. № 087-01
Цена 70 коп.
По плану отдела строительства
Типография № 2 Ленинграда
Figure 22. Annual mean temperature, °C (Rubin197).
Mean annual temperatures:

North Pole  -20°C  
South Pole  -50°C

Why is Antarctica colder than the Arctic?

(1) Zonal flow in atmosphere and ocean around Antarctica
(2) High elevation
(3) Snow-covered through the summer; high albedo
ANTARCTICA. The southern polar continent, Antarctica, is Earth’s modern-day example of a continental ice sheet. It is about the same size, both in area and in volume, as the ice sheet that covered part of North America during the most recent ice age. Antarctica is larger than Australia and smaller than South America. Its average surface elevation of 2.2 kilometers, greatly exceeding the 0.7-kilometer average for the other continents, is due to the ice sheet, the thickness of which averages 2.4 kilometers and in places approaches 5 kilometers. The amount of ice on Antarctica is 75 meters of sea-level equivalent; this means that if the ice melted completely into the ocean, global sea level would rise by 75 meters. The other great modern-day ice sheet, on Greenland, contains about 7 meters of sea-level equivalent.

Antarctica is divided into two parts by the Trans-Antarctic Mountains (Figure 1). The larger part, mostly in the eastern longitudes, is called East Antarctica; it contains 88 percent of the ice. The smaller part, in the western longitudes, includes the Antarctic Peninsula extending toward South America and is called West Antarctica. The elevation of the ice-sheet plateau is about 2,600 meters in East Antarctica but only 1,800 meters in West Antarctica. If all the ice were removed from Antarctica, and after the bedrock rebounded, only East Antarctica would remain as a continent (about 30 percent larger
## Table 1. Surface air temperatures at representative Antarctic stations

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<thead>
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<tbody>
<tr>
<td><strong>Station</strong></td>
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<td><strong>Byrd</strong></td>
<td><strong>South Pole</strong></td>
</tr>
<tr>
<td>Latitude (°S)</td>
<td>66</td>
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<td>80</td>
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</tr>
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<td>Elevation (meters)</td>
<td>30</td>
<td>40</td>
<td>1,500</td>
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<td>Station pressure (millibars)</td>
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*December 1978. New record high in 2011 is -12.3°C*
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(-129 F)
Near-surface temperature inversion in winter (no Sun)

(Hudson & Brandt 2005)

Fig. 3. Temperature profile measured at South Pole Station on 25 Sep 2001. Data above 660 hPa are from a routine radiosounding with an RS80; those below 660 hPa are from a tethered sounding with an RS80. (a) The full tropospheric sounding is shown, and (b) the lowest 500 m are enlarged. The surface pressure was 674 hPa.
Near-surface temperature inversion in winter (no Sun)

\[
\begin{align*}
\text{IR}_{\text{up}} & \approx \text{IR}_{\text{down}} \\
\varepsilon_s \sigma T_s^4 & \approx \varepsilon_a \sigma T_a^4 \\
\varepsilon_s & \approx 1 \quad \varepsilon_a < 1 \\
\text{Therefore} & \quad T_s < T_a
\end{align*}
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Fig. 3. Temperature profile measured at South Pole Station on 25 Sep 2001. Data above 660 hPa are from a routine radiosounding with an RS80; those below 660 hPa are from a tethered sounding with an RS80. (a) The full tropospheric sounding is shown, and (b) the lowest 500 m are enlarged. The surface pressure was 674 hPa.
Fig. 13. Median temperature difference relative to 2 m. Data are from South Pole during the 2001 polar night. Separate profiles are shown for the overall median (All Sky, solid line) and the clear-sky median (dashed line).
Fig. 12. Isolines of the average strength of the surface inversion in the winter (June-August). (After PHILLIPOT and ZILMAN (1969) with slight modifications.)
Diurnal cycle of temperatures on 32-meter tower at Plateau Station in February (80°S)
ANTARCTICA. Figure 2. *Surface air temperatures at South Pole Station.* Solid line: 20-year mean for each day. Dots: daily mean temperatures for the year October 1985–September 1986.

Maximum temperature 8 days after summer solstice
ANTARCTICA. Figure 2. *Surface air temperatures at South Pole Station.* Solid line: 20-year mean for each day. Dots: daily mean temperatures for the year October 1985–September 1986.

“Coreless winter”
DESTRUCTION OF TEMPERATURE INVERSION BY A CLOUD (winds light & variable)

CLOUD ARRIVED AT ~ 900 m

GMT HOUR, 8 SEPTEMBER 1992

INFRARED RADIATION (W/m²)

AIR TEMPERATURE (°C)

T₀ (21 m)

19 degrees

3 degrees

T₀ (1.8 m)
ANTARCTIC WINTER (no sunlight!)

- **Clear Atmosphere**
  - SN, LH
  - 60
  - 70
  - -86°C

- **Cloud**
  - 16°F
  - -40°C

- **Snow Surface**
  - 16°F
  - -40°C

- **Radiation**
  - 16°F
  - 16°F W/m²
What happens at -73.3°C?

ANTARCTICA. Figure 2. Surface air temperatures at South Pole Station. Solid line: 20-year mean for each day. Dots: daily mean temperatures for the year October 1985–September 1986.
Fig. 19. Annual number of days for 1957–2010 that the South Pole station has reported minimum temperatures at or below $-73.3 \, ^\circ C (-100 \, ^\circ F)$.
AN ARCTICA. Table 2. *Surface energy budget at Pionerskaya (70°S, 95°E, 2700 meters).* Energy fluxes are in watts per square meter; a positive number means that the flux is in the downward direction (from the atmosphere to the surface)

<table>
<thead>
<tr>
<th></th>
<th>June</th>
<th>December</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downward shortwave (solar) radiation</td>
<td>0</td>
<td>372</td>
</tr>
<tr>
<td>Upward shortwave radiation</td>
<td>0</td>
<td>-312</td>
</tr>
<tr>
<td>Downward longwave (infrared) radiation</td>
<td>106</td>
<td>173</td>
</tr>
<tr>
<td>Upward longwave radiation</td>
<td>-134</td>
<td>-209</td>
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<tr>
<td>Net radiation</td>
<td>-28</td>
<td>+24</td>
</tr>
<tr>
<td>Sensible heat</td>
<td>23</td>
<td>-16</td>
</tr>
<tr>
<td>Latent heat</td>
<td>1</td>
<td>-2</td>
</tr>
<tr>
<td>Sum</td>
<td>-4</td>
<td>+6</td>
</tr>
</tbody>
</table>
Water vapor, clouds, precipitation

“Precipitable” water vapor:
Midlatitudes & tropics  10-50 mm
Antarctic Plateau  0.1-1.5 mm  (good for astronomy)

Cloud cover
90% over Antarctic Ocean in summer
40% over East Antarctic Ridge (but the clouds are thin)
Cirrus
Stratocumulus
Stratus
Cloud optical depth over the Southern Ocean

(Fitzpatrick and Warren 2005)

Fig. 14. Cloud optical depth for different latitude intervals for all voyages of the Aurora Australis between 1991 and 2002 with concurrent observations of ocean, sea ice, and cloud conditions. The observations include all seasons and as such are biased toward spring and summer when a greater number of voyages occurred. The number of observations for each season and each latitude interval are shown in Table 2. Exponential fits are also given, where $\tilde{f}(\tau) = \tau_c^{-1} \exp(-\alpha/\tau_c)$. The values shown in the figure are percentages for bins of width $\Delta \tau = 5$. 
South Pole clouds
Mean optical depth $\sim 1$
(Mahesh, Walden, Warren (2001))