Meteorological Rocket Data, McMurdo Station, Antarctica, 1962-1963

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ABSTRACT

Wind and temperature measurements using meteorological sounding rockets were made in the upper atmosphere at McMurdo Station, Antarctica, between June 1962 and October 1963. These rocket soundings were the first to be made above normal radiosonde levels in the Southern Hemisphere. The most active and interesting period was the September-October early spring period; this period was marked by the reversal of wind direction and "explosive" warming. Strong zonal winds appeared near 35 km during late September. This "jet" completely disappeared over McMurdo Station by the end of October and was replaced by light easterly winds and warmer temperatures. The "explosive" warming occurred during the decline of this strong wind system.

1. Introduction

The development and expansion of the Meteorological Rocket Network (MRN) during the past five years have been primarily accomplished in the Northern Hemisphere. The northernmost stations are Ft. Greely, Alaska, at 64°00'N and Ft. Churchill, Canada, at 58°44'N. The network has stabilized with six active stations making coordinated and simultaneous rocket firings. McMurdo Station in Antarctica was the only station making high altitude soundings in the Southern Hemisphere, and at 77°53'S had no counterpart in the Northern Hemisphere.

The meteorological rocket program at McMurdo Station was supported under a research grant to Schellenger Research Laboratories of Texas Western College by the National Science Foundation. Rocket firings were conducted during an 18-month period, from June of 1962 through October of 1963. This 18-month period covered two Antarctic winter seasons and one summer season. Twenty-eight successful soundings were made using the ARCAS sounding rocket; 22 of these yielded usable temperature data. For the purposes of analyzing the rocket data from McMurdo Station, all available radiosonde data were obtained. However, the altitudes attained by the radiosondes during the winter season rarely exceeded 15 km, well below altitudes where significant changes in circulation were detected.

McMurdo Station is located at 78S, 168E, approximately 800 miles from the south geographic pole and 2400 miles south of New Zealand. The extreme surface weather conditions were generally less favorable to the operation of rocket launching and instrumentation tracking facilities than at other MRN stations. Observations were limited by the small number of available rockets during the 18-month period. In spite of the relatively low number of soundings (28), the time-

height cross sections of temperature and winds are sufficiently detailed to yield some interesting conclusions.

One of the most interesting questions which arises in analyzing the data concerns the correlation of Antarctic and Arctic data: Is there any similarity between Arctic and Antarctic circulation patterns; and if so, to what extent?

Since the Arctic stratosphere has been under intense observation for a number of years, certain features of the circulation and temperature profiles have been repeatedly observed. The formation of the polar night jet stream has been speculated upon for a considerable period and has been observed regularly over the last five years in rocketsonde observations at Ft. Greely and Ft. Churchill.

The seasonal conditions of the Arctic stratosphere, the predominantly westerly winds in winter above 20 km, the observed times of summer-winter reversals, and the disturbed conditions which exist during these reversals are well documented (Kellogg and Schilling, 1950; Murgatroyd, 1957; Teweles and Finger, 1958; Palmer, 1959). Unfortunately such is not the case for the Antarctic stratosphere. During the IGY, 1957-1958, the first Antarctic meteorological data were recorded on a synoptic basis, when a coordinated program was initially undertaken. However, the sparseness of observations, particularly in the southern oceans, rendered analysis difficult.

As data from the Antarctic became available, meteorologists recognized that certain similarities existed between the two hemispheres (Palmer, 1959; Wexler, 1961). A symposium in Melbourne, Australia, in February of 1959, was the first to be held concerning Antarctic IGY meteorological data. The proceedings of the symposium were subsequently published (Dwyer, L. J., ed., 1960).

The initial rocketsonde program at McMurdo Station was undertaken to shed some light on the following questions:

- (1) Does the Southern Hemisphere exhibit the seasonal zonal wind structure that is present in the Arctic? If so, at what altitudes, with what magnitudes, and over what time intervals?
- (2) Does a polar night jet stream exist in the Southern Hemisphere? When does it form and with what strength?
- (3) When does the sudden warming period usually occur, and at what altitude does the disturbance originate?
- (4) What temperature ranges exist in the upper levels of the stratosphere?

2. Operational procedure

All rocket firings at McMurdo Station were made with Arcas vehicles manufactured by Atlantic Research Corporation. The Arcas motor is a solid-fuel, end-burning sounding rocket approximately 6 ft long by $4\frac{1}{2}$ inches in diameter, capable of carrying up to 15 lb in 230 cubic inches to altitudes near 65 km (for sea-level launches). Burning time is approximately 30 seconds during which time the vehicle attains 16 km and a speed of 1100 meters per second. The vehicle coasts for an additional 100 seconds; near apogee, a pyrotechnic charge separates the payload from the expended motor.

The payload for this program was the Delta instrument package manufactured by the Lexington Army Depot in Lexington, Kentucky, and the 50% reflectivity parachute made by Atlantic Research Corporation. The instrument package was essentially an AN/AMT-4 transmitter, modified to use a VECO 10-mil bead thermistor as the temperature sensing element. The instrument frequently centered at 1680 mc so that standard Ground Meteorological Detectors (AN/GMD-1A) could be used for tracking. The 15-ft metalized nylon parachute provided a passive wind sensing radar target.

Only one parameter, temperature, was obtained from the package as it descended on parachute. A fixed calibration frequency was transmitted from the instrument at intervals of approximately 5 minutes to allow in-flight calibration of the temperature trace.

During the initial nine months of the program, two Ground Meteorological Detectors were used to determine instrument position. Azimuth and elevation angles of the two machines, as well as the length of the baseline between them, were used for a triangulation of instrument altitude and horizontal position. All computations were performed on a Bendix G-15 digital computer. The temperature record was combined with altitude-time for temperature vs. altitude.

Wind data were obtained by the conversion of sensor displacement during a fixed time interval into average velocity components. No correction was made to these components for errors due to the fall rate of the parachute. The altitude fixed for each wind component was the average altitude of the parachute during the time interval. Accuracy of the wind measurement using this procedure is considered to be within ± 3 m sec⁻¹ for the 15-ft parachute (Miers, 1963). A detailed discussion of the entire procedure may be found in Rotolante (1963).

The last nine soundings were tracked with an AA-M33C Fire Control System track radar which had been modified for use in tracking the Arcas parachute. Radar and Ground Meteorological Detector were slaved together for acquisition of the parachute. Data reduction techniques were similar for this tracking system with the exception that altitude and horizontal position data were obtained from radar plotting boards.

Reduction of the temperature trace was similar to the reduction of the radiosonde temperature trace. The major difference was that each rocketsonde thermistor was calibrated separately. Drift of the standard reference ordinate was applied proportionately to the temperature ordinate, and the corrected ordinate was correlated to temperature by the manufacturer's calibration. Temperature data are considered accurate to plus or minus 1.0°C at altitudes below 40 km and within plus or minus 5.0°C between 40 and 50 km (Wagner, 1961). Above 50 km, the corrections outlined by Wagner (1961) should be applied for more consistent results. A complete profile was obtained for each sounding as, for example, the 16 January 1963 sounding shown in Fig. 1. Radiosonde data were used to complete the profile since, for the most part, the parachute was out of tracking range below 15 km. Wherever possible, radiosonde and rocketsonde data were compared over the range in altitude where the measurements overlap. In a few cases the rocketsonde temperature measurements were adjusted to conform more closely with radiosonde temperatures. This has been the accepted procedure for rocketsonde observations, and in each case the adjustment was no greater than 10°C. A complete summary of the successful rocket soundings is shown in Table 1.

3. Seasonal wind structure

Each of the individual soundings was used to obtain a time-height cross section of zonal winds as shown in Figs. 2 and 3. It appears from inspection that the Antarctic year could best be divided into three "seasons": summer, winter, and late winter or early spring. The characteristics of each "season" are different: Summer is characterized by light easterly winds, increasing in strength above 40 km; winter exhibits westerly winds increasing in magnitude as the season progresses; late winter is the most turbulent, character-

MCMURDO STATION-ANTARCTICA-16 JANUARY 1963-0445Z

FIG. 1. Meteorological rocket sounding profile, McMurdo Station, Antarctica, 16 January 1963.

TABLE 1. Summary of rocket firings, McMurdo Station, Antarctica.

Date	Time (GMT)	Type rocket	Wind sensor	Temp. sensor	Temp. track (×10 meters)	Wind track (×10 meters)
19 June 1962	1633Z	Arcas	Chute	Gamma	4400-2262	3148-2222
21 July 1962	0551Z	Arcas	Chute	Gamma	5554-1956	5114-2090
16 Aug 1962	1539Z	Arcas	Chute	Gamma	4136-2084	4114-2168
11 Sept 1962	1732Z	Arcas	Chute	Gamma	6242-2216	6294-2228
21 Sept 1962	0314Z	Arcas	Chute	Broken Thermistor		6060-3480
27 Sept 1962	0419Z	Arcas	Chute	Gamma	6666-1628	6944-2152
03 Oct 1962	0334Z	Arcas	Chute	Gamma	6114-1978	6612-2340
18 Oct 1962	1634Z	Arcas	Chute	Gamma II	5060-2256	3140-2280
03 Nov 1962	0420Z	Arcas	Chute	Broken Thermistor		2816-1590
07 Nov 1962	1635Z	Arcas	Chute	Gamma II	5456-2338	5460-2038
15 Nov 1962	0547Z	Arcas	Chute	Broken Thermistor		6514-1844
28 Nov 1962	0314Z	Arcas	Chute	Gamma II	4892-1290	2864-1254
05 Dec 1962	0530Z	Arcas	Chute	Gamma II	4423-1969	4396-1568
12 Dec 1962	0417Z	Arcas	Chute	Gamma II	4640-1456	4620-1394
21 Dec 1962	0349Z	Arcas	Chute	Delta	6522-1006	6356 2028
09 Jan 1963	0320Z	Arcas	Chute	Delta	6110-1530	6318-2466
16 Jan 1963	0445Z	Arcas	Chute	Delta	6166-1080	6044-1626
06 Feb 1963	0535Z	Arcas	Chute	Delta	5890-0010	5232-0934
27 Feb 1963	0430Z	Arcas	Chute	Broken Thermistor		6208-1038
24 Apr 1963	0100Z	Arcas	Chute	Broken Thermistor		4148-1856
16 May 1963	0340Z	Arcas	Chute	Delta	3780-1926	3426-1904
29 July 1963	0348Z	Arcas	Chute	Delta	4510-1230	4070-1002
14 Aug 1963	0230Z	Arcas	Chute	Broken Thermistor		3684-1060
23 Aug 1963	0303Z	Arcas	Chute	Delta	3598-1358	3340-1150
17 Sept 1963	0330Z	Arcas	Chute	Delta	4386-2106	5480-2412
18 Sept 1963	0230Z	Arcas	Chute	Delta	5046-1670	4682-2334
27 Sept 1963	0300Z	Arcas	Chute	Delta	4010-1610	4810-1694
03 Oct 1963	0330Z	Arcas	Chute	Delta	2478-1456	2336-1048

FIG. 2. Time-height cross section for McMurdo winds (July 1962–March 1963) west (+) and east (–) components in m sec^{-1} .

FIG. 3. Time-height cross section for McMurdo winds (March 1963–December 1963) west (+) and east (–) components in m sec^{-1} .

FIG. 4. Typical McMurdo zonal wind profiles for summer, winter and late winter.

FIG. 5. Zonal flow (solid line) obtained by averaging the individual soundings over a 10-km layer centered at 40 km. Meridional flow is shown by dashed line. Positive values refer to west and south components.

ized by a strong westerly jet at 35 km followed by the return to summer circulation. Selected soundings characteristic of the three periods are shown in Fig. 4.

The occurrence of the westerly winds in late March coincided with the departure of sunlight. The westerly winds grew in strength throughout the continuous darkness period from mid-May through mid-July. This was evident at all altitudes to 50 km. With the return of daylight in late winter, a rapid buildup of winds with maximum strength near 35 km became predominate.

Shortly before continuous daylight began again, the westerly jet disappeared and the summer circulation began. During the summer months of November, December, January, and February, light easterly winds of the order of $5\text{--}20\text{ m sec}^{-1}$ appeared at all altitudes to 50 km.

Webb (1964), in an analysis of MRN data, devised a technique for showing the seasonal reversal of winds at various times throughout the year. Using the mean flow over a 10-km layer centered at 50 km as an indi-

FIG. 6. Comparison of zonal flow based on Arctic and Antarctic data.

cator of the circulation, the reversals which occur from summer to winter and winter to summer are clearly demonstrated. Using the same technique at 40 km, the shifts from winter to summer and summer to winter are shown in Fig. 5. The shift from winter to summer was a rapid and dramatic change, occurring entirely within the month of October. The summer to winter shift was slow, gradual, and unspectacular.

The meridional flow is also plotted in Fig. 5. A situation similar to the rapid shift from north to south accompanying the large temperature change between 27 September and 3 October of 1962 was not detected in 1963. While this change in meridional flow was no doubt closely linked with the sudden or "explosive" warming phenomenon, indications from radiosonde data were that a similar shift in meridional flow occurred during the third week in October of 1963, unfortunately after all available rocket vehicles had been expended.

Comparison of Arctic and Antarctic data can be performed by shifting the McMurdo data so that the equinoxes will coincide, winter data from Ft. Greely (64°N) are plotted with McMurdo data in Fig. 6. This is again the mean zonal flow at 50 km. Summer easterly circulation at the two stations seems to coincide, but the Southern Hemisphere data indicates an early shift from the winter regime. The summer season at McMurdo is shorter, possibly due to the shorter daylight period at the higher latitude. Winter westerlies begin sooner at greater velocities than were measured at Ft. Greely.

Southern Hemisphere data indicate a continued buildup throughout the winter season; Arctic data show maximum westerly strength in early winter, decreasing until early spring when the reversal occurs.

4. Seasonal temperature structure

The time-height cross section of temperatures is shown in Figs. 7 and 8. During the two winter seasons observed, minimum temperatures were recorded near 20 km. Temperatures decreased steadily after the disappearance of the sun and at 20 km the decrease measured about 0.3°C per day. The minimum temperature was recorded at -86°C at 20 km. This temperature persisted throughout July and August to mid-September. Near the end of September, the temperature rises rapidly at about 1.4°C per day at 20 km, to stabilize at -40°C during the summer season.

Rotolante (1964) surmised that the disturbance detected at 45 km on 27 September 1962 propagated downward, accounting for the rapid rise in temperature which was experienced on 3 October 1962. A similar disturbance was not detected with rocketsonde observations during 1963. Indications from radiosonde data were that the sudden warming occurred in 1963 during the third week in October.

Hanson (1960) detailed the stratospheric warming which occurred in October of 1958 at the South Pole; he pointed out that similar warmings were observed at all Antarctic stations within 24 hours. He also indicates

FIG. 7. Time-height cross section for McMurdo temperatures (July 1962–March 1963) in deg C.

FIG. 8. Time-height cross section for McMurdo temperatures (March 1963–December 1963) in deg C.

that the warming occurred in October of 1957, giving rise to the concentrated effort made at the South Pole stations to obtain high altitude data in 1958. It would appear on the basis of limited observations that the major disturbance of the year occurs sometime during the first three weeks in October. With this in mind, future operations in the Antarctic should include an increased effort during this period.

The outstanding feature of summer temperatures is the 15-km layer of relatively steady -40°C that is centered at 20 km. Winds during this period are easterly, calm, and steady, indicating the circulation under continuous daylight conditions.

The temperature range at 20 km is the most extreme for all altitudes through which temperatures were measured. Table 2 summarizes the temperature range exhibited at various altitudes. The scarcity of data at the 50-km level makes an estimate of the temperature range difficult. An approximate estimate based on the time-height temperature profile would be from $+30^{\circ}\text{C}$ to $+10^{\circ}\text{C}$, uncorrected for thermistor error at that altitude. Wagner (1961) has outlined a series of corrections based on the fall rate of the sensor for altitudes above 40 km.

Comparison with Ft. Greely temperatures is difficult, since for some months rocketsonde observations were not made. Summer observations were not made at Ft. Greely during June, July, August, September, and October of 1963.

Winter data from Ft. Greely indicate that the Northern Hemisphere temperatures are 15–20 degrees warmer than corresponding temperatures in the Southern Hemisphere, a situation which had been evident from research (Palmer, 1959) previous to the rocket observations.

5. Summary

From the initial sampling of the Antarctic upper stratosphere it appears that the most interesting and active period in south polar regions is the September–October early spring period. This period is marked by the winter–summer reversal of winds, immediately preceded by the strong zonal jet at 35 km. The sudden or “explosive” warming occurs during this period, and this event appears to propagate downward from an initial disturbance above 50 km. High altitude radiosondes are capable of detecting this disturbance, and all Antarctic stations notice the abrupt change in temperature within 48 hours of each other.

The warming and the appearance of the circumpolar jet stream at 35 km must be closely connected to the increase in available heat brought about by the return of sunlight in the August–September period. A better understanding of the mechanisms involved could be obtained from a detailed study of the meridional flow regime. A network of stations some 10 degrees apart

TABLE 2. Summary of temperature ranges at various altitudes.

Altitude	Temperature range
10 km	-74°C in early September to -50°C January thru April
20 km	-90°C during July, August and early September to -38°C during January and February
30 km	-58°C during May, June and July to -25°C during October, November and December
40 km	-20°C during April, May, June to $+04^{\circ}\text{C}$ October, November, December, January

along approximately the same meridian would probably be sufficient for this purpose.

The semi-controlled conditions existing in the Antarctic, the variation of sunlight and available radiant energy, make it the ideal place to study basic atmospheric processes in the stratosphere. Future studies are of course absolutely necessary in this region.

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