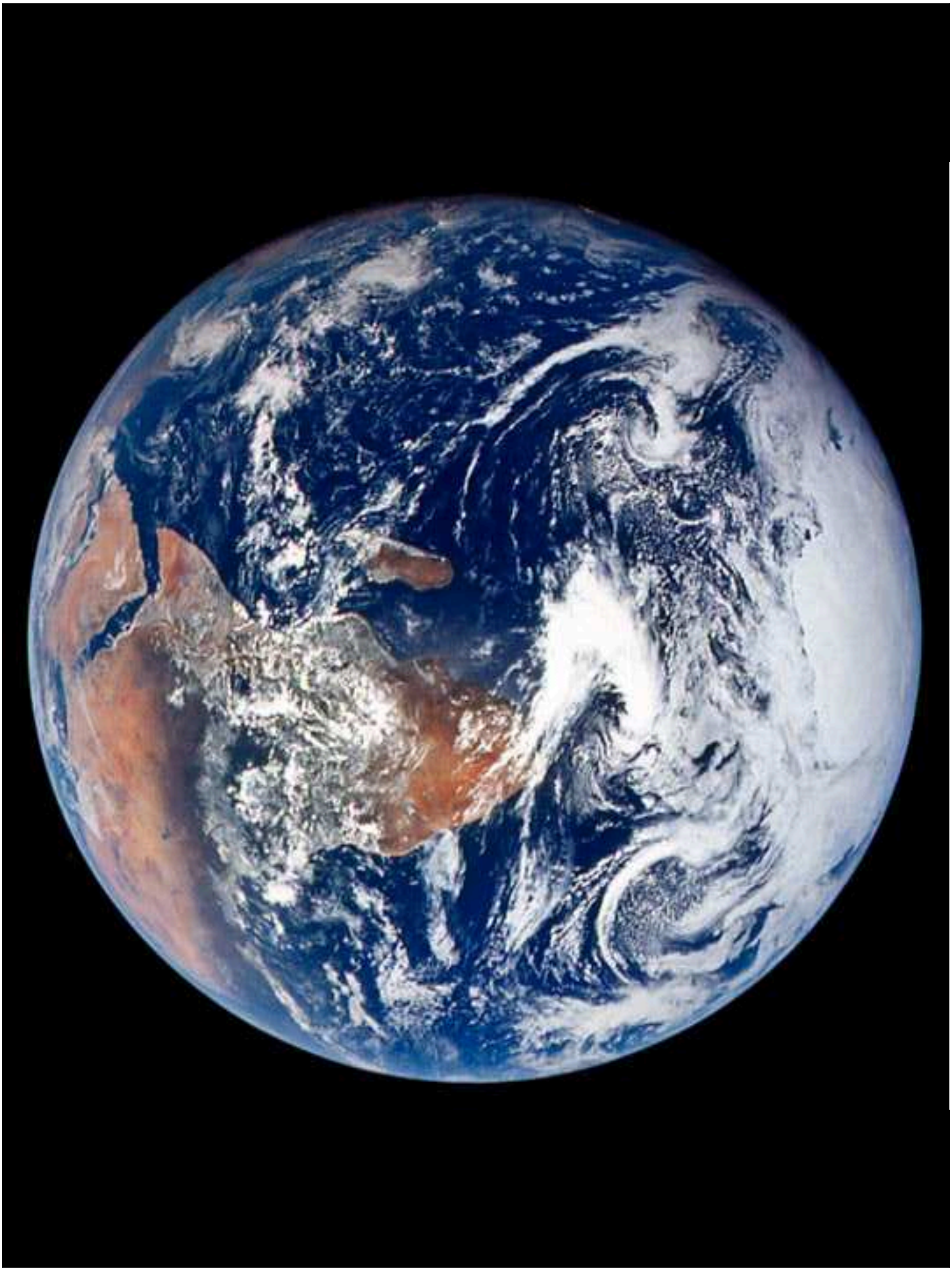
Climate of the Antarctic Ice Sheet

Stephen Warren
Department of Atmospheric Sciences
Department of Earth and Space Sciences

PCC Summer Institute 2016



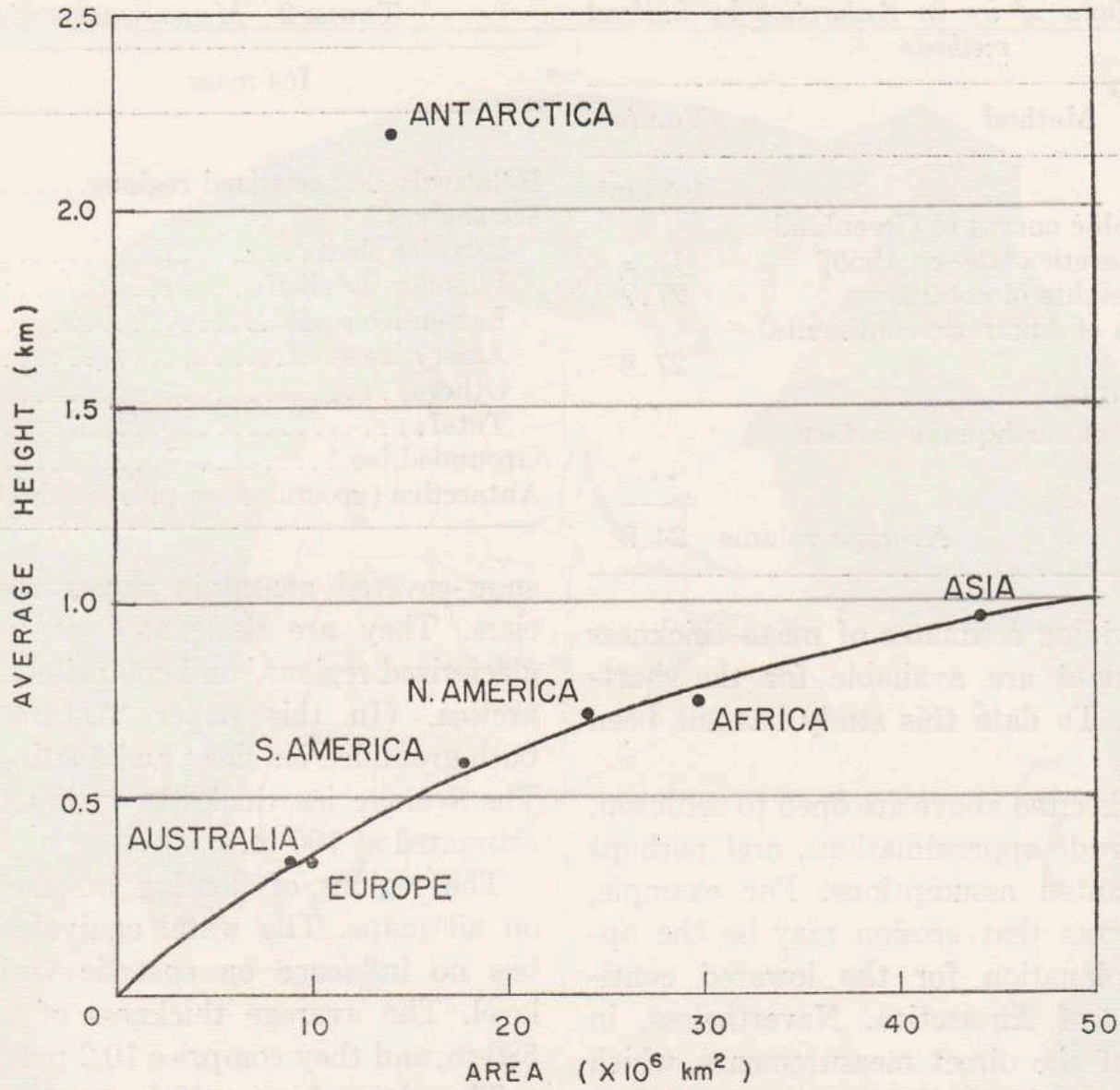
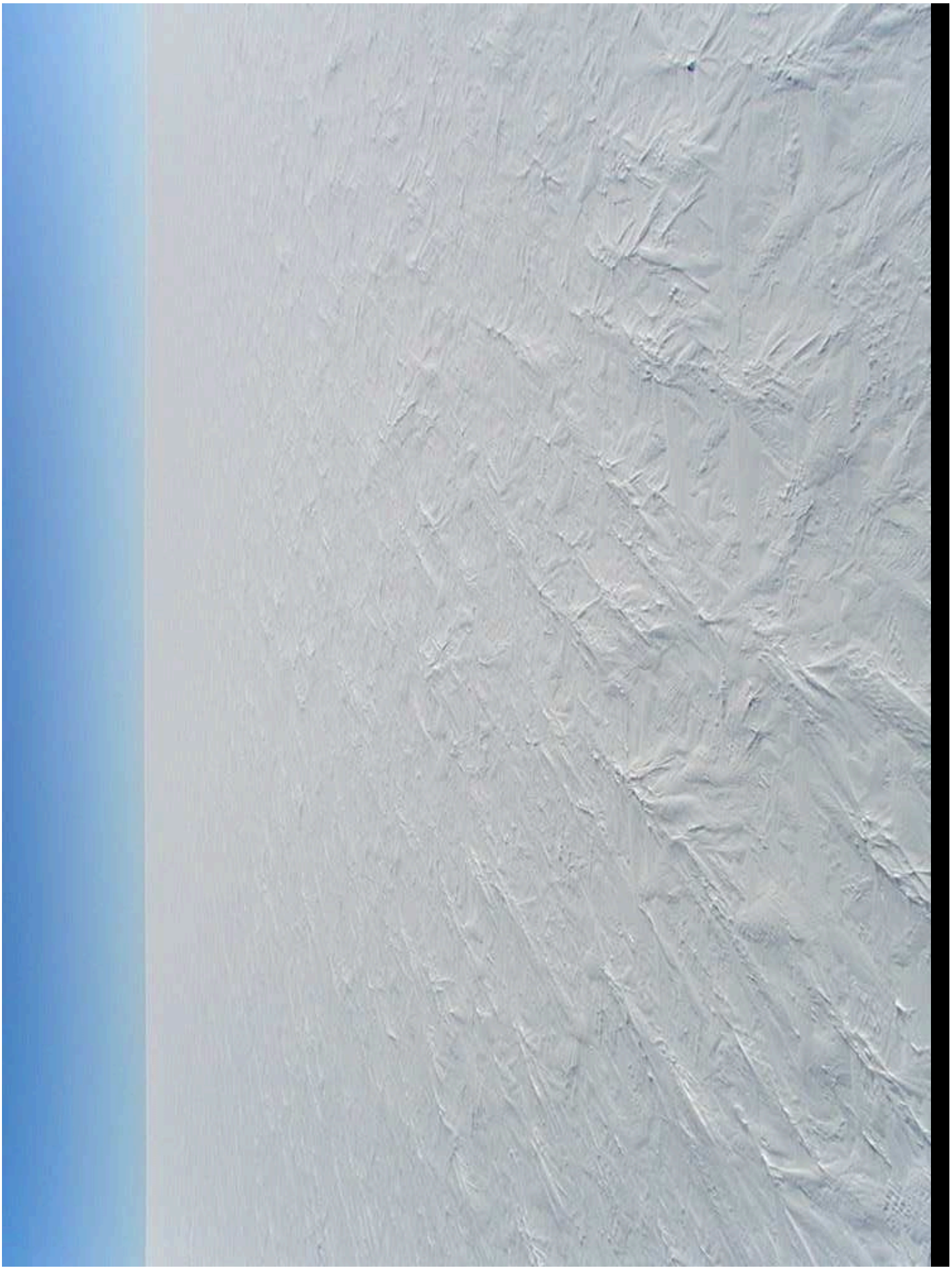
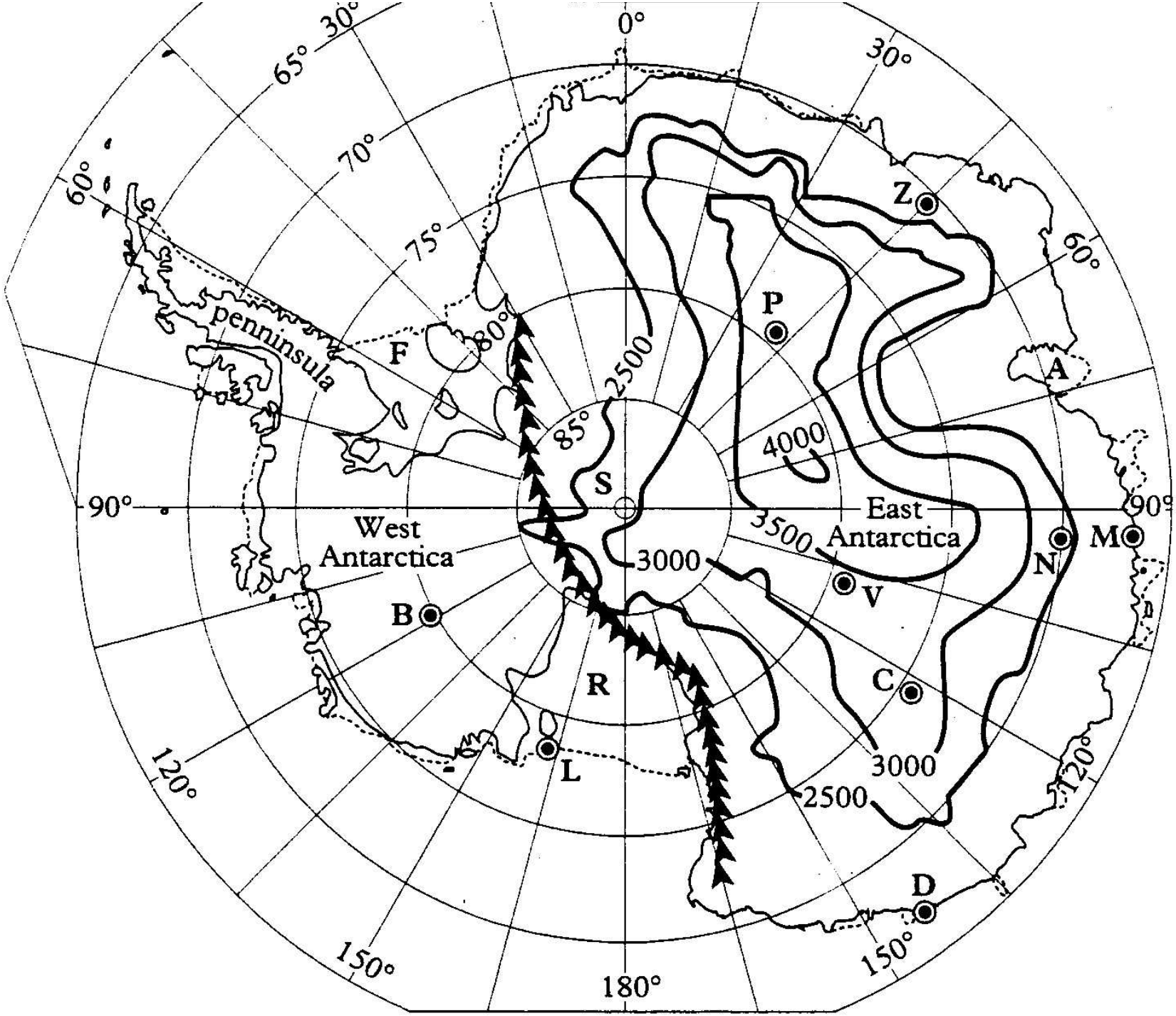
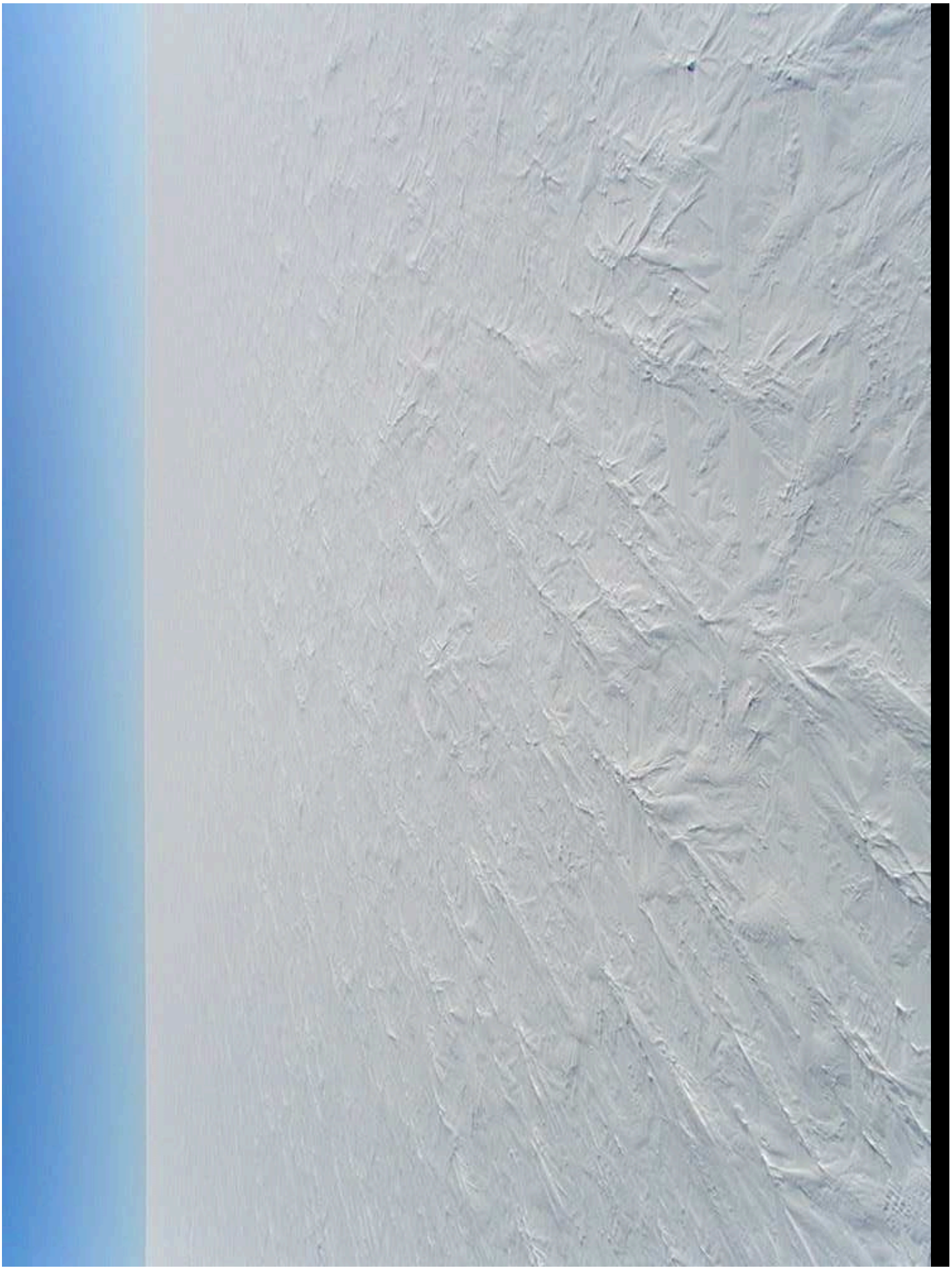
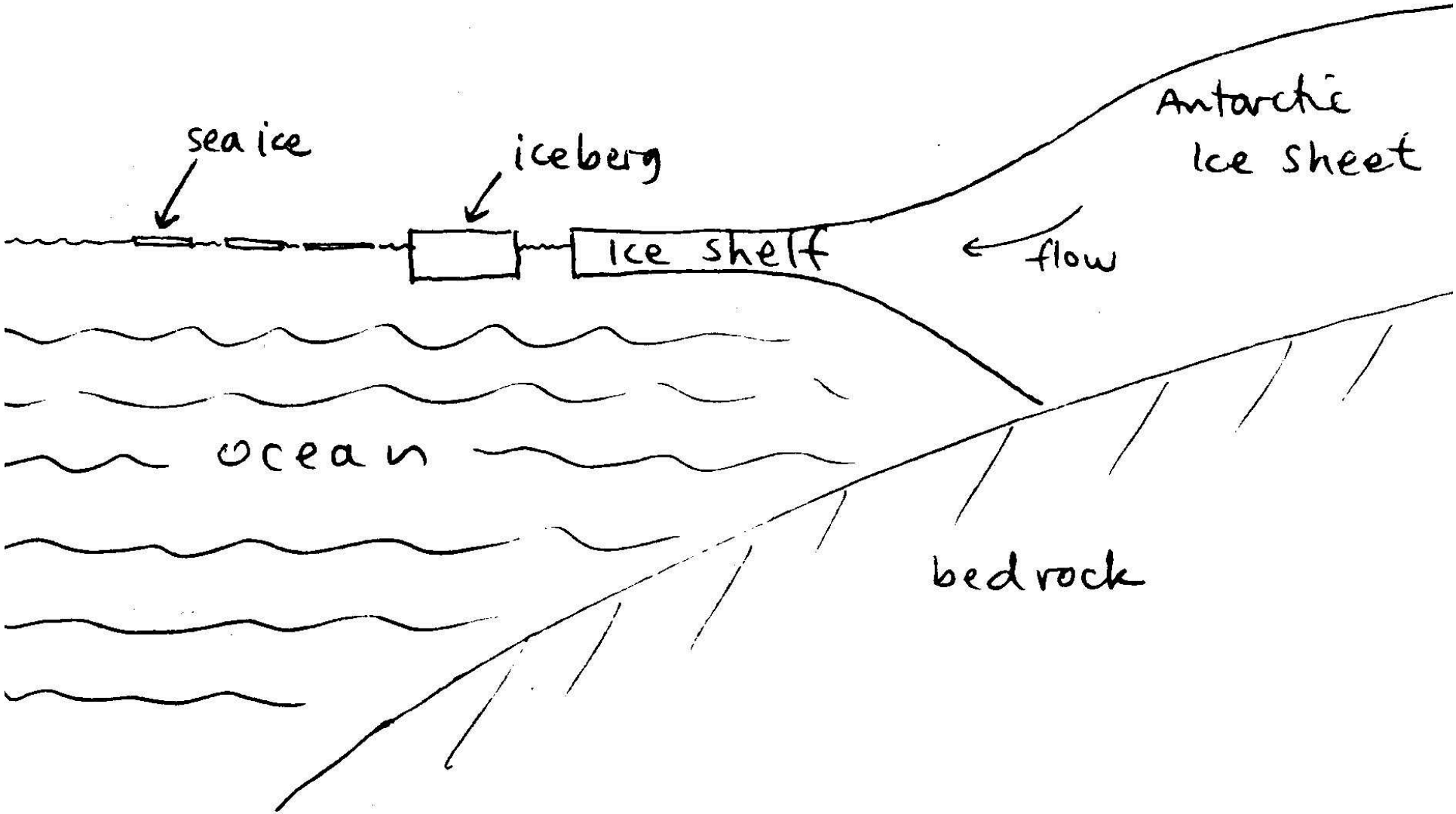


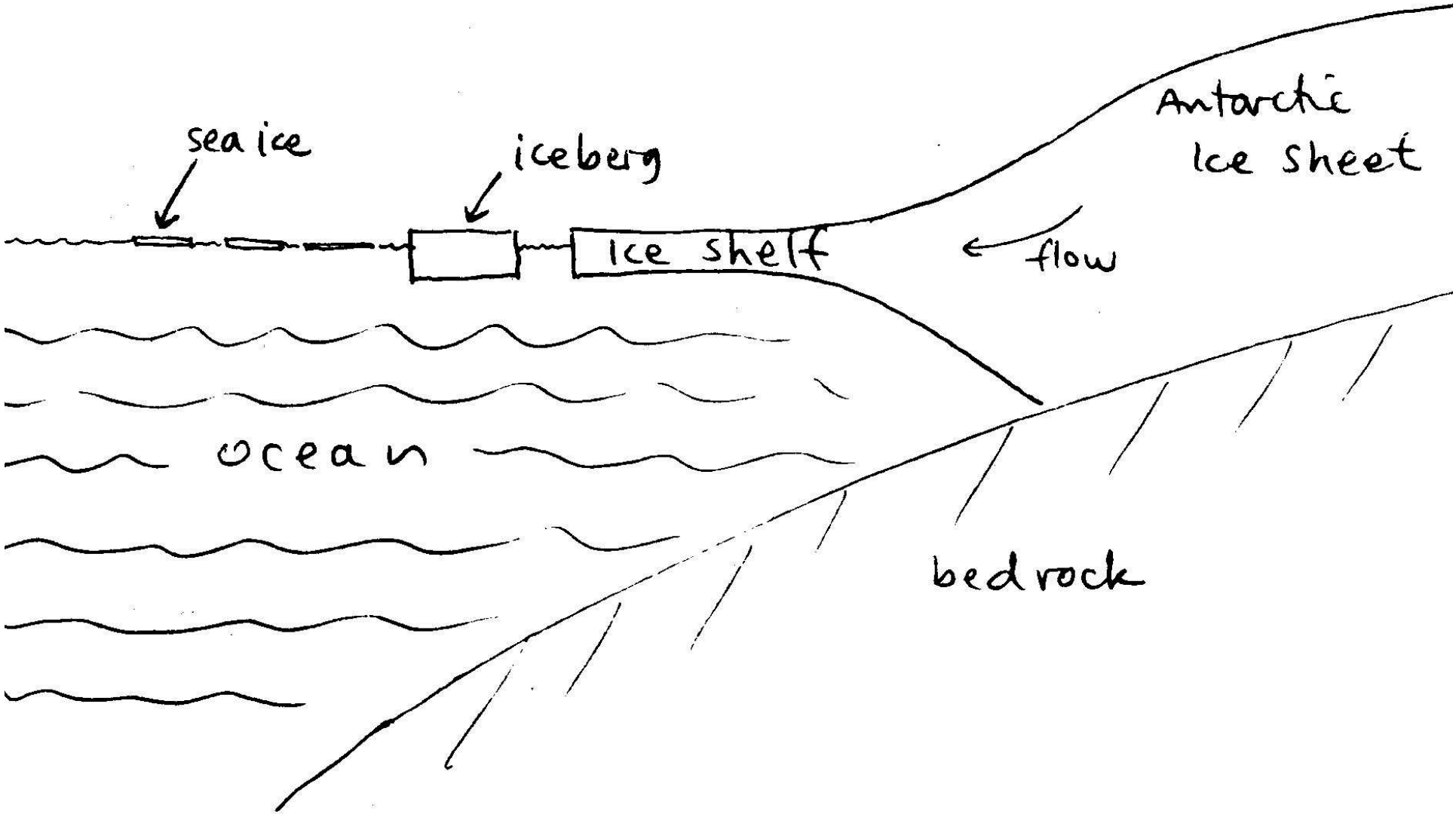
FIG. 1—Average heights of the continents [after *Kossina*, 1933]

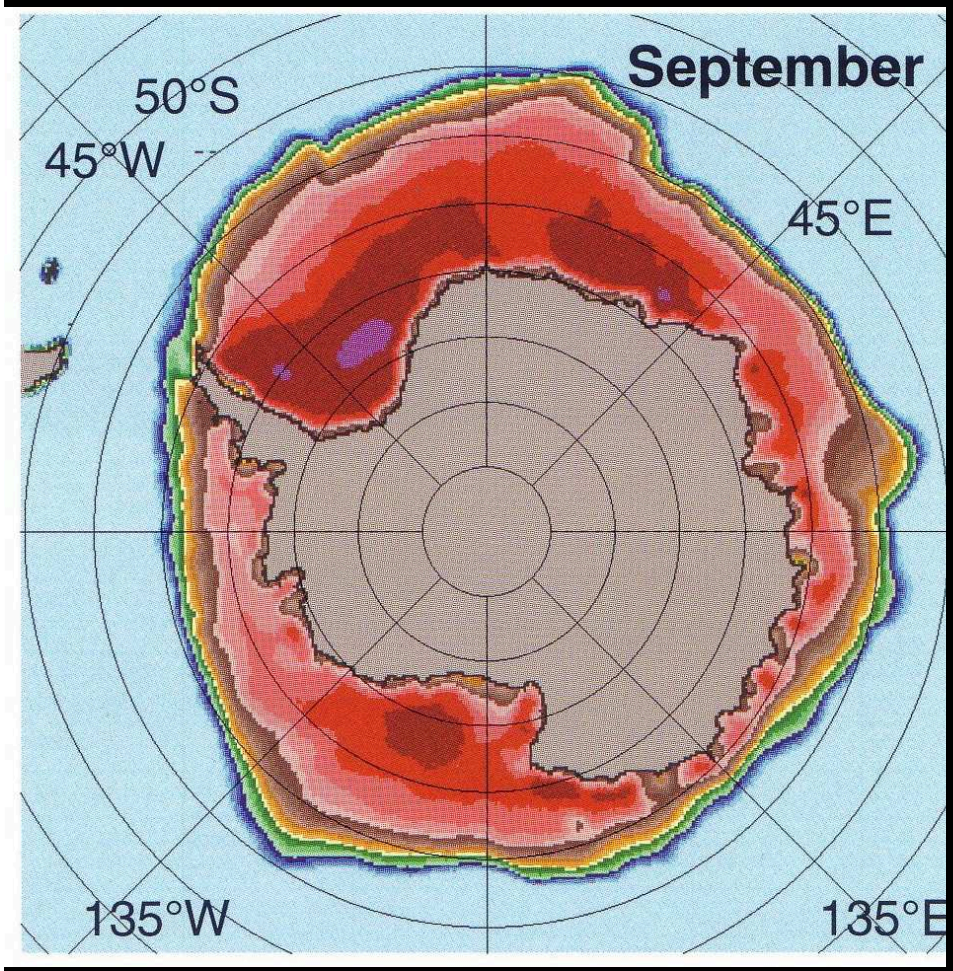


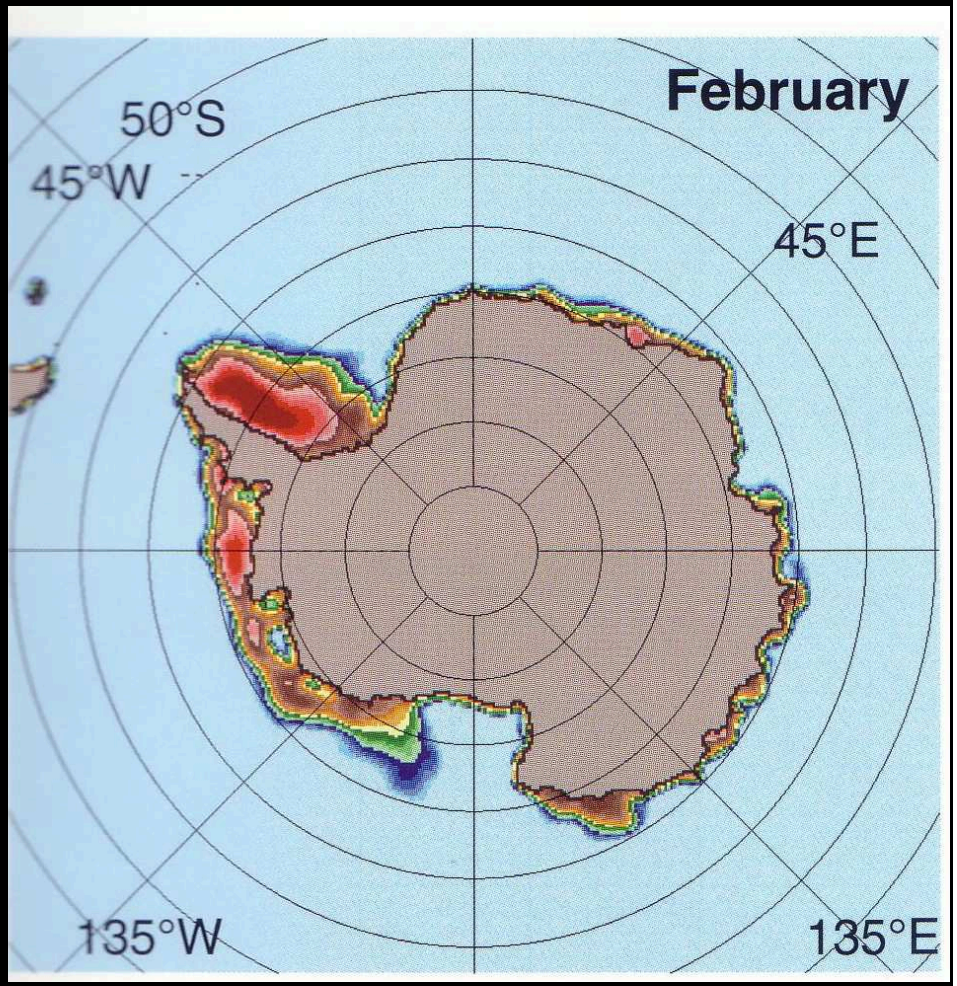

0°
30°
60°
65°
70°
75°
80°
85°
90°
120°
150°
180°
2500
3000
3500
4000
Z
P
A
F
S
M
N
V
B
R
C
L
D
West
Antarctica
East
Antarctica
penninsula




sea ice
iceberg
Antarctic
Ice Sheet
ice shelf
flow
ocean
bedrock


sea ice
iceberg
Antarctic
Ice Sheet
ice shelf
flow
ocean
bedrock


September
50°S
45°W
45°E
135°W
135°E


February
50°S
45°W
45°E
135°W
135°E

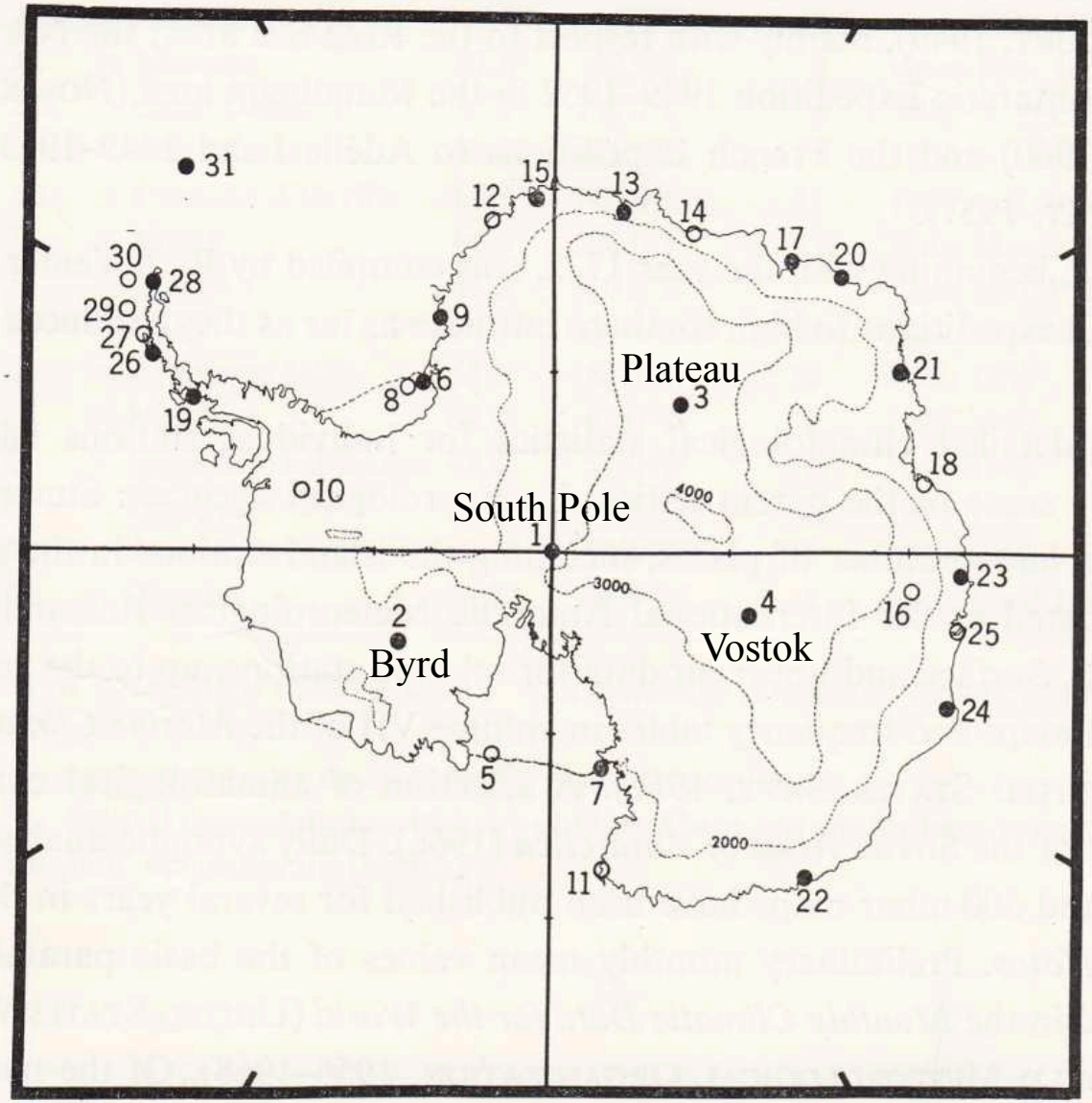


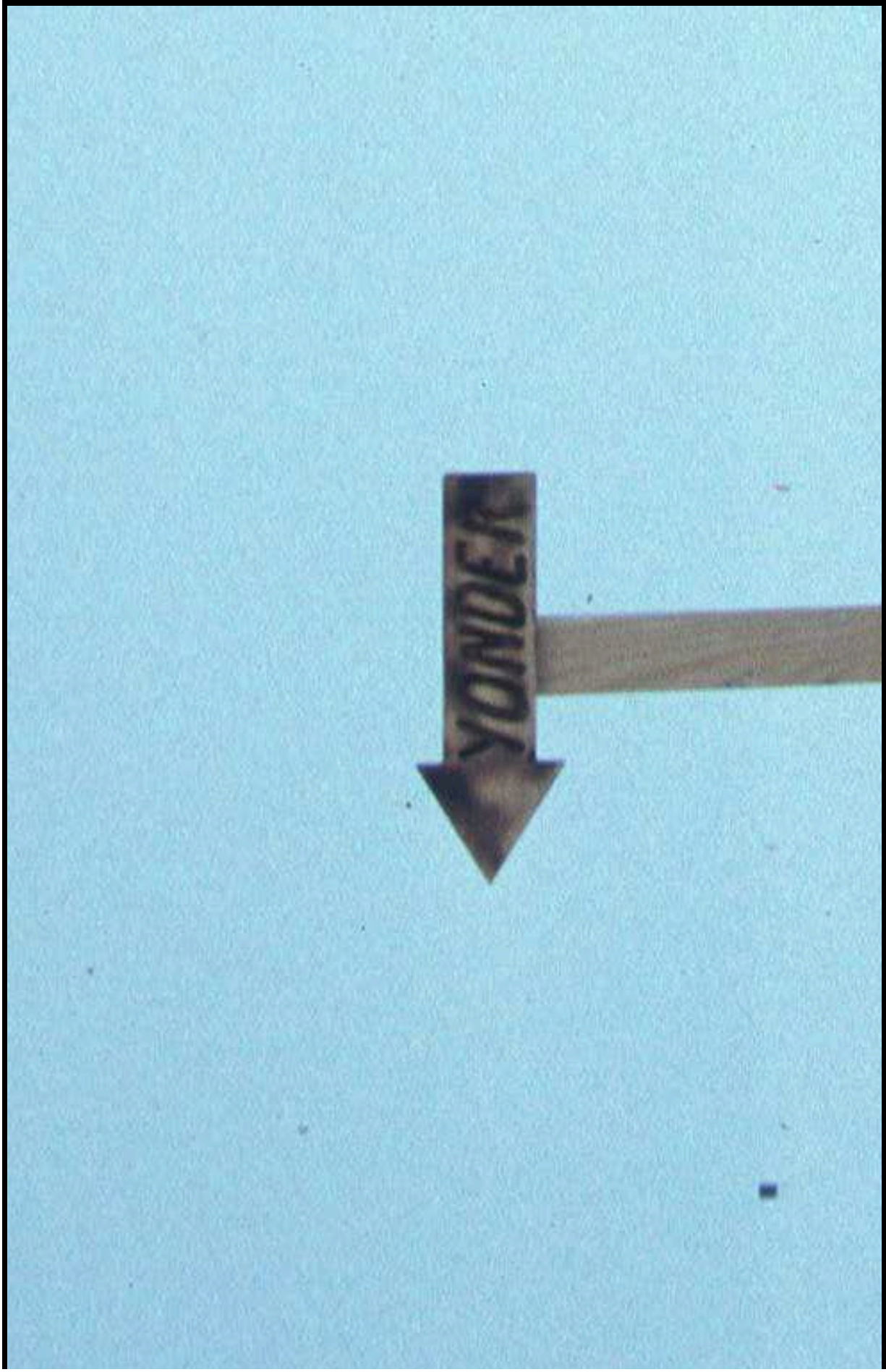
Fig.1. The Antarctic continent. Contourlines only for 2,000, 3,000 and 4,000 m elevation. Full circles = meteorological stations in operation in the winter of 1968. Open circles = stations in operation for two years or more at any time, but not in 1968. Station numbers refer to Table I.

Topics

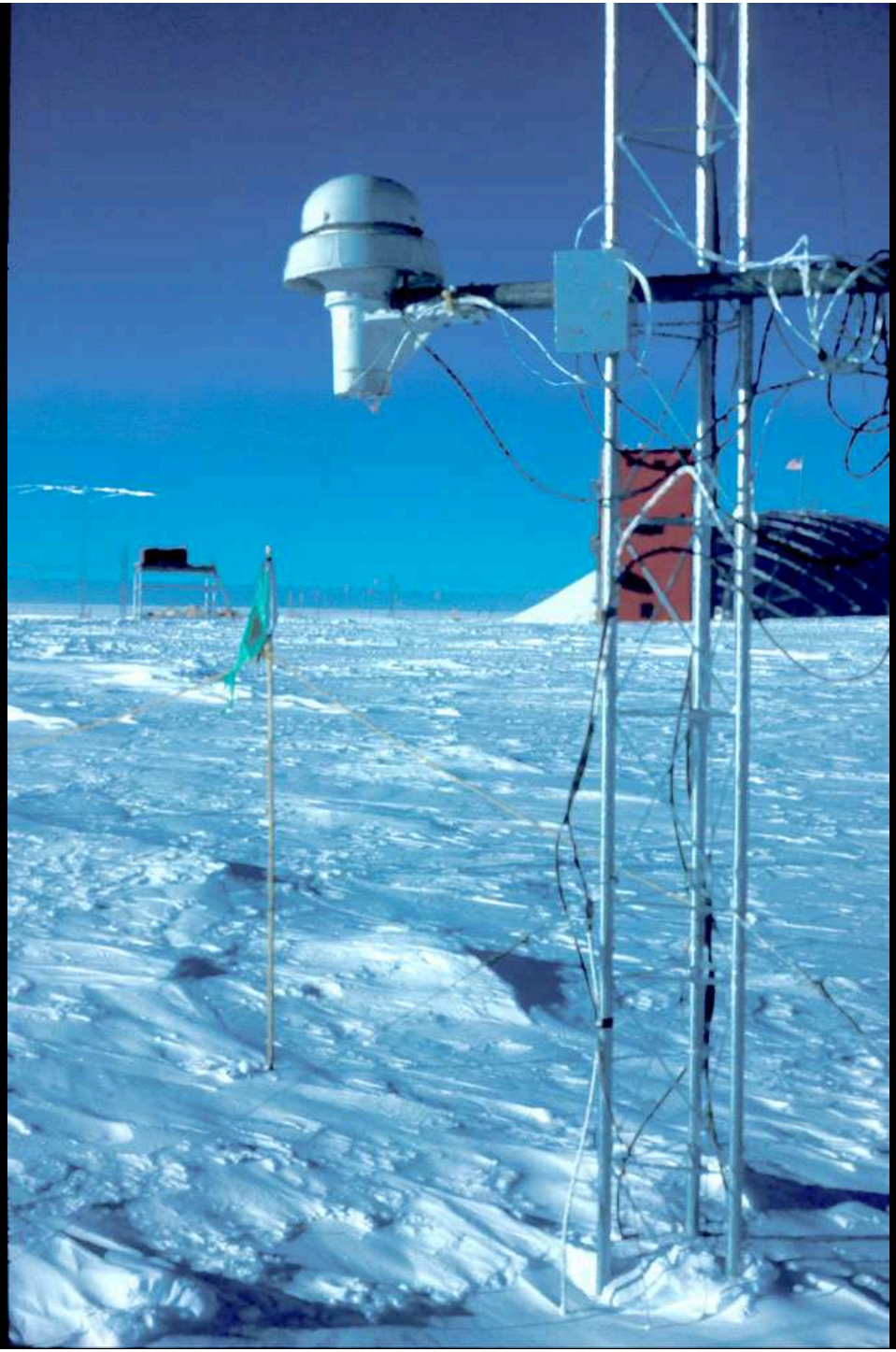
Surface temperature
Surface energy budget
Clouds
Snowfall
Stratosphere: temperature and clouds
Wind and drifting snow


South Pole Station

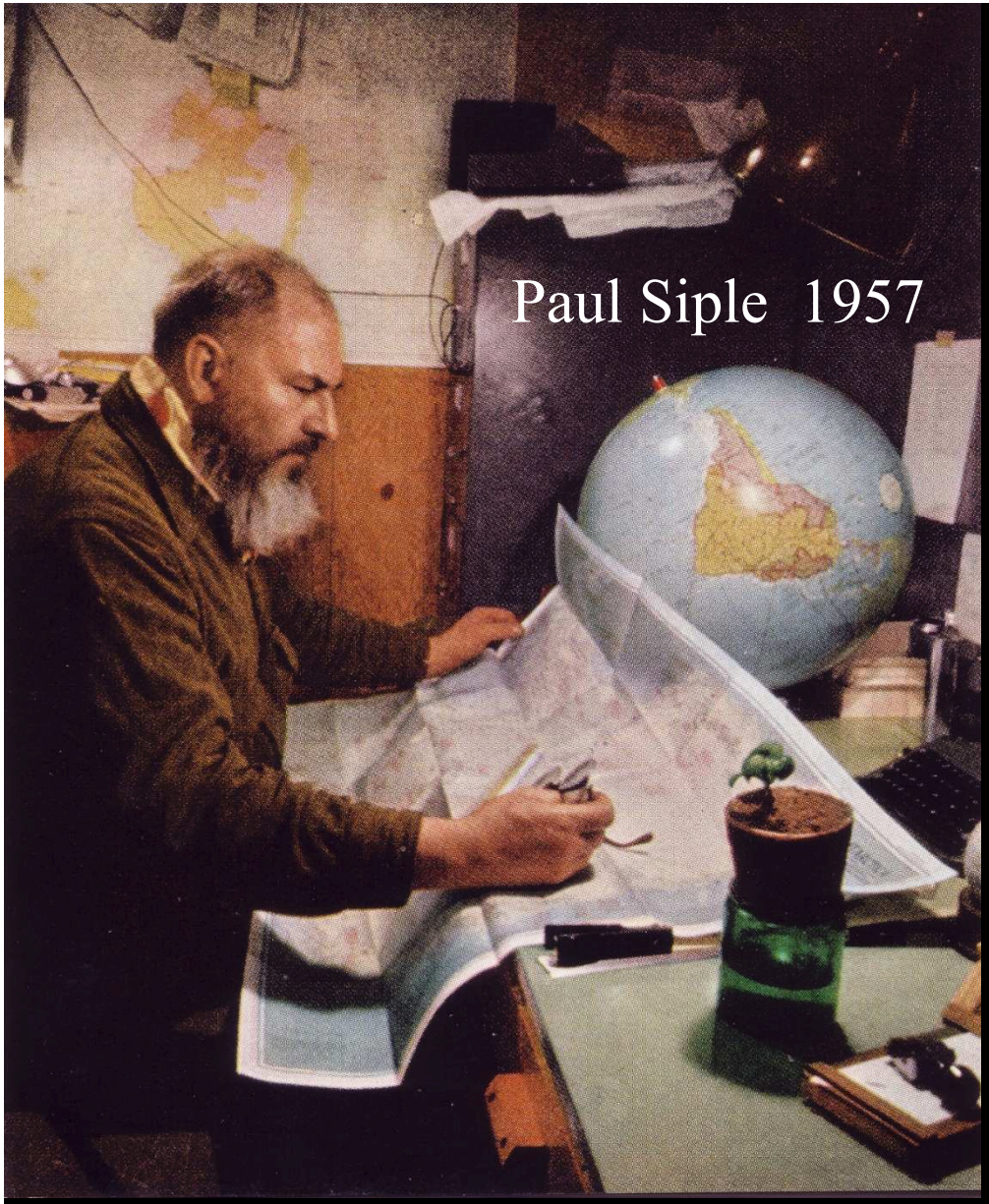

YONDER
GEOGRAPHIC
SOUTH POLE
9,301' ELEVATION
AVE. TEMP. -56° F
ICE THICKNESS IN EXCESS OF 9000'


YONDER


SOUTH POLE METEOROLOGY



30
15
360



VOL. CXIII, No. 4 WASHINGTON APRIL, 1958

THE NATIONAL GEOGRAPHIC MAGAZINE

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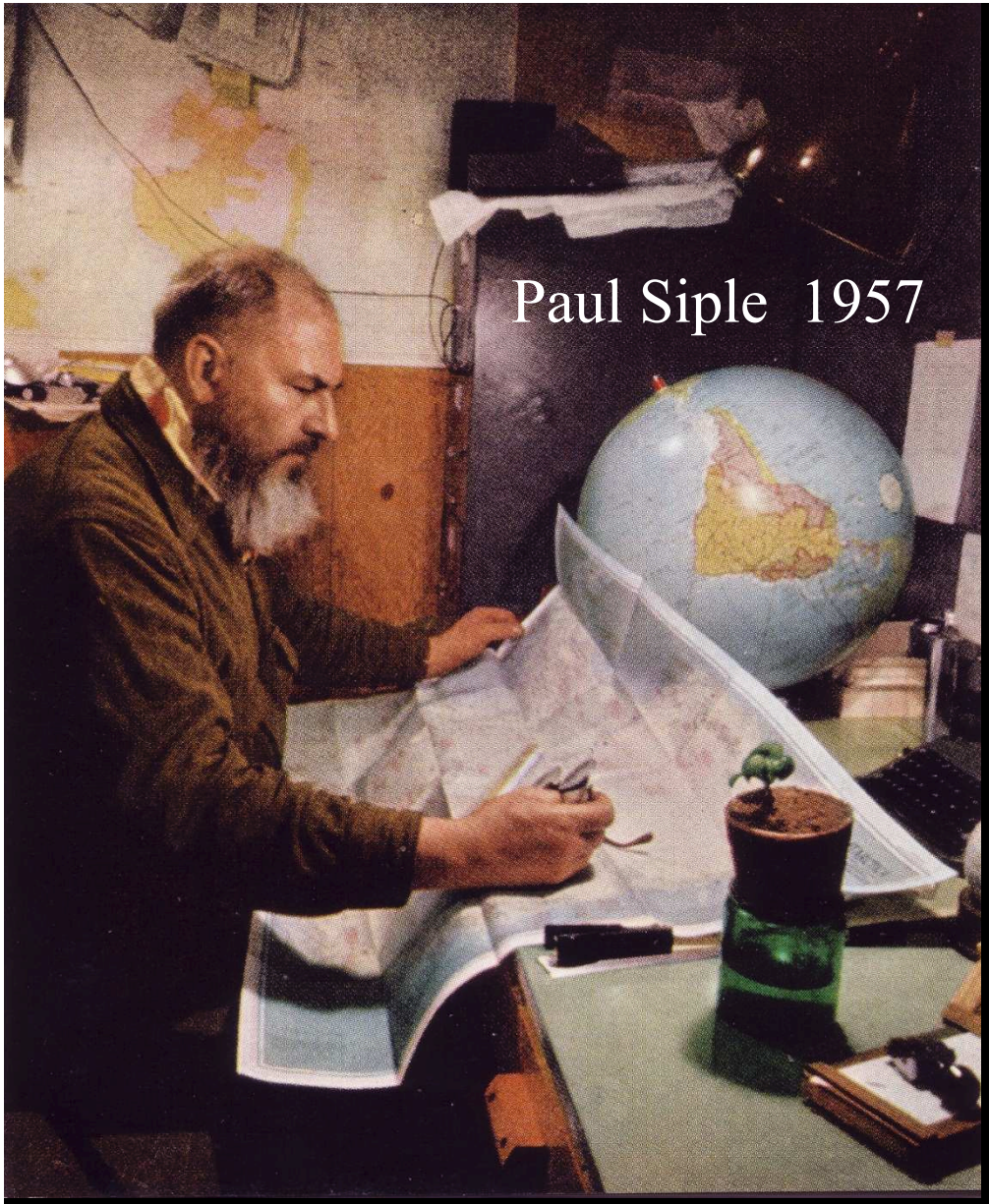
Cold Fiercer Than Men Had Ever Faced, Ceaseless Winds, a 6-Month Night—Yet 18 Pioneers of Science Survived, and Thrived

BY PAUL A. SIPLE, Ph.D., D.Sc.
Scientific Leader, Amundsen-Scott IGY South Pole Station

South Pole Station
established December 1956



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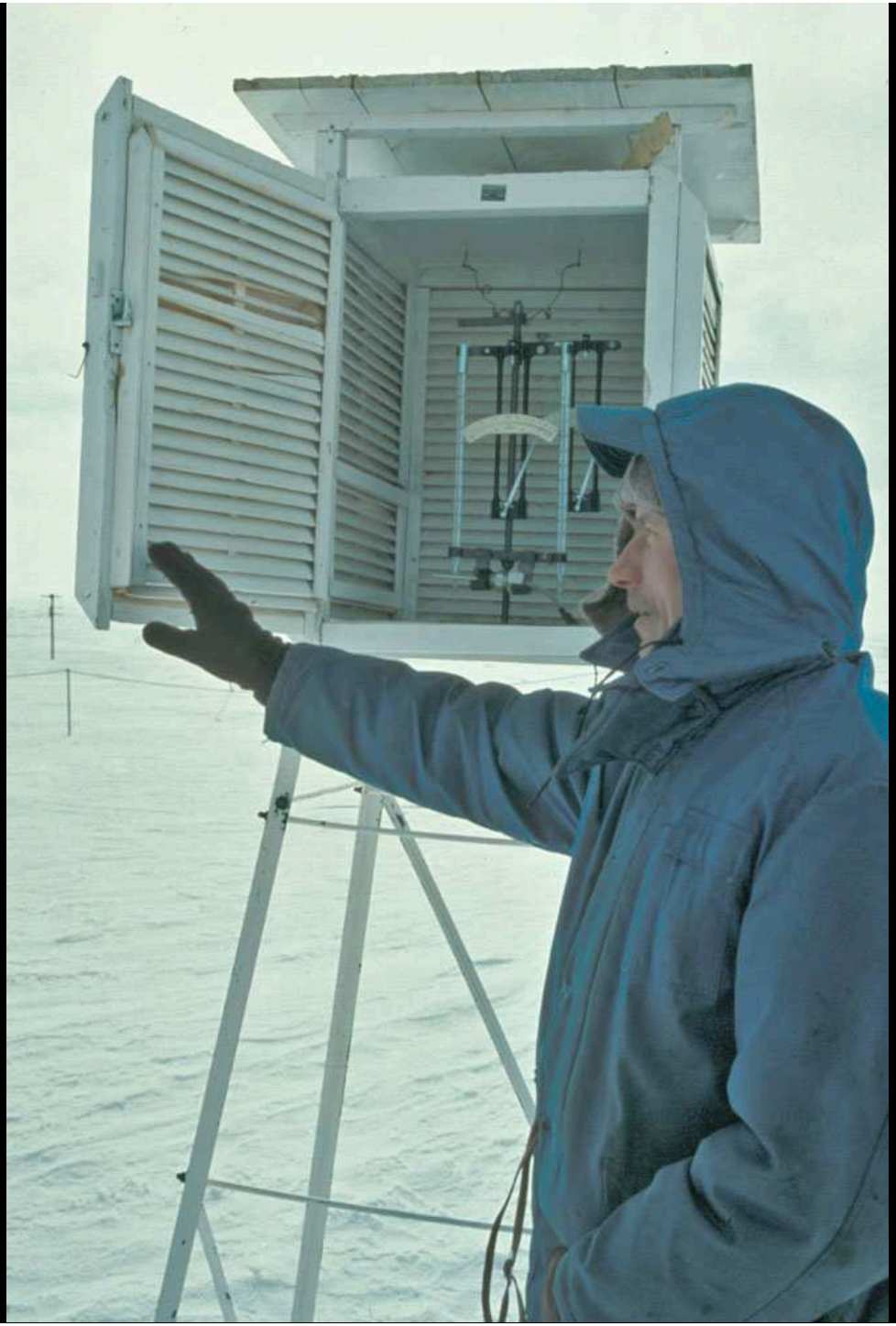
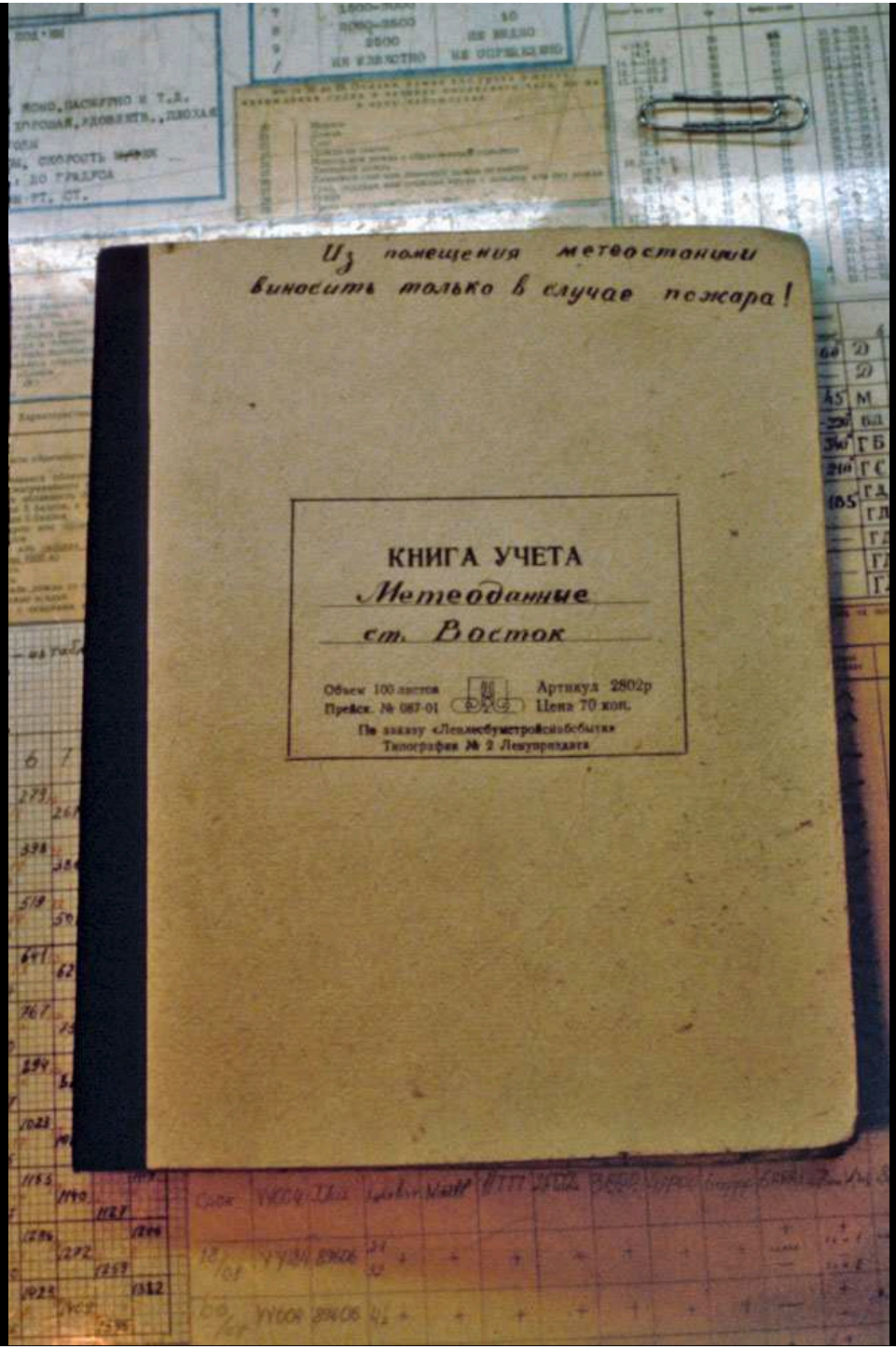
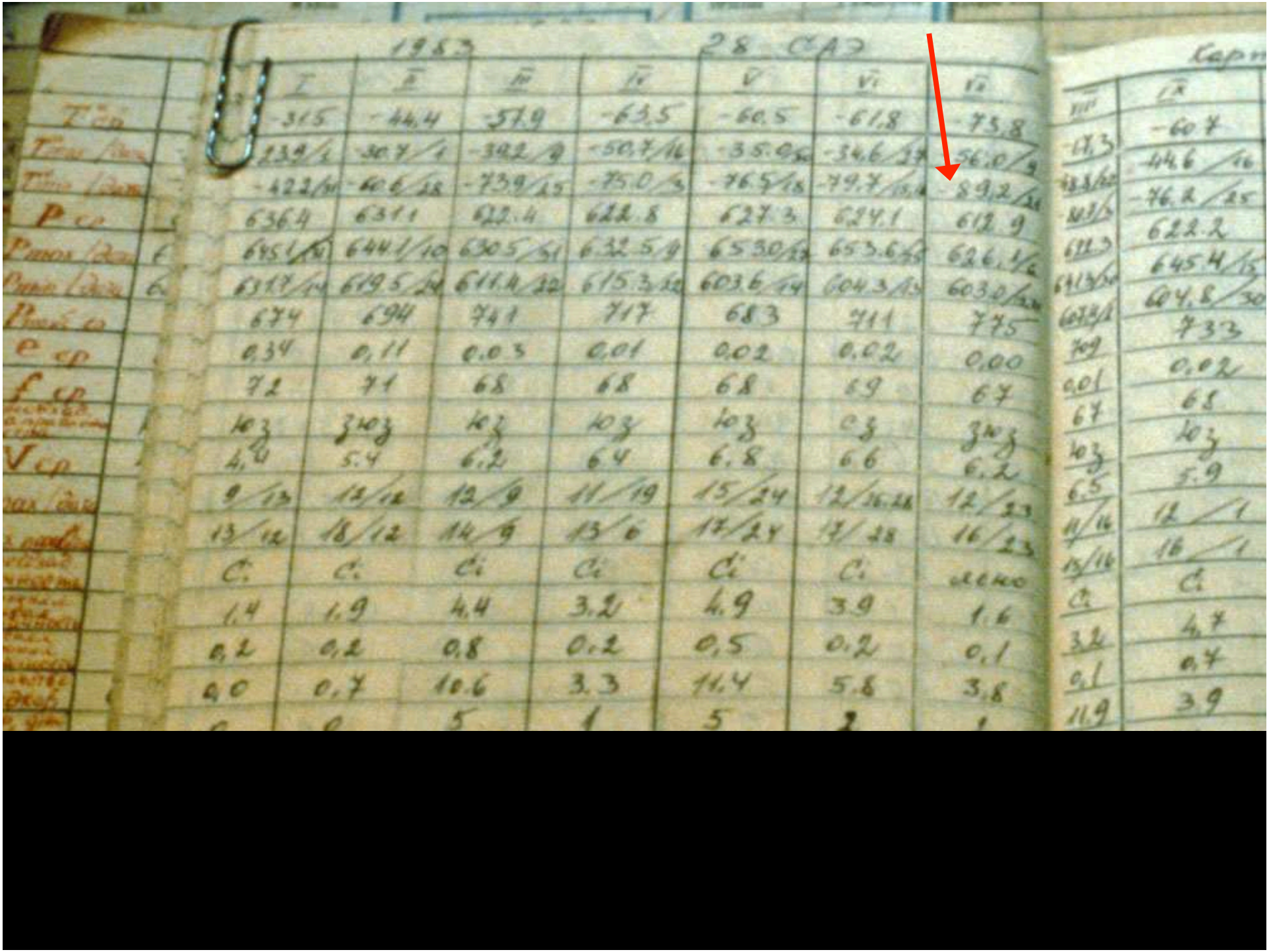
South Pole Station
established December 1956

February 1960
Paul Siple's lecture at
Purdue




Из помещения метеостанции
выносить только в случае пожара!
КНИГА УЧЕТА
Метеоданные
ст. Восток
Объем 100 листов
Прейск. № 087-01
Артикул 2802р
Цена 70 коп.
По заказу «Ленинградстройснабсбыта»
Типография № 2 Лениздата



1953 28 СА

	I	II	III	IV	V	VI	VII
T ср	-31.5	-44.4	-57.9	-63.5	-60.5	-61.8	-73.8
Tmax /дата	-23.9/1	-30.7/1	-39.2/9	-50.7/16	-35.0/30	-34.6/27	-56.0/9
Tmin /дата	-42.2/10	-40.6/28	-73.9/25	-75.0/3	-76.5/16	-79.7/15,16	-89.2/24
P ср	636.4	631.1	622.4	622.8	627.3	624.1	612.9
Pmax /дата	645.1/10	644.1/10	630.5/31	632.5/9	653.0/27	653.6/26	626.1/6
Pmin /дата	631.7/14	619.5/24	611.4/22	615.3/12	603.6/14	604.3/15	603.0/30
Pmax ср	674	694	741	717	683	711	775
e ср	0.34	0,11	0.03	0,01	0,02	0,02	0,00
f ср	72	71	68	68	68	69	67
	40з	30з	40з	40з	40з	0з	30з
V ср	4,0	5.4	6.2	6.4	6.8	6.6	6.2
max /дата	9/13	13/12	12/9	11/19	15/24	12/16,24	12/23
	13/12	18/12	14/9	13/6	17/24	17/28	16/23
	Ci	Ci	Ci	Ci	Ci	Ci	мало
	1.4	1.9	4.4	3.2	4.9	3.9	1.6
	0,2	0,2	0,8	0.2	0,5	0.2	0,1
	4.0	0,7	10.6	3.3	11.4	5.6	3,8
			5	1	5	2	1

Кар

VIII	Cx
-47.3	-60.7
43.5/22	44.6/16
40.3/5	-76.2/25
611.3	622.2
641.3/30	645.4/15
607.2/1	604.8/30
709	733
0,01	0,02
67	68
40з	40з
6.5	5.9
11/16	12/1
15/16	16/1
Ci	Ci
3.2	4.7
0,1	0,7
11.9	39

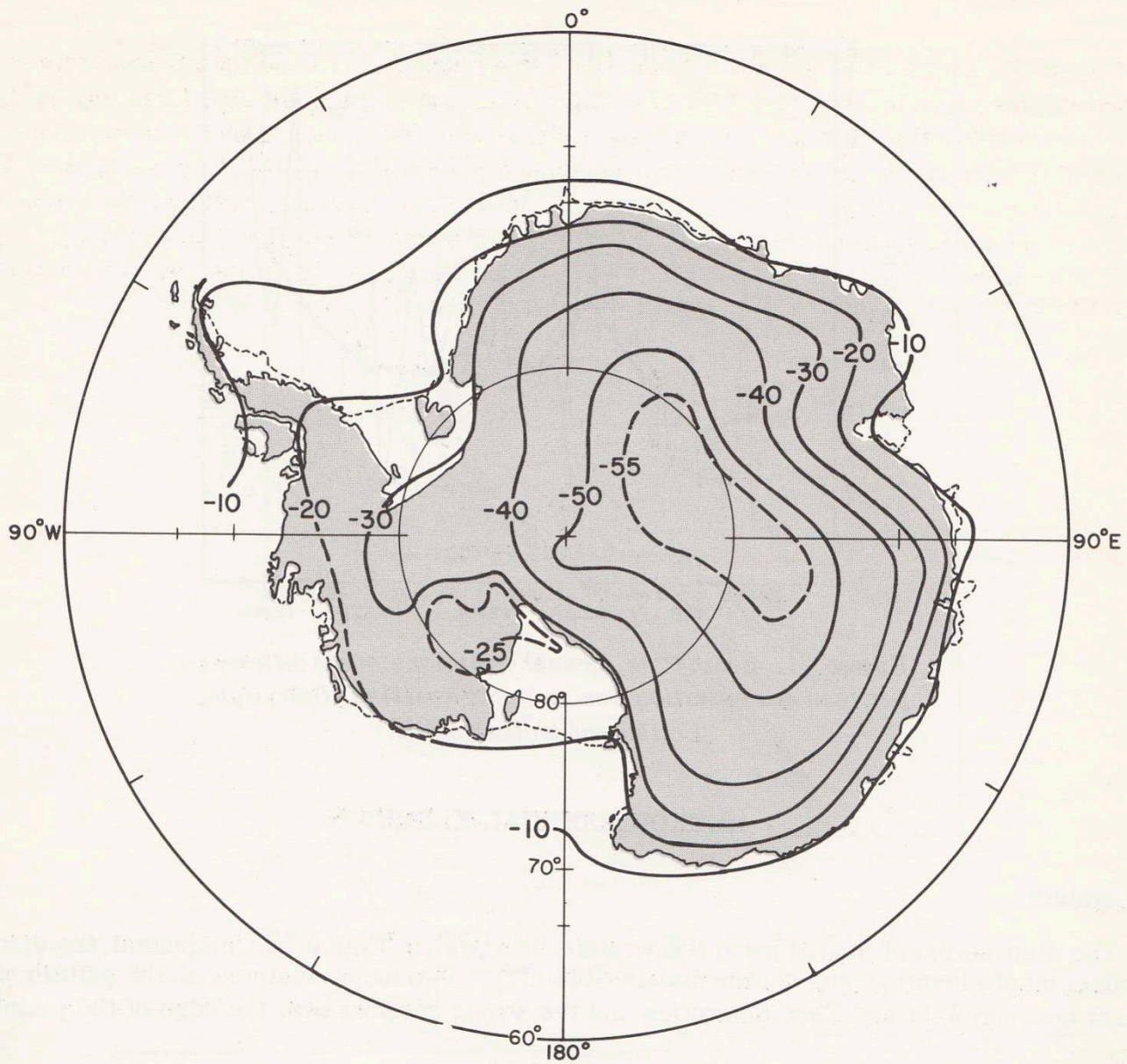


Figure 22. Annual mean temperature, °C (Rubin[197]).

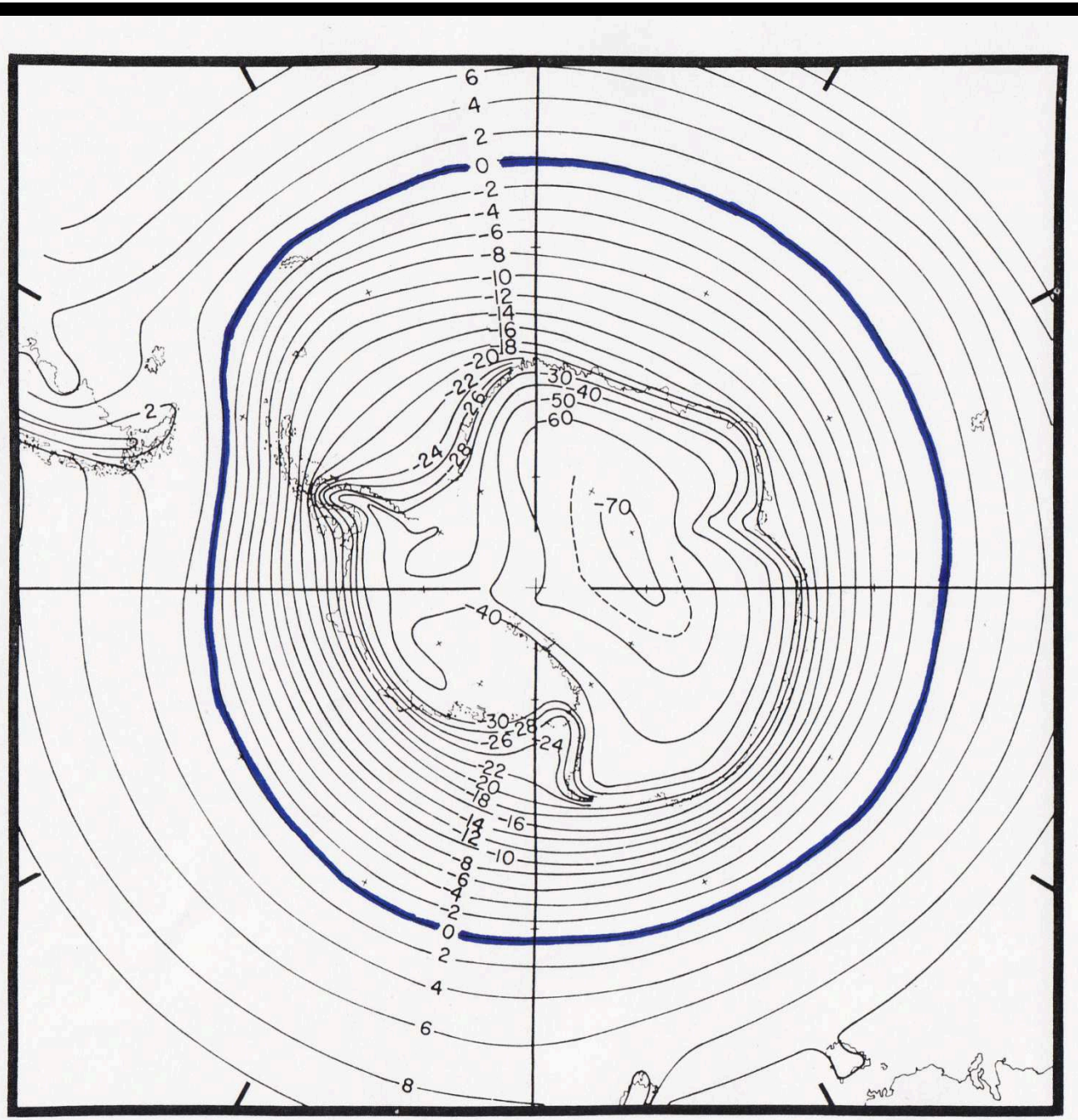


Fig 4. Mean isotherms at surface, July.

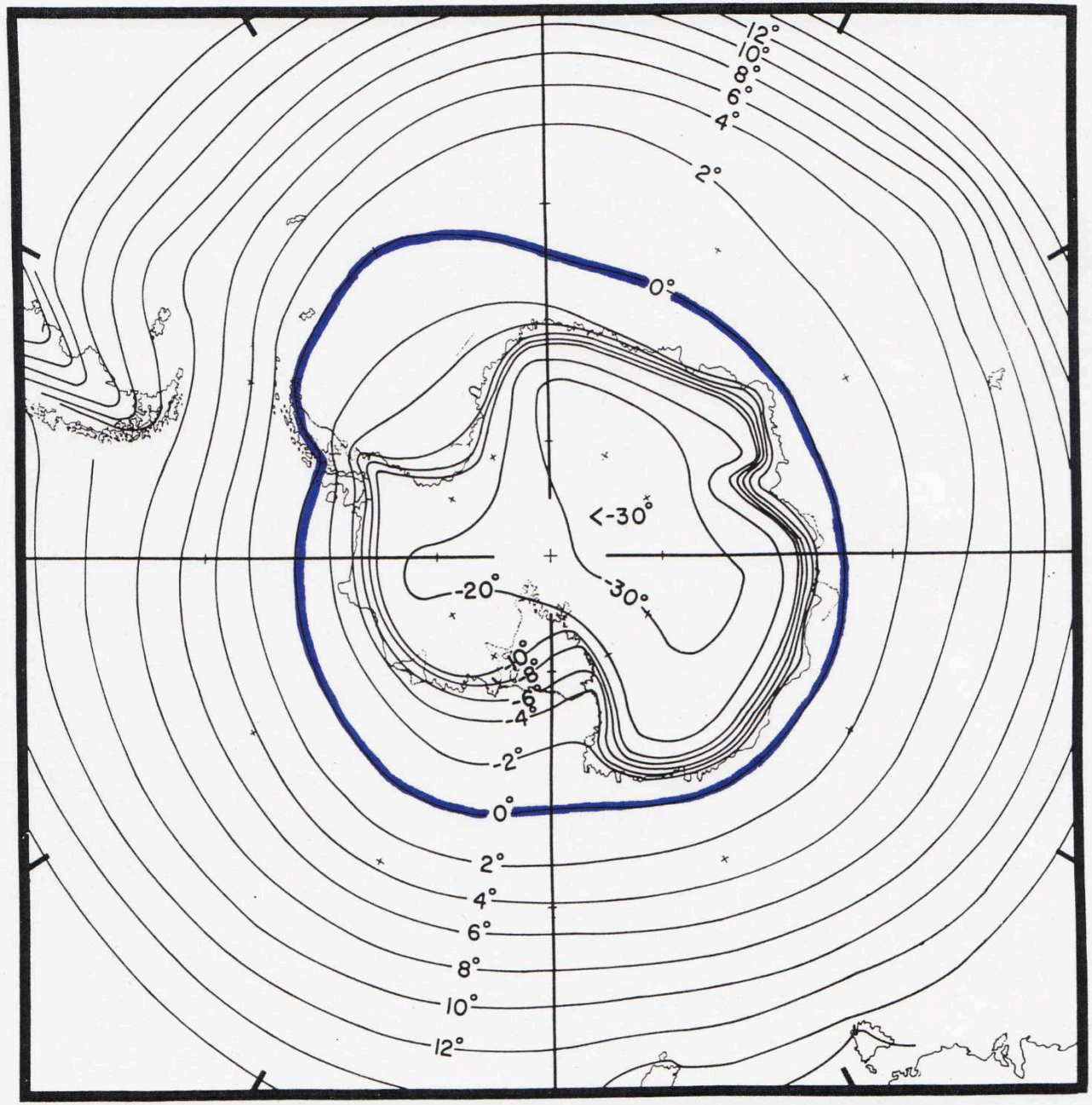


Fig.3. Mean isotherms at surface, January.

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

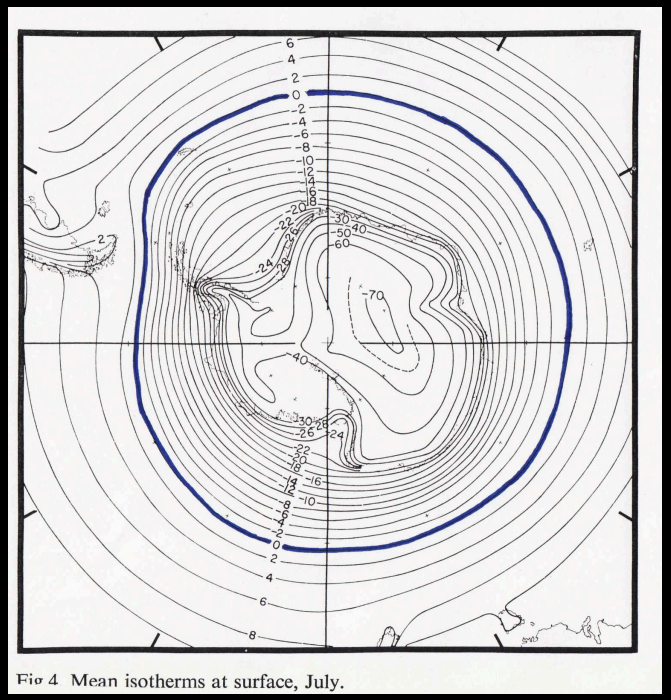


Fig 4 Mean isotherms at surface, July.

ENCYCLOPEDIA OF CLIMATE AND WEATHER

New York Oxford
OXFORD UNIVERSITY PRESS
1996

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

ANTARCTICA. Table 1. *Surface air temperatures at representative antarctic stations*

Region	Low-Latitude Coast	High-Latitude Coast	West Antarctica	East Antarctica	
Station	Mirnyy	Little America (Framheim)	Byrd	South Pole	Vostok
Latitude(°S)	66	78	80	90	78
Elevation (meters)	30	40	1,500	2,800	3,500
Station pressure (millibars)	980	980	800	680	620
Mean summer temperature (°C)	−2	−7	−15	−28	−33
Mean winter temperature(°C)	−16	−33	−34	−58	−66
Extreme maximum temperature (°C)	+8	+6	−1	−14*	−21
Extreme minimum temperature (°C)	−40	−61	−63	−81	−89

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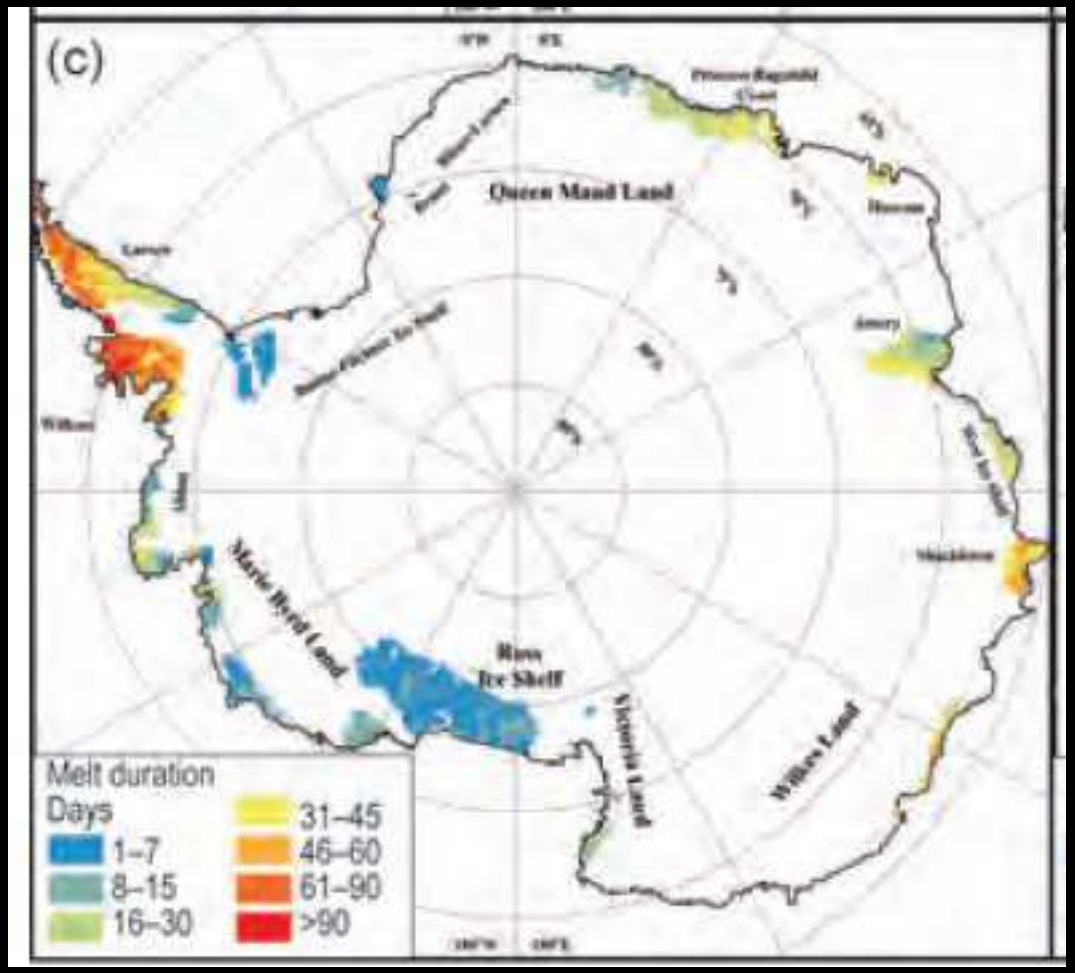
*December 1978. New record high in 2011 is -12.3°C



AMS Bulletin, August 2016

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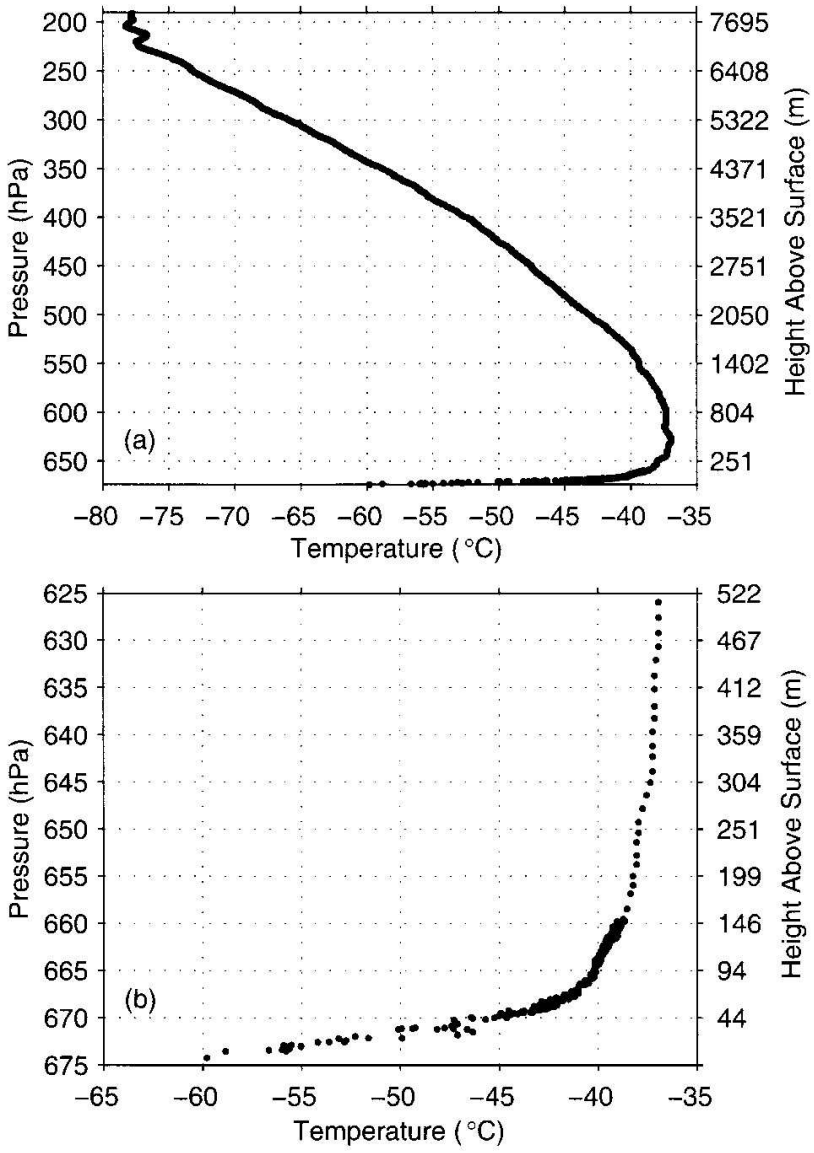
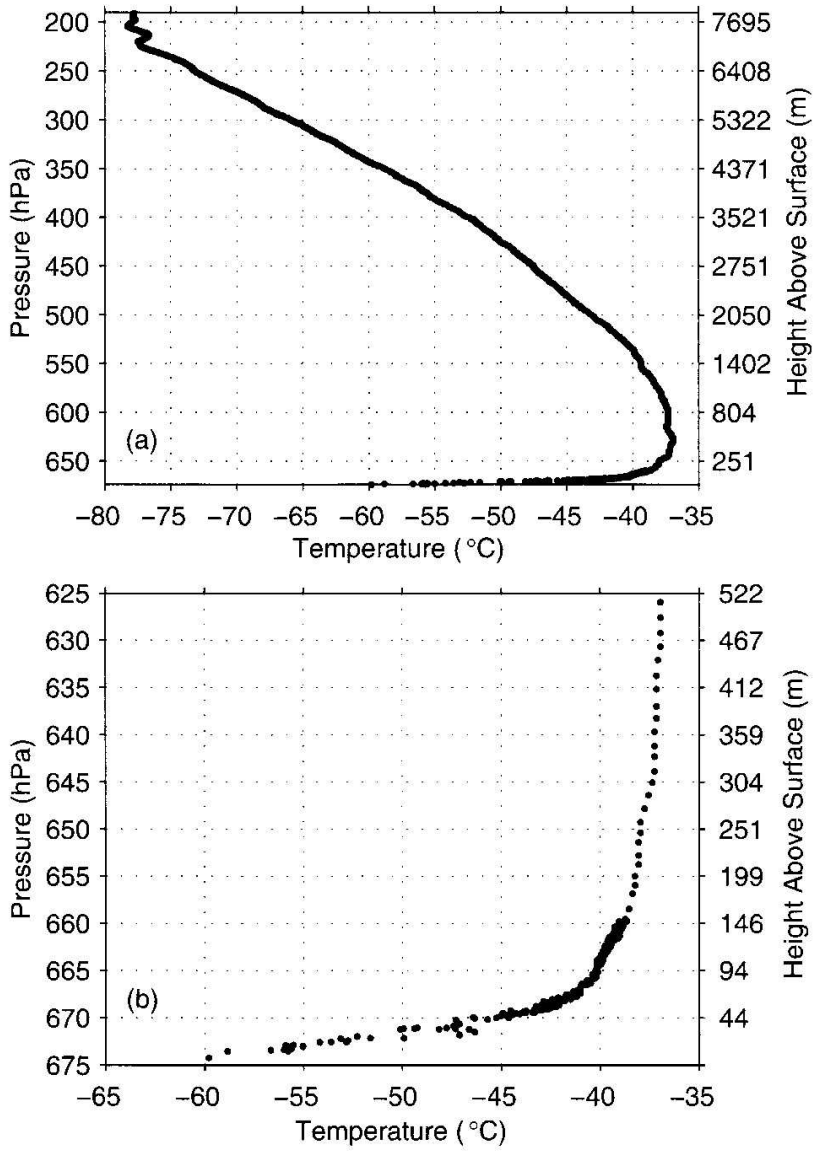


FIG. 3. Temperature profile measured at South Pole Station on 25 Sep 2001. Data above 660 hPa are from a routine radiosounding with an RS80; those below 660 hPa are from a tethered sounding with an RS80. (a) The full tropospheric sounding is shown, and (b) the lowest 500 m are enlarged. The surface pressure was 674 hPa.

Near-surface temperature inversion in winter (no Sun)

(Hudson & Brandt 2005)



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Near-surface temperature inversion in winter (no Sun)

$IR_{up} \approx IR_{down}$

$\varepsilon_s \sigma T_s^4 \approx \varepsilon_a \sigma T_a^4$

$\varepsilon_s \approx 1 \quad \varepsilon_a < 1$

Therefore

$T_s < T_a$

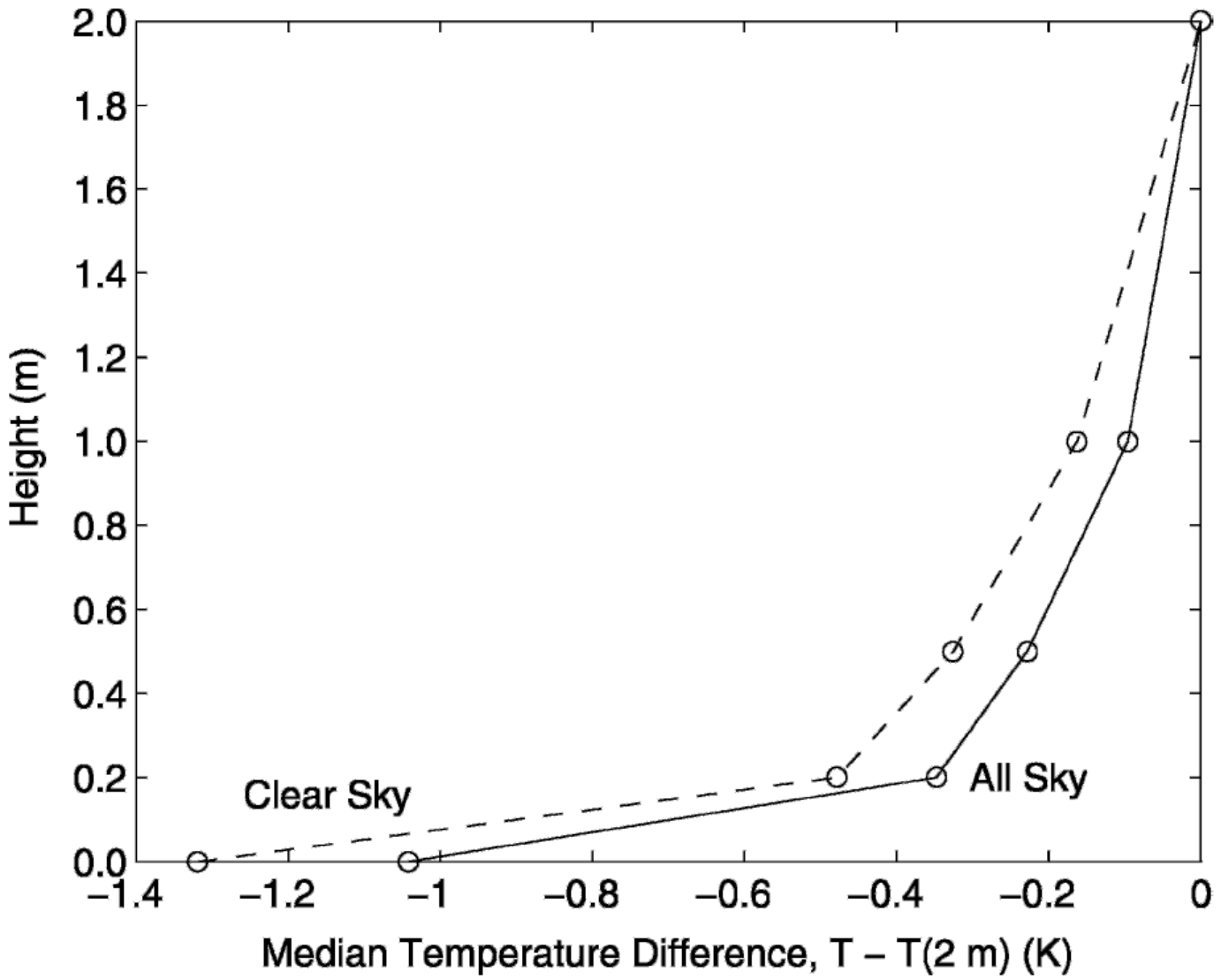


FIG. 13. Median temperature difference relative to 2 m. Data are from South Pole during the 2001 polar night. Separate profiles are shown for the overall median (All Sky, solid line) and the clear-sky median (dashed line).

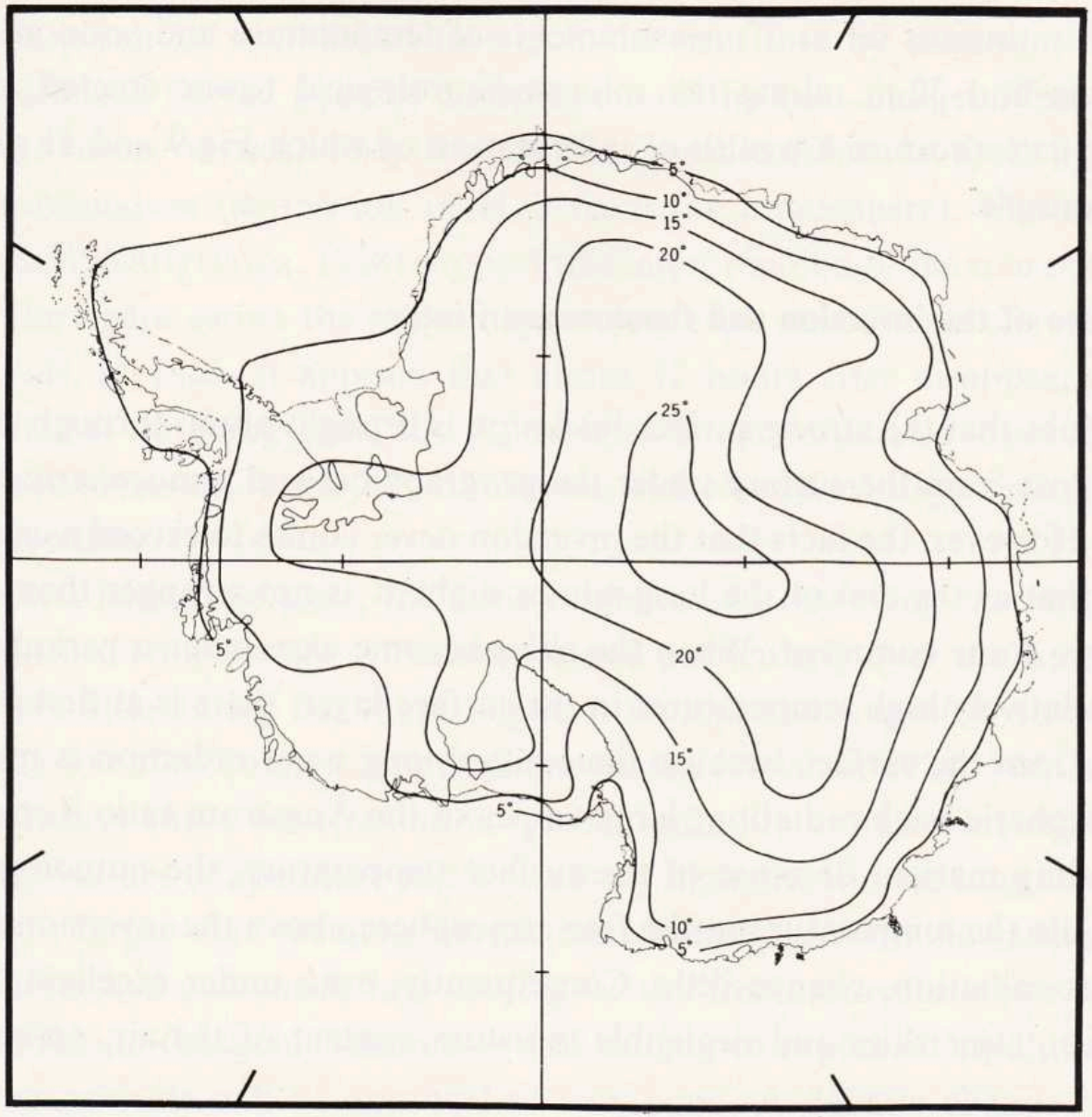
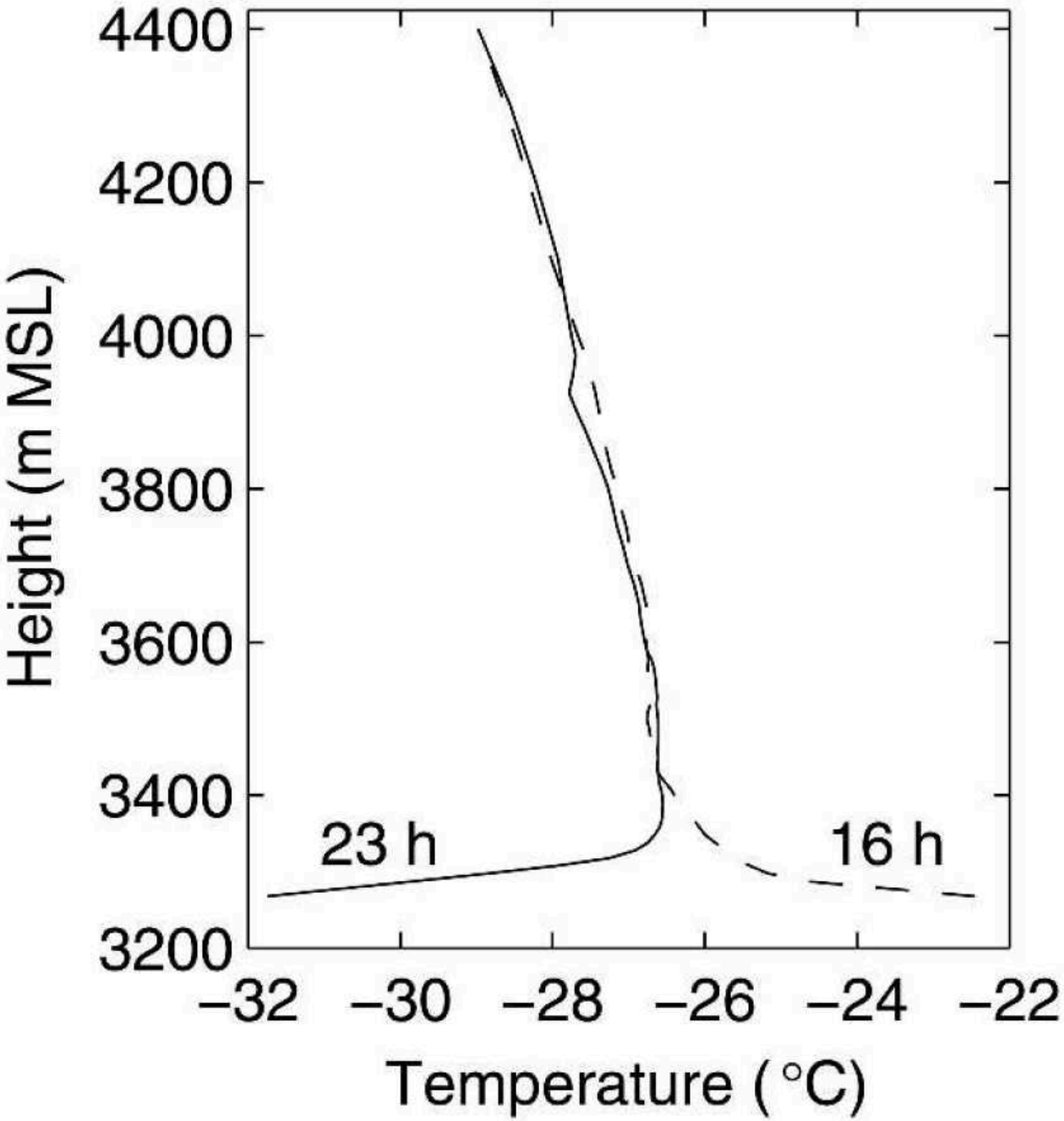
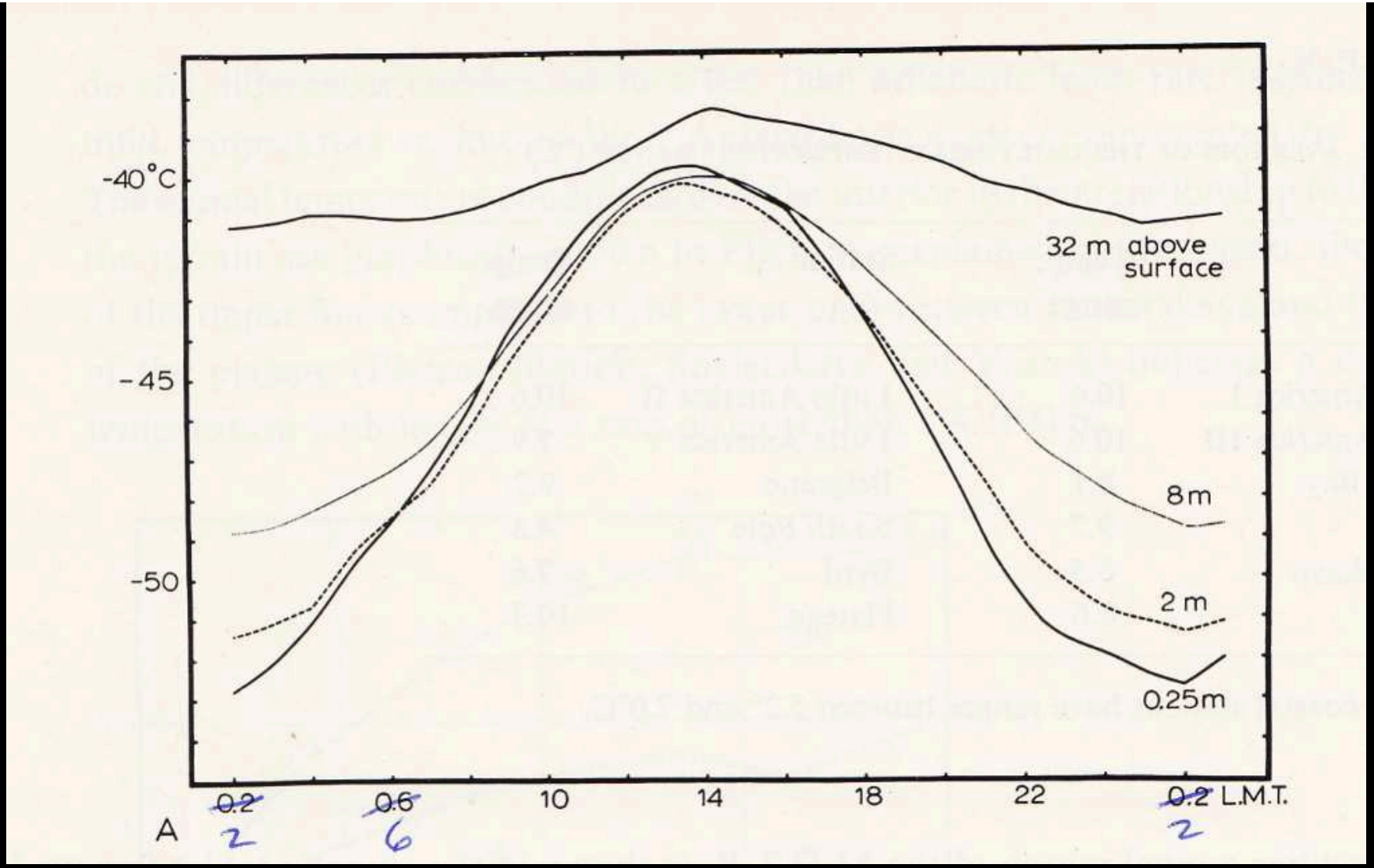


Fig.12. Isolines of the average strength of the surface inversion in the winter (June–August). (After PHILLPOT and ZILLMAN (1969) with slight modifications.)

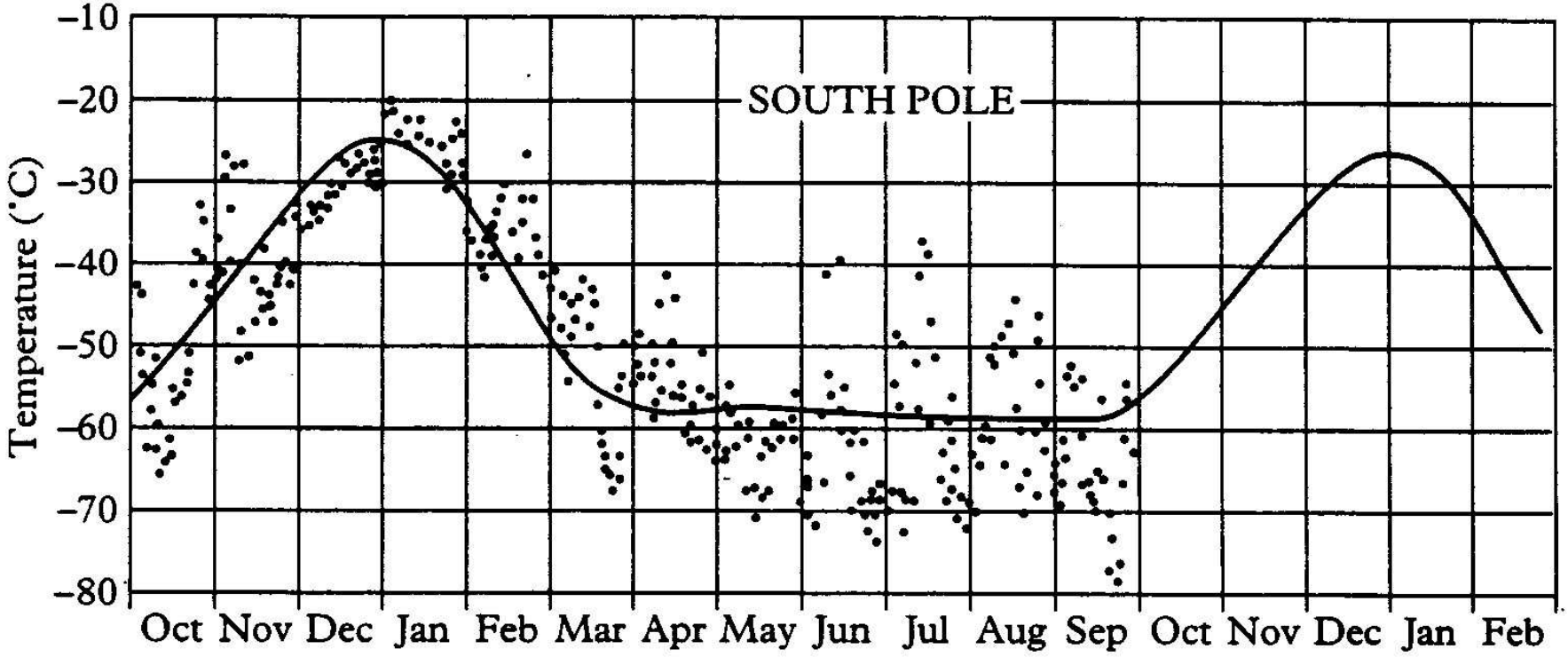


Summer
at Dome C
(75°S)



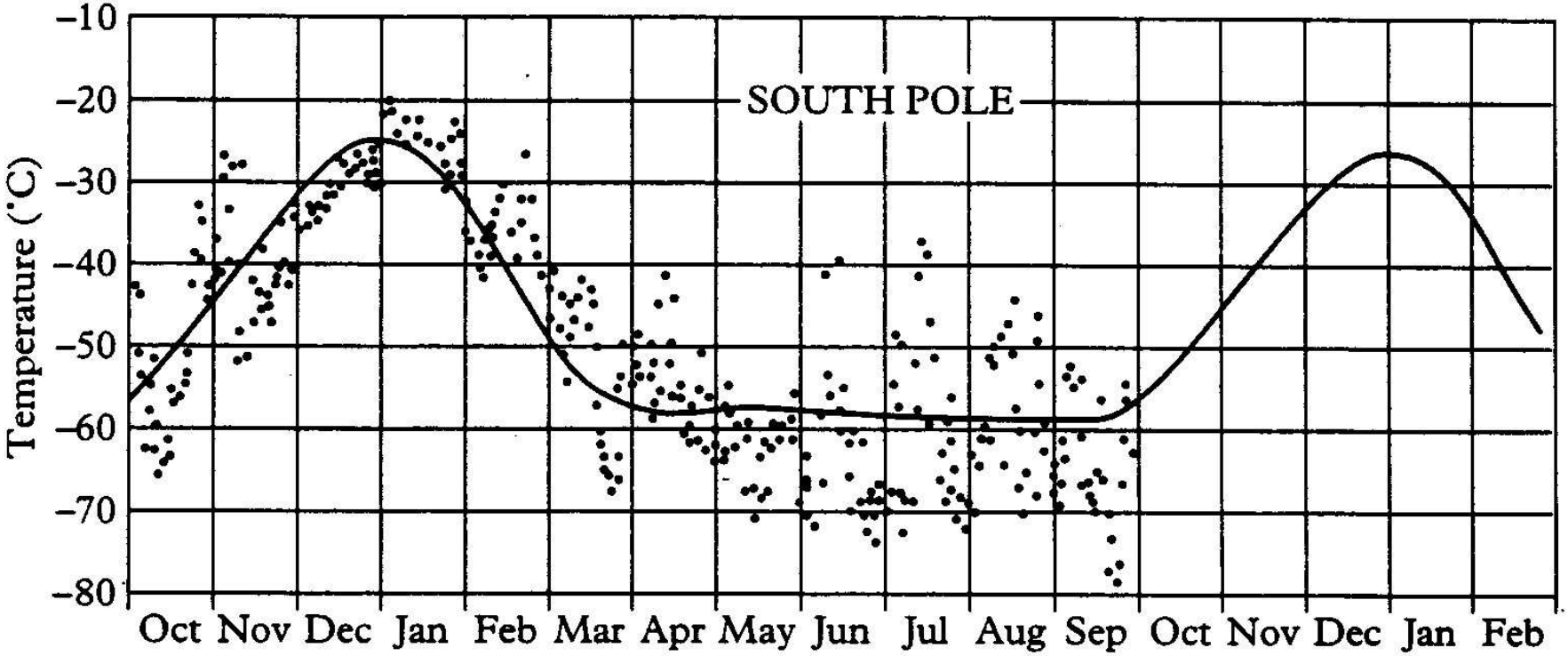
Diurnal cycle of temperatures on 32-meter tower at Plateau Station in February (80°S)


HEY KIDS
PLEASE DON'T
LEAN ON RAILING



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



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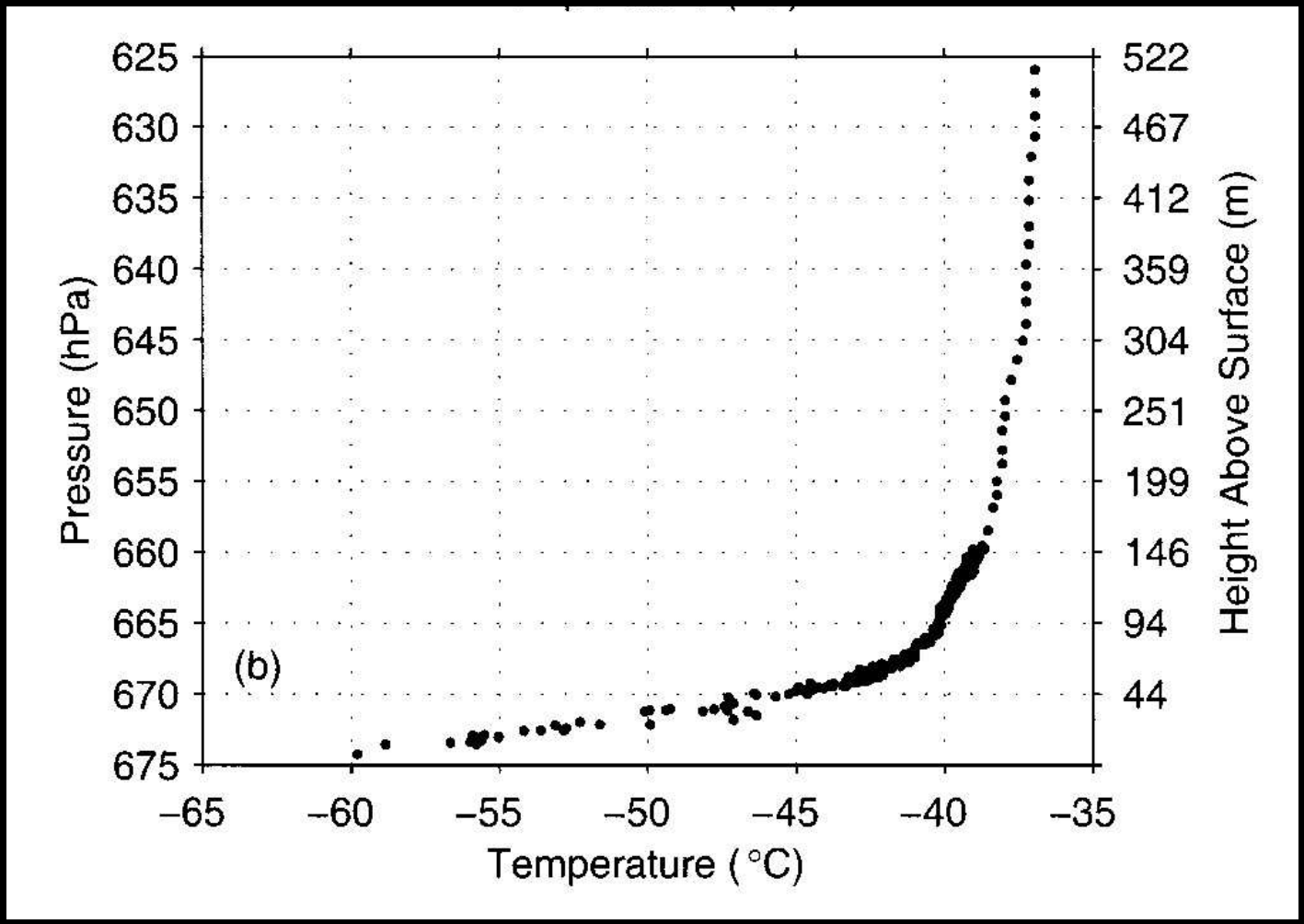
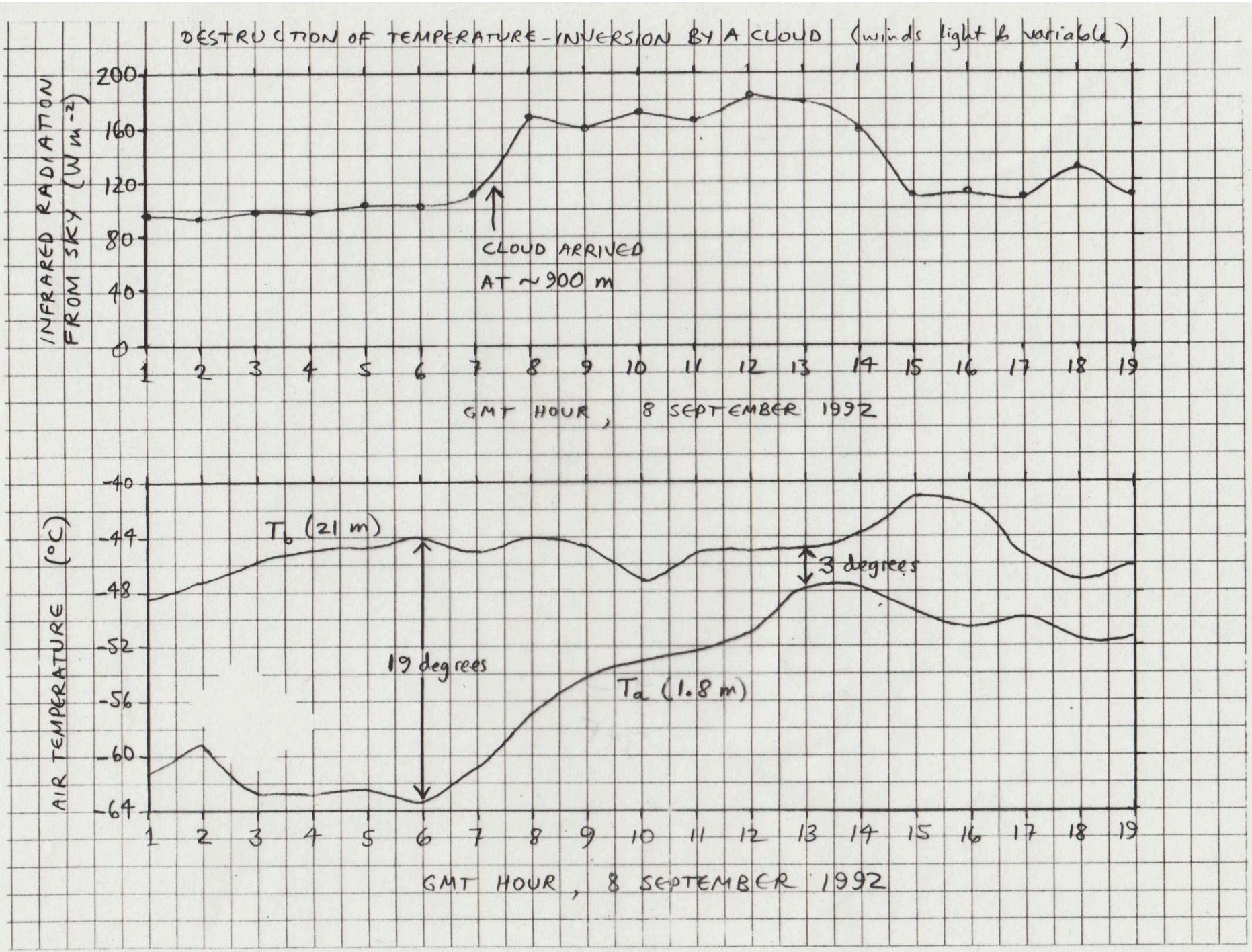
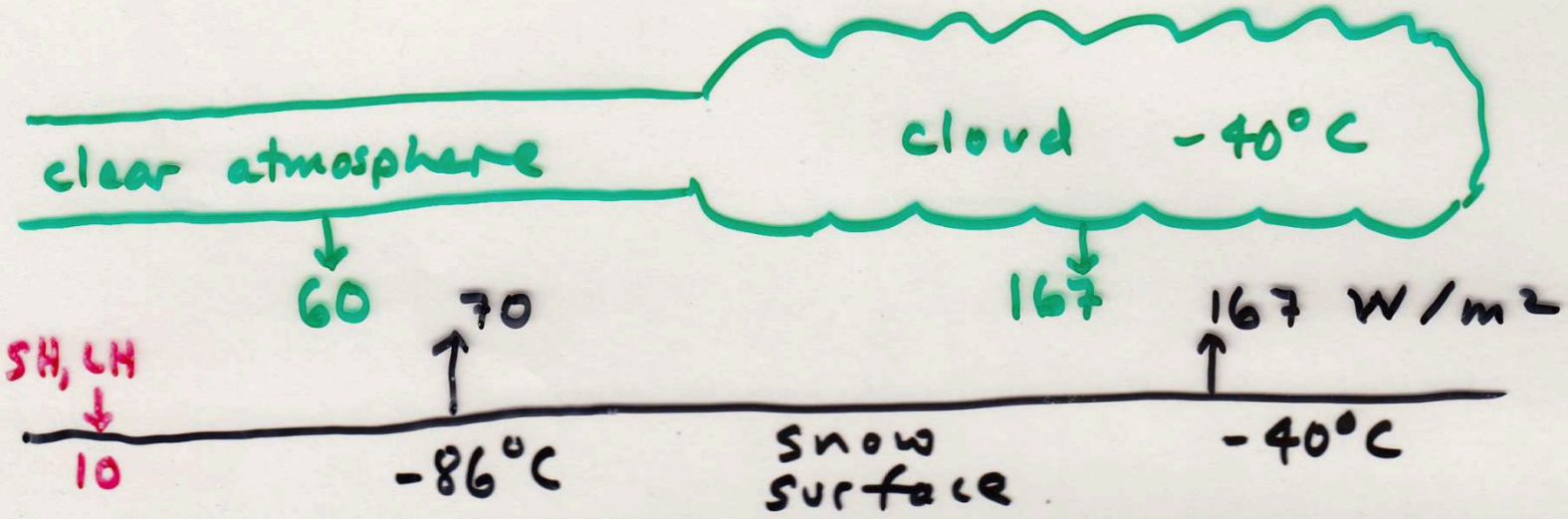
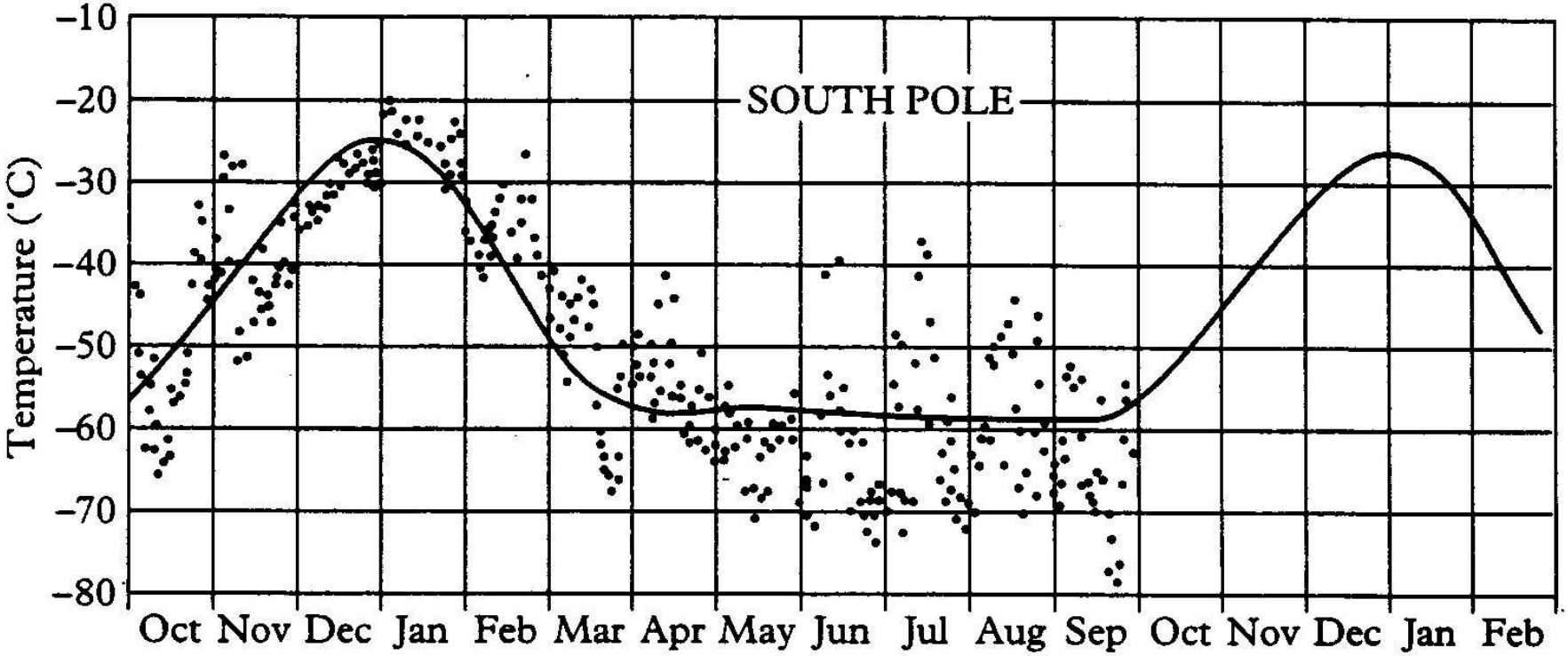
"Coreless winter"


625
630
635
640
645
650
655
660
665
670
675
Pressure (hPa)
522
467
412
359
304
251
199
146
94
44
Height Above Surface (m)
(b)
−65
−60
−55
−50
−45
−40
−35
Temperature (°C)


DESTRUCTION OF TEMPERATURE-INVERSION BY A CLOUD (winds light & variable)
INFRARED RADIATION FROM SKY (W m⁻²)
200
160
120
80
40
0
CLOUD ARRIVED AT ~ 900 m
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
GMT HOUR, 8 SEPTEMBER 1992
AIR TEMPERATURE (°C)
-40
-44
-48
-52
-56
-60
-64
T_b (21 m)
T_a (1.8 m)
19 degrees
3 degrees
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
GMT HOUR, 8 SEPTEMBER 1992

ANTARCTIC WINTER (no sunlight !)





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.

What happens at -73.3°C?


Three Hundred Club

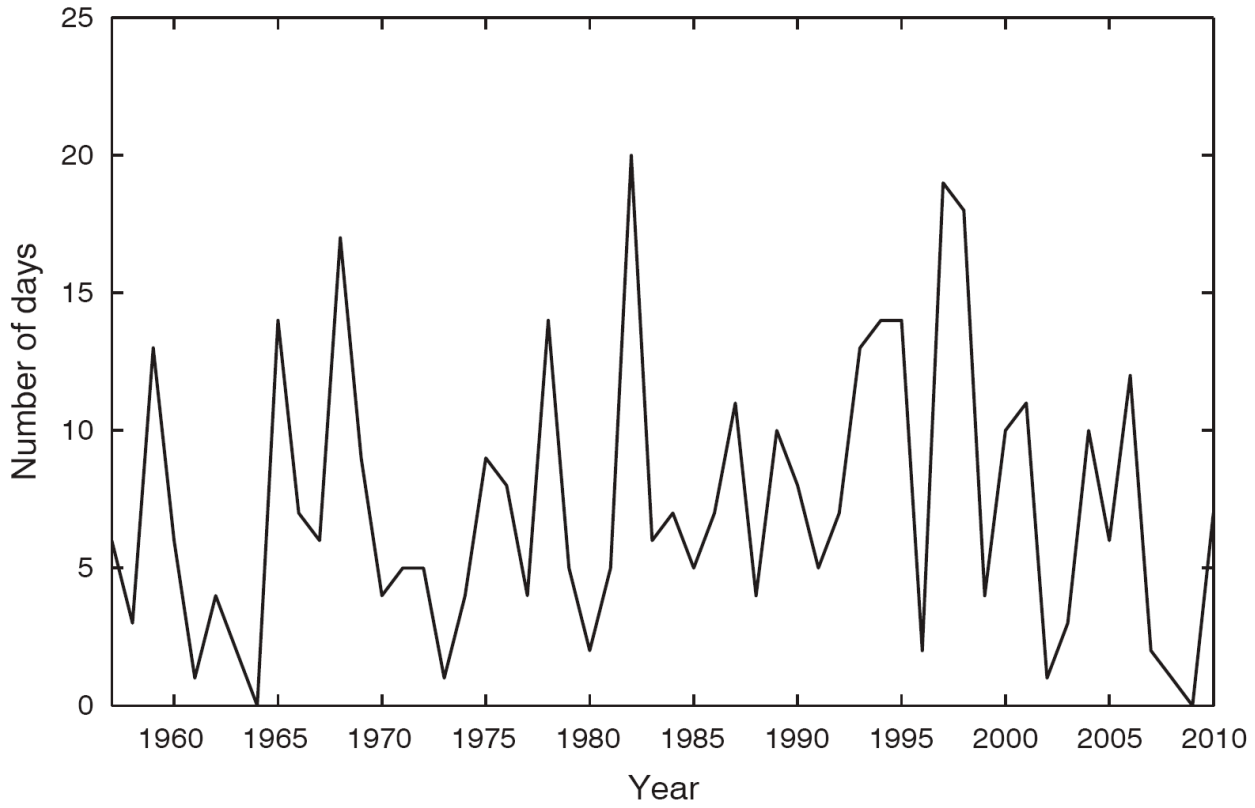


Fig. 19. Annual number of days for 1957–2010 that the South Pole station has reported minimum temperatures at or below −73.3 °C (−100 °F).

Lazzara et al. 2012

Surface Energy Budget

ANTARCTICA. 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)

	June	*December*
Downward shortwave (solar) radiation	0	372
Upward shortwave radiation	0	−312
Downward longwave (infrared) radiation	106	173
Upward longwave radiation	−134	−209
Net radiation	−28	+24
Sensible heat	23	−16
Latent heat	1	−2
Sum	−4	+6

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

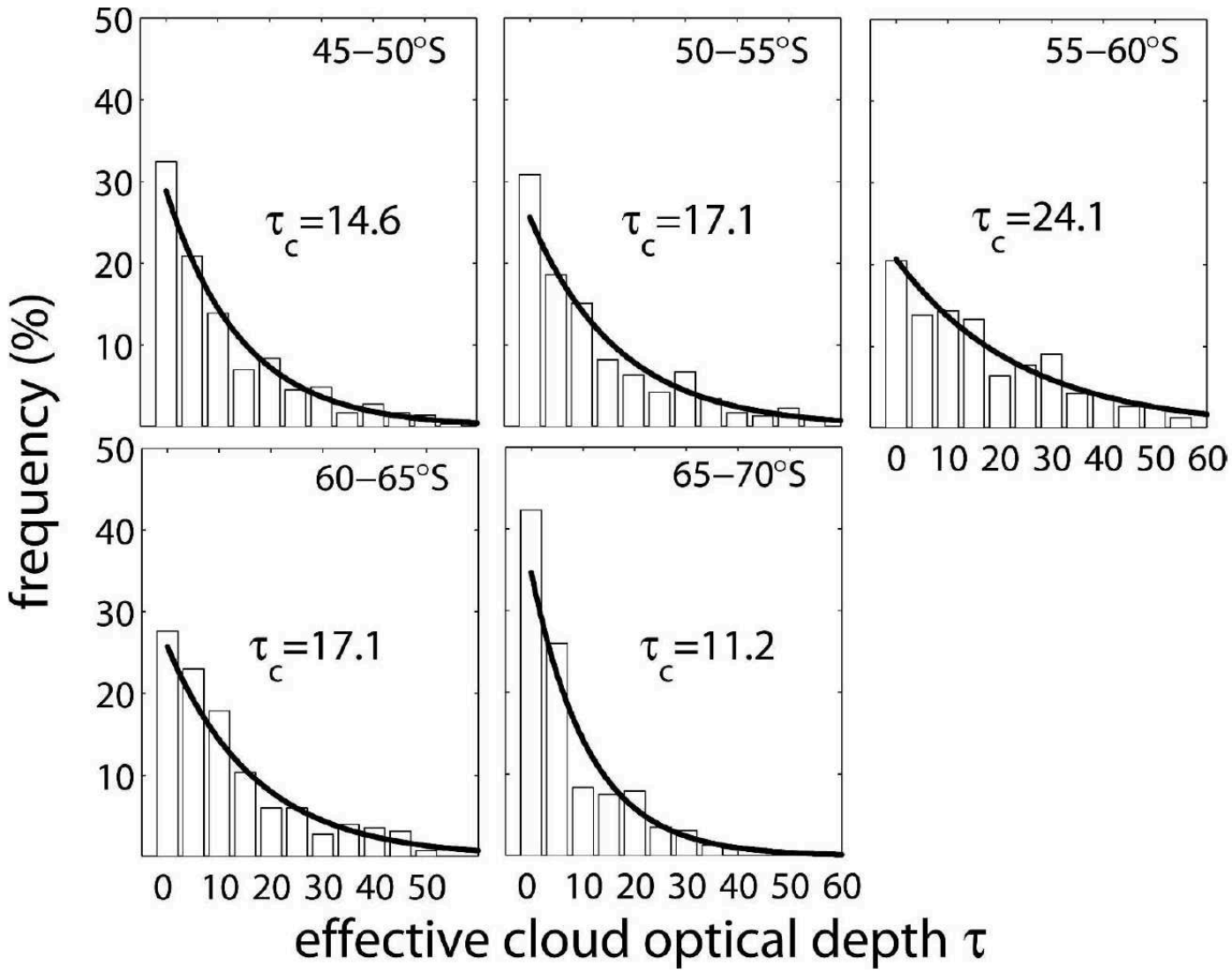
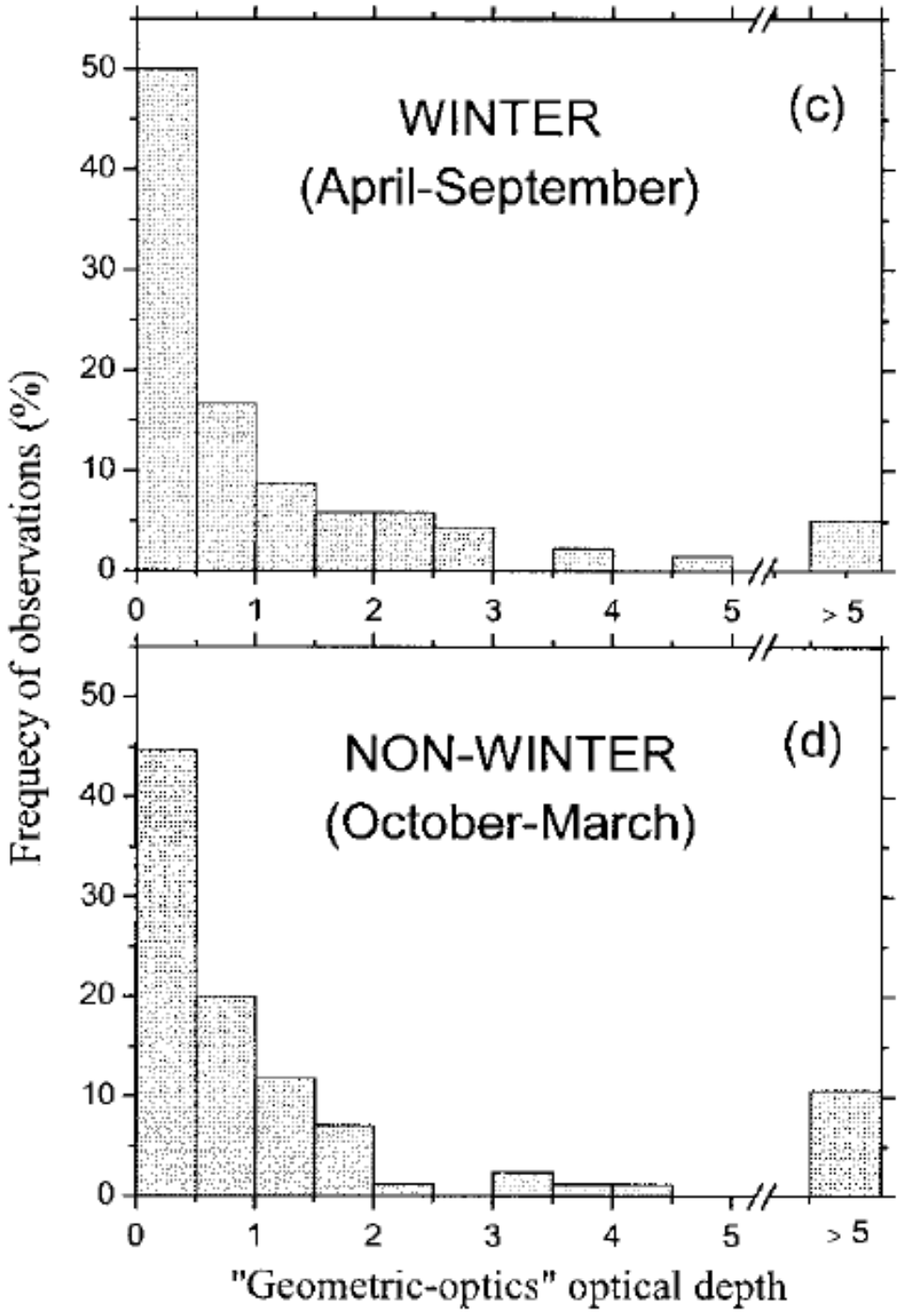


FIG. 14. Cloud optical depth for different latitude intervals for all voyages of the *Aurora Australis* between 1991 and 2002 with concurrent observations of ocean, sea ice, and cloud conditions. The observations include all seasons and as such are biased toward spring and summer when a greater number 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 $f(\tau) = \tau_c^{-1} \exp(-\tau/\tau_c)$. The values shown in the figure are percentages for bins of width $\Delta\tau = 5$.

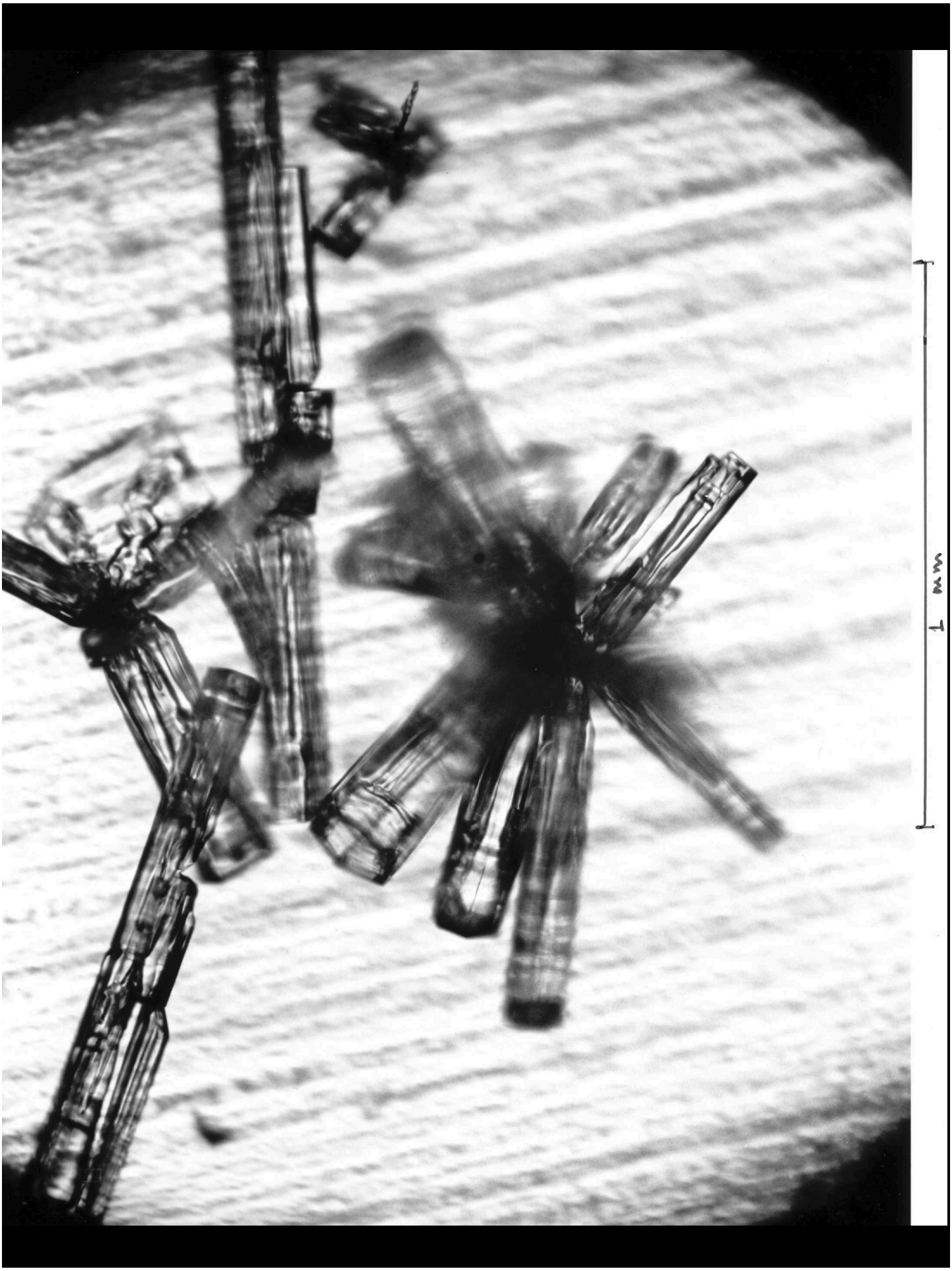
Cloud optical depth over the Southern Ocean

(Fitzpatrick and Warren 2005)



South Pole clouds
Mean optical depth ~1

(Mahesh, Walden,
Warren (2001)


1 mm