Rocketsonde Wind and Temperature Measurements Between 30 and 70 km for Selected Stations

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ABSTRACT

Rocketsonde wind and temperature measurements from most of the National Meteorological Rocket Network (or simply Rocket Network) stations are studied. In the altitude region considered, there were over 1100 wind measurements and some 200 temperature soundings. This includes Rocket Network data through August 1962 and a few 1957 and 1958 soundings taken prior to the initiation of the Rocket Network. A simple statistical treatment has been used to determine mean temperatures and mean wind speeds, components, shears, and a measure of variability. The wind data presented generally support previously constructed cross sections of the wind regime over North America. A significant mass transport from subtropical to midlatitudes was indicated. The meridional component of the subtropical wind did not reverse direction with the seasonal change in the zonal wind. In the subpolar stratosphere the seasonal changes of temperature are much more pronounced; the summer is warm (near subtropical values) and the winter much colder. The subtropical summer temperatures were found to be colder than the subtropical winter temperatures. There is still a significant disagreement as to the more refined temperature structure of the subtropical region.

1. Introduction

As of July 1963, over 2000 soundings of the upper atmosphere have been gathered by the National Meteorological Rocket Network (NMRN), hereinafter called the Rocket Network. All of these soundings provided wind structure data, and over 20 per cent of the soundings included temperature measurements. Although the network began operation in the fall of 1959, widespread application of the data has been hindered by several factors; i.e., availability, the researchers' awareness of its existence, and to some extent, the confidence placed in the data (e.g., some researchers are unaware that temperatures can be corrected and smoothing techniques applied to the winds). Despite these factors, significant applications of Rocket Network data began to appear early in 1960 and have increased both in scope and quantity. The present situation is much improved because the program is relatively well known, the data are available, and the confidence level is higher. Improvements have been made in all phases of the network operation, including firing schedules, performance of rocket-sensor systems, and in data processing and dissemination. Probably the most important improvement relative to data processing has been its transfer to punch cards and magnetic tape. This will encourage a further expansion of the scope of applications.

This study incorporates Rocket Network data through August 1962 (over 1100 soundings).[1] Included are a few 1957 and 1958 soundings taken prior to the initiation of the Rocket Network. A tabulation of the stations and the number of wind profiles is given in Table 1, and station locations are shown in Fig. 1. A simple statistical treatment has been used to determine mean wind speeds, components, shears, and a measure of variability. These statistical tabulations are presented in Tables 3 and 4. Although the number of temperature soundings is small, a similar treatment is given temperature and presented in Tables 2 and 5.

2. Discussion of wind data

The Rocket Network wind measurements are derived from position plots of a falling sensor. The tracking device is usually radar and the sensor is either a metallized parachute, a balloon-sphere, or radar chaff. Various types of radar and radar-sensor systems are employed, and the resulting accuracy of the wind measurements vary. Most of the systems and accuracies have been discussed elsewhere (Lally and Leviton, 1958; Rapp, 1960; Jenkins, 1962) and will not be discussed further except to say that the data are usually considered accurate to within ± 3 m sec^{-1} for parachutes and spheres. However, some measurements based on radar chaff undoubtedly contain greater errors due to chaff dispersion as do those measurements made when the sensor fall velocity was excessive. The latter case usually occurs above 50 km and is a function of the particular sensor.

The stations were divided into subtropical and subpolar categories. The subtropical grouping contains eight stations in the latitude range 22N to 38N, while

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[1] Inter-Range Instrumentation Group, Meteorological Working Group, Data Reports of the Meteorological Rocket Network, IRIG-MWG: No. 1 (April 1960) through No. 12 (March 1963). Available through USA ERDA, White Sands Missile Range, New Mexico.

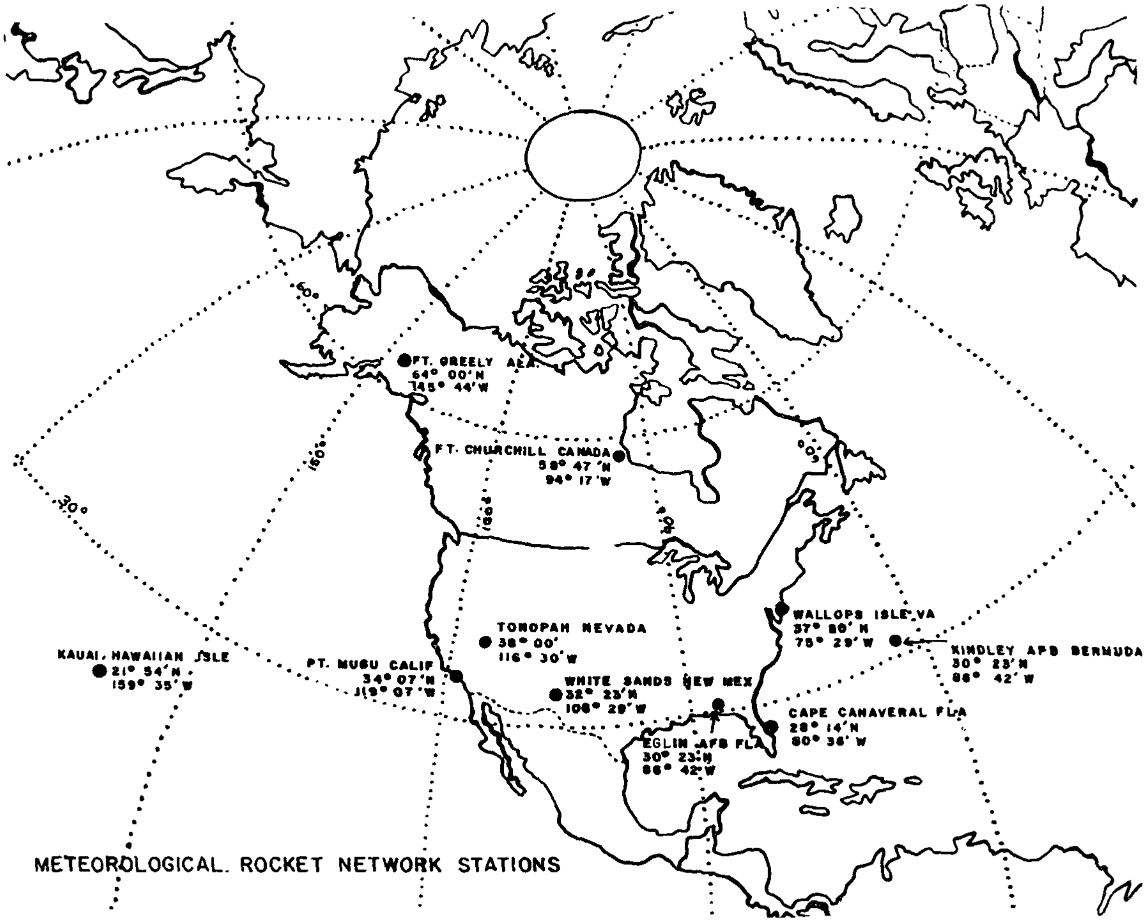

Fig. 1. Geographical location of Meteorological Rocket Network stations used in this study.

the subpolar group has Ft. Greely (64°00′N), Alaska, and Ft. Churchill (58°47′N), Canada. (See Table 1.) In a strict sense Tonopah, Nev., and Wallops Island, Va., lie outside the subtropical division; however, these stations were considered subtropical for this study.

Fig. 2 affirms the basis for dividing the yearly data into two seasonal groups or regimes and considering the intervening time periods as transition or reversal periods. As a result, the months of November, December, January, and February were chosen to represent the winter regime at all stations while the summer regime period differed slightly for the subpolar and subtropical groups. The subpolar summer was determined to be May, June, July and August while the subtropical summer included June, July, August, and September. In a detailed study of 1960–1962 subtropical stratospheric reversals, Miers (1963) found that the reversal periods usually occur outside the time frames of the winter and summer seasons chosen for this study.

Fig. 3 presents the mean total speed, the standard deviation, and 1 per cent probability level for the subtropical and subpolar stations using all available data. (The 1 per cent level is that level which is exceeded in only 1 per cent of the cases). Several significant features of the total wind speed are evident. Among them are the well defined maximum (39 m sec^{-1}) of the subpolar mean speed at 54 km and its decrease to 27 m sec^{-1} at 59 km. These features are the result of the winter flow regime. Other prominent details of the means include the fairly linear increases to maximum values and the mean subtropical maximum (48.5 m sec^{-1}) at 60 km. However, it should be noted from the 1 per cent probability that the individual maximum (121.5 m sec^{-1}) occurs at 53 km. A good correlation exists between the slopes of the standard deviations to the means. The mean wind speed and the values of the 1 per cent probability for the sub-tropical stations are greater at all levels above 30 km (except for 36 km) than those of the subpolar stations. A considerable range of wind speeds from one seasonal regime through a reversal to the other seasonal regime is observed; therefore, the size of the standard deviation is not surprising.

A closer study of the winter Wallops Island data revealed that higher wind velocities were measured above

TABLE 1. Number of wind data points for each station for selected levels and seasons.

Subpolar	Total km levels									Summer (May, June, July, Aug.) km levels									Winter (Nov., Dec., Jan., Feb.) km levels								
Station	30	35	40	45	50	55	60	65	70	30	35	40	45	50	55	60	65	70	30	35	40	45	50	55	60	65	70
Ft. Churchill, Canada	79	66	50	32	27	17	4	1	0	18	13	6	4	4	1	0	0	0	34	30	25	18	15	10	1	0	0
Ft. Greely, Alaska	57	54	47	32	22	11	4	1	1	4	3	2	0	0	0	0	0	0	16	16	15	12	9	4	2	0	0
Total	136	120	97	64	49	28	8	2	1	22	16	8	4	4	1	0	0	0	50	46	40	30	24	14	3	0	0

Subtropical	Total km levels									Summer (June, July, Aug., Sept.) km levels									Winter (Nov., Dec., Jan., Feb.) km levels								
Station	30	35	40	45	50	55	60	65	70	30	35	40	45	50	55	60	65	70	30	35	40	45	50	55	60	65	70
Cape Canaveral, Fla.	135	161	162	158	146	111	44	5	0	59	71	73	72	64	51	25	3	0	26	31	30	29	29	20	7	1	0
Eglin, AFB, Fla.	21	46	58	56	49	37	23	13	0	11	34	43	43	38	27	14	5	0	3	4	7	5	3	3	2	2	0
Kauai, Hawaii	29	40	39	37	32	8	0	0	0	14	27	28	28	24	3	0	0	0	8	6	4	4	3	2	0	0	0
Kindley AFB, Bermuda	7	8	8	5	3	1	0	0	0	4	4	4	2	2	0	0	0	0	3	4	4	3	1	1	0	0	0
Pt. Mugu, Calif.	193	201	197	179	159	99	31	7	1	79	86	85	77	63	41	7	1	0	40	41	39	34	40	24	13	0	0
Tonopah, Nev.	54	57	48	18	12	11	9	5	3	17	20	21	9	7	6	4	1	0	21	20	15	4	2	2	2	3	2
Wallops Island, Va.	135	144	142	126	103	51	31	9	2	52	58	57	47	38	10	3	1	1	39	39	40	39	27	17	13	3	1
Holloman AFB and White Sands, N. Mex.	332	354	323	281	253	226	175	88	27	144	152	131	113	107	89	64	36	15	87	81	83	62	64	66	63	24	4
Total	906	1011	977	860	757	544	313	127	33	380	452	442	391	343	227	117	47	16	227	226	222	180	169	135	100	33	7

TABLE 2. Number of temperature data points for each station for selected levels and seasons (including only stations reporting usable temperatures).

Subpolar	Totals km levels						Summer (May, June, July, Aug.) km levels						Winter (Nov., Dec., Jan., Feb.) km levels					
Station	30	35	40	45	50	55	30	35	40	45	50	55	30	35	40	45	50	55
Ft. Churchill, Canada	30	29	24	21	14	6	3	5	3	3	3	0	18	16	14	12	7	4
Ft. Greely, Alaska	50	49	43	26	15	9	4	3	2	0	0	0	11	12	10	7	3	1
Total	80	78	67	47	29	15	7	8	5	3	3	0	29	28	24	19	10	5

Subtropical	Totals km levels						Summer (June, July, Aug., Sept.) km levels						Winter (Nov., Dec., Jan., Feb.) km levels					
Station	30	35	40	45	50	55	30	35	40	45	50	55	30	35	40	45	50	55
Cape Canaveral, Fla.	8	11	9	9	7	1	1	2	3	2	1	0	5	5	2	2	2	0
Kauai, Hawaii	5	5	3	3	1	1	0	0	0	0	0	0	5	5	3	3	1	1
Pt. Mugu, Calif.	42	43	39	35	25	25	11	12	12	11	6	2	15	16	12	10	9	7
Wallops Island, Va.	5	4	3	2	1	2	1	0	0	0	0	0	0	0	0	0	0	0
Holloman AFB and White Sands, N. Mex.	71	81	76	64	48	39	35	35	33	27	20	18	17	21	21	19	14	5
Total	131	144	130	113	82	68	48	49	48	40	27	20	42	47	38	34	26	13

TABLE 3. Computed wind values for subtropical stations. (A) mean wind speed m $\sec^{-1}$, (B) standard deviation m $\sec^{-1}$, (C) one per cent probability level of mean wind speed m $\sec^{-1}$, (D) mean wind shear m $\sec^{-1}$ km^{-1}, (E) ten per cent probability level of wind shears m $\sec^{-1}$ km^{-1}, (F) north (+) south (−) wind components m $\sec^{-1}$, (G) east (+) and west (−) wind components m $\sec^{-1}$.

Alt. km	All data subtropical					Winter subtropical							Summer subtropical						
	A	B	C	D	E	A	B	C	D	E	F	G	A	B	C	D	E	F	G
30	15.4	9.4	51.4	3.7	6.8	19.1	13.3	56.4	4.3	8.3	− 2.0	−13.2	17.4	6.2	29.9	3.3	6.3	− 0.9	+17.0
31	16.5	9.9	55.0	3.6	6.7	20.5	14.2	61.4	4.4	7.6	− 1.8	−14.6	18.2	6.4	31.2	3.2	5.5	− 1.2	+17.6
32	17.5	10.6	56.7	4.1	7.5	22.4	15.5	66.7	5.2	9.4	− 2.2	−16.4	18.7	6.8	32.6	3.6	6.1	− 1.3	+18.1
33	18.6	11.8	60.0	4.2	7.8	24.9	17.6	80.0	5.1	8.5	− 2.7	−18.9	19.1	7.2	34.0	3.8	6.9	− 1.1	+18.6
34	20.0	12.7	62.1	4.3	7.9	27.0	18.8	90.9	5.5	9.4	− 2.5	−21.3	20.0	7.8	35.1	3.6	6.3	− 1.2	+19.3
35	21.6	13.6	70.3	4.3	7.6	29.1	19.9	97.0	5.4	10.0	− 2.1	−23.5	21.0	8.2	38.2	3.8	6.8	− 1.0	+20.3
36	22.8	14.2	69.9	4.4	7.7	30.9	20.6	96.1	5.4	9.3	− 1.8	−25.6	21.9	8.6	38.5	4.0	6.9	− 0.9	+21.2
37	24.4	14.8	74.2	4.4	8.3	33.4	20.9	89.5	5.3	9.4	− 1.9	−28.1	23.2	9.1	40.7	4.2	7.8	− 0.6	+22.5
38	25.8	15.1	74.2	4.3	7.8	35.7	20.1	83.3	5.2	9.4	− 1.8	−30.1	24.7	9.1	44.0	4.1	7.3	− 0.7	+23.8
39	27.1	16.0	76.9	4.3	7.9	37.7	20.9	91.0	5.3	10.2	− 2.5	−32.1	26.1	9.7	43.9	4.1	7.3	− 0.9	+25.4
40	28.1	16.5	77.5	4.4	8.4	39.5	21.1	94.2	5.4	10.0	− 3.4	−33.9	27.5	10.0	44.1	4.1	7.6	− 0.6	+26.8
41	29.5	17.2	82.7	4.3	8.2	41.8	22.2	97.7	5.4	9.7	− 4.7	−37.1	29.1	10.4	45.7	4.0	7.3	− 0.4	+28.4
42	31.1	17.7	87.3	4.3	7.8	44.4	22.7	101.0	5.1	9.3	− 5.8	−39.5	30.9	10.4	49.7	4.2	7.5	− 0.5	+30.2
43	32.5	18.0	91.8	4.5	8.6	46.1	22.8	99.2	5.1	9.4	− 6.5	−41.2	32.6	11.1	52.3	4.4	8.6	− 1.1	+31.8
44	33.9	18.9	91.9	4.2	7.8	48.1	23.7	100.3	4.9	9.0	− 7.2	−43.6	34.2	11.8	54.5	4.2	7.5	− 2.0	+33.5
45	35.3	19.7	94.8	4.1	7.4	50.1	24.6	102.9	4.7	8.4	− 8.2	−45.5	35.6	12.4	57.6	4.3	7.8	− 2.8	+34.8
46	36.7	20.4	97.6	4.3	8.1	52.3	25.2	108.8	4.9	9.4	− 8.9	−47.8	36.9	12.9	59.7	4.4	8.3	− 3.3	+35.9
47	37.8	21.0	100.9	4.2	8.0	54.4	25.9	111.9	5.1	9.4	− 9.6	−49.9	37.6	13.2	60.7	4.3	8.0	− 3.7	+36.4
48	38.6	21.2	101.5	4.1	7.6	55.3	26.2	114.8	4.4	8.4	− 9.2	−50.9	38.4	13.1	61.8	4.2	7.6	− 4.1	+37.0
49	39.5	21.5	103.7	4.1	7.8	56.0	26.8	119.2	4.3	8.0	−10.1	−51.8	39.6	13.4	63.3	4.3	8.1	− 4.7	+38.1
50	40.2	21.9	104.9	4.4	8.5	56.4	27.3	121.1	4.7	9.6	−10.6	−52.1	40.2	13.9	65.4	4.6	8.6	− 5.0	+38.5
51	40.7	22.1	104.0	4.4	8.4	56.3	26.6	126.5	4.8	9.0	−10.8	−52.0	41.0	14.6	67.5	4.5	8.8	− 5.6	+39.1
52	41.7	23.0	116.5	4.4	8.3	57.3	28.1	133.5	5.0	9.5	−10.8	−53.2	42.2	15.2	70.3	4.5	8.3	− 5.9	+40.4
53	42.7	24.0	121.0	4.3	8.3	58.0	28.6	138.7	4.6	8.6	− 9.9	−54.4	42.6	16.4	74.9	4.7	8.7	− 6.0	+40.6
54	43.3	23.2	111.3	4.8	9.8	58.9	26.7	131.3	5.1	10.4	− 9.6	−55.2	42.6	15.7	71.9	5.2	10.5	− 5.8	+40.3
55	44.0	22.9	109.7	4.9	10.2	59.5	25.1	119.0	5.2	9.6	−10.0	−55.6	42.7	15.8	70.9	5.1	10.6	− 5.4	+40.1
56	44.6	22.9	111.3	5.4	11.5	60.0	24.6	118.4	6.0	11.7	− 9.8	−55.9	42.8	16.4	71.9	6.0	12.1	− 5.1	+40.3
57	45.6	23.5	111.0	5.7	11.6	63.0	24.0	118.5	6.3	11.7	−10.5	−58.5	42.3	16.6	75.1	6.2	13.1	− 4.1	+40.2
58	46.7	23.7	109.3	5.6	11.0	64.6	23.7	119.0	6.3	13.0	−11.3	−61.6	42.8	17.7	74.8	6.2	11.0	− 2.9	+40.5
59	47.7	24.0	111.8	6.0	11.6	66.0	23.7	116.1	5.6	9.2	−10.5	−63.5	44.2	18.2	77.8	7.0	14.7	− 3.0	+41.4
60	48.6	24.2	107.5	6.1	12.7	65.7	23.0	111.8	6.0	11.3	− 9.6	−63.3	45.5	19.6	76.3	6.7	15.0	− 2.8	+42.1
61	47.9	25.0	105.7	6.2	12.1	64.3	22.8	119.2	6.7	12.7	− 8.0	−61.8	45.1	22.9	84.2	6.3	10.7	− 4.3	+40.8
62	47.6	24.8	104.5	6.2	12.4	64.3	21.5	119.1	5.8	9.6	− 7.8	−62.3	45.8	24.0	94.7	7.1	16.3	− 6.8	+40.1
63	47.0	24.8	105.4	6.6	12.6	63.1	22.9	123.5	6.1	11.4	− 7.0	−61.1	44.5	23.5	95.3	8.4	14.7	− 7.0	+36.8
64	47.7	24.1	100.3	7.0	13.8	63.6	23.1	123.8	7.0	11.8	− 5.6	−61.0	44.6	22.0	89.1	7.6	16.3	− 9.0	+36.1
65	45.4	23.0	100.2	7.1	14.0	62.5	22.1	114.5	6.5	11.5	− 1.8	−58.9	42.0	21.5	82.5	7.3	16.6	− 7.2	+33.1
66	45.8	22.4	97.9	7.2	14.8	63.4	20.4	101.0	7.5	13.8	− 2.4	−59.0	41.3	20.6	84.0	7.5	17.3	− 5.0	+31.3
67	44.5	21.9	87.7	8.3	17.4	42.4	18.0	—	8.9	15.1	+ 0.6	−56.8	40.5	20.6	79.8	9.2	19.8	− 8.8	+29.4
68	42.5	19.9	86.3	8.2	15.8	63.9	18.2	—	6.2	8.4	+ 2.1	−61.6	39.7	15.8	67.5	9.9	21.2	− 9.9	+29.6
69	43.8	22.4	94.3	8.2	14.3	69.4	16.9	—	7.2	10.4	+ 3.2	−65.9	39.3	14.9	67.7	9.1	15.9	− 8.1	+27.7
70	43.7	21.4	9.16	8.2	13.2	72.0	17.7	—	9.2	—	+ 6.0	−66.5	42.6	14.2	—	8.7	13.8	−10.1	+31.2

65 km than at any other station; however, this feature was not evident in the summer data. There were insufficient data from Tonopah for a valid comparison. One reason for the high velocities at Wallops Island could be the launch azimuth (easterly) which could result in erroneous data at high levels, another could be some feature of the circulation that is not evident farther south or north.

Figs. 4 and 5 contain the total mean speeds divided into the two seasonal regimes and the subtropical and subpolar divisions. The data in these figures show that the winter circulations are more intense both in the mean and extremes. The maximum of the winter subtropical mean is 65.8 m $\sec^{-1}$ at 59 km and the maximum of the one per cent probability is 138.7 m $\sec^{-1}$ at 53 km. The maximum of the summer subtropical mean is 46.0 m $\sec^{-1}$ at 62 km and the maximum of the one per cent probability is 95.4 m $\sec^{-1}$ at 63 km. The subpolar winter profiles indicates a maximum of 43.7 m $\sec^{-1}$ at 54 km and the possibility of higher wind speeds above 60 km. The 1 per cent probability maximum of 86.0 m $\sec^{-1}$ occurs at 44 km. However, the small number of data points make any conclusions concerning the subpolar profiles indefinite. Even fewer data points are available for the summer subpolar profiles. It is apparent that the subtropical stations consistently measure higher wind speeds than the subpolar stations. Another characteristic that should be mentioned is the greater variability in the winter as indicated by the large standard deviations.

The winter and summer regimes are shown in components in Figs. 6 and 7. The dominance of the zonal flow is apparent. Both latitude groups show the summer easterlies and winter westerlies. This is in general agreement with the cross section of Batten (1961). The subtropical summer easterlies have a mean maximum speed

TABLE 4. Computed wind values for subpolar stations (A) mean wind speed m sec^{-1}, (B) standard deviation of mean wind speed m sec^{-1}, (C) one per cent probability level of mean wind speed m sec^{-1}, (D) mean wind shear m sec^{-1} km^{-1}, (E) ten per cent probability level of wind shears m sec^{-1} km^{-1}, (F) north (+) south(−) wind components m sec^{-1}, (G) east (+) west (−) wind components m sec^{-1}.

Alt km	All data subpolar					Winter subpolar							Summer subpolar						
	A	B	C	D	E	A	B	C	D	E	F	G	A	B	C	D	E	F	G
30	16.5	11.6	50.0	4.3	7.3	19.5	14.3	54.2	4.4	7.8	+ 4.8	− 9.6	8.7	4.4	18.0	2.0	3.8	−1.5	+ 7.8
31	17.3	12.6	56.4	4.3	8.1	21.1	15.8	60.1	4.4	10.0	+ 4.3	−11.6	9.0	4.0	14.5	3.1	6.1	−0.6	+ 8.2
32	18.0	12.7	56.5	4.0	7.4	22.2	15.5	58.2	4.5	8.5	+ 4.6	−12.8	10.6	4.0	16.2	2.4	4.5	−0.3	+ 9.7
33	18.7	12.2	58.7	4.2	8.7	21.8	15.0	58.8	4.3	8.8	+ 4.9	−12.2	11.6	4.5	—	3.5	6.1	−1.2	+10.4
34	19.1	11.9	55.1	4.2	8.0	22.2	14.3	59.4	5.0	9.9	+ 4.6	−12.0	11.8	5.6	—	2.1	3.6	0	+10.6
35	20.0	12.5	62.0	4.8	8.0	23.6	15.8	65.0	5.4	12.7	+ 5.6	−13.0	12.6	6.2	—	4.0	6.8	−0.2	+11.1
36	22.1	14.6	71.9	4.5	8.7	26.6	18.5	74.9	4.6	8.7	+ 5.8	−15.4	12.0	4.8	—	3.6	5.1	−1.1	+ 9.6
37	23.0	14.6	71.8	4.3	9.0	27.9	17.7	76.4	5.1	10.0	+ 6.0	−16.4	12.4	3.8	—	2.6	5.5	−1.4	+ 8.2
38	23.7	14.6	68.7	3.8	7.5	28.8	17.2	74.1	4.4	8.8	+ 7.2	−17.6	12.2	4.8	—	2.5	4.1	−0.9	+ 8.4
39	24.6	15.2	72.0	4.1	7.8	30.0	17.2	75.0	4.5	9.3	+ 8.1	−17.5	11.4	5.0	—	3.1	5.6	−0.7	+ 7.7
40	26.3	15.8	74.1	4.3	8.0	31.9	17.1	71.8	4.5	8.1	+ 8.2	−17.1	11.9	4.8	—	2.6	3.5	+0.5	+ 9.4
41	26.5	15.0	67.2	3.8	6.9	32.0	17.4	70.2	3.7	6.8	+ 9.8	−15.6	14.1	4.5	—	2.9	4.2	+0.7	+10.6
42	27.0	15.5	73.7	3.9	7.3	31.5	17.6	74.1	4.1	8.4	+11.2	−16.7	15.9	5.5	—	4.3	6.5	+1.8	+11.2
43	27.1	15.0	77.5	3.5	6.4	31.9	18.4	79.9	3.9	6.4	+11.5	−17.3	18.6	7.6	—	2.2	—	+3.1	+13.5
44	28.3	15.2	79.1	3.4	5.8	32.3	18.8	85.7	4.1	5.6	+13.5	−17.9	23.6	—	—	1.0	—	+2.5	+23.1
45	28.7	15.2	75.9	3.4	7.3	32.5	19.0	82.1	4.2	7.3	+14.1	−17.3	25.6	—	—	2.5	—	+2.0	+25.2
46	29.2	14.8	64.3	3.6	6.9	33.1	17.8	64.8	4.7	7.1	+12.6	−19.8	25.3	—	—	4.4	—	+2.0	+24.9
47	30.0	14.2	61.8	3.4	6.9	33.5	17.1	62.4	4.3	8.1	+12.3	−21.9	27.5	—	—	3.6	—	−0.6	+26.9
48	30.4	14.8	64.2	3.4	6.1	33.6	17.8	64.3	3.7	6.8	+10.2	−23.0	27.8	—	—	3.6	—	−2.5	+26.7
49	31.9	15.5	64.1	3.3	5.9	35.2	18.1	64.6	3.4	5.5	+ 9.8	−24.5	29.2	—	—	4.5	—	−5.0	+27.9
50	32.9	15.7	64.6	4.0	6.2	35.8	17.9	65.6	4.2	6.2	+ 7.3	−26.6	31.1	—	—	3.7	—	−2.8	+29.5
51	34.8	16.9	61.9	3.8	6.2	39.1	17.6	64.0	3.4	5.7	+ 6.0	−29.8	31.9	—	—	3.3	—	−7.8	+30.2
52	34.9	17.6	78.3	4.3	8.4	39.9	16.8	—	4.7	8.9	+ 4.5	−33.9	32.1	—	—	2.8	—	−9.1	+29.7
53	35.6	19.5	82.0	3.7	8.3	41.2	17.2	—	4.4	8.5	+ 4.8	−34.8	—	—	—	—	—	—	—
54	37.1	20.1	82.2	3.9	8.5	43.6	18.3	—	4.5	8.5	+ 6.1	−35.5	—	—	—	—	—	—	—
55	34.9	19.4	82.6	3.6	7.3	41.9	18.2	—	4.6	8.0	+ 4.1	−34.0	—	—	—	—	—	—	—
56	31.7	17.3	79.2	3.8	6.6	41.7	18.2	—	5.1	10.4	+ 4.3	−34.0	—	—	—	—	—	—	—
57	31.6	18.7	84.5	3.9	7.1	40.2	21.2	—	4.3	6.8	+ 7.7	−32.9	—	—	—	—	—	—	—
58	30.1	20.3	—	4.9	9.1	38.5	23.5	—	4.6	—	+ 7.3	−30.7	—	—	—	—	—	—	—
59	26.5	14.4	—	4.7	7.7	32.7	17.1	—	—	—	+13.3	−24.8	—	—	—	—	—	—	—
60	28.8	18.2	—	4.7	7.8	38.9	—	—	—	—	+20.4	−27.8	—	—	—	—	—	—	—
61	32.6	19.8	—	2.8	4.7	53.5	—	—	—	—	+27.1	−37.3	—	—	—	—	—	—	—
62	33.2	22.0	—	2.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

TABLE 5. Mean temperature values for subtropical and subpolar stations. (A) mean of all temperature data, deg C, (B) standard deviation of all temperature data, deg C, (C) mean of winter temperature data, deg C, (D) standard deviation of winter temperature data, deg C, (E) summer temperature data, deg C, (F) standard deviation of summer temperature data, deg C.

Alt km	Subtropical temperature data						Subpolar temperature data					
	A	B	C	D	E	F	A	B	C	D	E	F
30	−45.6	6.1	−46.4	6.8	−45.2	5.7	−51.2	6.8	−52.7	7.2	−46.2	6.1
31	−43.6	6.5	−44.8	6.7	−43.4	6.1	−50.6	7.4	−52.2	7.3	−43.4	6.3
32	−41.9	6.7	−42.8	7.3	−42.2	5.8	−49.6	8.5	−52.0	8.0	−42.9	6.3
33	−39.3	6.7	−40.2	7.1	−39.8	5.9	−48.2	9.2	−51.3	8.6	−38.3	6.6
34	−36.6	7.3	−37.2	7.9	−37.2	5.9	−46.1	9.3	−50.9	8.1	−34.8	7.3
35	−33.6	7.6	−34.3	7.9	−34.7	6.1	−44.5	10.1	−49.2	9.1	−31.8	8.0
36	−30.2	8.2	−31.8	8.0	−31.4	6.6	−42.2	11.1	−47.5	10.1	−28.7	7.7
37	−26.9	9.7	−28.9	10.3	−29.4	7.2	−40.1	11.5	−46.6	10.1	−27.6	7.7
38	−23.5	10.6	−25.8	11.1	−25.5	7.9	−37.8	11.8	−44.6	8.9	−23.9	8.4
39	−20.4	10.2	−21.5	11.6	−22.3	7.8	−35.6	12.5	−43.0	9.0	−23.7	—
40	−17.9	10.0	−19.2	10.3	−19.8	8.2	−31.9	13.7	−40.4	10.4	−20.0	—
41	−14.3	10.3	−15.1	11.3	−16.4	8.2	−29.1	14.3	−38.1	10.8	−11.0	—
42	−10.8	10.3	−11.1	10.6	−13.3	9.4	−25.6	14.6	−34.4	11.4	− 6.6	—
43	− 8.0	9.8	− 7.2	10.3	−11.0	7.8	−23.8	14.6	−34.0	10.6	− 3.7	—
44	− 5.5	10.1	− 4.7	10.8	− 8.1	8.1	−21.9	13.3	−31.0	9.0	− 8.8	—
45	− 4.1	9.7	− 3.9	9.7	− 6.1	8.4	−21.6	11.7	−29.7	8.3	− 8.4	—
46	− 2.3	9.2	− 1.9	8.0	− 4.6	8.4	−18.8	12.4	−27.2	8.6	− 6.4	—
47	− 0.8	9.3	+ 0.7	8.7	− 3.9	8.3	−16.3	12.7	−26.4	6.9	− 2.6	—
48	0.0	9.6	+ 1.0	8.8	− 3.2	8.9	−12.8	12.2	−22.1	8.5	− 2.1	—
49	+ 1.1	10.1	+ 1.6	9.5	− 2.8	9.2	−10.3	10.2	−18.4	6.3	− 0.9	—
50	+ 1.5	9.7	+ 1.5	10.5	− 2.5	9.1	− 9.2	9.9	−15.2	7.2	+ 0.5	—
51	+ 2.2	9.8	+ 2.6	10.2	− 2.0	9.6	− 6.3	9.1	−10.6	9.0	—	—
52	+ 2.7	10.1	+ 4.7	9.9	− 2.5	9.9	− 5.2	9.0	− 9.7	9.1	—	—
53	+ 2.8	10.3	+ 5.7	10.4	− 4.0	9.4	− 4.6	8.7	− 7.8	9.3	—	—
54	+ 2.9	10.3	+ 5.8	11.5	− 3.4	8.2	− 3.2	9.1	− 6.0	9.9	—	—
55	+ 2.4	9.8	+ 0.9	13.3	− 2.3	6.2	− 2.3	10.1	− 7.6	—	—	—

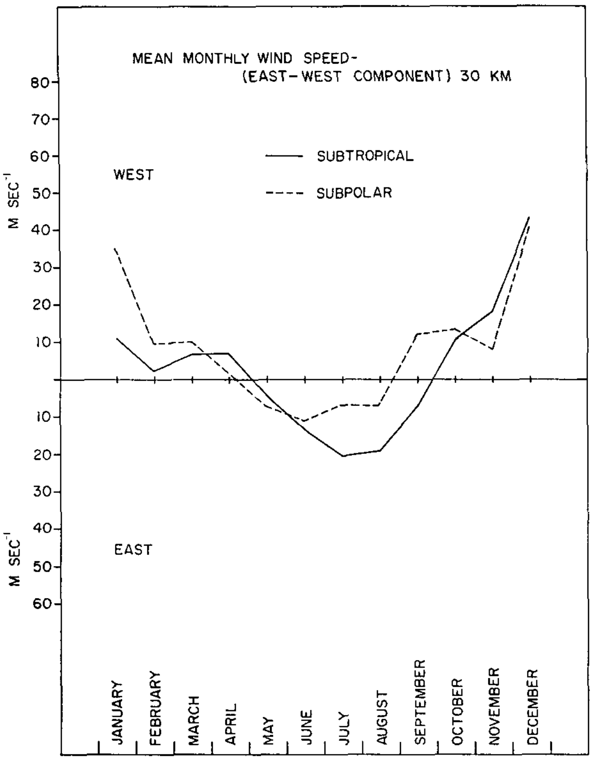

FIG. 2. Mean monthly east–west component of the wind (m sec^{-1}).

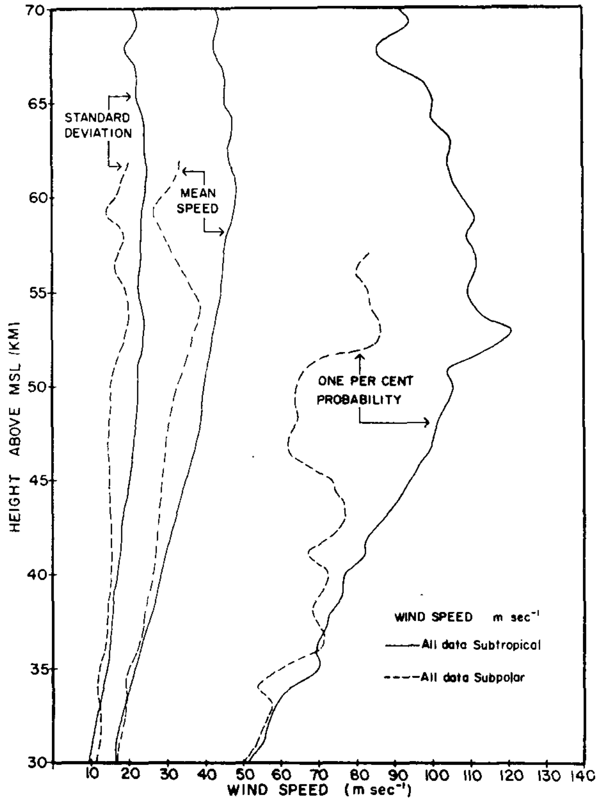

FIG. 3. Mean wind speed, standard deviation and one per cent probability level using all data for subtropical and subpolar stations.

of 42 m sec^{-1} at 60 km while the maximum of the mean winter westerlies is 64 m sec^{-1} at 60 km. Again the scarcity of subpolar data is restrictive, but it appears that there are at least two maximums of the mean westerlies during the subpolar winter below 65 km. One would expect that the stratospheric polar jet would influence the winter zonal mean flow or at least the standard deviation but apparently these two subpolar stations do not lie in the area of the polar stratospheric jet stream (Godson and Lee, 1958). Consequently, the wind speed values of the subpolar stations would be greater than observed if the stations were located closer to the stratospheric jet. The meridional profiles indicate that during the winter the flows are in opposite directions. A northerly transport is found in subtropical regions in the winter while a southerly transport is observed in the subpolar regions. A general convergence then occurs near midlatitudes at these altitudes during the winter over North America. In summer the magnitudes of the meridional components are much smaller and not uniformly opposite. The subtropical meridional component is southerly throughout the altitude range. The subtropical component averaged under 2 m sec^{-1} from 30 to 43 km, increasing to 6 m sec^{-1} at 53 km, decreasing to 3 m sec^{-1} at 60 km, then generally increasing to 11 m sec^{-1} at 70 km. The subpolar meridional structure shows a northerly component between 39 and 47 km with a maximum of 3 m sec^{-1} at 33 km. Below 39 km there is a 1 m sec^{-1} southerly component. The subpolar profile above 47 km indicates some significant southerly components.

The shears are summarized in Figs. 8, 9 and 10. It was decided to include only the mean value and a 10 per cent probability level (the 10 per cent probability is equivalent to the 90 per cent confidence level). The 1 per cent probability would merely represent those soundings which measured extreme apparent wind speed shears which actually were errors due to sensor tracking difficulties. Chaff dispersion is the foremost cause of such errors. If the 1 per cent probability of shears is desired, a careful subjective analysis must be made of any chaff data or perhaps a complete exclusion of chaff derived winds. The largest wind shears were measured during the summer in subtropical regions above 60 km. In the mean, the subtropical shears were larger than the subpolar shears. In the mean, the winter subtropical shears were about 5 m sec^{-1} km^{-1} up to 55 km increasing thereafter to a maximum of 8.8 m sec^{-1} km^{-1} at 67 km. The summer subtropical shears averaged about 4 m sec^{-1} km^{-1} up to 50 km, increasing thereafter to maximum of 9.9 m sec^{-1} km^{-1} at 68 km. The 10 per cent probability profile generally followed the configuration of the mean shear profile. The mean of the subpolar winter

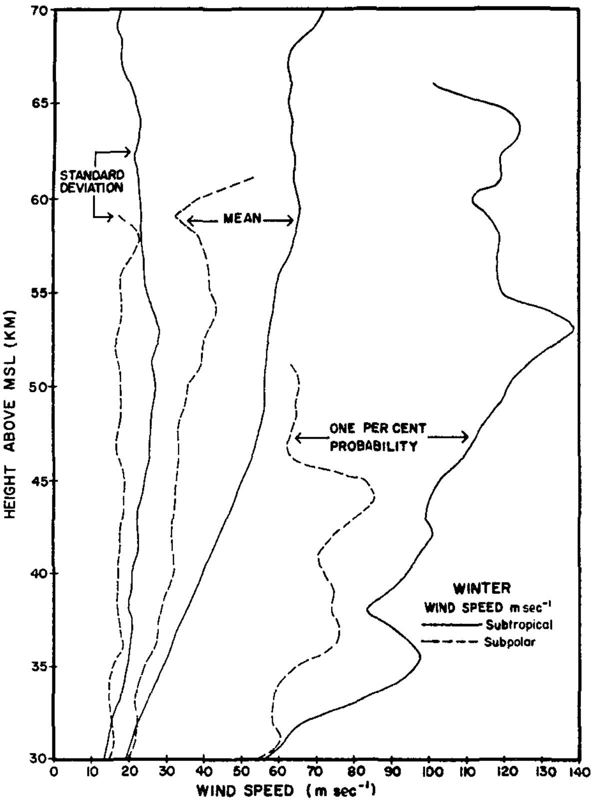

Fig. 4. Mean wind speed, standard deviation and one per cent probability level using winter data for subtropical and subpolar stations.

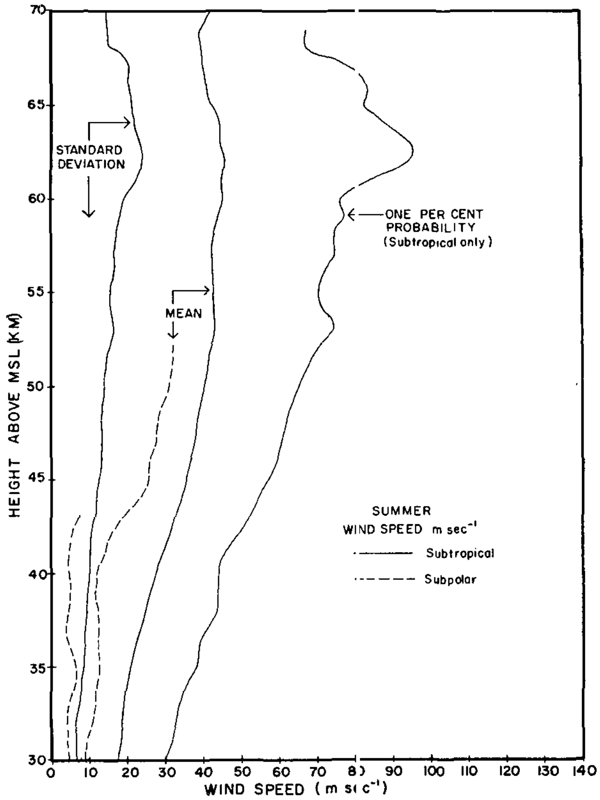

Fig. 5. Mean wind speed, standard deviation and one per cent probability level using summer data for subtropical and subpolar stations.

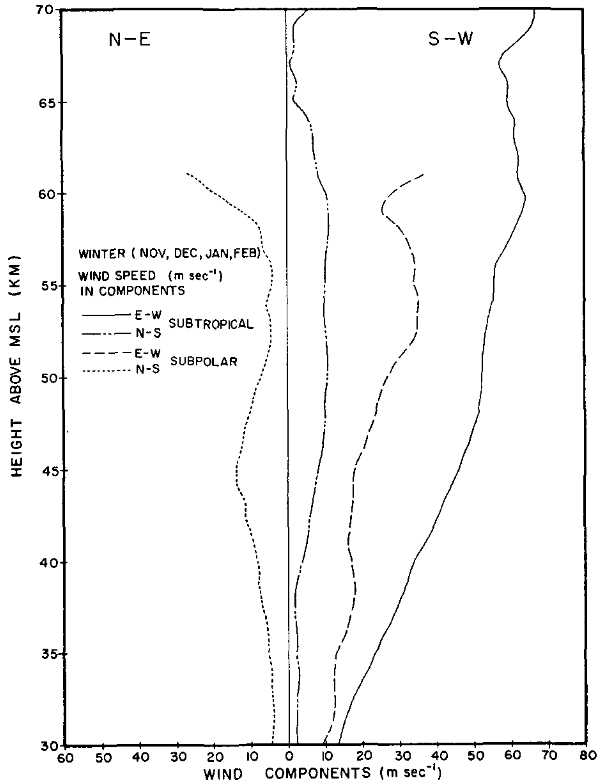

Fig. 6. Wind components for winter season for subtropical and subpolar stations.

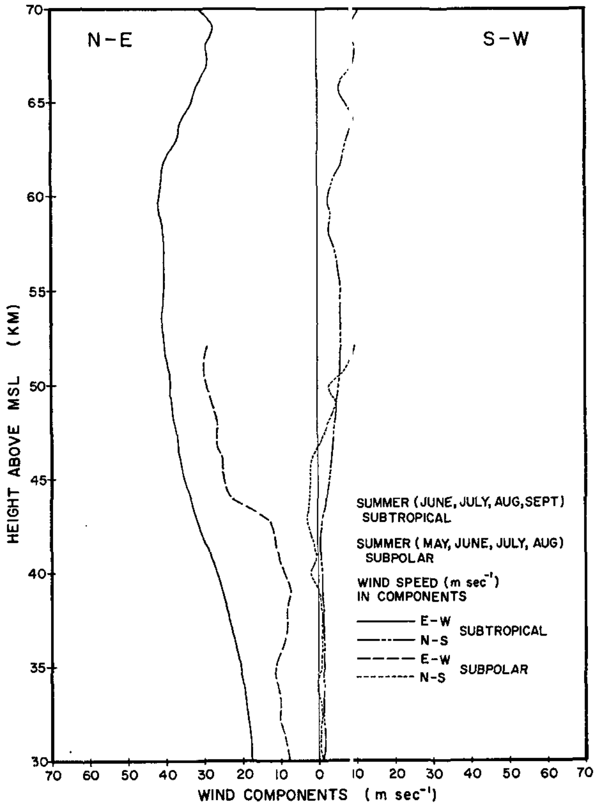

Fig. 7. Wind components for summer season for subtropical and subpolar stations.

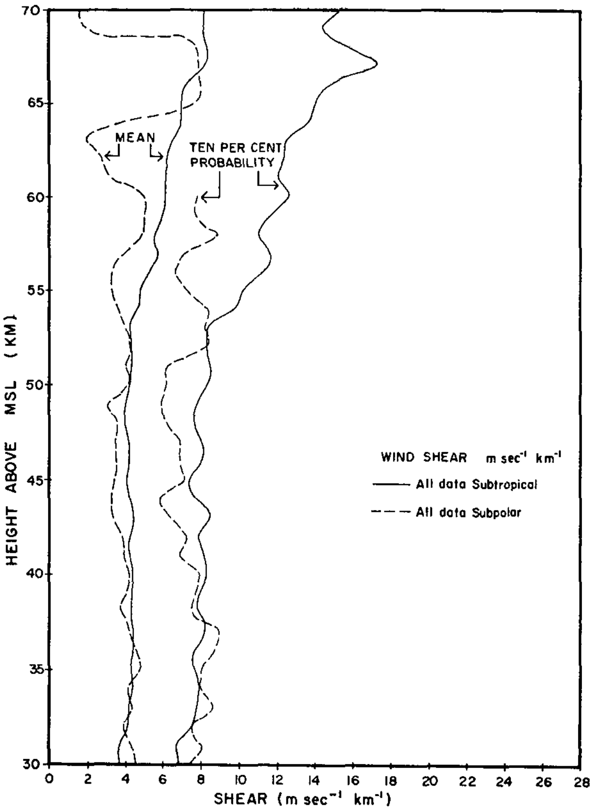

Fig. 8. Mean wind shears and ten per cent probability level using all data.

shears was 1 m sec^{-1} km^{-1} less than that of the subtropical shears.

3. Temperature data

All temperature data used in this study were gathered with standard Rocket Network parachute-bead thermistor systems. Although there has been a continual program of improvement involving electronic component modification of the flight instrument, the 10 mil bead thermistor has remained the sensing device.

The Rocket Network temperature systems allow for a nearly continuous recording of temperature as the instrument descends after expulsion at the rocket apogee. The relative detail of the actual temperature structure which can be recorded is then limited only by the time constant of the system together with its descent rate. Wagner (1961) has considered these factors as well as others concerning the accuracy of the system. In general, the time constant varies from about 0.9 sec at 40 km to 1.6 sec at 50 km to 4 sec at 60 km.

Data used in this report have been corrected in accordance with a differential equation given by Wagner (1963). This equation considers the effects of forced convection, radiation, self heating (a result of the measuring current), viscous dissipation, and conduction along the lead wires of the thermistor. After these corrections have been applied the accuracy of the temperature curve should be about ±1C or less below 55 km.

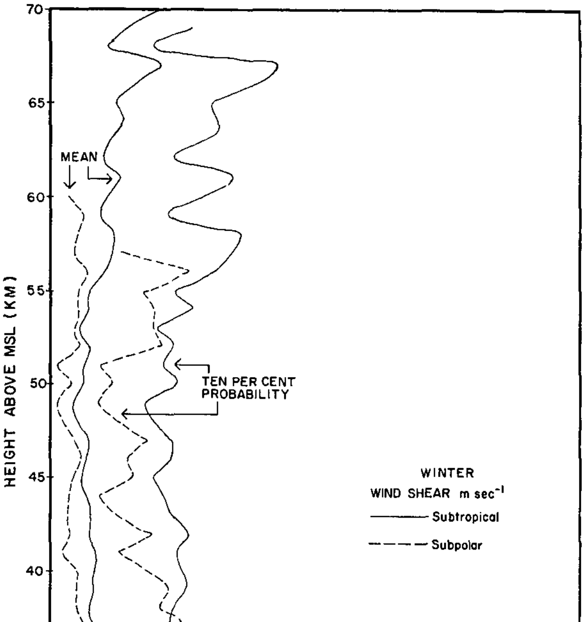

Fig. 9. Mean wind shears and ten per cent probability level using winter data.

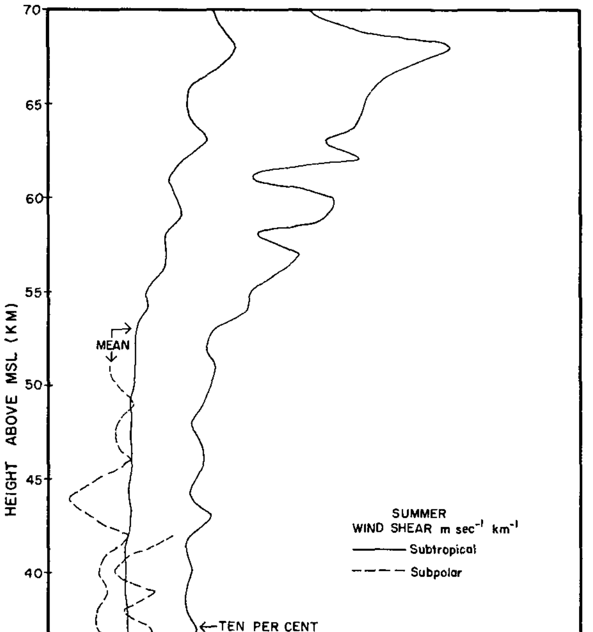

Fig. 10. Mean wind shears and ten per cent probability level using summer data.

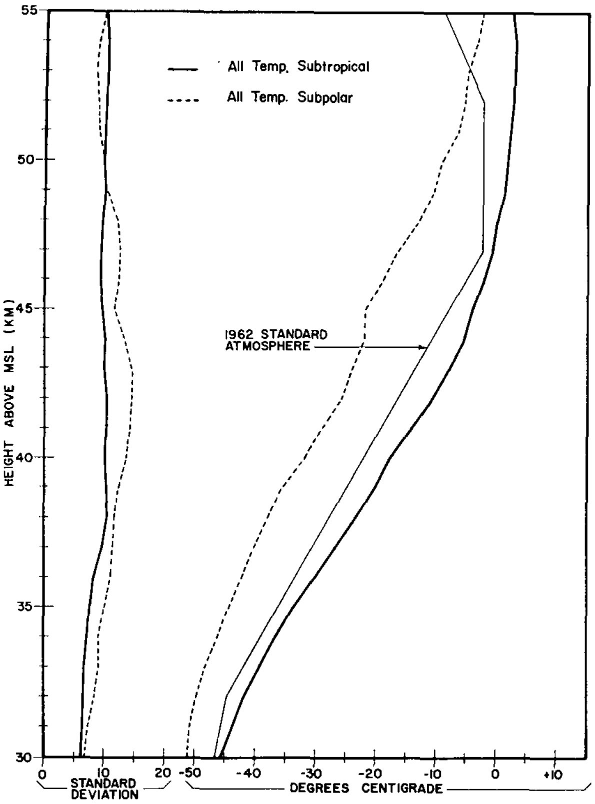

Fig. 11. Mean temperatures and standard deviations using all data.

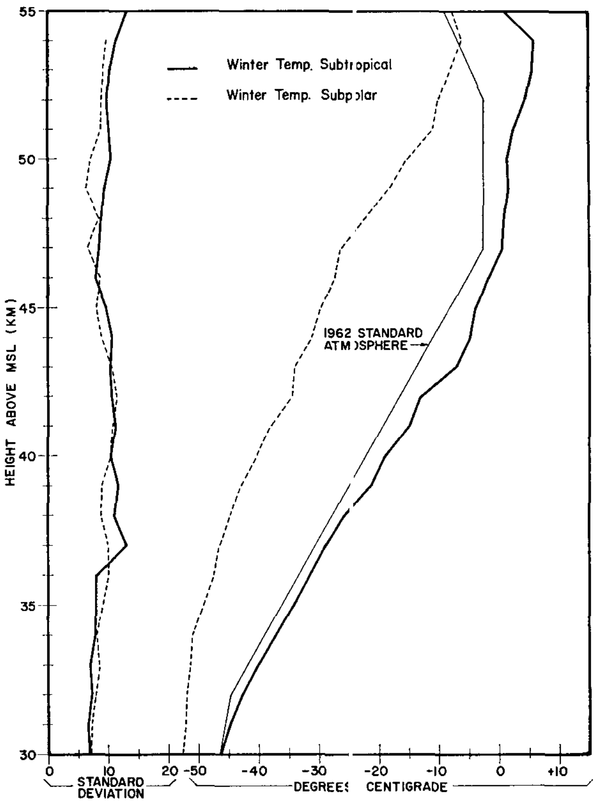

Fig. 12. Mean temperatures and standard deviations using winter data.

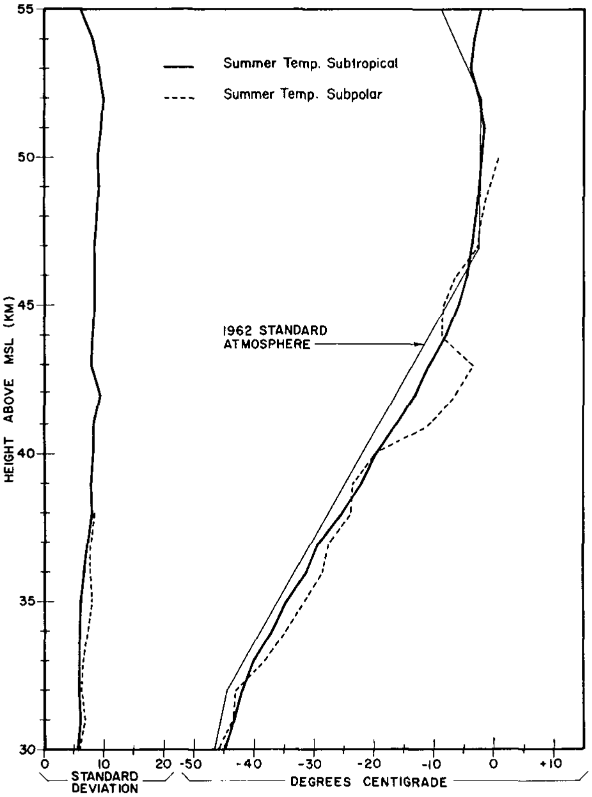

Fig. 13. Mean temperatures and standard deviations using summer data.

For this study we have restricted the data to the altitude range between 30 km and 55 km. Table 2 lists the number of soundings for various levels of the subpolar and subtropical divisions. Very few soundings were taken during the summer at the subpolar stations; and it can be noted that the subtropical profiles are biased to the White Sands and Point Mugu data.

Fig. 11 contains the "all-data" means and standard deviations for the two latitude groups. Also included in this (and following graphs) is the 1962 standard atmosphere which applies to typical midlatitude year around conditions. Obviously, the standard does fall within the temperature range as determined by the rocketsonde network. However, the subpolar profile is biased toward winter. The two means differ by 5C at 30 km with the difference increasing with altitude so that at 45 km, it has reached 17C. Between 45 and 50 km the difference between means decreases to 10.5C. The standard deviation of the subpolar data is generally greater than that of the subtropical. However, the sample size might explain this.

Figs. 12 and 13 contain the seasonal means and deviations. Outstanding, of course, is the tremendous change from season to season in the subpolar temperature structure. Summer profiles have warmed more than 6C at 30 km to near 25C at 45 km. The subtropical profiles are much smoother than subpolar ones which again probably results from an insufficient number of

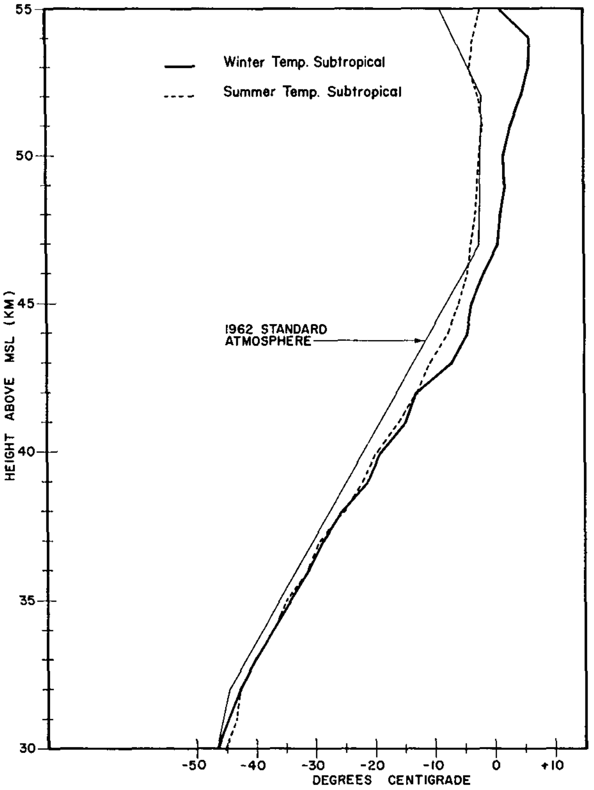

Fig. 14. Comparison of observed mean subtropical winter and summer temperatures.

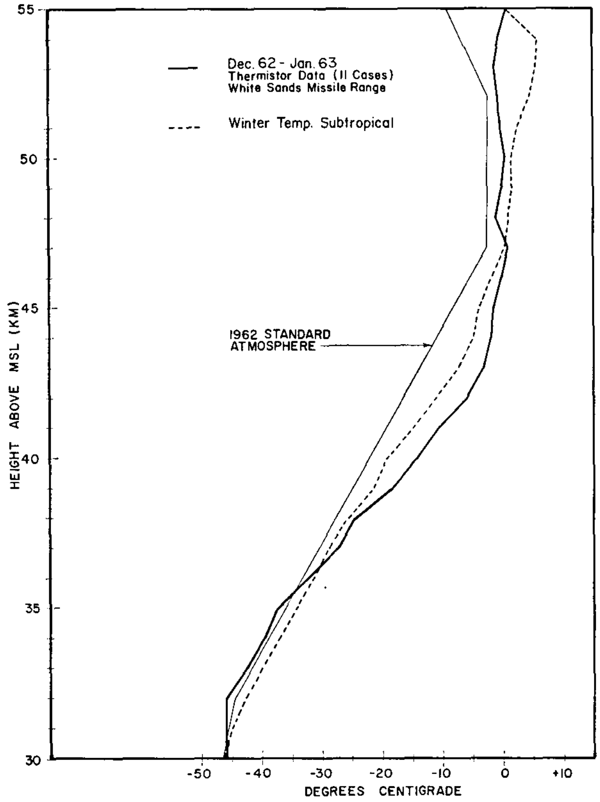

Fig. 15. Comparison of December 1962–January 1963 temperature curve and mean subtropical winter temperature curve.

subpolar soundings. The subtropical profiles are much more consistent from season to season. Of considerable interest is the fact that above 40 km, the subtropical winter is warmer than the summer by 3 to 4C (Fig. 14). These data do not agree with the standards of Kantor and Cole (1963). A possible explanation for the colder subtropical summer lies in the advection implied by the thermal wind equation. In winter, west winds increase with height indicating colder temperatures to the north. In summer, east winds increase with height indicating warmer temperatures to the north. Therefore, the stronger meridional flow from the south during the winter could advect warm air into subtropical regions. The weaker southerly flow in the summer could advect cooler air to subtropical latitudes. In order to further check the validity of subtropical summer and winter profiles, a special effort was made to examine more recent data. Consequently, the data in Fig. 15 are included here. Note that these data are for White Sands only and include nine soundings during December 1962 and two soundings from January 1963. The warming of January 1963 is not included in these data. The following summary results from a comparison between these data and the subtropical winter profile of Fig. 12. The 1962–63 winter profile shows about 2C colder between 31 and 35 km, 1C warmer at 37 km, up to 5C warmer from 38 km to 46 km and 1.5C colder to 50 km. Again then, the subtropical winter stratosphere from 38 to 46 km appears generally warmer than the summer for the "all-data" case (Fig. 15). Also plotted in the figure is Kantor and Cole's (1963) subtropical winter standard temperature profile. As can be seen in Fig. 12 when comparing subpolar with subtropical, the winter subpolar profile is much colder than the subtropical while in summer the subpolar stratosphere actually appears to be slightly warmer than the subtropical. Thiele (1963) has found similar seasonal and latitudinal density variations based on much of the same data.

4. Conclusions

The wind data presented in this study generally support previously constructed cross sections of the wind regime over North America. The zonal easterlies and westerlies dominated the summer and winter seasons, respectively. The meridional component of the wind at subtropical latitudes remained southerly throughout the year with a stronger component present in the winter. This means that there is a significant mass transport toward midlatitudes from subtropical latitudes over North America. Since the meridional component did not reverse direction with the seasonal change in the zonal wind, this fact will have to be explained in future studies of the circulation of the stratosphere. The low wind speeds measured near 30 km by the subpolar stations indicated that these stations lie outside the mean position of the stratospheric jet stream. The largest wind shears were measured over the subtropical stations above 60 km in the summer.

In the subpolar stratosphere even fewer soundings are available. The seasonal changes are much more-pronounced; the summer is warm (near subtropical values) and the winter is much colder. Certainly, more soundings are needed in the subpolar and polar regions for any detailed study of the temperature structure. One would expect very large variations to occur throughout the subpolar stratosphere as is evidenced at the 10-mb level during the sudden warmings.

Although the general temperature structure of the subtropical stratosphere is well known, obviously there is still significant disagreement as to the more refined structure. Certainly more measurements are needed to determine optimum standards and ranges of variability. Until the distribution of such parameters is known the explanations of the distributions and consequently a complete understanding of the interactions in the atmosphere will remain incomplete.

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REFERENCES

Batten, E. S., 1961: Wind systems in the mesosphere and lower ionosphere. *J. Meteor.*, **18**, 283–291.

Committee on Extension to the Standard Atmosphere, 1962: *The U. S. Standard Atmosphere, 1962*. Washington, U. S. Govt. Printing Office, 278 pp.

Godson, W. L., and R. Lee, 1958: High level fields of wind and temperature over the Canadian arctic. *Beitr. Phys. Atmos.*, **31**, 40–68.

Jenkins, K. R., 1962: Empirical comparisons of meteorological rocket wind sensors. *J. appl. Meteor.*, **1**, 196–202.

Kantor, A. J., and A. E. Cole, 1963 Tropical and subtropical atmospheres. *J. appl. Meteor.*, **2**, 90–98.

Lally, V. E., and R. Leviton, 1958: Accuracy of wind determination from the track of a falling object. *Air Force Surveys in Geophys.*, No. 93, Air Force Cambridge Research Laboratories, Mass. [ASTIA document, Order No. 146858.]

Miers, B. T., 1963: Zonal wind reversal between 30 and 80 km over the Southwestern United States. *J. atmos. Sci.*, **20**, 87–93.

Rapp, R. R. 1960: The accuracy of wind derived by the radar tracking of chaff at high altitudes *J. Meteor.*, **17**, 507–514.

Thiele, O. W., 1963: Mesospheric density variability based on recent meteorological rocket measurements. *J. appl. Meteor.*, **2**, 649–654.

Wagner, N. K., 1961: Theoretical time constant and radiation error of a rocketsonde thermistor. *J. Meteor.*, **18**, 606–614.

——, 1963: Theoretical accuracy of the meteorological rocketsonde thermistor, electrical engineering research laboratory. Report No. 7–23, University of Texas. [ASTIA Document, Order No. unassigned.]