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EXTREME MOMENTUM PROFILES IN THE TROPOSPHERE

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U. S. NAVY WEATHER RESEARCH FACILITY
BUILDING R-48, U. S. NAVAL AIR STATION
NORFOLK, VIRGINIA 23511

MAY 1967

Errata

"Extreme Momentum Profiles in the Troposphere," NWRF 35-0567-124, May 1967.

page v and page 7 - The title of figure 4.1 should be "Latitudinal" ... vice "Longitudinal" ...

FOREWORD

This publication was prepared under Navy Weather Research Facility Task 35, ''Meteorological Techniques for Naval Missile and Satellite Operations,'' by Dr. Herbert Riehl, Professor of Atmospheric Science, Colorado State University. It provides a summary of research accomplished to develop an objective method of characterizing extreme wind and momentum profiles for winter in the upper troposphere, and a missile design climatology, for coastal and oceanic regions of the Northern Hemisphere.

Mr. Robert S. Haltiner of NWRF assisted Professor Riehl in this study and coordinated the data collection program.

Reviewed and approved on 29 May 1967.

W. L. Somervell

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1. INTRODUCTION

As is the case with all weapons systems, guided missiles are affected by the environment. This report is a climatological study of the effect of extreme winds and wind shears upon the flight of these vehicles during their ascent.

Missile guidance systems are designed with a capability to compensate for the influence which wind exerts to deflect them from their intended course. At times, however, this influence may be so great upon a particular missile that special precautionary measures must be taken to ensure a successful launch.

It is important for planning purposes to know the probability of occurrence of these extreme cases. If these events occur with such rarity that the likelihood of misadventure is remote, it is equally unlikely that the operational system will be degraded to the point where it is a matter of concern — or that the occurrence of the event will be predicted in advance. On the other hand, should such an extreme represent a relatively frequent occurrence, it is necessary that the problem be examined in sufficient detail to assess the reliability of this missile system and the necessity for incorporating additional guidance capabilities.

The effectiveness with which the wind is able to deflect a launch vehicle to the point that its guidance system may be overcome is, of course, dependent upon wind velocity and the rapidity with which the wind changes along the missile's trajectory. However, it is also directly related to the density of the air. Thus, a given wind velocity would produce a much greater effect upon the missile at sea level, where air density is greatest, than in the stratosphere. Therefore, considerations of wind effect require that the wind and its variations be studied in terms of air momentum, rather than of simply wind.

Our knowledge of lower tropospheric wind variations is obviously much greater than that at higher levels. Moreover, the existence of an extreme wind situation in the lower troposphere will generally be apparent from surface data alone. Consequently, the purpose of this study is to develop a climatology for coastal and oceanic regions of wind profiles which represent extreme upper tropospheric (above 10,000 feet) momentum increases.

Situations wherein such momentum increases occur are almost invariably associated with jet streams. It is well known that while the wind speed undergoes large vertical variations through the jet stream, the wind direction changes very little through jet-stream layers. The directional turning of wind with height may therefore be neglected, and the momentum shear approximated by a scalar quantity.

2. DEFINITION OF PARAMETERS

Given the air density ρ and the wind speed u, the linear momentum is defined as

$$M = \rho u . \qquad (1)$$

Taking logarithms and differentiating

$$\frac{1}{M}\frac{\partial M}{\partial z} = \frac{1}{u}\frac{\partial u}{\partial z} + \frac{1}{\rho}\frac{\partial \rho}{\partial z}, \qquad (2)$$

where z is the vertical coordinate, positive upward. For momentum constant along the vertical

$$\frac{1}{u}\frac{\partial u}{\partial z} = -\frac{1}{\rho}\frac{\partial \rho}{\partial z}, \qquad (3)$$

a situation often closely approximated in middle latitudes where u normally increases with height below the tropopause irrespective of wind direction. The critical cases are those where $\frac{\partial M}{\partial z}$ increases upward. Then $\frac{1}{u}\frac{\partial u}{\partial z} > \left|\frac{1}{\rho}\frac{\partial \rho}{\partial z}\right|$. Now, $\frac{1}{\rho}\frac{\partial \rho}{\partial z}$ is a very slowly varying function of height in the troposphere. Therefore, $\frac{1}{M}\frac{\partial M}{\partial z}$ is most likely to be positive when $\frac{\partial u}{\partial z}$ is large at small values of u, that is, at relatively low altitudes in the westerlies.

Although only the scalar and not the vector shear of momentum will be analyzed, the variety of observed wind and momentum profiles is very great and cannot readily be expressed as any simple function. After preliminary testing, six parameters were defined for describing the momentum profile during one balloon ascent:

(1) Height of base of layer with momentum increase above 10,000 feet;
(2) Wind speed at base;
(3) Thickness of layer with positive momentum shear (one of the two most important parameters characterizing the profile);
(4) Average slope of the momentum profile over the layer with positive shear (the second parameter of major importance);
(5) Extreme slope of the momentum profile through at least 2,000 feet thickness within the layer measured in item 3;
(6) Location of the extreme slope on the profile.

Table 2.1 gives the class intervals used for tabulating these parameters. Initially, there was much concern about possible double peaks in the momentum profiles. However in these instances the upper peak was minor compared to the lower one, in spite of occasional very high wind speeds, and could be neglected. The absolute value of the momentum for jet streams with deep layers of constant momentum was also studied. Aside from observations from the Japanese Islands through the winter jet stream off Eastern Asia, mean momentum values failed to reach magnitudes of apparent interest; and this aspect of the study was not pursued.

Table 2.1. Classification of Momentum Soundings.

Schedule (1) Height of base (ft.)	Class	Schedule (2) Velocity at base (mps.)	Class	Schedule (3) Thickness of Layer (ft.)	Class
10,000	1	less than 15	1	6 - 10,000	1
12 - 16,000	2	15 - 24.9	2	12 - 16,000	2
18 - 22,000	3	25 - 34.9	3	18 - 22,000	3
24 - 28,000	4	35 - 44.9	4	24 - 28,000	4
30 - 34,000	5			30 - 34,000	5
				36 - 40,000	6

Schedule (4) Slope (units/2000 ft.) (gm./cm.²/sec.)	Class	Schedule (5) Extreme Slope (units/2000 ft.) (gm./cm.²/sec.)	Class	Schedule (6) Center of height of extreme slope portion of profile	Class
less than .1	0	No extreme slope	0	No extreme slope	0
.10 - .199	1	.3 - .399	1	upper third	1
.20 - .299	2	.40 - .499	2	middle third	2
.30 - .399	3	.50 - .599	3	lower third	3
.40 - .499	4	.60 - .699	4		
.50 - .599	5	.70 - .799	5		
.60 - .699	6	.80 - .899	6		
.70 - .799	7	.90 - and greater	7		
.80 - .899	8				
.90 - and greater	9				

3. ANALYSIS OF MOMENTUM PROFILES

3.1. Initial Analysis Program

According to the initially formulated plan, momentum profiles were to be computed for a large number of rawinsonde stations outside the tropics for the available periods of record. Limits of extreme profiles were then to be defined. It was specified that soundings should attain at least 50,000 feet geometric height; that wind speed should attain at least 100 knots; and that the wind profile was to be smoothed in the vertical by a technique [1] for eliminating unrepresentative wind oscillations in shallow layers frequently found in jet-stream wind profiles.

The result of the computations was entirely unsatisfactory, as shown in the breakdown of the sample of Ocean Ship "P" (50° N., 140° W.) data contained in Table 3.1. This ship had one of the better records among the 55 stations for which computations were made.

Table 3.1. Summary of Ocean Ship "P" Sounding Data (May 1953 - April 1963).

Number of possible flights (one sounding per day)	3652
Did not reach 50,000 feet	460
Missing data within flight	1924
No wind speed greater than 100 knots	967
Used for computer program	301

Evidently, the percentage of soundings analyzed in the computer program is very small; probably many extreme soundings are buried in the two groups *did not reach 50,000 feet* and *missing data within flight*. Apparently, the root of the difficulty still lies in the method of wind observation. At high wind speeds, soundings may terminate below 50,000 feet because of low elevation angles. The reason for data missing in flight is not obvious, but might also be related in part to the jet-stream situations themselves. While the existence of measurement problems was, of course, realized before the study, the very high percentages of soundings ending below 50,000 feet or having missing data in flight were not anticipated.

It became evident that another approach was needed to determine the extreme climatology. However the data from all stations, taken together, furnished at least an approximation to the limits of extreme profiles. Table 3.2 gives the frequency distribution of thickness of positive momentum shear layers against the average slope of the profile in the layer. The place where frequency falls off rapidly on each horizontal line is quite obvious, and it is marked in the table. The definition of extreme soundings as shown there held up very well. The only modification made later was that the soundings just to the left of the dividing line were examined for extreme slope, and classified as extreme if they possessed an exceptionally steep slope over part of the ascent.

3.2. Second Analysis Program

The second attempt was based on the premise that it is necessary to know, as far as possible, what happened at each station on each day, in order to arrive at a realistic extreme climatology. Accordingly, Navy Weather Research Facility personnel inspected the daily National Meteorological Center 300-mb. analyses from December 1956 to February 1963 to determine, according to the analyses for a selected number

Table 3.2. Frequency Distribution of Extreme Soundings from First Program.

Thickness of Layer with Momentum Increase	Slope of Momentum Profile (units/2000 feet)							
(1000's feet)	.15	.25	.35	.45	.55	.65	.75	.85
30 - 34	3	-	-	-	-	-	-	-
24 - 28	314	4	-	-	-	-	-	-
18 - 22	+	207	9	1	1	-	-	-
12 - 16	+	+	187	36	5	-	1	-
6 - 10	+	+	+	64	16	1	2	1

of stations, whether the wind speed was: less than 100 knots; 100 - 120 knots; 130 - 150 knots; or greater than 160 knots. Additionally, the winter (December to February) soundings for these same stations over the latest available ten-year period of record were classified from National Weather Records Center card files as follows:

Soundings for which momentum classification could be made;

Soundings with more than one missing level between 700 and 400 mb.;

Soundings with no winds of 100 knots or greater;

Soundings with a momentum increase present, but which could not be classified (so-called *undefined layer*);

Soundings which did not reach 400 mb.

Comparison of the two types of output should indicate whether upper wind soundings did, in fact, abort selectively during jet-stream conditions. Such comparison could be made for the following stations: Caribou, Maine; New York, N.Y.; Norfolk, Va.; Cape Hatteras, N.C.; Tatoosh Island, Wash.; Oakland, Calif.; San Diego, Calif.; Pt. Barrow, Alaska; Fairbanks, Alaska; and Churchill, Canada. In addition, the National Weather Records Center prepared statistical analyses for four stations outside the area of the available analyzed 300-mb. charts: Thule, Greenland; Keflavik, Iceland; Tripoli, Libya; and Okinawa, Ryukyu Islands.

3.3. Analysis of Data

3.3.1. Incomplete Observations

Table 3.3 shows the percent frequency distribution of sounding classifications for each station. There were very few or no missing observations between 700 and 400 mb. at most stations, in contrast to missing data over the entire sounding on the first analyses. Missing data were not well correlated with jet-stream incidence. Soundings that did not reach 400 mb. occurred mainly in the early years, when SCR-658 equipment was widely in use. Of the soundings with an *undefined layer* , a substantial fraction occurred with high wind speeds at 300 mb. The layer was classified *undefined* because the soundings passed into a regime with upward momentum increase, but were terminated before reaching its top.

All of these soundings were examined and extrapolated upward a distance sufficient to classify the momentum profile. The 300-mb. analyses plus prior and subsequent soundings at each station proved of much assistance in this qualitative step, since extreme situations generally build up and then recede over several 12-hour periods. Analogue comparison was also made with similar situations for which complete profiles did exist.

Table 3.3. Percent Distribution of Soundings for Selected Stations.

1953 - 1963	Soundings classified by codes of table *2.1.*	More than one missing observation between 700 and 400 mb.	No wind speed of 100 knots or more	"Undefined layer"	Sounding did not reach 400 mb.
Fairbanks	1.5	-	97.5	0.5	0.5
Pt. Barrow	1.5	0.5	96.0	1.0	1.0
Churchill	2.0	-	94.0	1.0	3.0
Thule	1.0	-	97.0	0.5	1.5
Keflavik	9.5	1.5	85.0	2.5	1.5
San Diego	6.0	-	87.5	2.0	4.5
Oakland	7.0	-	87.0	3.0	3.0
Tatoosh Is.	6.0	1.0	87.0	4.0	2.0
Cape Hatteras	30.5	1.0	61.0	6.5	1.0
Norfolk	31.0	1.5	54.0	11.0	2.5
Caribou	11.0	-	83.0	4.0	2.0
Tripoli	20.0	1.0	74.5	4.0	0.5
Okinawa	45.0	2.0	34.5	16.0	2.5

Table 3.4. Number of Extreme Soundings

	Number of observations per day	Complete	Extrapolated	N
Fairbanks	2			
Pt. Barrow	2	1	7	8
Churchill	2			
Thule	4	0	0	0
Keflavik	4	15	5	20
San Diego	2	2	3	5
Oakland	2 or 4	4	4	8
Tatoosh Is.	2	9	15	24
Cape Hatteras	2	1	0	1
Norfolk	2 or 4	7	3	10
New York	2	5	6	11
Caribou	2	6	5	11
Tripoli	2 or 4	8	5	13
Okinawa	4	18	25	43
TOTALS		76	78	154

3.3.2. Number of Extreme Cases

Of course, any extrapolation procedure leaves much to be desired, and should be avoided whenever possible. However, as table 3.4 demonstrates, the number of extreme soundings changes considerably at most stations (and almost certainly in a realistic sense) when the extrapolated soundings are included. For the construction of this table the complete extreme profiles, as defined in table 3.2, were at first located in each station record and examined for machine computation errors. This led to rejection of an unexpectedly large fraction of cases at several stations. In addition, each wind profile was inspected for extreme increases of wind speed near the top of an ascent; such cases were also rejected as due probably to instrumental difficulties.

The number of residual complete and of extrapolated extreme soundings is given in table 3.4. The most peculiar result is that of Cape Hatteras where practically no extreme wind profiles were observed, in spite of many soundings approaching 200 knots. This is due to the fact that the high wind speeds occurred most frequently near an altitude of 40,000 feet (subtropical jet stream), at the top of a layer with gradually rising wind speed. Consequently, the slope of the momentum profile was small. The large difference between Cape Hatteras and Norfolk remains unexplained. Another item of interest is that the number of extreme Arctic soundings was so small that these had to be combined in order to obtain any sample at all. Strong jet streams pass over the American Arctic only very rarely in winter. As is shown by table 3.3, 95 percent or more of the observations failed to attain wind speeds of 100 knots.

3.3.3. Adjustments for Jet Stream Occurrence

Comparing the statistics prepared by the Navy Weather Research Facility with those of the National Weather Records Center (NWRC), it was discovered that the Research Facility found jet-stream speeds on many days when the NWRC tabulation, for a variety of reasons, failed to record such speeds. Since this difference did not vary by extremely large factors among stations, except with very small samples, all data were combined to form table 3.5.

Table 3.5. Comparison of Navy and NWRC Wind Speed Classifications.

	300 mb. speed (knots)		
	100 - 120	130 - 150	≥160
Tabulated by NWRC plus *undefined soundings*	653	253	73
Observed by Navy, not tabulated by NWRC	523	80	9
Ratio (percent)	80	34	12

Evidently, the discrepancy is very large, especially at the lowest jet-stream speeds. However the reason for the distribution with lowest ratio at highest jet-stream speeds is not obvious.

All extreme soundings at each station — complete plus extrapolated (table 3.4) — were next classified as either *polar* or *subtropical* jet-stream type, and then associated with the appropriate class of 300-mb. wind speed. Distinction between jet-stream types was made on the basis of the altitude at which the momentum increase began. Soundings with momentum increase starting between 10,000 and 18,000 feet height were classified as *polar* ; those in which the momentum increase occurred only at higher elevations were classified as *subtropical*.

Next, the number of extreme soundings in each wind speed class was increased according to the ratios in table 3.5. This should give the best possible approximation to the total number of extreme soundings that would have been observed at each station, had the record of wind observations and processing been perfect. For example, table 3.6 shows how the frequencies were adjusted at Tatoosh Island. Where a fraction of a case was involved, numbers were rounded up for a slight safety margin.

After executing the procedure illustrated in table 3.6, we obtain the summary of table 3.7.

Table 3.6. Adjustment of Frequency of Extreme Soundings: Tatoosh Island.

Wind Speed at 300 mb. (knots)	N (complete plus extrapolated) Polar Jet Type		Subtropical Jet Type	
less than 100	3		-	
100 - 120	8		-	
130 - 150	4		2	
≥160	5		2	
TOTALS	20	+	4	= 24
		Maximized		
less than 100	3		-	
100 - 120	14		-	
130 - 150	5		3	
≥160	6		2	
TOTALS	28	+	5	= 33

Table 3.7. Summary : Frequency of Extreme Soundings

	Polar Type	Subtropical Type	Total	Maximized Percent of Observation
Fairbanks				
Pt. Barrow	6	2	8	0.24
Churchill				
Keflavik	16	4	20	0.76
San Diego	4	1	5	0.37
Oakland	4	4	8	
Tatoosh Is.	20	4	24	1.95
Cape Hatteras	1	0	1	-
Norfolk	8	2	10	0.40
New York	5	6	11	1.95
Caribou	6	5	11	0.90
Tripoli	8	5	13	0.75
Okinawa	14	25	43	1.60

4. RELATIONSHIP TO POLAR JET STREAM

It had been expected that there would be a clear separation between polar and subtropical types of extreme profiles according to latitude, or at least with respect to the mean position of these currents [2] (see appendix A, fig. A-1). Table 3.7 demonstrates that this is not the case. The percent frequency of extreme soundings of the polar type is surprisingly large at the subtropical stations. At high latitudes, even Iceland, subtropical type profiles appear occasionally in the middle of winter with southerly to southwesterly jet streams. Therefore, we cannot deduce the percent frequency of extreme soundings over the oceans in a simple, geographical way.

We can, however, plot the distribution of all soundings with respect to the average, polar, jet-stream axis (figure 4.1). In spite of the diverse geographical location of stations used, a smooth curve is readily fitted to the data points. Highest incidence is about two percent in a narrow band just equatorward of the mean jet-stream axis. From there, the percent frequency falls off rapidly toward the polar zone and toward the lower middle latitudes. Over the entire polar jet-stream belt with width of about 20° latitude, the frequency of extreme soundings is near one percent.

As already stated, a similar diagram could not be prepared relative to the average subtropical jet-stream axis, due to apparently large geographical differences in the marked concentration of extreme soundings along the Asiatic and American east coasts. We may conclude from the scanty material, that an estimate of one percent in a narrow band centered on the subtropical jet-stream axis probably represents the mean frequency averaged over the oceans relatively well. However a station such as Cape Hatteras, virtually free from extreme soundings, must also be fitted into the picture in some way. It appears that processing of a much greater data sample, well distributed regionally, is required before a firm answer can be given.

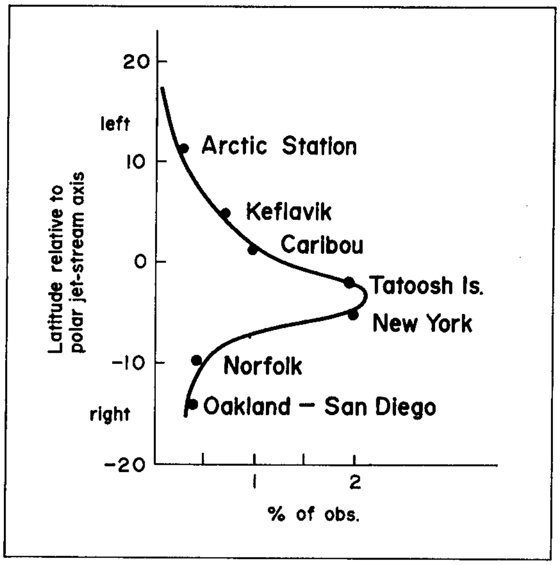

Figure 4.1. Longitudinal Distribution of Extreme Profiles with Respect to the Polar Jet Stream.

5. EXTREME SOUNDING CHARACTERISTICS

We should now proceed to a regional frequency distribution of the different types of soundings composing the whole extreme class defined in table 3.2. Because of the small number of such soundings and the great variety of types of extreme profiles, this distribution is quite impossible. Indeed, it appeared probable for some time that no meaningful results beyond those of figure 4.1 could be developed. Detailed inspection of all stations, however, revealed the surprising fact that no geographical arrangement of types of extreme soundings was evident, in marked contrast to the geographical distribution of jet-stream types themselves (Okinawa was an exception). It was therefore considered permissible to combine all extreme cases, and to determine the percent distribution of different slopes of the momentum profile in terms of the thickness of the layer with momentum increase. This is done in table 5.1. An adjustment in frequency was made only at Okinawa, where the large number of extrapolated soundings was reduced by 50 percent; so that table 5.1 contains 141 cases, while there are 154 in table 3.4.

Since there remain 4 degrees of freedom in each of the subgroups of table 5.1 (see table 2.1), analytical expressions for the profiles are not given. Instead, figures A-1 to A-12 contain typical soundings for most of the classes. The numerical data are appended for experimentation on computers with simulated missile flights.

Table 5.1. Composition of Extreme Soundings.

	Thickness of Layer (1000's feet)							
Average slope (momentum units per 2,000 feet height)	6 - 10		12 - 16		18 - 22		24 - 28	
	n	%	n	%	n	%	n	%
0.2 - 0.29					13	9	20	14
0.3 - 0.39			21	15	8	6		
0.4 - 0.49	11	8	24	17	2	1.5		
0.5 - 0.59	7	5	4	3				
0.6 - 0.69	11	8						
0.7 - 0.79	4	3						
0.8 - 0.89	2	1.5						
Layer starts above 18,000 ft.	11	8	3	1				
TOTALS	46	33.5	52	36	23	16.5	20	14

N = 141

The horizontal lines correspond to the cut-off values in table 1.2. The soundings above these lines are included because of presence of extreme slopes.

6. FUTURE WORK

This study has demonstrated, not unexpectedly, that (in view of the shortcomings of the observations) it is a very difficult task to arrive at a realistic estimate of the climatology of extreme momentum profiles. Numerous assumptions and extrapolation procedures had to be introduced in order to overcome the problems of observations and data processing. It is believed that the resulting analysis is the most reasonable approach permitted by the difficulty of the circumstances.

Clearly, the results must be treated as highly tentative, especially since they are only based on a pilot selection of stations. For a more complete picture, the procedure followed here should be extended to a much greater number of stations during the winter season. Further, the analysis should be carried out in the other seasons at high latitudes, when the frequency of extreme cases will probably be substantially greater than in winter.

Still another approach can be envisioned. On synoptic charts, areas with extreme profiles can be located, measured and followed in time. Such analysis should lead to recognition, and possibly to short-term prediction, of these areas. If the analysis is performed over sufficiently long period of record, the percent frequency distribution of severe sounding incidence thus determined may be compared with the one statistically derived. This would serve as a check on figure 4.1. The early stages of work following this approach are presently in progress.

REFERENCES

1. RIEHL, H., *"Quantitative Representation of the Velocity Distribution along the Vertical (mimeographed)."* 1961.

2. RIEHL, H., *"Jet Streams of the Atmosphere."* *Tech. Report No. 32, Department of Atmospheric Science, Colorado State University*, 117p., 1962.

Altitude (1000's feet)	Wind (V) Unit: m./sec.	Momentum (M) Unit: g./cm.^{2}/sec.
30	50	2.4
28	50	2.6
26	50	2.8
24	50	3.0
22	53	3.3
20	54	3.7
18	51	3.8
16	46	3.4
14	29	2.3
12	18	1.5
10	14	1.2

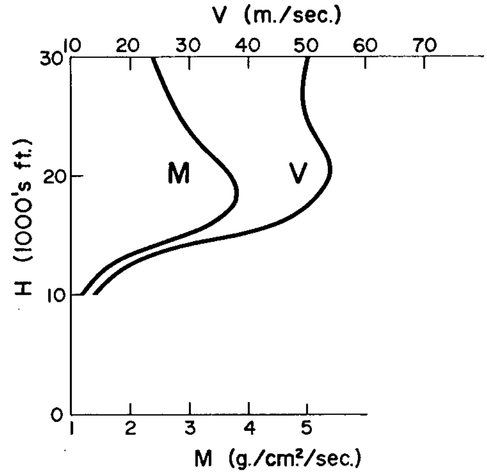

Figure A-1. Code: 111662 (according to table 2.1).

Altitude (1000's feet)	Wind (V) Unit: m./sec.	Momentum (M) Unit: g./cm.^{2}/sec.
30	85	3.5
28	83	3.9
26	80	4.0
24	69	3.8
22	53	3.2
20	35	2.3
18	21	1.4
16	19	1.4
14	22	1.7
12	23	1.9
10	22	2.0

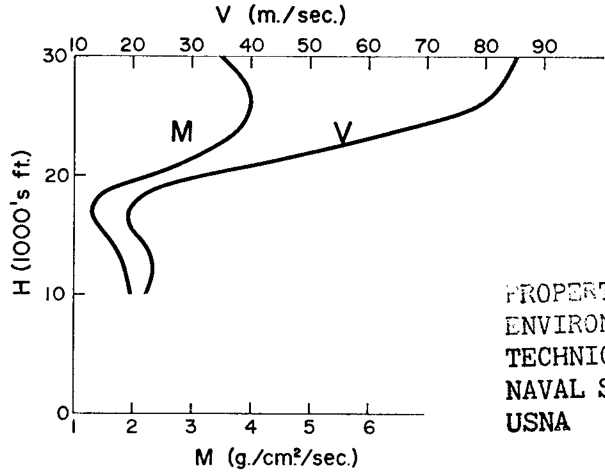

Figure A-2. Code: 321652 (according to table 2.1).

Altitude (1000's feet)	Wind (V) Unit: m./sec.	Momentum (M) Unit: g./cm.^{2}/sec.
30	50	2.1
28	50	2.3
26	51	2.6
24	51	2.9
22	52	3.2
20	54	3.5
18	54	3.8
16	43	3.2
14	26	2.1
12	18	1.5
10	17	1.5

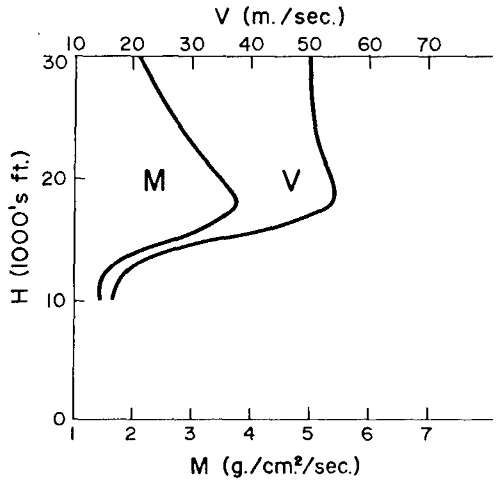

Figure A-3. Code: 221772 *(according to table 2.1).*

Altitude (1000's feet)	Wind (V) Unit: m./sec.	Momentum (M) Unit: g./cm.^{2}/sec.
30	65	3.0
28	67	3.2
26	68	3.4
24	67	3.7
22	66	3.9
20	64	4.1
18	60	4.3
16	45	3.4
14	28	2.2
12	20	1.7
10	20	1.8

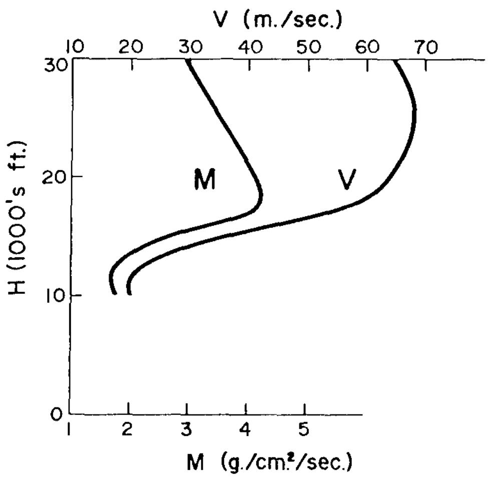

Figure A-4. Code: 221872 *(according to table 2.1).*

Altitude (1000's feet)	Wind (V) Unit: m./sec.	Momentum (M) Unit: g./cm.^{2}/sec.
30	64	3.0
28 (27)	78 (85)	3.8 (4.3)
26	79	4.1
24	58	3.3
22	42	2.6
20	32	2.2
18	25	1.8
16	20	1.6
14	16	1.4
12	13	1.2
10	11	1.1

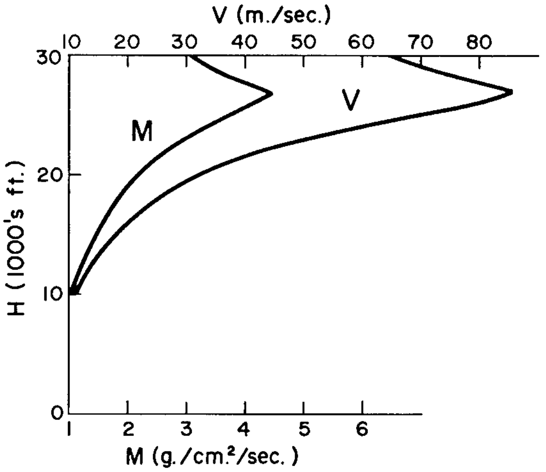

Figure A-5. Code: 112341 (according to table 2.1).

Altitude (1000's feet)	Wind (V) Unit: m./sec.	Momentum (M) Unit: g./cm.^{2}/sec.
30	75	3.5
28	81	3.9
26	89	4.6
24	76	4.2
22	64	3.8
20	53	3.4
18	42	3.0
16	34	2.6
14	27	2.1
12	20	1.7
10	15	1.3

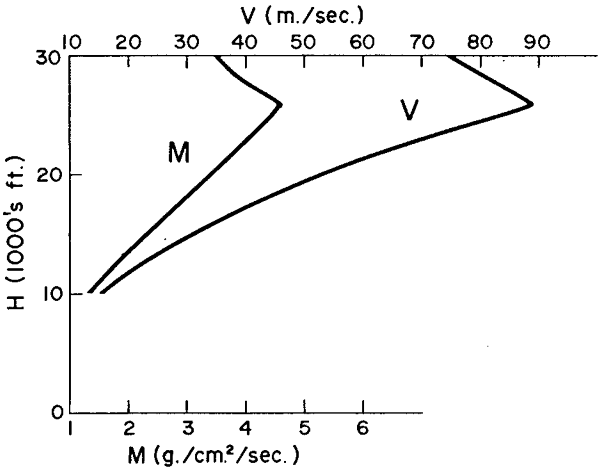

Figure A-6. Code: 122400 (according to table 2.1).

Altitude (1000's feet)	Wind (V) Unit: m./sec.	Momentum (M) Unit: g./cm.²/sec.
30	67	3.0
28	65	3.1
26	63	3.2
24	61	3.3
22	58	3.5
20	50	3.2
18	36	2.5
16	21	1.5
14	15	1.1
12	12	0.9
10	9	0.8

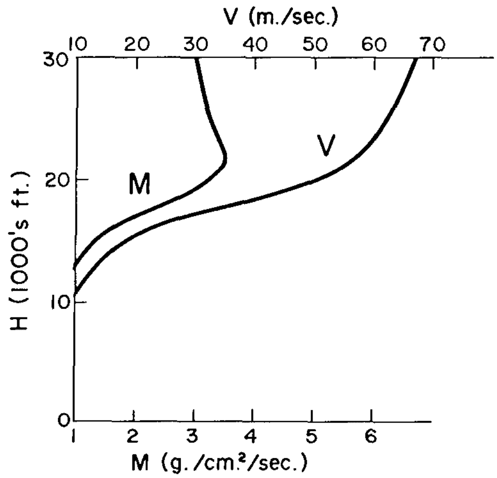

Figure A - 7. Code: 112452 (according to table 2.1).

Altitude (1000's feet)	Wind (V) Unit: m./sec.	Momentum (M) Unit: g./cm.²/sec.
30	55	2.5
28	60	2.9
26	65	3.4
24	70	4.0
22	74	4.5
20	65	4.1
18	47	3.3
16	35	2.5
14	27	2.1
12	21	1.7
10	17	1.5

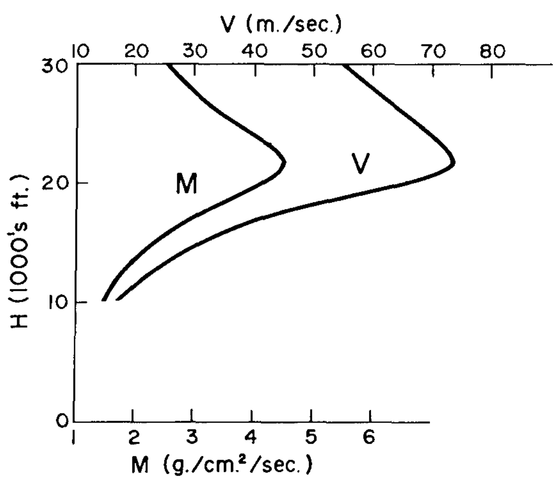

Figure A - 8. Code: 122541 (according to table 2.1).

Altitude (1000's feet)	Wind (V) Unit: m./sec.	Momentum (M) Unit: g./cm.^{2}/sec.
30	73	3.5
28	71	3.6
26	68	3.5
24	63	3.5
22	57	3.4
20	50	3.2
18	35	2.4
16	23	1.8
14	20	1.7
12	18	1.5
10	16	1.5

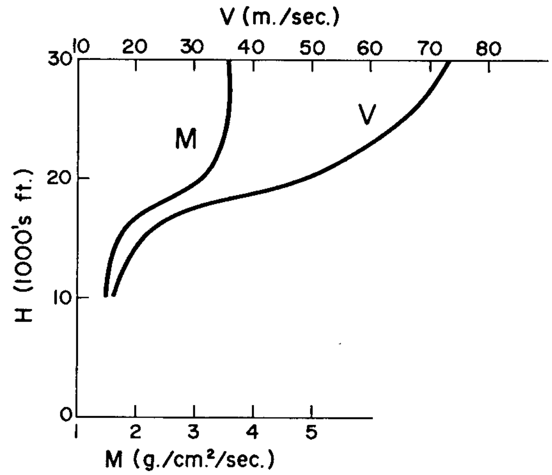

Figure A - 9. Code: 223232 (according to table 2.1).

Altitude (1000's feet)	Wind (V) Unit: m./sec.	Momentum (M) Unit: g./cm.^{2}/sec.
34	79	3.0
32	82	3.3
30	82	3.6
28	76	3.7
26	63	3.3
24	46	2.6
22	38	2.3
20	33	2.1
18	28	1.9
16	24	1.7
14	19	1.5
12	15	1.2
10	10	0.9

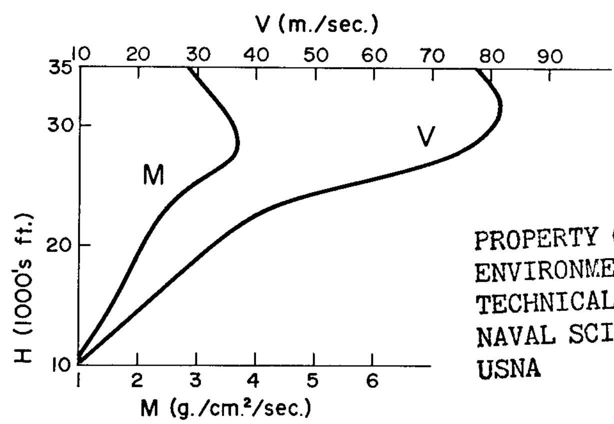

Figure A - 10. Code: 113321 (according to table 2.1).

Altitude (1000's feet)	Wind (V) Unit: m./sec.	Momentum (M) Unit: g./cm.²/sec.
34	91	3.2
32	98	4.1
(31)	(102)	
30	100	4.6
28	91	4.7
26	83	4.6
24	74	4.3
22	62	3.9
20	49	3.3
18	36	2.3
16	26	1.8
14	19	1.3
12	11	0.9
10	5	0.5

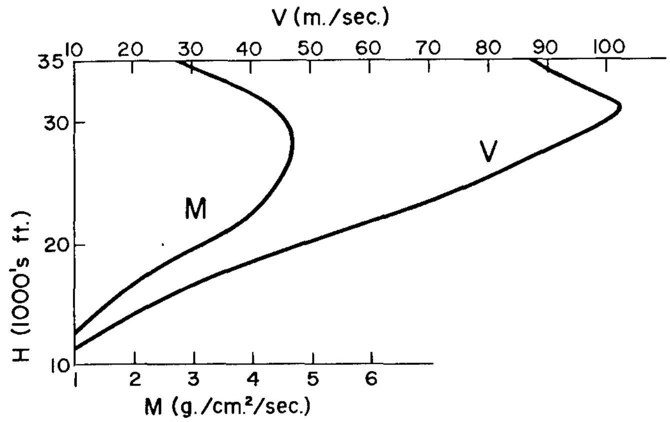

Figure A - 11. Code: 113452 (according to table 2.1).

Altitude (1000's feet)	Wind (V) Unit: m./sec.	Momentum (M) Unit: g./cm.²/sec.
40	79	2.3
38	87	2.8
36	90	3.2
(35)	(91)	
34	90	3.5
32	83	3.5
30	75	3.4
28	68	3.3
26	60	3.1
24	52	2.9
22	42	2.5
20	30	2.0
18	24	1.7
16	21	1.6
14	18	1.4
12	15	1.2
10	12	1.1

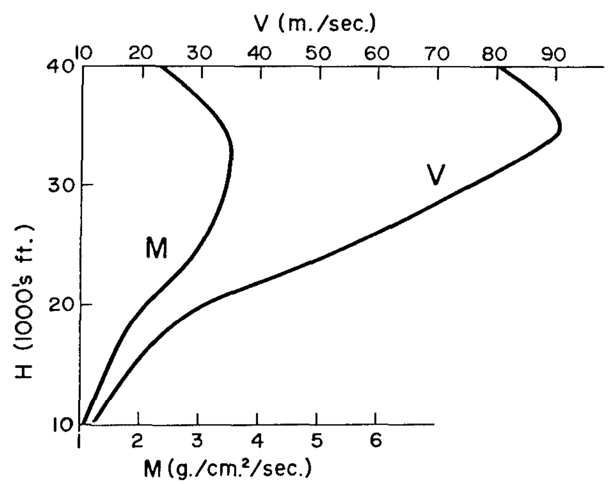

Figure A - 12. Code: 114212 (according to table 2.1).

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An attempt is made to develop a climatology of extreme wind and momentum profiles in the troposphere in winter for coastal and oceanic regions of the Northern Hemisphere. The percent frequency distribution of extreme soundings with respect to the average position of the polar jet-stream axis in winter is determined for a pilot sample of stations. The extreme momentum profiles are divided into a number of classes. Their percent frequency distribution is computed, and 14 typical soundings are presented which characterize the range of observed profiles.

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5. AUTHOR(S) *(Last name, first name, initial)*

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