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THE ROYAL METEOROLOGICAL SOCIETY, CANADIAN BRANCH

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TOPOCLIMATOLOGY

by

L. B. MacHattie

INTRODUCTION

The atmosphere is too extensive in space, and too variable in time for a meteorologist to keep track of all of it. We each specialize our attention. The aviation meteorologist lives mainly in the "free air", and only comes down to earth on certain artificially smoothed out areas, (airports). He sees the broad sweep of atmospheric motions, neglecting as far as possible the fine scale complications at its surface. The public forecaster is obliged to give these surface complications some consideration. But the forest meteorologist is completely embedded in them.

Aloft, acre-sized cold or warm pockets of air may be neglected as having equally transient effects at all points as they drift with the wind. But near the ground cold and warm pockets do not drift along and "average out". They are tied to the topography. A tree may spend its whole blighted life in one cold pocket.

For the aviation meteorologist the main spatial variations of weather are delineated by the synoptic network, and the fine scale spatial variations are derivable from series of observations at single stations. There is no such easy conversion from time-variation to space-variation for the forest meteorologist.

Since time-variations are so much easier to measure than space-variations, our accumulated mass of meteorological data leans heavily in this direction. Consider surface temperature observations. At airway weather stations we can be confident year after year that no significant temperature change goes unobserved. But in between the observing stations how many significant changes occur between dry upland and moist lowland, between windward slopes and sheltered areas - significant differences which are never observed?

Mr. MacHattie is a specialist in forest meteorology and has been seconded to the Forestry Branch of the Department of Northern Affairs and National Resources by the Meteorological Branch.

USE OF OBSERVATIONS

Actually, when one comes to think of it, the main use of surface weather observations is not to tell what the weather is at the exact point of observation, but to indicate what the weather is in nearby areas. The temperature in the Stevenson screen is assumed to represent the temperature over a whole airport, and often that of the city adjacent to the airport. But how well does an observation represent the surrounding area?

The obvious correlation between observations from adjacent stations on a synoptic chart shows that a temperature or humidity observation made in a Stevenson screen at a site where there is very free air movement closely represents conditions at similar, well-ventilated sites for say 25 miles around. But how much difference is there between well-ventilated sites and sheltered sites? This is an important question in forestry.

In the forest, variations in growth, apparently due to variations in climate, are observable from one square mile to another, or even from acre to acre. These must be taken into account by any lumber company which is going to match its cutting program to the growth potential of its forests.

EXPERIMENTAL DESIGN

To get an idea of the size of local differences in climate associated with topography, a series of daily observations was made in 1955 at the Petawawa Forest Experiment Station under the direction of Mr. R.J. McCormack, then a research forester of the federal Forestry Branch. To isolate the topographic effect from that of variations in forest cover the observations were taken down the centre line of a strip cleared of trees. The cleared strip was 200 ft. wide and extended 1500 ft. north-south across an east-west ridge, whose profile is shown in the bottom half of Figure 1. For comparison, a few observations were also made on a forested ridge of similar general slope whose profile is shown in the top half of Figure 1. Twelve observation stations were set up on the cleared ridge at each of which four-inch soil temperature, one-foot air temperature, and Piche evaporation at one foot were observed daily from May 1st through September 30th. On the wooded ridge, air temperature and Piche evaporation were observed at four stations.

To cover diurnal variations on the cleared ridge, half-hourly observations were made from dawn till dark on two clear days. On these days soil surface temperature was observed in addition to the other variables. Mercury-in-glass thermometers were exposed lying on bare mineral soil with the bulbs covered by a double layer of burlap.

RESULTS

Since a complete account of these observations is being published elsewhere, attention here is concentrated on illustrating the effect on local climate of two factors; site ventilation and soil moisture. Observations taken on the cleared ridge are considered first. Then a comparison is made between these and observations on the wooded ridge.

SITE VENTILATION

The mean daily Piche evaporation for the season May 1 - September 30 is plotted for each station on the cleared ridge; against its elevation in Figure 2, and against its mean daily maximum temperature in Figure 3. These show (1) a clear correlation of evaporation with elevation, and (2) a much less definite correlation of evaporation with maximum temperature, which surprisingly is in the inverse sense. It is felt that the basic physical relation is the dependence of evaporation on ventilation or air movement. Air movement would be expected to vary with elevation; maximum temperature would be expected to vary inversely with air movement.

SOIL MOISTURE

The effect of soil moisture is illustrated by the contrast in temperatures observed at stations 1 and 2 on the steep north slope of the cleared ridge. Although the difference in soil moisture between stations 1 and 2 was not obvious to one walking over the ground, the observational data point clearly to such a difference. The difference shows up most strongly with surface temperature. On June 16th, starting from the same temperature, 56°F. at 0430, station 1 rose to 118°F at midday, while station 2 rose to only 85°F. On August 9th the early morning surface temperature at station 2 was 3°F lower than at station 1, but its maximum surface temperature was 27°F lower. Since slope, aspect, and vegetative cover were substantially the same at station 2 as at station 1, the much lower daytime surface temperatures could only be account for by:

1 Higher evapotranspiration
or 2 More rapid conduction of heat into the soil
or 3 More rapid loss of heat to the air

If 2 were the case, then besides the maximum surface temperature being lower at station 2 than at 1, the minimum surface temperature at station 2 should be higher than at station 1. But this did not occur. In fact on August 9th the minimum at 2 was 3°F lower than at 1, even though four-inch soil temperatures were 9 and 8°F higher respectively than the surface temperatures. Further, higher soil heat conductivity at station 2 would tend to give it a greater diurnal range in the four-inch soil temperature. But the diurnal ranges observed on June 16th and August 9th at station 2 were the same as or less than those at station 1.

With regard to 3, Figure 4 shows that throughout June 16th the one-foot air temperature at station 2 was higher than the surface temperature. Hence the surface was not losing heat to but gaining heat from the air. The data for August 9th are similar. At all the other stations the surface temperature during the early afternoon was higher than the one-foot air temperature at two-thirds of the stations on August 9th the surface temperature was 20°F or more warmer than the one-foot air temperature.

It seems clear that higher evapotranspiration at station 2 accounts for its being so much cooler than station 1. This higher evapotranspiration would be primarily due to higher soil moisture content.

A further check on this was made by comparing the maximum one-foot air temperature at stations 1 and 2 on successive days after rain. The reasoning was that immediately after a rain, station 1 should be just as wet as station 2, and the difference in day-time temperature less than after station 1 had had a chance to dry out. Six cases were found where a general rain of more than 0.15 in. was followed by seven days without rain. The average amount by which the maximum temperature at station 1 exceeded that at station 2 for these six cases are tabulated by "days since rain" in Table 1. The gradual increase in this differential after the second day supports the conclusion that station 2 dries out more slowly than station 1.

TABLE 1

Average differences in daily maximum one-foot air temperature between stations 1 and 2 on the cleared ridge, shown for successive dry days following a substantial rainfall.

Days since rain	1st	2nd	3rd	4th	5th	6th	7th
Difference in maximum temperature Station 1 - Station 2	1.7°F	1.0	2.5	2.8	2.8	3.0	3.5

COMPARISON OF THE TWO RIDGES

Observations on the wooded ridge were only taken at stations 2, 7, 9 and 11, locations are shown in Figure 1. These are compared below with the observations for stations 1, 4, 8 and 12 on the cleared ridge.

Averaging for all four stations over the full season, the wooded ridge is found to have a 3°F higher daily minimum temperature and 4°F lower daily maximum temperature than the cleared ridge. Comparisons of individual stations lead to generally similar results except for daily maximum temperature on the lower south slope. This was actually higher on the wooded ridge than on the cleared ridge by approximately 1°F. Apparently the effect on temperature of less sunshine reaching the forest floor on the wooded ridge was more than balanced by less air movement, and consequent slower dissipation of heat into the free atmosphere.

Piche evaporation on the wooded ridge was found to be about 65% of that on the cleared ridge. This ratio stayed fairly constant throughout the season except on the lower north slope where the monthly ratios May through September were: 70%, 45%, 45%, 65% respectively. The low ratio June - August appears to be due to the low bushy vegetation being denser on the north slope than on the ridgetop and south slope. The large change from May to June is thought to be due to leafing out of this lesser vegetation. If so, it would be a progressive change. When the ratios were worked out for successive five-day periods through May the following values were obtained: 85%, 70%, 70%, 65%, 65%, 45%. Similarly, the large change from August to September might be accounted for by leaf fall. Successive five-day ratios for September were 55%, 60%, 65%, 70%, 65%, 75%.

CONCLUSION

These results have been presented as being of general interest in the field of public weather as an indication of the effect of variations in soil moisture on temperature and of the effect of variations in site ventilation on temperature and evapotranspiration.

One wonders how large are the effects on meso- and micro-climate of soil moisture differences resulting from different moisture capacities, and rates of drying, or from differences in precipitation.

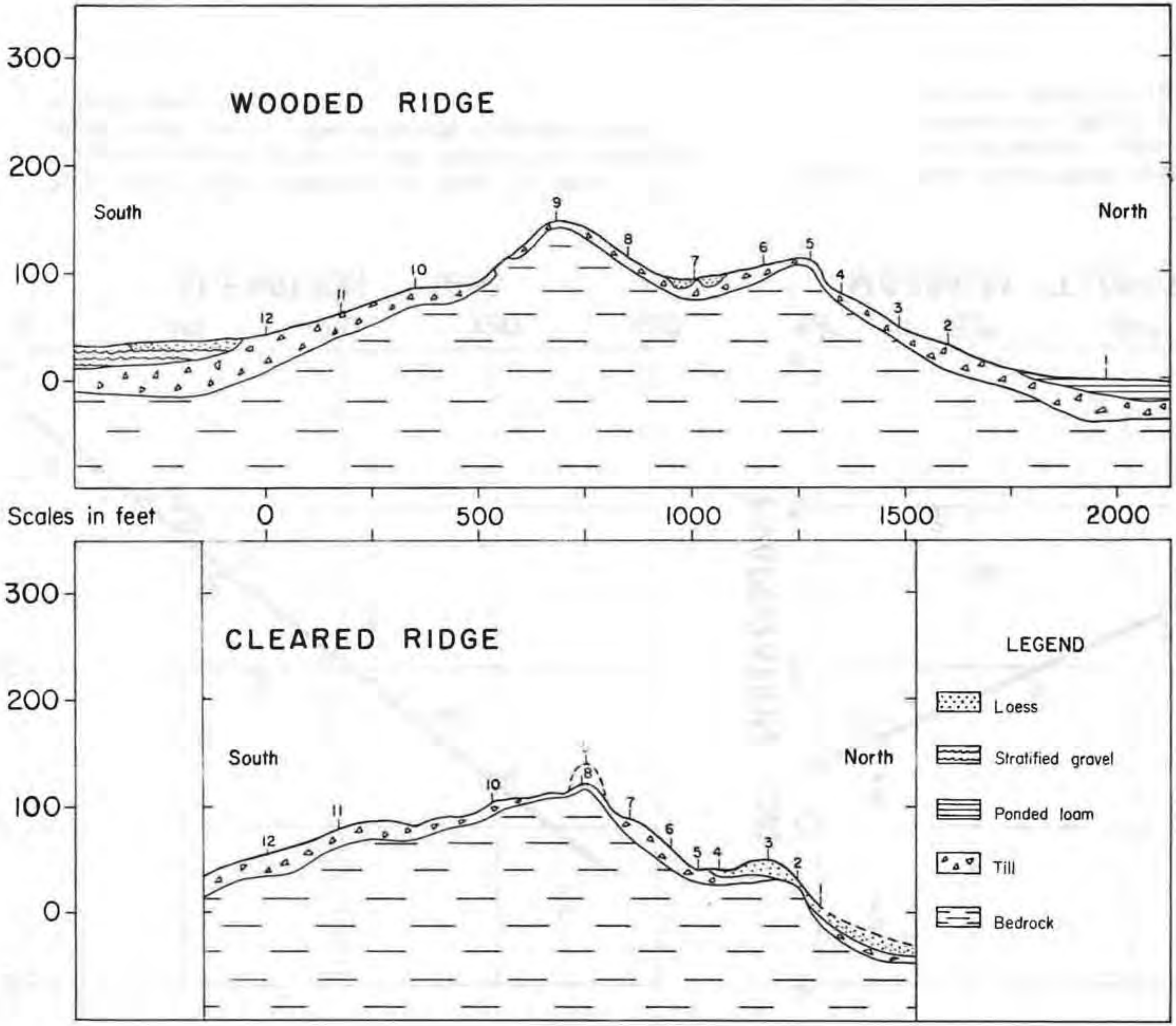

Fig. 1 The profiles of the two ridges showing soil structure, and the location of observation stations.

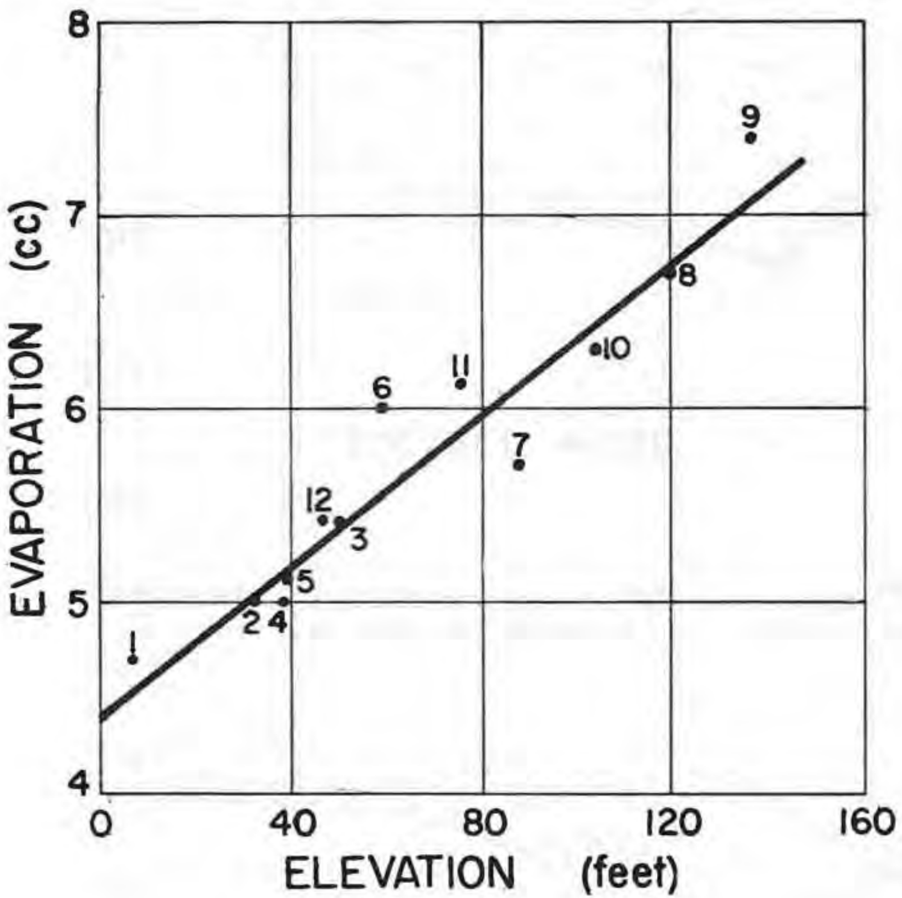

Fig. 2 Mean daily Piche evaporation (May 1 - Sept. 30) plotted against elevation of observation stations above road level. The straight line was drawn simply from inspection.

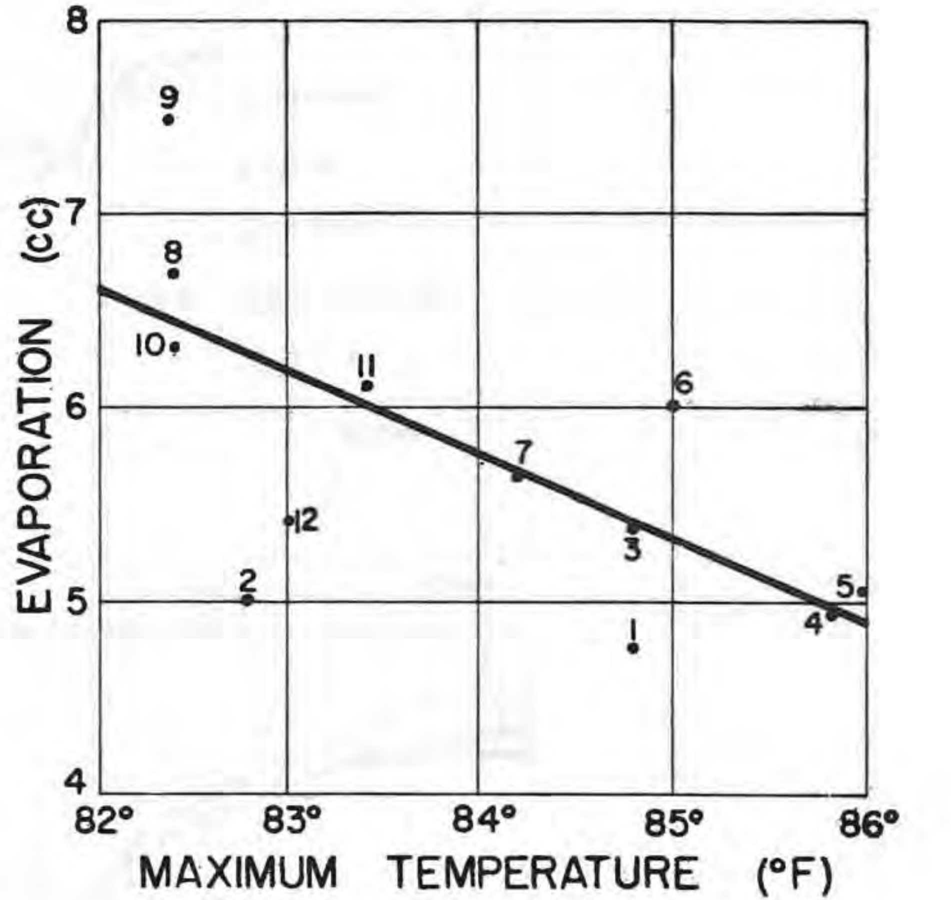

Fig. 3 Mean daily Piche evaporation (May 1 - Sept. 30) plotted against mean daily maximum one-foot air temperature (May 1 - Sept. 30). The straight line was drawn simply from inspection.

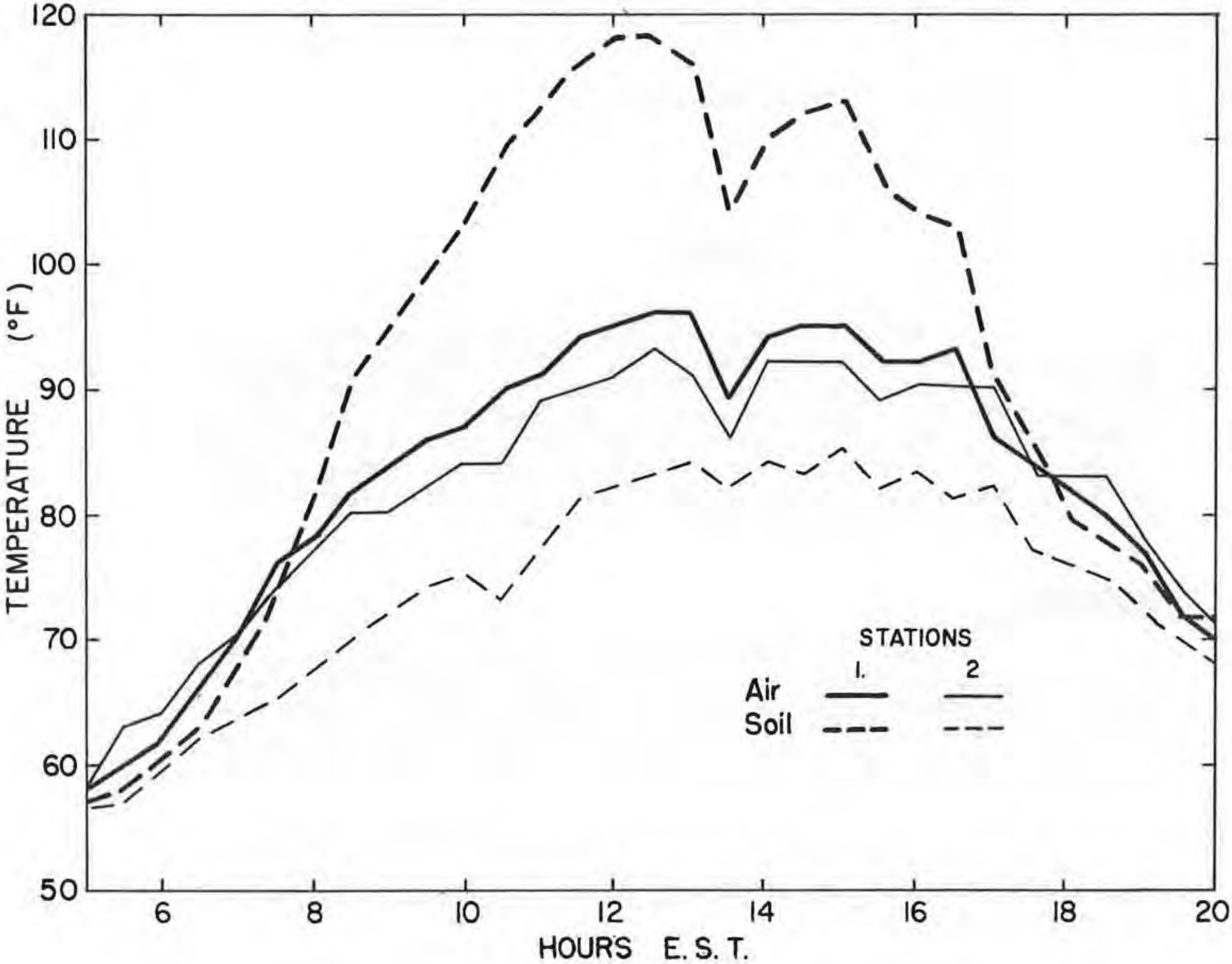

Fig. 4 Diurnal march of one foot air and soil surface temperature at stations 1 and 2 on the cleared ridge on June 16, 1955.

APPLICATIONS OF THICKNESS METHODS TO FORECASTING "D" FACTORS AND TO INTERPOLATING

by

James A.W. McCulloch

ABSTRACT

The use of thickness patterns for forecasting heights and "D" factors between mandatory levels is described. Tables are presented showing the vertical lapse-rate of "D" factor as a linear function of thickness between two mandatory levels. An example of the determination of "D" factors along a flight-route by applying forecast thickness values to these tables is provided. A method of constructing contour height-charts at levels between mandatory levels is described; the solution is extended to the construction of "D" factor charts.

INTRODUCTION

Interpolation between upper-air charts has been one of the main tools of the meteorologist in providing wind forecasts for aircraft. However, as aircraft design advances and aircraft cruise altitudes rise, the levels between which interpolations must be made become more widely separated. As a result, it becomes imperative to consider the temperature distribution within the layer.

To further increase the demands on the weather service, aircraft in many cases require special flow charts for use by the air-crew. The preparation of such charts becomes a difficult task for an understaffed weather office.

Thickness patterns have long been a tool for analysis and prognosis. These patterns can also be used in graphical methods of interpolation and in preparing special charts. The purpose of this paper will be to describe several such applications. It is admitted that other more rigorous and time-consuming methods will produce more accurate charts and forecasts, however, it has become essential to strike a balance between the time required by the meteorologist to prepare them and the quality of the results.

Mr. McCulloch is a shift supervisor on the forecasting staff at the Main Meteorological Office, Goose Bay, Labrador.

DIFFERENTIAL ANALYSIS AND PROGNOSIS

A complete description of the technique of differential analysis is given by A.H. Mason (1). Only a few general comments on the technique will be given here.

The density of upper-air observations in many oceanic regions is often insufficient for an accurate ab initio contour analysis. The use of thickness methods in constructing upper-air charts yields more accurate charts since it incorporates additional information such as surface pressure distribution, frontal locations, thermal winds, and temperature distributions within the various layers. It should be noted that temperature distribution is one of the considerations in the interpolations we propose.

Thickness patterns, because of their map-to-map continuity, are much easier to forecast than, say, contour patterns. As a result, given a surface prognosis, a set of consistent upper-air progs can be prepared. The forecast surface chart is converted to 1000 mb, and to it is added the forecast thickness pattern for the layer between 1000 and 700 mb. The resulting 700-mb prog may be similarly used to produce a forecast 500-mb chart. While hydrostatic consistency alone is not sufficient to ensure accuracy, it is a necessary requirement.

FORECASTING "D" FACTORS

The raw materials used to forecast "D" factors by this method are the forecast thickness values over the points in question.

Consider the following relations:

$$\Delta (h_2 - h_1) = Z_{h_2} - Z_{h_1}$$

where $\Delta (h_2 - h_1)$ is the thickness between levels h_2 and h_1

Z_{h_2} & Z_{h_1} are the heights of these levels

By definition

$$D_{h1} = Z_{h1} - Z_{ph1}$$

where D_{h1} is the "D" factor at h_1

Z_{ph1} is the height in the standard atmosphere of h_1

Therefore

$$\Delta (h_2 - h_1) = D_{h_2} + Z_{ph_2} - (D_{h_1} + Z_{ph_1})$$

or

$$D_{h2} - D_{h1} = \Delta (h_2 - h_1) - \Delta_p (h_2 - h_1)$$

where $\Delta_p (h_2 - h_1)$ is the thickness in the standard atmosphere between levels h_2 & h_1 and is constant.

Thus, tables or graphs showing the change in "D" between two standard levels as a linear function of the thickness between them can be constructed. It was decided to use tables because the data are presented in a neater and a more compact form. The tables also indicate the change of "D" per thousand ft to make them more versatile.

It is suggested that, for complex forecasts (such as these illustrated by the example below), special care be taken in collecting the basic data. At offices using differential methods, a rapid sketch of surface fronts and isobars along a strip two or three hundred miles on either side of the proposed track is easily done on an "acetate". Using this as a base, the thicknesses between the standard pressure levels can be sketched in the same strip. The completion of the forecast then consists of reading the required values from the sketches, entering them in the work sheet, and using the tables.

For forecasts in which only "D" values at the ends of a long track are required the thicknesses may be found by inspection of the current analyses. The sketches in the case of more complex forecasts are to insure that errors at adjacent points are related, thus reducing the total error. At offices where charts prepared by differential analysis are not available, it will be necessary to obtain the basic data by prognostic tephigrams over the points in question. The thicknesses may then be read directly.

It will be noted that the surface temperature is also required. However, the "D" factor at 1000 mb is not very sensitive to this parameter, so it will be sufficient to forecast it to an accuracy of only ten or fifteen degrees F.

Having arrived at the forecast "D" values at the standard pressure levels, it will be necessary to interpolate. This is easily accomplished by using the tephigram as in the example below. Alternately, using the change of "D" per thousand ft (F) from the tables, the following approximate equations may be used.

For levels below 700 mb

$$D_h = D_{1000} + \left(\frac{h}{10^3} - 1/3\right) F$$

for levels between 700 mb and 500 mb

$$D_h = D_{700} + \left(\left(\frac{h}{10^3} - 10\right) + \frac{1}{8}\right) F$$

for levels between 500 mb and 300 mb

$$D_h = D_{500} + \left(\left(\frac{h}{10^3} - 18\right) - \frac{2}{7}\right) F$$

for levels between 300 and 200 mb

$$D_h = D_{300} + \left(\left(\frac{h}{10^3} - 30\right) - \frac{1}{20}\right) F$$

In practice, the corrections represented by the fractions in the above equations are likely unnecessary due to the limits of accuracy of the method.

EXAMPLE

To illustrate, given the synoptic analysis for 0030Z September 4, 1955, as well as the upper-air analyses at 700, 500, 300, and 200 mb for 1500Z, September 3, and adequate history, make the following forecasts for a jet aircraft ETD Goose Bay at 1430Z on September 4 enroute to a base in England:

"D" factor for 32000 ft at 1500Z at 54N 51W (point A)
34000 ft at 1630Z at OSV Charlie (point B)
36000 ft at 1800Z at OSV Julliet (point C)
38000 ft at 1845Z at Valencia (03953) (point D)

This represents a typical request received at Goose one hour prior to briefing time. These particular points are chosen to facilitate verification.

As suggested in the general description of the method, a sketch was made and the necessary values inserted in the work sheet (appendix 1a). Then the nomogram and tables (appendices 2, 3, 4, 5, & 6) were consulted to interpret the basic data. When the forecast "D" values for 300 mb and 200 mb were found, the tephigram was used to interpolate (appendix 1b).

The table in appendix 1c shows how the forecast verified. The error in "D" difference in the leg AB was 115 ft. This error is over a track leg of 540 nautical miles, representing an error of about 5 kt in crosswind component for the leg. Thus at point B, the aircraft would be about $6\frac{1}{2}$ nautical miles off track. Note that the error in the leg BC is of different sign than the one in AB, so the errors would tend to cancel. In the example, the net error from A to D would put the aircraft only $1\frac{1}{2}$ nautical miles off track. As a general criterion, one airline using single heading flight plans considers that an error of less than 15 miles over a track of 600 nautical miles is acceptable.

The above forecast was made by the writer in 35 minutes. It is assumed that with a little more practice, the time could be reduced. Admittedly, prognostic charts would be a far superior means of filling such a request, however, the time to prepare such charts is often not available.

INTERMEDIATE LEVEL CHARTS

Recently, the requirement for winds between the levels for which we analyse upper-air charts has become more difficult to fulfill. For example, turboprop aircraft like the Viscount have a requirement for both winds and a flow chart at 400 mb. The layer between 500 and 300 mb is fairly deep and, at the present time, no routine analysis is made for the 400-mb level at Goose Bay.

If we can assume that within a layer between standard pressure levels the lapse rate remains constant, then thickness methods offer a rapid means of interpolating graphically between these levels to produce a set of contour lines that will approximate the actual contours for an intermediate height: i.e., we assume

$$\Delta \frac{b}{a}(h_2 - h_1) = \frac{b}{a} \Delta (h_2 - h_1) \quad \text{where a and b are constants.}$$

In the example to be discussed, the only cases that will be badly distorted will be where a deep frontal inversion or a tropopause is located between 400 and 340 mb. For the region of the map to which these apply, some adjustment must be made to the winds forecast.

Suppose that a flow chart for 400 mb is required. This level is almost half way between 500 mb and 300 mb (actually, the half way point is about 393 mb). Assuming a uniform lapse rate, then 200-ft thickness lines from 500 to 300 mb represent 100-ft thickness lines from 500 to 400 mb. These added graphically to 500-mb contours at 100-ft intervals will then produce 100-ft contours at 400 mb to a sufficient degree of accuracy. Some examples of charts produced by this method are given in appendix 7.

The success of this method is not seriously impaired by the assumption of constant lapse rate. This is confirmed by Berggren (2). A surprisingly high correlation coefficient between 500- to 400-mb thickness and 500-mb temperature has been computed. It would seem that the correlation between 500-400-mb thickness and the mean temperature of the layer 500-300 mb should be at least as great.

At one time, there was a requirement for "7000-ft prog charts" for one influential operator. These were provided by various methods, however, the one which fitted best with the prognostic program in effect at the time was a further application of this idea of graphical interpolation. The forecast 200-ft thickness lines for the 1000- to 700-mb layer were treated as 140-ft thicknesses between 1000 mb and 7000 ft (or rather 793 mb). The lines were then redrawn at 200-ft intervals and graphically added to the 1000-mb prognosis. The resulting chart was as satisfactory as any prepared by other methods and was easier to handle.

The same process may be used for any level. Frequently, a jet aircraft on a long flight requests a "35000-ft prog". Since this level is about 5/8 of the way between 300 mb and 200 mb, the thickness lines between these levels may be treated as 125-ft intervals and used as above. The accuracy in this case would not be as great as in the case of the lower level because of tropopause intersections, but it will be as satisfactory as any other method consuming the same time in preparation.

To carry the problem a little further, a "D" factor prog chart can be made for any level. This requirement is particular to the military at the present time, but is just as easily filled as the request for the "35000-ft prog". Before gridding in the example above, the 300-mb contours are re-labelled in terms of difference from standard, or "D" value. The thickness lines labelled in terms of the change of "D" within the layer 300 mb to 35000 ft and redrawn at 200-ft intervals. The two sets of lines are then gridded to produce the chart that has been requested.

CONCLUDING REMARKS

This approach to aircraft operations at levels a fair distance from our normal working charts has been developed to cope with one of the problems existing at Goose Airport. At the present time, the variety of types of aircraft and aircraft operations here is probably greater than at any other location in Canada. The variability of the demands made on the forecast staff here is evident from the examples given above, for these are in addition to the normal requirements of commercial interests. The unscheduled nature of much of the flying, and the lack of notice of flights attendant to this condition is just an additional hardship. In this light, it was felt necessary to examine the present operating procedures to see if they could be extended with sufficient accuracy within the limits set by the operations themselves.

With commercial jets and longer-ranged turboprops just around the corner for many offices in Canada, perhaps these suggestions will have some value in meeting the increased requirements of aviation.

ACKNOWLEDGEMENTS

The writer would like to acknowledge the suggestions of many of the staff at the MMO Goose Airport, particularly those of Messrs. G.H. Muttitt, C.E. Stevens, and R.E. Vockeroth.

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2. Berggren, R., 1956: Correlation between the 500-mb temperature and the 500-400-mb thicknesses. Met. Mag., 85: 1009: 171-181.

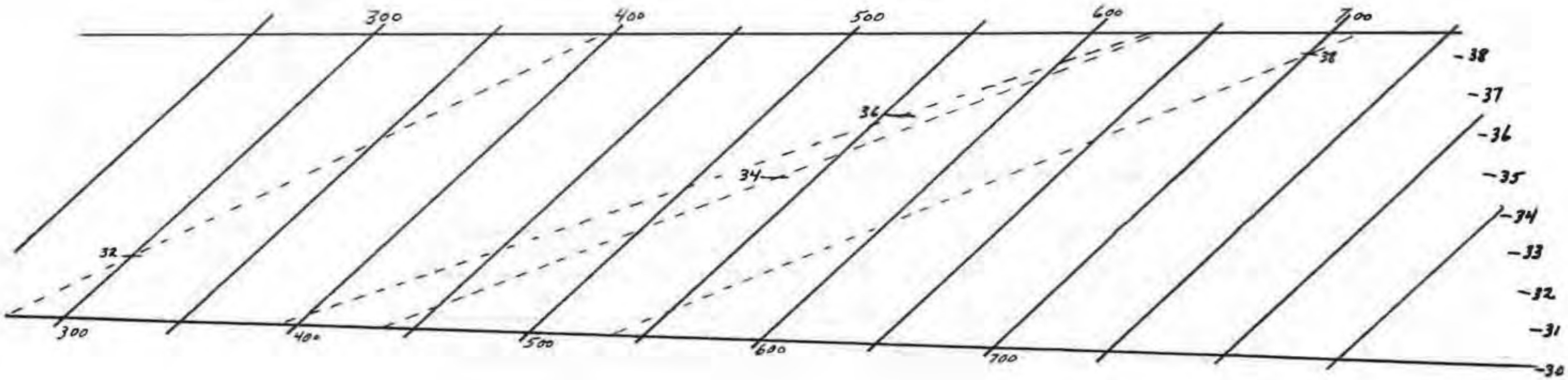
3. Canada. Dept. of Transport, Met. Div., 1950: Forecast procedure necessary to provide information for determining a single heading. CIR-1816, TEC-77.

APPENDIX 1.

A. WORK SHEET

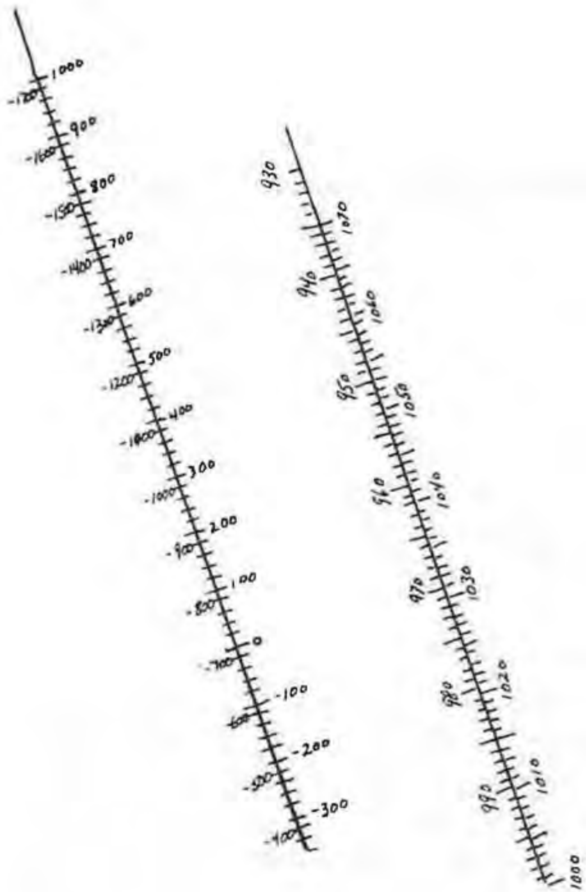
POINT	SFC PRESS.	SFC TEMP	"D"$_{1000}$	$\Delta_{1000-700}$	"D" CHANGE	"D"$_{700}$	$\Delta_{700-500}$	"D" CHANGE	"D"$_{500}$	$\Delta_{500-300}$	"D" CHANGE	"D"$_{300}$	$\Delta_{300-200}$	"D" CHANGE	"D"$_{200}$	REQD "D"
A 54N 51W	996	50	-465	975	+220	-245	863	+220	-25	210	+300	+275	870	+120	+395	+305
B OSV C	1007	55	-175	965	+130	-45	862	+210	+165	208	+270	+435	880	+190	+625	+520
C OSV J	1010	55	-95	958	+50	-45	860	+200	+155	204	+240	+395	883	+230	+625	+555
D 03953	1012	60	-35	963	+110	+75	862	+220	+295	204	+240	+535	879	+180	+715	+700

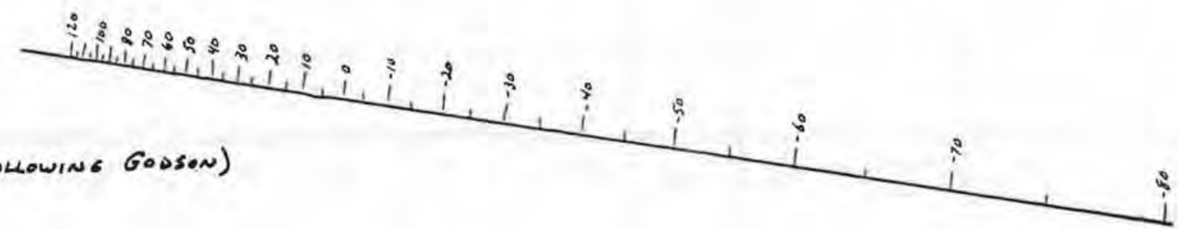
B. INTERPOLATING WITH THE TEPHIGRAM.



Point		Fcst. "D"	Fcst "D" Diff.	Actual "D"	Actual "D" Diff.	Error "D" Diff	Leg of Track	Error x Wnd Comp	Dist. off Track at End of Leg
A	32000	+305		+620					
B	34000	+520	+215	+720	+100	-115	540 nm	-5 kts	6·5 nm
C	36000	+555	+35	+590	-130	+165	570 nm	+7 kts	10 nm
D	38000	+700	+145	+700	+110	-35	340 nm	-2·5 kts	2 nm

APPENDIX 1 c. VERIFICATION OF EXAMPLE





APPENDIX 2.

NOMOGRAM FOR "D"1000 (FOLLOWING GODSON)

APPENDIX 3

Layer 1000-700 mb

	8400	8500	8600	8700	8800	8900	9000	9100	9200	9300	9400	9500	9600	9700	9800	9900	1000
00	-1120	-1020	-920	-820	-720	-620	-520	-420	-320	-220	-120	-20	80	180	280	380	480
	-11.8	-10.7	-9.66	-8.61	-7.56	-6.51	-5.46	-4.41	-3.36	-2.31	-1.26	-0.21	0.84	1.89	2.94	3.99	5.04
10	-1110	-1010	-910	-810	-710	-610	-510	-410	-310	-210	-110	-10	90	190	290	390	490
	-11.7	-10.6	-9.56	-8.51	-7.46	-6.41	-5.36	-4.31	-3.26	-2.21	-1.16	-0.11	0.95	2.00	3.05	4.10	5.15
20	-1100	-1000	-900	-800	-700	-600	-500	-400	-300	-200	-100	0	100	200	300	400	500
	-11.6	-10.5	-9.45	-8.40	-7.35	-6.30	-5.25	-4.20	-3.15	-2.10	-1.05	0	1.05	2.10	3.15	4.20	5.25
30	-1090	-990	-890	-790	-690	-590	-490	-390	-290	-190	-90	10	110	210	310	410	510
	-11.5	-10.4	-9.35	-8.30	-7.25	-6.20	-5.15	-4.10	-3.05	-2.00	-0.95	-0.11	1.16	2.21	3.26	4.31	5.36
40	-1080	-980	-880	-780	-680	-580	-480	-380	-280	-180	-80	20	120	220	320	420	520
	-11.4	-10.3	-9.24	-8.19	-7.14	-6.09	-5.04	-3.99	-2.94	-1.89	-0.84	0.21	1.26	2.31	3.26	4.41	5.46
50	-1070	-970	-870	-770	-670	-570	-470	-370	-270	-170	-70	30	130	230	330	430	530
	-11.3	-10.2	-9.14	-8.09	-7.04	-5.99	-4.94	-3.89	-2.84	-1.79	-0.74	0.32	1.37	2.42	3.47	4.52	5.57
60	-1060	-960	-860	-760	-660	-560	-460	-360	-260	-160	-60	40	140	240	340	440	540
	-11.2	-10.9	-9.03	-7.98	-6.93	-5.88	-4.83	-3.78	-2.73	-1.68	-0.63	0.42	1.47	2.52	3.57	4.62	5.67
70	-1050	-950	-850	-750	-650	-550	-450	-350	-250	-150	-50	50	150	250	350	450	550
	-11.1	-9.99	-8.93	-7.88	-6.83	-5.78	-4.73	-3.68	-2.63	-1.58	-0.53	0.53	1.58	2.63	3.68	4.73	5.78
80	-1040	-940	-840	-740	-640	-540	-440	-340	-240	-140	-40	60	160	260	360	460	560
	-10.9	-9.68	-8.82	-7.77	-6.72	-5.67	-4.62	-3.57	-2.52	-1.47	0.42	0.63	1.68	2.73	3.78	4.83	5.88
90	-1030	-930	-830	-730	-630	-530	-430	-330	-230	-130	-30	70	170	270	370	470	570
	-10.8	-9.76	-8.72	-7.67	-6.62	-5.57	-4.52	-3.47	-2.42	-1.37	-0.32	0.74	1.79	2.84	3.89	4.94	5.99

Total change of "D" in feet

Change in "D" in tens of feet per thousand feet

APPENDIX 4

Layer 700 mb to 500 mb

THICKNESS	7800	7900	8000	8100	8200	8300	8400	8500	8600	8700	8800	8900	9000
00	-600	-500	-400	-300	-200	-100	0	100	200	300	400	500	600
	-71.5	-59.5	-47.6	-35.7	-23.8	-11.9	0	11.9	23.8	35.7	47.6	59.5	71.5
10	-590	-490	-390	-290	-190	-90	10	110	210	310	410	510	610
	-70.3	-58.3	-46.4	-34.5	-22.6	-10.7	1.1	13.0	24.9	36.8	48.7	60.7	72.6
20	-580	-480	-380	-280	-180	-80	20	120	220	320	420	520	620
	-69.1	-57.1	-45.2	-33.3	-21.4	-9.5	2.3	14.2	26.1	38.0	49.9	61.9	73.8
30	-570	-470	-370	-270	-170	-70	30	130	230	330	430	530	630
	-67.9	-55.9	-44.0	-32.1	-20.2	-8.3	3.5	15.4	27.3	39.2	51.1	63.1	75.0
40	-560	-460	-360	-260	-160	-60	40	140	240	340	440	540	640
	-66.7	-54.7	-42.8	-30.9	-19.0	-7.1	4.7	16.6	28.5	40.4	52.3	64.3	76.2
50	-550	-450	-350	-250	-150	-50	50	150	250	350	450	550	650
	-65.5	-53.5	-41.6	-29.7	-17.8	-5.9	5.9	17.8	29.7	41.6	53.5	65.5	77.4
60	-540	-440	-340	-240	-140	-40	60	160	260	360	460	560	660
	-64.3	-52.3	-40.4	-28.5	-16.6	-4.7	7.1	19.0	30.9	42.8	54.7	66.7	78.6
70	-530	-430	-330	-230	-130	-30	70	170	270	370	470	570	670
	-63.1	-51.1	-39.2	-27.3	-15.4	-3.5	8.3	20.2	32.1	44.0	55.9	67.9	79.8
80	-520	-420	-320	-220	-120	-20	80	180	280	380	480	580	680
	-61.9	-49.9	-38.0	-26.1	-14.2	-2.3	9.5	21.4	33.3	45.2	57.2	69.1	81.0
90	-510	-410	-310	-210	-110	-10	90	190	290	390	490	590	690
	-60.7	-48.7	-36.8	-24.9	-13.0	-1.1	10.7	22.6	34.5	46.4	58.3	70.3	82.2

Total change of "D" in feet

Change in "D" in tens of feet per thousand feet

APPENDIX 5 | Layer 500-300 mb

	080	090	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240
00	-970	-870	-770	-670	-570	-470	-370	-270	-170	-70	30	130	230	330	430	530	630
	-82.4	-73.9	-65.4	-56.9	-48.4	-39.9	-31.4	-22.9	-14.4	-5.9	2.5	11.0	19.5	28.0	36.5	45.0	53.5
10	-960	-860	-760	-660	-560	-460	-360	-260	-160	-60	40	140	240	340	440	540	640
	-81.5	-73.0	-64.5	-56.0	-47.5	-39.0	-30.5	-22.0	-13.5	-5.0	3.3	11.8	20.3	26.8	37.3	45.8	54.3
20	-950	-850	-750	-650	-550	-450	-350	-250	-150	-50	50	150	250	350	450	550	650
	-80.7	-72.2	-63.7	-55.2	-46.7	-38.2	-29.7	-21.2	-12.7	-4.2	4.2	12.7	21.2	29.7	38.2	46.7	55.2
30	-940	-840	-740	-640	-540	-440	-340	-240	-140	-40	60	160	260	360	460	560	660
	-79.8	-71.3	-62.8	-54.3	-45.8	-37.3	-28.8	-20.3	-11.8	-3.3	5.0	13.5	22.0	30.5	39.0	47.5	56.0
40	-930	-830	-730	-630	-530	-430	-330	-230	-130	-30	70	170	270	370	470	570	670
	-79.0	-70.5	-62.0	-53.5	-45.0	-36.5	-28.0	-19.5	-11.0	-2.5	5.9	14.4	22.9	31.4	39.9	48.4	56.9
50	-920	-820	-720	-620	-520	-420	-320	-220	-120	-20	80	180	280	380	480	580	680
	-78.1	-69.6	-61.1	-52.6	-44.1	-35.6	-27.1	-18.6	-10.1	-1.6	6.7	15.2	23.7	32.2	40.7	49.2	57.7
60	-910	-810	-710	-610	-510	-410	-310	-210	-110	-10	90	190	290	390	490	590	690
	-77.3	-68.8	-60.3	-51.8	-44.3	-34.8	-26.3	-17.8	-9.3	-0.8	7.6	16.1	24.6	33.1	41.6	50.1	58.6
70	-900	-800	-700	-600	-500	-400	-300	-200	-100	0	100	200	300	400	500	600	700
	-76.4	-67.9	-59.4	-50.9	-42.4	-33.9	-25.4	-16.9	-8.4	0	8.4	16.9	25.4	33.9	44.3	51.8	60.3
80	-890	-790	-690	-590	-490	-390	-290	-190	-90	10	110	210	310	410	510	610	710
	-75.6	-67.1	-58.6	-50.1	-41.6	-33.1	-24.6	-16.1	-7.6	0.8	9.3	17.8	26.3	34.8	44.3	51.8	60.3
90	-880	-780	-680	-580	-480	-380	-280	-180	-80	20	120	220	320	420	520	620	720
	-74.7	-66.2	-57.7	-49.2	-40.7	-32.2	-23.7	-15.2	-6.7	1.6	10.1	18.6	27.1	35.6	44.1	52.6	61.1

Total change of "D" in feet

Change of "D" in tens of feet per thousand feet

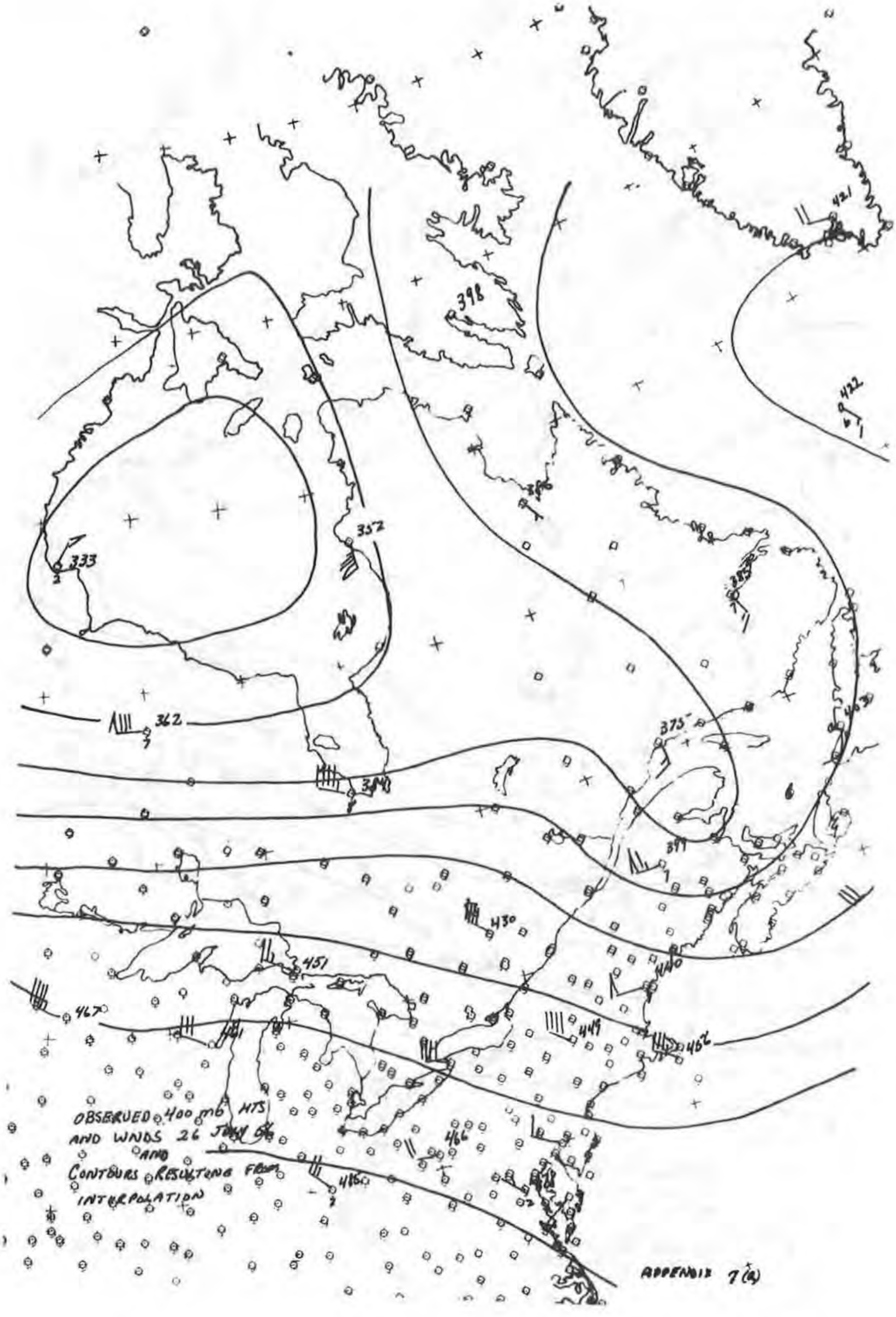
APPENDIX 6

Layer 300-200 mb

	8000	8100	8200	8300	8400	8500	8600	8700	8800	8900	9000	9100	9200
00	-610	-510	-410	-310	-210	-110	-10	90	190	290	390	490	590
	-70.8	-59.2	-47.6	-36.0	-24;4	-12.8	-1.2	10.4	22.1	33.7	45.3	56.9	68.5
10	-600	-500	-400	-300	-200	-100	0	100	200	300	400	500	600
	-69.7	-58.1	-46.5	-34.8	-23.2	-11.6	0	11.6	23.2	34.8	46.5	58.1	69.7
20	-590	-490	-390	-290	-190	-90	10	110	210	310	410	510	610
	-68.5	-56.9	-45.3	-33.7	-22.1	-10.4	1.2	12.8	24.4	36.0	47.6	59.2	70.8
30	-580	-480	-380	-280	-180	-80	20	120	220	320	420	520	620
	-67.3	-55.8	-44.1	-32.5	-20.9	-9.3	2.3	13.9	25.6	37.2	48.8	60.4	72.0
40	-570	-470	-370	-270	-170	-70	30	130	230	330	430	530	630
	-66.3	-54.6	-43.0	-31.4	-19.7	-8.1	3.5	15.1	26.7	38.3	50.0	61.5	73.2
50	-560	-460	-360	-260	-160	-60	40	140	240	340	440	540	640
	-65.0	-53.4	-41.8	-30.2	-18.6	-7.0	4.6	16.3	27.9	39.5	51.1	62.7	74.3
60	-550	-450	-350	-250	-150	-50	50	150	250	350	450	550	650
	-63.8	-52.3	-40.6	-29.0	-17.4	-5.8	5.8	17.4	29.0	40.6	52.3	63.8	75.5
70	-540	-440	-340	-240	-140	-40	60	160	2260	360	460	560	660
	-62.7	-51.1	-39.8	-27.9	-16.3	-4.6	7.0	18.6	30.2	41.8	53.4	65.0	76.6
80	-530	-430	-330	-230	-130	-30	70	170	270	370	470	570	670
	-61.5	-50.0	-38.3	-26.7	-15.1	-3.5	8.1	19.7	31.4	43.0	54.6	66.2	77.8
90	-520	-420	-320	-220	-120	-20	80	180	280	380	480	580	680
	-60.4	-44.8	-37.2	-25.6	-13.9	-2.3	9.3	20.9	32.5	44.1	55.8	67.3	79.0

Total change of "D" in feet

Change in "D" in tens of feet per thousand feet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421
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333
362
385
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430
451
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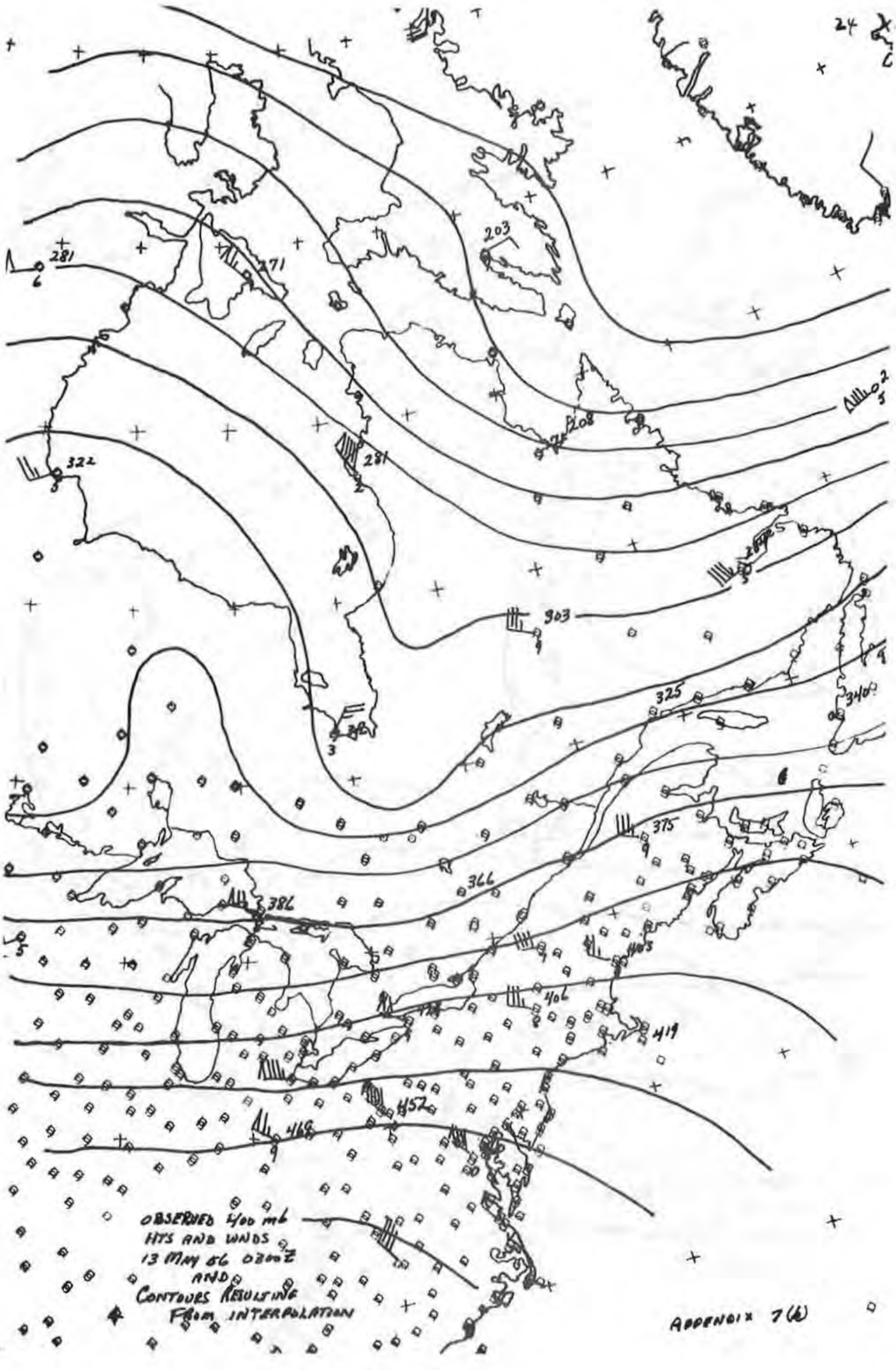
466
486
OBSERVED 400 mb HTS
AND WNDS 26
AND
CONTOURS RESULTING FROM
INTERPOLATION

APPENDIX 7(a)



OBSERVED 400 mb
HTS AND WNDS
13 MAY 56 0300Z
AND
CONTOURS RESULTING
FROM INTERPOLATION

APPENDIX 7(b)

AN INDEX OF FIRE-DANGER BUILD-UP

by

J. A. Turner

ABSTRACT

An index of fire-danger build-up has been developed using a technique suggested by Amble (1) for the smoothing of time series by the use of a greatly damped synthetic sensing instrument. This index has a physical meaning and is shown to be related to fire behavior.

INTRODUCTION

Landsberg and Jacobs (1951) include fire-weather relationships with the most complex of climatic problems, - namely the multiple point - complex time - multiple element group. In this paper one aspect of the complex time part of the problem is attacked.

MOISTURE CONTENT OF FOREST FUELS

It is household knowledge that the intensity of a wood fire depends on the dampness of the fuel. The moisture content of the kindling controls the ease with which the fire may be started, and the wetness of the logs governs the resultant heat of the fire.

Knowledge of the distribution of the moisture content throughout the range of fuel sizes is then essential to the understanding of the behavior of forest fires. Almost without exception forest protection organizations use some technique for measuring or estimating the moisture content of at least one significant fuel size. Since occurrence of fire is usually the first concern the emphasis is generally on the moisture content of the kindling sized fuels. The moisture content of the coarser fuels is then usually deduced in a subjective way based on conditions during the past few days and referred to as 'build-up'. One or two organizations which do make an objective estimate of this factor make use of days since rain which assumes a more or less uniform pattern of drying after each rainy period. This system appears to break down in British Columbia where considerable variations in the rates of drying after rain have been observed.

In British Columbia the moisture content of twig sized fuels is determined by routine weighings of standardized sets of half inch dowels of Douglas Fir cut to 100 grams oven dry weight. The excess weight due to the absorbed moisture indicates directly the moisture content as a percentage of the oven dry weight. These 'hazard sticks' as they are called are mounted ten inches above the ground, fully exposed to sunshine and rain, in an attempt to simulate conditions in the logging debris or 'slash' which is so exposed.

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The moisture content of these standard indicating sticks has been related to fire occurrence and fire behavior by McQueen (1939) and others, and such measurements have now become a fundamental part of protection planning through British Columbia. (As a matter of interest roughly 700 sets of these sticks were distributed through the province in 1957.)

OBSERVATIONS OF MOISTURE CONTENT OF COARSER FUELS

During the 1954 slash burning season moisture contents of the heavier fuels were determined principally by the use of a resistance meter and by oven drying samples taken from larger logs. Commencing with the 1955 fire season series of observations of the moisture content of three to four inch logs were obtained under various conditions. These logs were cut to 36 inches in length, peeled of bark and sealed at the ends. The oven dry weight was estimated by oven drying end samples at the time the logs were prepared. Weight readings were taken by means of a spring balance which gave an accuracy to the resulting moisture contents of slightly under 1%. Routine fire weather observations including measurement of the moisture content of the standard half inch sticks were taken for comparison.

Figure 1 illustrates the variations in moisture content of the two sizes of fuel during July 1955.

DEVELOPMENT OF INDEX

From observations made during controlled slash burns during 1953-54 it became evident that the moisture content of the coarser fuels was an important factor in determining the effect of such burns. None of the methods currently available for determining this seemed to lend themselves to routine measurement, so it then appeared desirable to develop an index which would give a reasonably accurate representation of the moisture content of the coarser fuels.

Such an index should, if possible, be a simple function of one or more of the routine measurements currently being made at fire weather stations.

After the initial inspection of the first year's data it appeared to be possible to make the following assumptions:

1. that the moisture content of the half inch sticks could be treated as a relatively sensitive record of some synthetic element which would have the same effect on the moisture content as the actual rainfall, relative humidity and wind;

2. that the large logs behaved as relatively insensitive indicators of this synthetic weather element.

Amble (1953) discusses the effects of using a greatly damped barometer as a smoothing device, and he develops the simple relationship that

$$y_n - y_{n-1} = (1 - k)(p_n - y_{n-1}) \qquad \text{where}$$

y_{n-1} and y_n refer to two successive values taken by the synthetic instrument (or index) and p_n is the value of the weather element at the end of the interval i. That is to say, the change in the index over any interval is given by some fraction of the difference between the actual value of the element and the preceding value of the index.

The relationship between the coefficient (1 - k) and the more familiar 'lag coefficient' is given below (in units of one interval).

Factor (1 - k) :	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Lag Coefficient:	9.5	4.5	2.8	2.0	1.4	1.0	0.8	0.6	0.4

An alternative form of the relationship given above is

$$y_n = ky_{n-1} + (1 - k)p_n.$$

It can be shown that the coefficient of autocorrelation r_a of a series y_n derived in this way is equal to

$$k + (1 - k) \quad r_{yp}$$ where r_{yp} is the

coefficient of correlation between y_{n-1} and p_n. Making the plausible assumption that the correlation coefficient r_{yp} will be negligible it follows that the coefficient of autocorrelation

$$r_a = k.$$

The values of the autocorrelation coefficient r_a were computed for the shaded and the unshaded series of measured moisture contents obtained during 1955 and found to be 0.89 and 0.91 respectively. This results in a value of 0.9 for k and a value of 0.1 for the coefficient (1 - k).

The resultant form of the desired index is therefore given by $y_n = 0.9\ y_{n-1} + 0.1p_n$ where y refers to the values taken by the index and p refers to the observed value of the standard half inch moisture content.

It is most convenient to use intervals of one day for computing successive values of the index. However the moisture content of the standard half inch sticks follows a fairly regular diurnal pattern with a maximum about daybreak and a minimum about sunset. It follows that the absolute value of the index will depend on the time of the observation used for its computation; however changes in the index should be a reflection in changes in the moisture content of four inch logs.

In order to obtain the daily value of the index as early as possible it was decided to use the 8AM (PDT) value of the half inch moisture content as the value from which the index is derived. Other times could have been chosen, but the absolute value of the index would have been slightly different.

Comparisons of the index computed in this way, and the measured values of moisture content of the logs are shown in figures 1, 2 and 3. Unfortunately the logs used during the 1957 season were closer to three inches in diameter, so that some other, smaller value for k would probably have given a better fit. To allow for this and to eliminate apparently erratic variations in the observed moisture contents of the 1957 series, they were smoothed by a process similar to the calculation of the index, but using a value of 0.5 for k. Figure 3(b) shows the comparison between the smoothed series and the index, and the resulting closer agreement.

At this stage it is not clear why the observed values of moisture content should be higher than the index values, particularly since the 8AM values of half inch moisture content must be close to the daily maximum value. Some of this discrepancy may be a result of the non-uniform nature of the logs, which of necessity included both heartwood and sapwood.

CUMULATIVE EFFECT OF PAST WEATHER

An index such as we are considering must of course be affected by conditions which occurred over the past few days or even weeks. An indication of the extent of the effects of the past weather may best be obtained by considering what effect a change of one unit in the index 'n' days ago would have on the value of the index today. Half of the effect of this change would be felt one week later, while the effect is reduced to one-quarter in thirteen days and one-tenth in three weeks. What this means is that the index is sensitive to conditions over the past month, and so by inference, the moisture content of four inch logs reflects the conditions over the same period.

It follows that calculations of the index at the beginning of the fire season should make use of two well separated assumed starting values. The two curves will come together after approximately one month; in the meantime the separation of the two curves gives an indication of the probable accuracy of the index. In practise it appears to be possible to make a reasonably good estimate of the starting value of the index with a superficial knowledge of weather conditions over the past few weeks.

APPLICATION AND RESULTS

Values of the index have been computed for several series of observations from stations scattered throughout British Columbia. There is some evidence that this type of time series smoothing eliminates some of the irregularities which appear when the data are plotted on a map, leaving only those differences which are significant.

In any event, it appears that index values from one station may be representative of a larger area than unsmoothed day by day readings. With this in mind values of the index were computed for five years of back records from Benson Lookout. The index values were grouped into five classes, Nil, Low, Moderate, High and Extreme*, such that Nil and Extreme each occurred once in eight days, while each of the other three classes occurred once in four days. These limits were originally thought to produce too large a proportion of extreme cases, but it is of interest to note that an independent, subjective estimate of fire danger conditions over the Vancouver Forecast District, issued weekly during 1956 agreed with the index classes as defined above on all but two occasions during the fire season.

In order to show the effect of conditions indicated by the build-up index on fire behavior, the occurrence of fires of 10 acres or more by index classes has been plotted in figure 4. It was necessary to separate the effect of wind speed because the greater proportion of days with low wind speeds tended to obscure the effect of build-up on the days with stronger wind. The proportion of all fires occurring in each class which reached 10 acres are also shown.

CONCLUSION

An index of fire danger build-up has been developed. This index gives an indication of the changes in moisture content of some of the coarser fuels and is related to fire behavior.

* A seasonal correction of ½% per month was applied to take care of weathering loss by the sticks.

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(2) LANDSBERG, H.E. and W.C. JACOBS: Appliced Climatology in Compendium of Meteorology, American Meteorological Society, Boston. 1951. p 976-992.

(3) McQUEEN, I.C.: Progress report on fire occurrence and behavior studies. British Columbia Forest Service (mimeographed).

FIGURE 1.

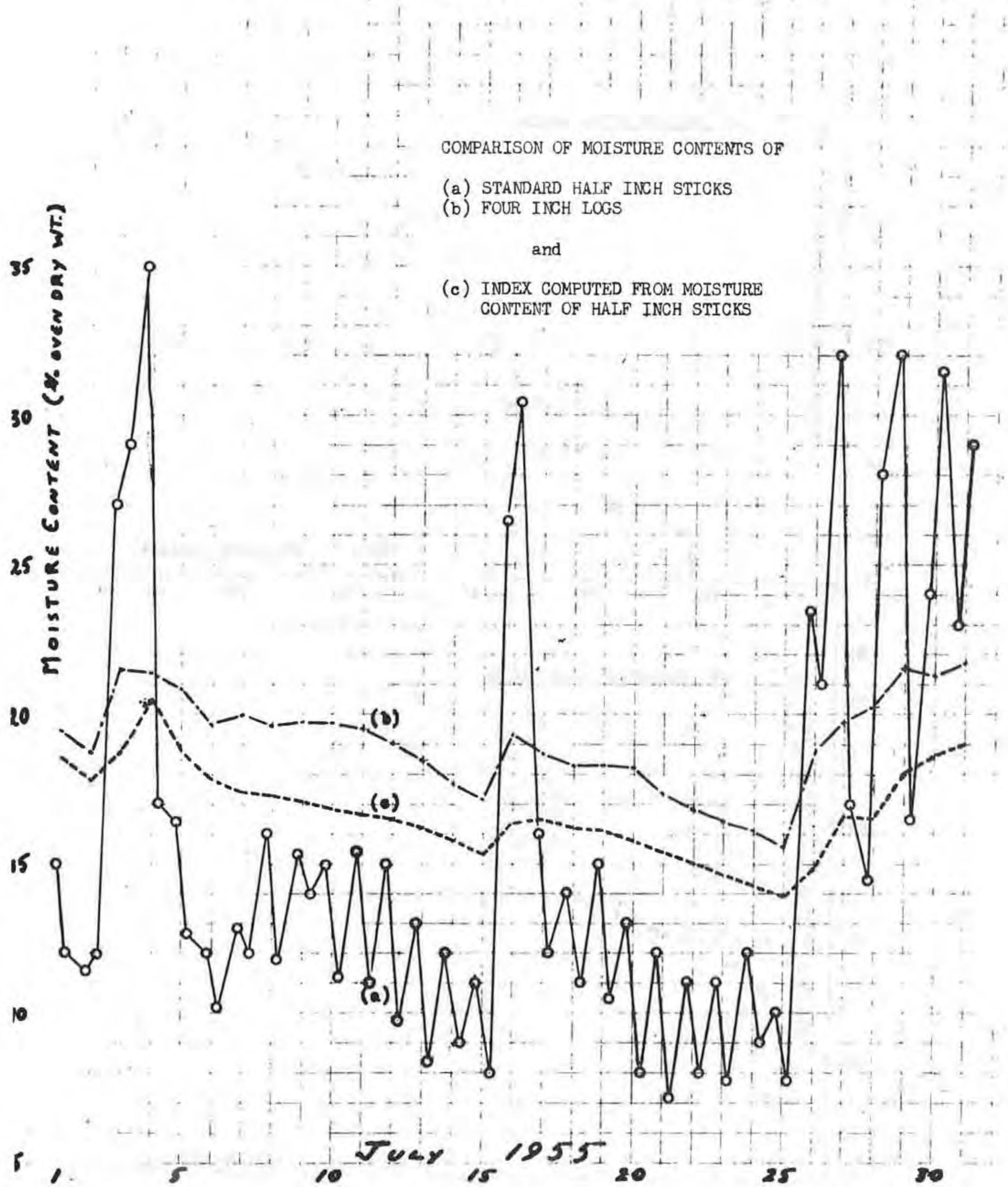


Fig. 1 Comparison of index computed from value of half inch moisture content with moisture content of four inch logs for July 1955.

FIGURE 2.

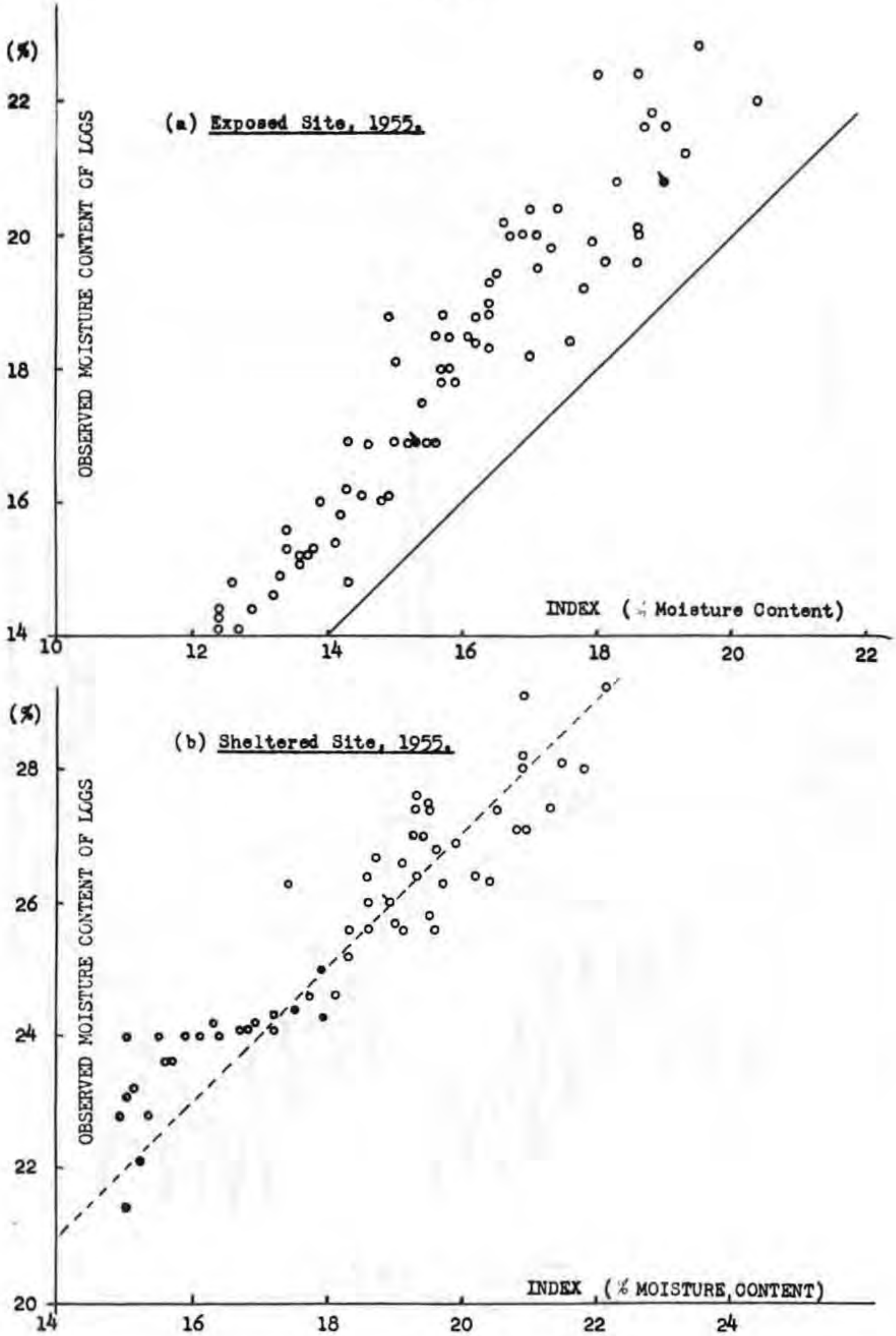
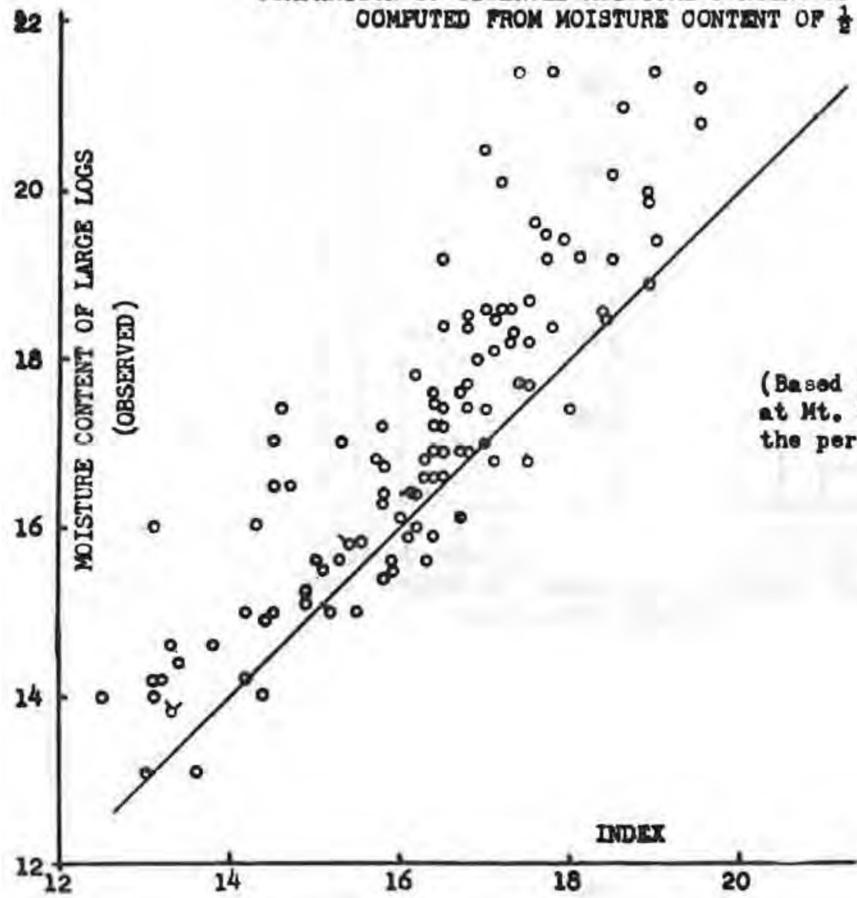


Fig. 2 Relationship between measured moisture content of four inch logs and computed index for 1955 series from shaded and unshaded sites.

FIGURE 3.

COMPARISON OF OBSERVED MOISTURE CONTENT OF LOGS WITH INDEX COMPUTED FROM MOISTURE CONTENT OF ½ " STICKS.



(Based on observations taken at Mt. Shepherd Lookout, during the period June 1st–September 18th, 1957.)

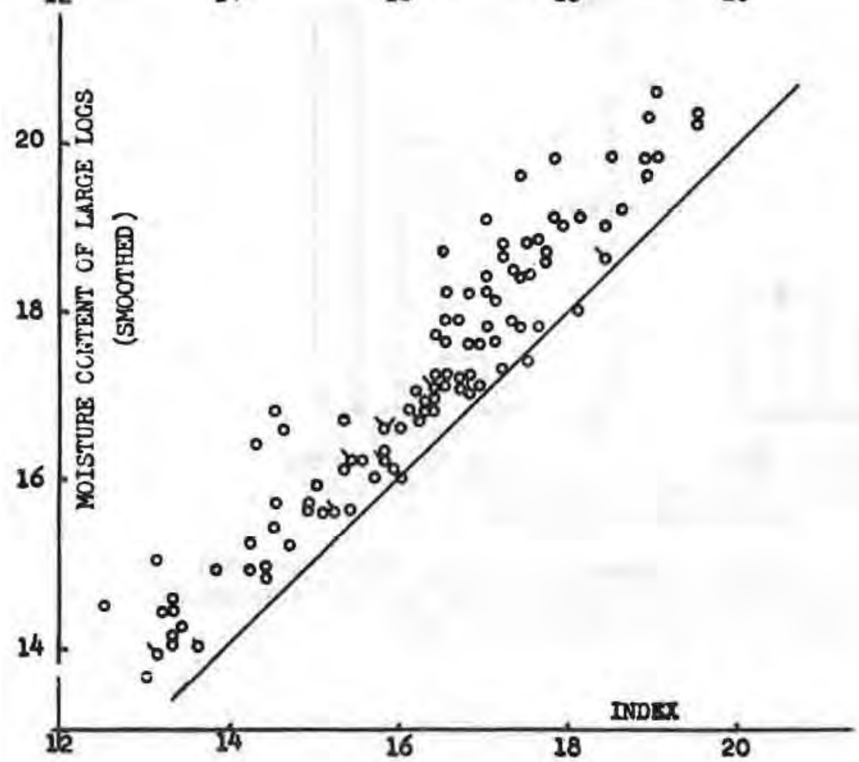
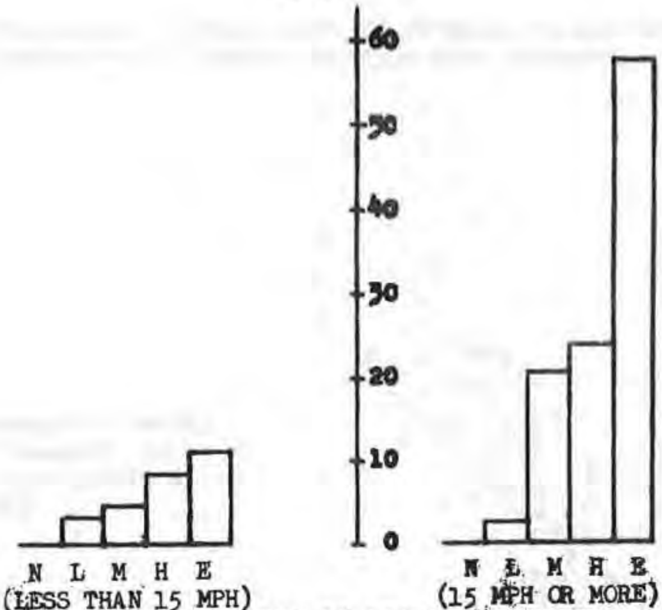
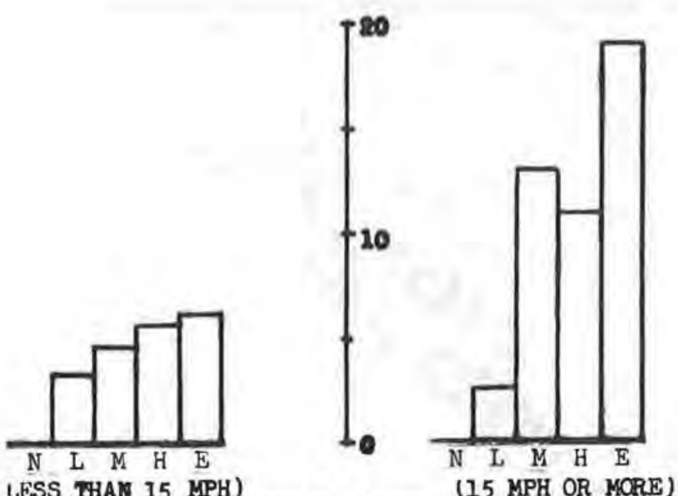


Fig. 3 Relationship between measured moisture content of logs and computed index for 1957 (unshaded) series.

Figure 4.



NUMBER OF FIRES OVER 10 ACRES PER HUNDRED DAYS
IN EACH INDEX CLASS



PERCENTAGE OF ALL FIRES OCCURRING IN EACH CLASS
WHICH REACHED 10 ACRES.

FIRE OCCURRENCE ON VANCOUVER ISLAND, JUNE-SEPTEMBER 1950-55, BY BUILD-UP INDEX CLASSES AND 8AM WIND SPEED AS OBSERVED AT MOUNT BENSON LOOK-OUT.

Fig. 4 Relationship between index and occurrence of fires of ten acres or more.

THE SEVERE LOCAL STORM CENTRE AT KANSAS CITY

by

John L. Knox

ABSTRACT

The history of tornado forecasting in the U. S. A. is traced with some brief reference to tornado climatology. The SELS unit organization is discussed with reference to such ancillary features as: the U. S. Radar Network; the Radar and Weather Warning Teletype Circuit; Non-scheduled Radiosonde Flights; State Police Cooperation; and the relationship between the SELS Unit, the District and Local Forecast Offices and the consumer. Principle techniques used in Severe Weather Forecasting are surveyed and illustrated by the situation on May 22, 1957 when a severe weather warning was issued by the Malton DPWO. The work of the SELS Unit is evaluated with particular reference to those procedures of greatest interest to Canadian Forecast Offices.

HISTORY

The history of Severe Weather Forecasting in the United States dates back to the 1880's, when a man named Finley studied a large number of tornadoes and was among the first to present detailed information on their development and motion in relation to synoptic pressure patterns on the daily weather map. Due to the widely spaced weather reporting stations at that time and limited communications, the forecasts issued were of a very generalized nature, so generalized in fact, as to be of little value, and so toward the end of the nineteenth century the issuing of forecasts referring specifically to tornadoes was abandoned. In fact, in 1905 the Weather Bureau's Station Regulations contained the statement: "Forecasts of tornadoes are prohibited". From 1905 to 1934 forecasters were instructed to predict destructive local storms, but not to mention the word tornado since it was felt that it would cause public alarm and panic. This policy was changed about 1938, but because of the limited knowledge of meteorological processes involved very few forecasts were issued.

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The kite and airplane observations of the 1920's gave meteorologists a chance to get some idea of the air-mass characteristics of a tornado situation. In 1926, W. J. Humphreys made a fairly shrewd appraisal when he stated "Mid-air temperature inversions appear to be quite common, with the lapse rate above these inversions often nearly of adiabatic value".

The development of the radiosonde provided an opportunity to obtain soundings of greater detail and frequency and this resulted in an important paper by Lloyd "The Development and Trajectories of Tornadoes" in which the convective instability of several precedent soundings was illustrated. Further studies by Showalter and Fulks pointed the way toward tornado forecasting but few tornado forecasts were issued by the Weather Bureau during the 1940's.

The Air Weather Service of the USAF became interested in tornado forecasting when one resulted in severe damage at Tinker Field, Oklahoma in 1948. Two Army forecasters, Fawbush and Miller suggested six specific criteria, some, or all of which had to occur in typical tornado situations. These men began issuing tornado forecasts for the Tinker Air Force Base area in 1949 and by 1952 their unit had grown into the Severe Weather Warning Centre of the Air Weather Service which issued forecasts of severe weather for the United States.

At this time, the Weather Bureau entered the picture and after a 2 year developmental period at Washington, D. C., moved their centre to Kansas City, Missouri. The move was made primarily to provide closer contact and more rapid communications among the three forecast centres (Kansas City, Chicago and New Orleans). There it was known as the Severe Local Storm Centre and this became abbreviated to SELS Centre.

PURPOSE

The primary function of the SELS Centre is to forecast areas in which conditions are favourable for the development of Severe Local Weather. Severe Local Weather is defined by the occurrence of one or more of the following:

1. Surface gusts of 75 mph or more.
2. Sustained surface winds of 60 mph or more.
3. Hail having a diameter of 3/4 inch or larger.
4. Severe or extreme turbulence.

The forecast areas will vary in size but an average would be 20,000 square miles which sounds like a lot of territory but when you draw a rectangle say 100 x 200 miles on a synoptic weather chart it turns out to be an area in which on an average there are from two to three synoptic stations using the Southern Canada coverage as a criterion. The smaller the area, the more specific and, therefore, the more valuable the forecast. The SELS Unit attempts to keep these areas, or "boxes" as they call them, as small as possible. A secondary function of the Centre is developmental. There are thirteen meteorologists assigned to the Centre including Mr. D. C. House who is in charge. During the tornado months of March, April, May and June, a 24 hour operation is maintained and most of the staff including Mr. House is on line forecasting. When the tornado season abates, the night shift is discontinued and it is then possible to accelerate the development and research program by making use of the extra staff which become available. When I was down there in September, there were five meteorologists engaged in investigations and studies all directed primarily toward gaining a better understanding of the atmospheric processes associated with the development of severe thunderstorms or tornadoes. I have brought back with me several of their studies which will be of interest both to Research and Training and Field Meteorologists of our own Service.

ORGANIZATION

Before issuing a "box" the SELS Centre always phones the District Forecast Office concerned, so that the District Forecaster understands on what basis the "box" was issued. It is then the responsibility of the District Office in liaison with the Local Office to interpret the box in terms of its forecast area and to relay their version of the warning to the press and radio and other interested authorities such as the Red Cross. It is also the Forecast Offices' responsibility to send the "All Clear". Thus, the entire onus of making public the actual warning, interpreting the warning and sounding the all clear rests with the District and Local Forecast Office.

Speaking of the "All Clear", Mr. House said there was a period, before the present close coordination became effective, when once in a while a local office would jump the gun in issuing the "All Clear". This proved to be particularly embarrassing in one instance when one of the offices took it upon themselves to issue an "All Clear". By the time this was being broadcast by the local radio station a severe storm swept in, blew the transmitting aerial mast down and the station went off the air right in the middle of the "All Clear" announcement.

The SELS Unit is completely insulated from the immediate demands of the consumer, and thereby is in a position to carry out without interruption the actual work of forecasting.

RADAR

The success of the U. S. severe storm warning system depends in no small measure on the detecting role played by the closely knit radar network. The density of the radar network is staggering, -- 63 USWB Units, 41 AWS Units, and 62 ADC Units, making a total of 166 radar sets available for the storm detection.

Once a warning goes out all radar observers are alerted. (The ADC radar are primarily for A/C spotting but they can and are used for detecting storms if not otherwise in use at the time). The optimum use of radar is on the local station level where the proper interpretation of the scope patterns can pinpoint the severe phenomena and thereby make the local warnings extremely effective.

Public cooperation is enthusiastic. Once a severe storm is suspected from the intensity of the radar echo, (and sometimes the shape), its exact location is noted, and, if near a populated area, a resident will be phoned for an eye-witness account of the storm. Or if the storm is not near accessible population then the State Police, will, on request, proceed to where the storm is located and phone in an eye-witness account. When a tornado is confirmed and appears to be heading toward a populated area, local radio and television cut off their current programs, provide up-to-the-minute reports on the storm's position, and tell the people what to do.

This is where the educational program of the Weather Bureau has paid dividends. When a warning is issued there is no longer any panic. If the people hear about a tornado or severe thunderstorm heading for their area they follow its progress closely on television or radio and if it is likely to strike nearby, act accordingly.

The May 20th, 1957 tornado which crossed the edge of Kansas City, occurred within the SELS "box". The storm was picked up on radar several miles southwest of the city and there was ample time to alert the residents. In spite of all precautions 30 lives were lost and of course there was tremendous damage. The loss of life was due to the fact that some residents simply didn't have basements to go to, and that others, foolishly took shelter in a supermarket and a school gymnasium both of which were severely damaged. It cost $1,300,000 to rehabilitate the disaster area.

The SELS Centre is in direct teletype communication with radiosonde stations within the central U. S. A. Should the Centre want a sounding at <u>any</u> time, they have merely to ask the station concerned and an ascent will be made. There were 150 special ascents made during the 1957 tornado season. Incidentally the USWB isn't entirely consistent in its radiosonde policy. As of October 1st all 6 hourly intermediate ascents were discontinued. The SELS people were most unhappy with this development and envisaged a stepped-up number of "radiosondes on request" for 1958.

The SELS predictions are short-range, covering a period of 12 hours or less, with the onset of severe weather generally from 2 to 6 hours after time of issue. It has been found that if the warnings are issued more than six hours in advance of when severe weather is expected to break out, the public will tend to anticipate the severe weather prematurely. Then, because nothing has happened for a few hours, they might shrug off the warning as a false alarm at the very moment when the situation has become most critical. And so, SELS forecasters often hold a warning even though the evidence is overwhelmingly in favour of severe weather, rather than by early release, alert the population for too long a period of time.

VERIFICATION

All occurrences of severe weather regardless of the source of the report are plotted. Hail size is reported in comparative terms, e.g.: pea size, walnut, golf ball, tennis ball and grapefruit. Hail size forecasts often come surprisingly close to the mark and SELS forecasters are very encouraged by the results of their hail forecasting techniques. I brought back with me one of their overlays designed for this purpose. The overlay is designed to fit the Weather Bureau pseudo-adiabatic diagram but could probably be adapted to fit the Canadian tephigram without too much difficulty. I suggest this because although hailstorms do not occur with the same severity and regularity in Ontario as they do in the Central States we do have our hail-prone areas - one of them being our Western Lake Erie Region.

While down at Kansas City I asked how the forecasters reacted to the afternoon and evening "returns" on a day when they had issued a Severe Weather Warning indicating likelihood of tornado development. The answer was that ordinary thunderstorm occurrences were greeted with a certain degree of satisfaction, severe thunderstorms with increasing enthusiasm and tornadoes with great whooping and waving of teletype copy and general backslapping all around. So, they are much the same as forecasters everywhere. No one wishes severe weather on anybody but if it must occur it's satisfying to be able to call it.

APPENDIX I

RADAR

The USWB operates a network of 60 low power 10 cm wave length radar units at first order reporting stations. These sets were obtained from obsolete wartime Navy aircraft at no cost to the Weather Bureau, and then adapted for weather detection purposes. In addition the Air Weather Service operate a network of 40 units of the McGill type, so that there are over 100 radar units throughout central and eastern U. S. A. for weather detection purposes only. There are also the Air Defence Command sets, very powerful and sensitive, adapted primarily to tracking aircraft, but which can be used to detect precipitation. There are over 60 of these units, so that, altogether there are over 160 radar units available for weather detection purposes.

The USWB and AWS Units report every hour. The reports are funneled into Kansas City over the so-called RAWARC teletype circuit, a circuit established exclusively for the dissemination of Weather Warnings and Radar reports. This circuit is operated by the Weather Bureau which in the States is an unorthodox arrangement, since, unlike Canada, their communications system by and large comes under a separate authority, namely the Civil Aeronautical Administration.

At Kansas City the reports are plotted hourly, edited, and then transmitted as the collective SD-1 MKC over both RAWARC and primary circuits 5-6-7-8. The editing process consists of: (a) eliminating superfluous reports of the same echo, (b) assigning relative strength values to the echo, (by knowing the type of set which reported, the echo can be assessed, e.g. if a USWB low power set gives an echo it can be assumed that the rain is at least moderate), (c) Grouping the reports according to the pattern shown by the hourly plot.

Each station is equipped with a camera, so that, a continuous record of the echoes is made on film. The Radar Development Unit, under Mr. Hal Foster analyzes and classifies the film patterns.

APPENDIX II

SELS Forecast Office Chart Procedures

Although these procedures are described in the USWB publication - "Forecasting Guide No. 1" I would like to comment on those which might be of interest to our own forecast offices.

The SELS forecaster keeps his finger on the pulse of the weather by analyzing surface charts every hour. The coverage varies with the synoptic situation; the forecaster will indicate on a blank chart the area he wishes the plotter to cover. Every six hours he receives a copy of a synoptic surface chart of the continent analyzed by the Kansas City District Forecast Office, which operates in the same room, and this enables him to keep in touch with the broader picture.

Upper air soundings are analyzed in detail. The following data are extracted from these soundings and transferred to a blank base map: 1. Stability Index, 2. Mixing Ratio (mean of lower 3000 ft.), 3. Potential Temperature - at convective condensation level), 4. Level of Free Convection, and 5. Computed hail size. This chart provides a bird's eye picture of the overall stability situation.

Prognostic soundings are constructed for points where the possibility of severe weather is suspected. These are then analyzed in the same way as were the actuals. This procedure is very worthwhile because it enables the forecaster to make a systematic assessment of changes in the vertical, changes which are not always apparent from consideration of previous soundings.

The SELS Centre prepares a rather special chart designed to portray the jet stream. At each radiosonde station the strongest wind in the ascent is plotted along with the height of that wind and the tropopause temperature. Streamlines are drawn, the jet stream is indicated and tropopause isotherms are drawn.

The SELS Centre pay a great deal of attention to this jet chart, and watch the jet carefully for signs of branching, sudden displacement, or reorientation. They prefer this jet chart to the 500 mb chart. On the other hand the Air Weather Service Severe Weather Warning Centre, their military counterpart, operating next door, use the strongest winds between 700 mb and 500 mb as a basis for assessing the upper level dynamics.

SELS 850 mb and 700 mb charts show not only contours (every 100 feet) and isotherms (every 2°C), but also dew point isopleths (every 2°C). The areas where dew points are 10°C at 850 mb and 0°C at 700 mb are shaded in green, thus showing at a glance the significant moisture patterns.

APPENDIX III

Climatology of Tornadoes

There is a distinct geographic, seasonal and diurnal distribution of tornado occurrences. Figure 1: (Forecasting Guide No. 1) shows the occurrences of all reported tornadoes from 1916 to 1955, and it will be noted that the maximum annual frequency is in the Kansas-Iowa area. Figure 5: (Forecasting Guide No. 1) shows the mean monthly number of tornadoes in the United States 1916-1955 based on 7.867 tornadoes and it will be noted that March, April, May and June are the top tornado months with an abrupt decrease in July followed by a steady tapering off toward the end of the year. Figure 9: (Forecasting Guide No. 1) shows the diurnal distribution of tornadoes in the United States from 1916-1955 and the distrubition is much as one would expect.

Additional features of tornado climatology are: (a) The geographic shift of the seasonal maximum from early spring in the Southeastern States (March-April) to mid-spring in the central plain states (April-May-June) to late spring or early summer in the northern plains states (May-June-July), (b) The diurnal variation of tornadoes in the Southeastern States is much less marked than the diurnal variation in the central and northern plains states.

APPENDIX IV

Comments on SELS Procedures

In the early years of the SELS Centre the tendency was to overweigh the sounding of the air mass, and this resulted in overforecasting severe weather.

The typical tornado sounding is frequently found on the west side of a tropical anticyclone over the U. S. If there is no occasion for cyclonic activity of any kind then this is a "blue sky" sounding. (Some early morning stratus perhaps, under the inversion, but that is all.) Surface heating is often insufficient to wipe out the inversion. There must be an additional agency to do this thereby allowing the release of the instability.

In more recent years the tendency has been to assign more weight to such factors as the high level jet and its position relative to the low level jet (approximately 850 mb). By examining the intersections of upper and lower flow patterns it is possible to get some idea of whether the dynamic situation is favourable for the development of an area of convergence near the surface and an area of divergence aloft. If it is, then an instability line is likely to develop. The point I would like to stress, then, is that the primary technique at the SELS Centre is to wed the sounding to the surface and upper air patterns.

In recent publications by the SELS Centre staff, it is pointed out that the so-called typical tornado sounding is a precedent sounding - that is to say, a sounding taken several hours before, or, well removed spatially from the occurrence of the tornado. The proximity sounding, or sounding near the tornado in space and time looks quite different. By that time, the inversion is eliminated, and the moisture has been distributed to much higher levels. At this point, I would like to show some diagrams drawn by Mr. House, which show schematically the dynamics of the process which produces the severe weather. Figure 1 (a): shows a V-type precedent sounding, a sounding often associated with the subsequent occurrence of tornadoes over the northern plains states in the summertime. Figure 1 (b): shows the corresponding proximity sounding. Figure 1 (x) and 1 (y): show schematically the development of upper flow and low level moisture configurations which accompany the conversion of 1(a) into 1 (b). Figures 2 (a) and 2 (b), 2 (x) and 2 (y): show how a shallow moisture layer deepens under a suitable configuration aloft into a tornado producing situation. Figures 3 (a), 3 (b), 3 (c), 3 (x), 3 (y) and 3 (z): show the sequence, -- typical tornado precedent sounding, proximity sounding along squall line, sounding following squall line.

APPENDIX V

Malton Tornado Warning of May 22nd, 1957

I would like to say a few words regarding the synoptic situation on May 22, 1957, when a severe weather warning was issued by the Malton Forecast Office indicating the possibility of tornado development over Southwestern Ontario.

During the two-day period May 20-21st, the total of 60 tornadoes were reported in the central United States. The synoptic situation was such that by the morning of May 22nd, the tornado spawning air mass had spread across Southern Ontario.

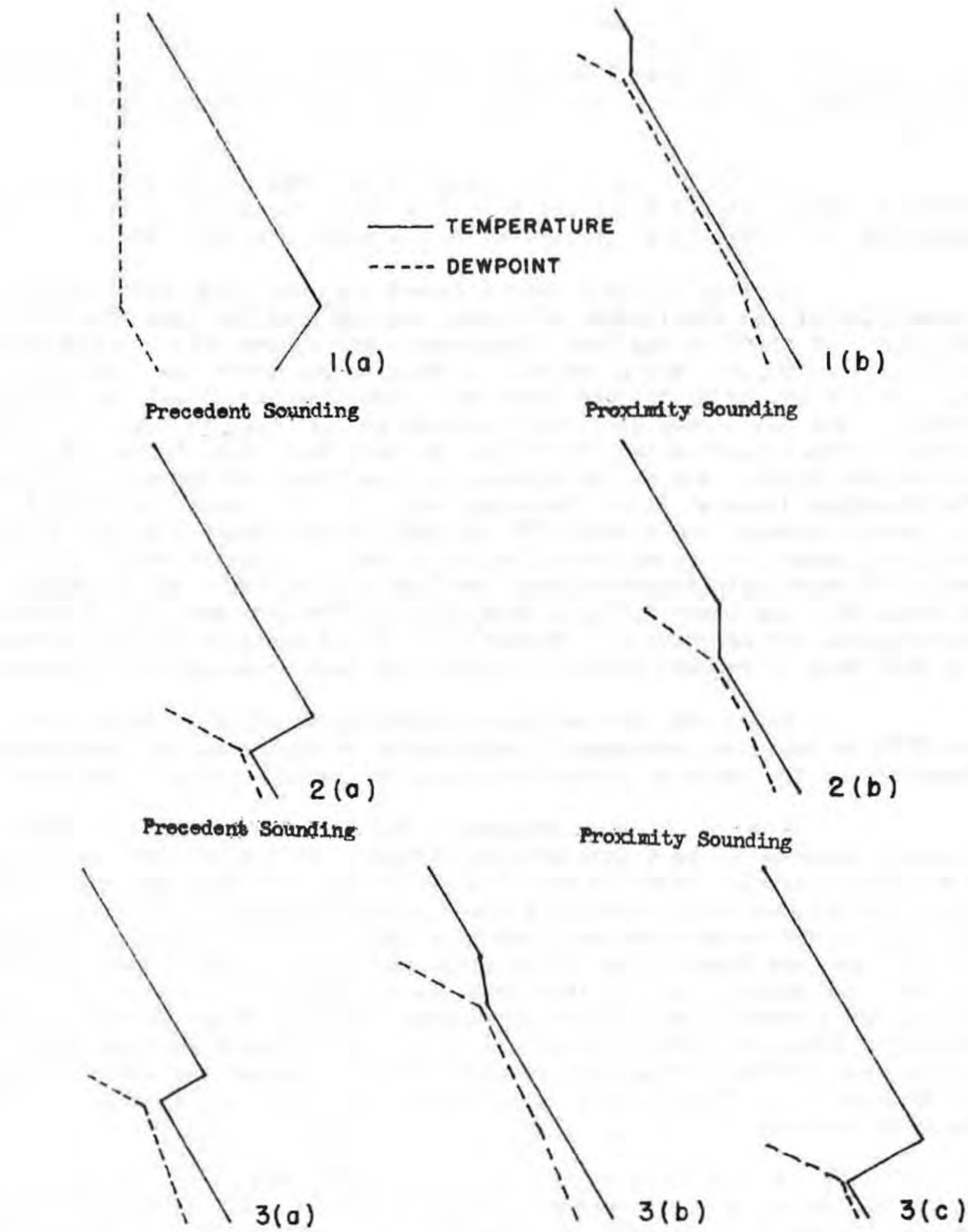
Mr. House, who is in charge of the SELS Cente, very kindly consented to bring out all their charts and we spent the better part of a day examining the situation as it existed on the morning of May 22nd.

A study of these charts showed that the upper air conditions were favourable for the development of severe weather over Southwestern Ontario on May 22nd. At 0300Z of May 22nd, there was a pronounced moist tongue from Arkansas to Sault Ste. Marie. Along the axis of this tongue there was a band of strong winds at 850 mb, 40-45 kts and these were advecting warm moist air into Southern Ontario. The jet stream aloft had branched across lower Michigan such that its northern branch intersected the 850 mb jet near Sault Ste. Marie and its southern branch near Flint. And on the surface, a cold front was approaching Lake Michigan. The Stability Index at Flint, Michigan, was (-4). In short the situation was ripe for severe weather, and at 0610 CST the SELS Centre issued a Convective Outlook, "Activity ahead cold front now in Wisconsin and Illinois expected to increase by early afternoon with thunderstorms, reaching severe limits across Northern Indiana, Northern Ohio and Lower Michigan spreading into Western New York and Western Pennsylvania during evening". Needless to say if Southern Ontario had been in the SELS area of responsibility it would have been included in this message.

We do not receive these Convective Outlooks at Malton, so I consider the SELS estimate an independent confirmation of the essential correctness of our judgement of the synoptic situation during the early morning of May 22nd.

However, nothing happened. The forecast was "bust". Why? What actually happened is best indicated by reference to the synoptic and 850 mb charts. A meso-scale trough formed in the warm sector air over Michigan state about mid-morning and moved with astonishing speed across Southwestern Ontario, so that, by noon the 850 mb moisture axis had been effectively rotated from Michigan to central New York State. The 850 mb winds had shifted from 210/45 to 250/30 kts, so that, the moisture supply from below was cut off. Subsidence to the rear of the trough prevented any further development, this in spite of the fact that the Stability Index at Flint at 1500Z was -3.5. (Incidentally low stability indices to the rear of fast-moving meso-troughs are not uncommon and point up the importance of not treating the index per se but always in conjunction with other synoptic factors.)

Mr. House said that, in his opinion, these meso-troughs are the key factor to the majority of severe weather situations. In the above instance the Centre did not actually issue a warning for Lower Michigan, not because they didn't expect severe weather later in the day for they did at the time when they issued the Convective Outlook, but because it is their policy not to issue warnings with too long a period between time of issue and expected occurrence. So, they held the warning, and then, when it became apparent from later hourly charts that the meso-trough was cutting off the ascending motion over Michigan a warning was no longer necessary.



Precedent Sounding

Proximity Sounding

Post-squall
Line Sounding

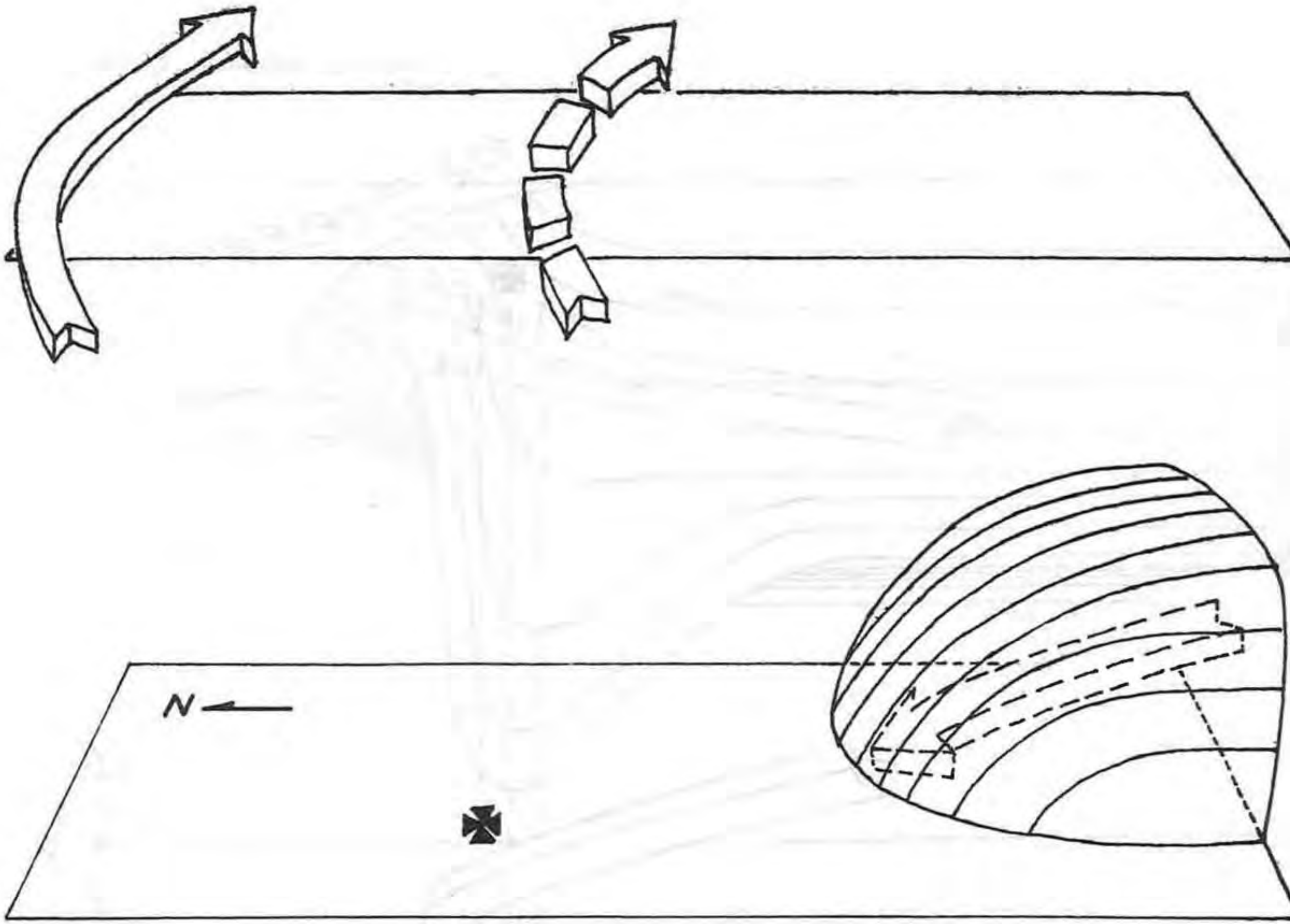


Fig. 1 (x) Corresponding to precedent sounding 1 (2)

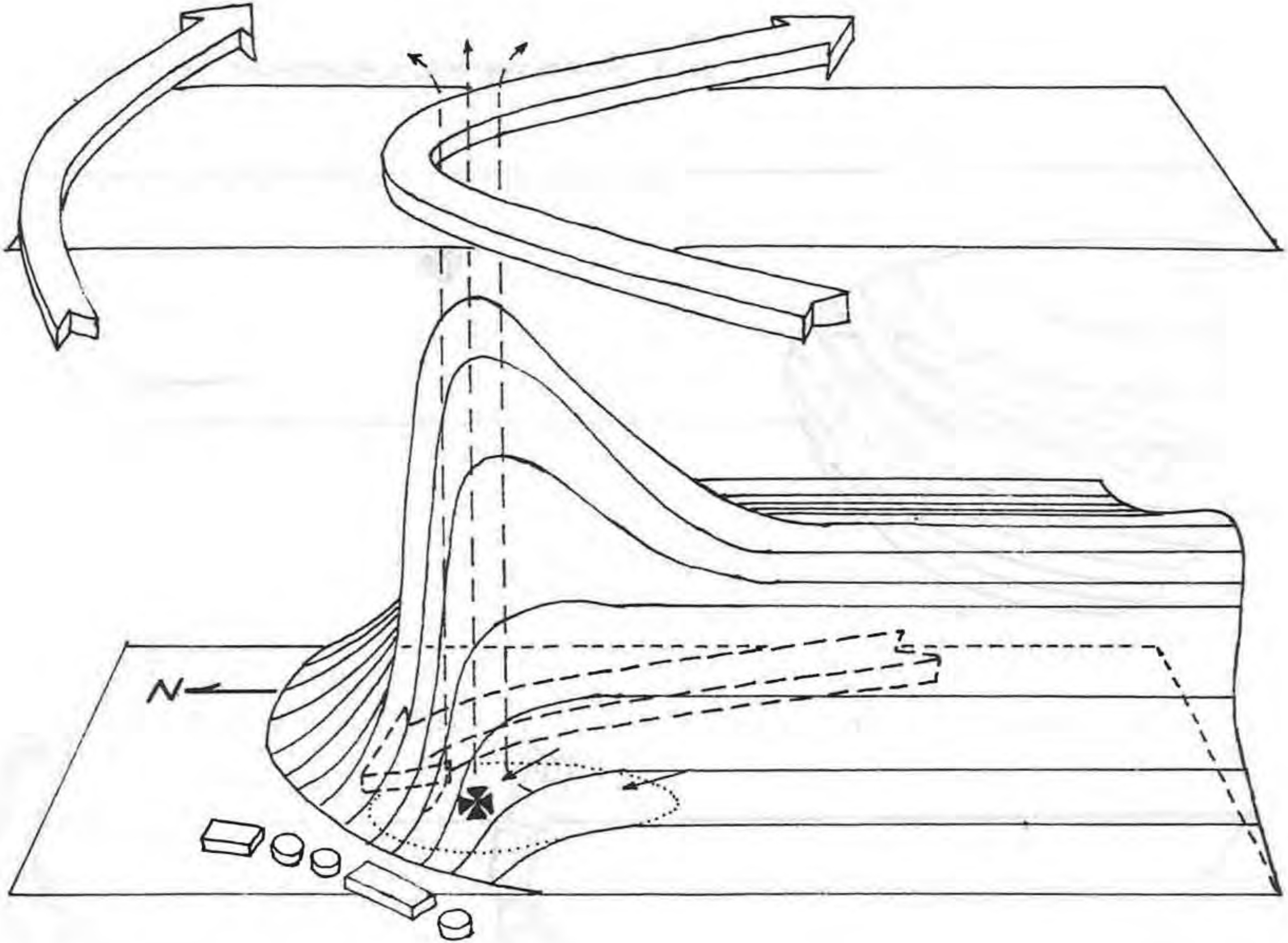
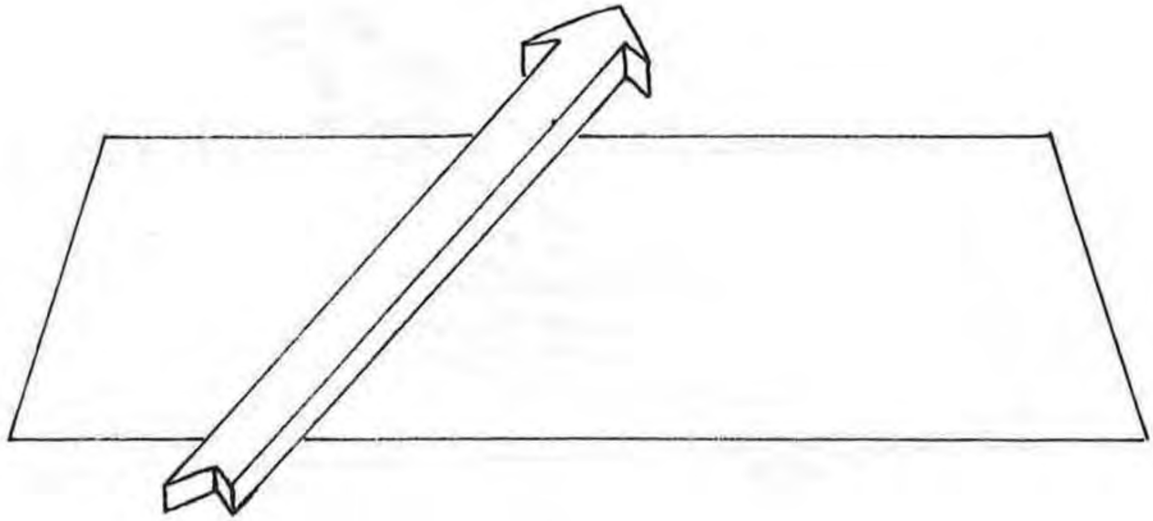


Fig. 1 (y) Proximity Sounding 1 (b)



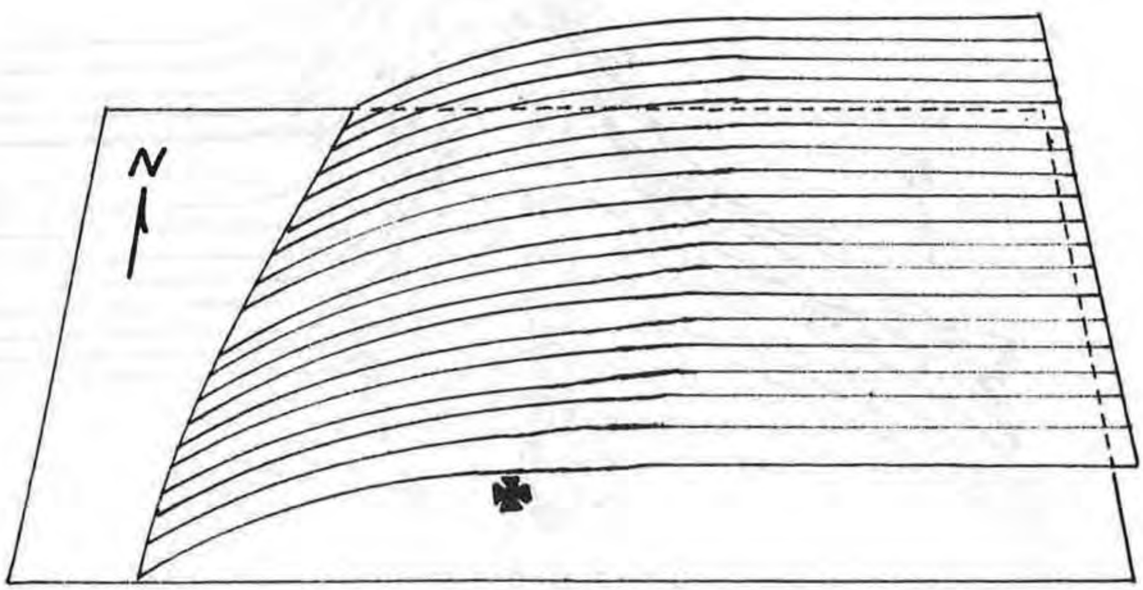


Fig.2 (x) Corresponding to Precedent Sounding 2 (2)

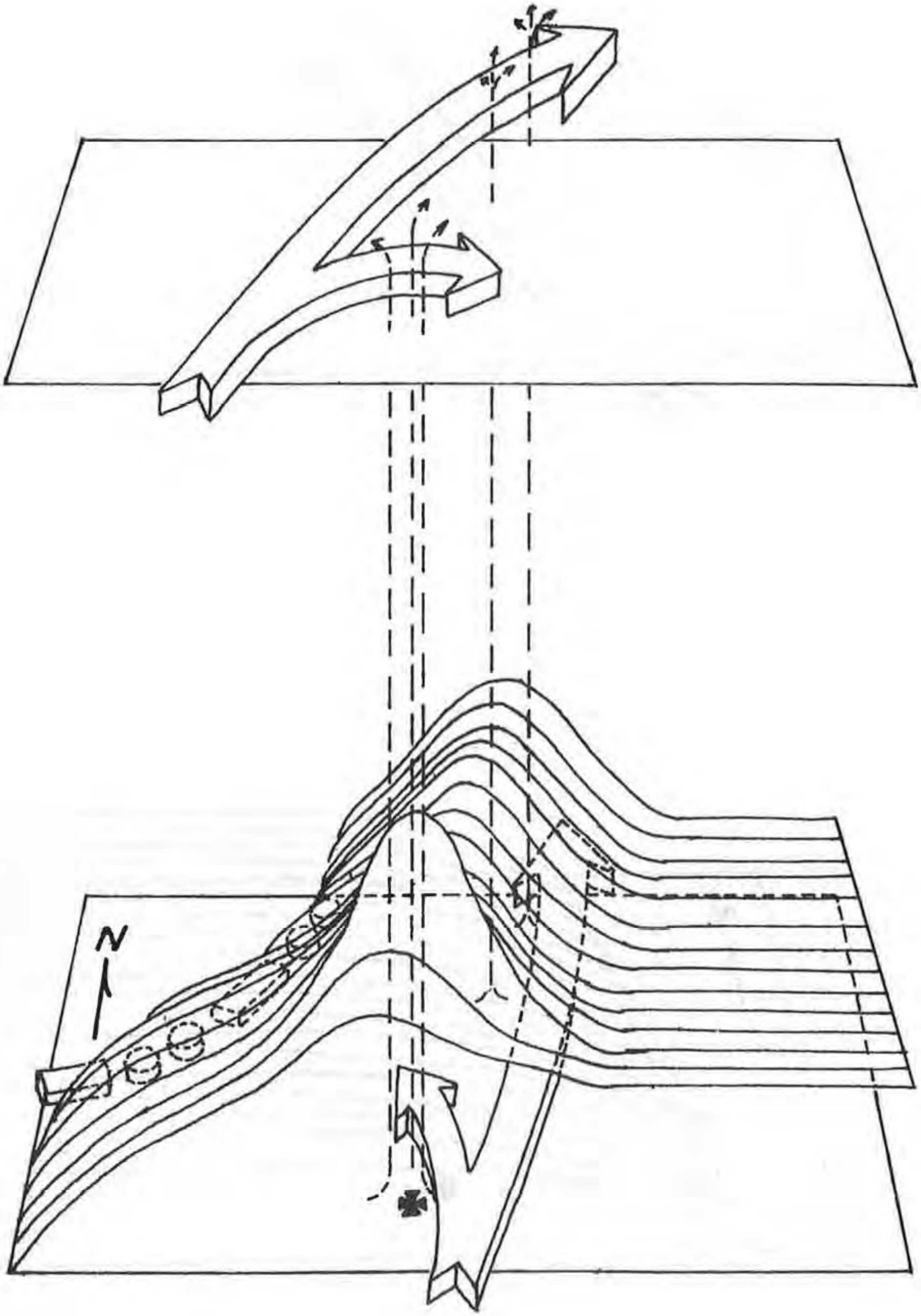


Fig. 2 (y) Corresponding to proximity sounding 2 (b)

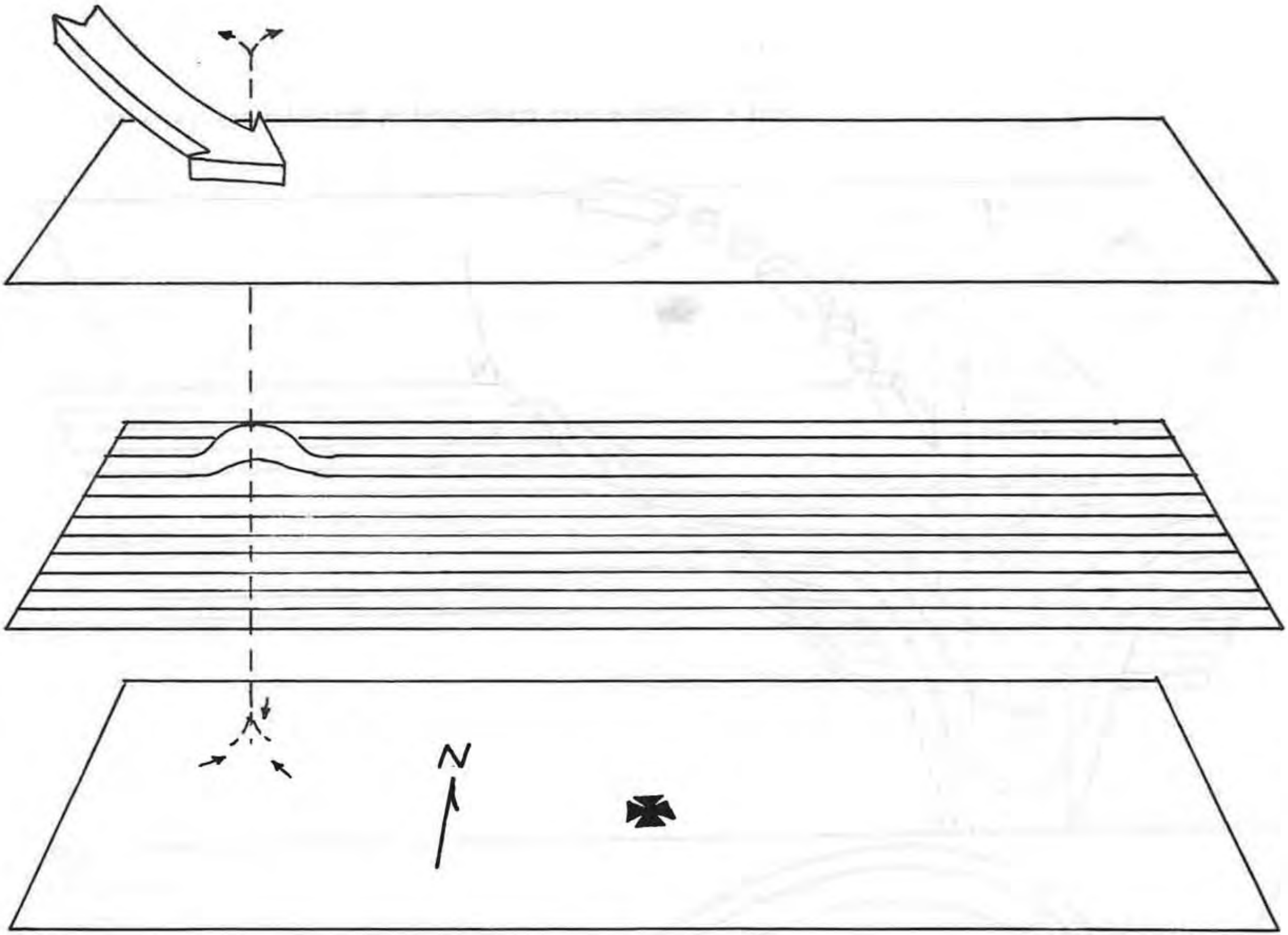


Fig. 3 (x) Corresponding to precedent sounding 3 (a)

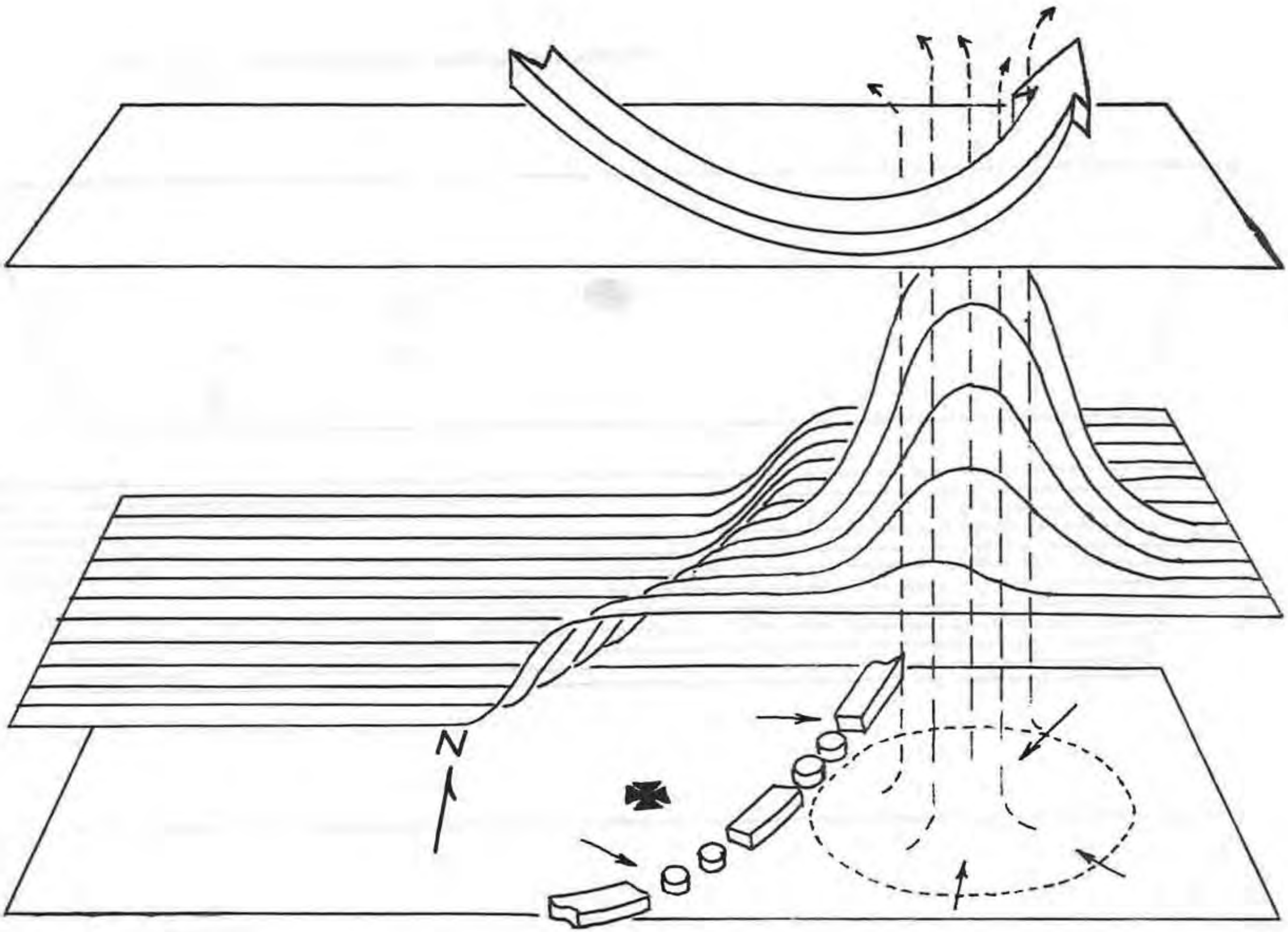


Fig. 3 (z) Corresponding to post-squall line sounding 3 (c)

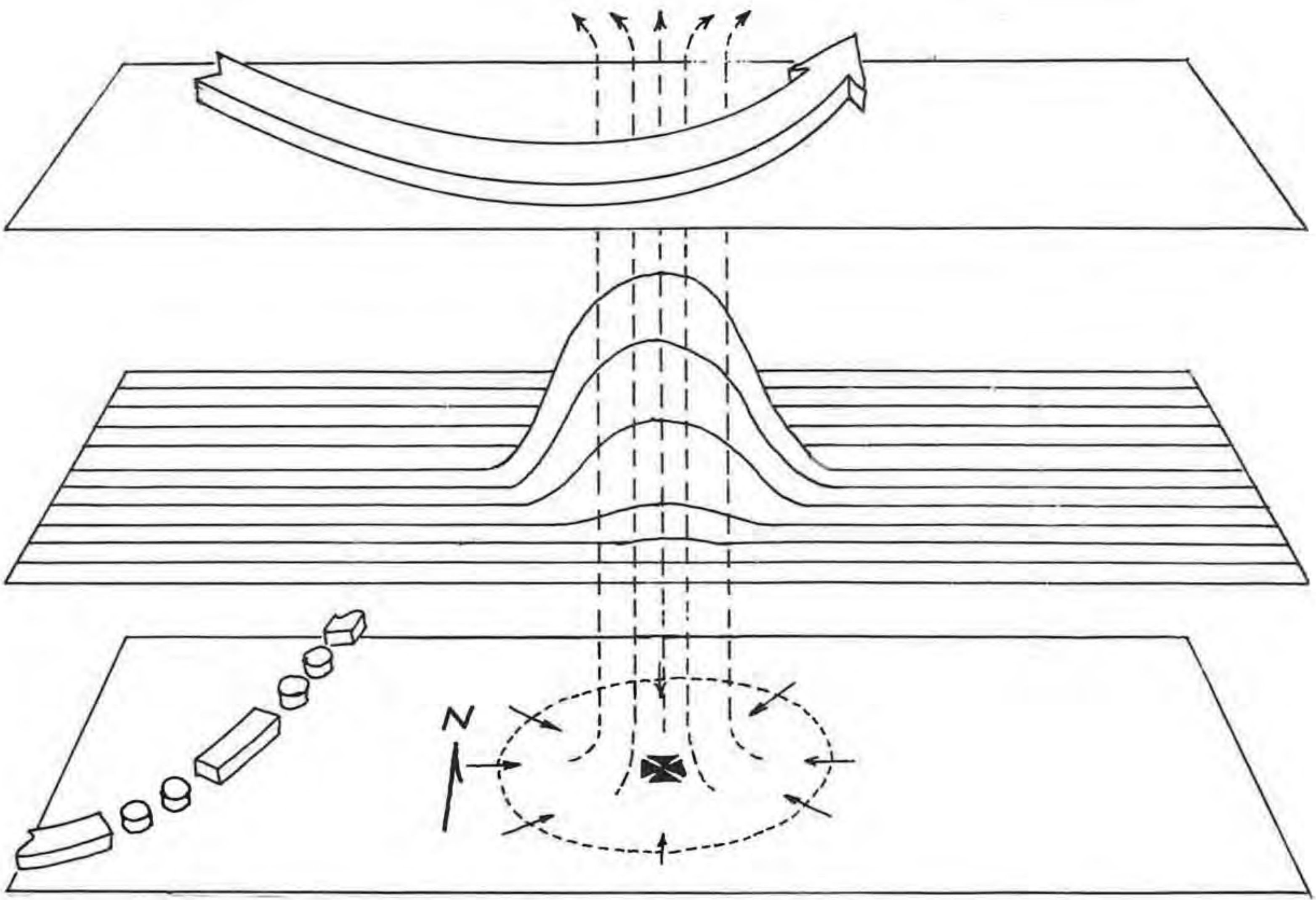


Fig. 3 (y) Corresponding to proximity sounding 3 (b)