WINTER PRECIPITATION FORECASTING FOR SUNSHINE VILLAGE, BANFF NATIONAL PARK

K.W. Daly

Introduction

The number and severity of snow avalanches is directly related to the amount and rate of snowfall (Perla and Martinelli, 1976). Avalanche hazard evaluation and control may be facilitated by timely and accurate forecasts of those meteorological parameters that contribute to avalanches and snow metamorphism. In Canada, the Department of the Environment, Atmospheric Environment Service (AES) has been assigned the responsibility to provide these forecasts.

In 1970, the Warden Service of Parks Canada at Banff National Park requested the Alberta Weather Office (AES) to provide daily weather forecasts in support of avalanche control activities. These forecasts were to be for 24 hours, with a further outlook for the following day. Initially, the forecasts were mostly subjective, based on the meteorologist's knowledge and experience. It soon became apparent that a more systematic and objective technique would have to be developed to give guidance in the area of quantitative precipitation forecasting. This paper will describe the approach taken to develop the technique.

Numerical Weather Prediction and Quantitative Precipitation Forecasting

The advent of high-speed computers has made possible the timely prediction of the future state of the atmosphere, including the amount of precipitation. Precipitation forecasting is dependent on the measurement and prediction of atmospheric moisture and vertical motion (Davies and Olson, 1973). The input for the numerical atmospheric models consists of data obtained from the upper air observations and, more recently, satellite observations. The observations are made twice-daily (0000 and 1200 hours GMT) from the stations shown in Fig. 1. The meteorological parameters observed are temperature, dewpoint depression, pressure and winds from the surface to approximately the 10 mb level (31 km). The output of the quantitative precipitation forecast (QPF) is a forecast of the water equivalent averaged over a 190 km grid for up to 36 hours following observation time. The points at the centre of the grids are shown in Fig. 2.

The main problems with the QPF are sparse observational network and the averaging of the precipitation over a large grid in mountainous terrain. Due to these inadequacies, it was suggested that an attempt be made to use a statistical method to correlate the snowfall at Sunshine Village with some recurring meteorological parameter. Sunshine Village was chosen because of its location near the mountain ridge line and the availability of data from an established snow plot. Several parameters, such as wind direction and speed, temperature, dewpoint depression and the 1000-500 mb thickness, were tested with little success.

Map Typing

Lund (1963) developed a technique of objectively identifying recurring synoptic map configurations. Using linear correlation methods, gridded or station data can be correlated to arrive at sets of similar configurations. In this technique, the computer objectively substitutes the "experience" factor of the meteorologist in recognizing various map patterns.

The atmospheric pressure is approximately 1000 mb at sea level and decreases with height to 1 mb at 50 km. The 500 mb level is at approximately 5 km. The actual height of the 500 mb level is determined from the upper air observation and plotted on a map. Contour lines are drawn joining points of equal height producing a map very similar to a common topographical map with the contour orientation determining the wind direction and gradient determining the wind speed. The 500 mb map is one of the meteorologist's main diagnostic tools.

There are 35 basic recurring 500 mb map patterns with a correlation coefficient of 0.85 or higher that affect northwestern North America (Kociuba 1974). Examples of some of these patterns (types) are shown in Fig. 3. These maps are taken from the 500 mb map catalogue and are the representative map for the type. The 35 basic map types and the uncorrelated patterns may be correlated with the simultaneously occurring weather to develop a prediction technique.

The Method of Approach

The preliminary investigation into the snowfall at Sunshine Village, using the 1972-1974 data, indicated that map types would be useful in assessing the probability of precipitation. However, the actual amount could not be determined in case of higher snowfall.

The Warden Services provided daily weather reports that included the 24-hour snowfall amount at 0800 MST. These reports were compared with the 1200 GMT (0500 MST) 500 mb map type for the previous day (i.e., three hours prior to the onset of the snowfall reporting period). The results are tabulated in Table 1. Discussions with the Wardens indicated that a "prediction range" of snowfall would be useful. Two cm, or less, snowfall in 24 hours was considered to be insignificant. It was decided that the most useful ranges would be 5 cm centred on a multiple of 5 cm (i.e., 3-7, 8-12).

The importance of accurate observations and reporting cannot be over-emphasized. Future forecasts depend wholly on the data used to develop the prediction technique. The location of snow plots must be chosen with care in order to keep the amount of snow which is blown or drifted into the plot at a minimum. This is especially important when snow plots are located at higher elevations near mountain ridges. Drifted or blown snow can lead to measurements of supposed snowfall that have no relationship to atmospheric dynamics. Therefore, it is essential that snow plot sites be chosen carefully and that the observations be made by competent observers.

Table 1 shows that there is a good separation between types that produce snow and those that do not. However, there is a problem in certain types, such as types 1, 2, 11, and 14, which can produce snowfall amounts ranging from zero to in excess of 25 cm in a 24-hour period. It was then necessary to find some other means of separating the snowfall amounts within a type. The secondary predictors would have to be capable of being forecast with a fairly high degree of accuracy.

The theory of precipitation suggested that the snowfall amount separation could be made on the basis of the moisture content and vertical motion of the atmosphere. However, both of these parameters are very difficult to measure directly. Therefore, a method of deriving or implying these parameters had to be discovered.

The deviation of map heights from the catalogue map type heights gives an indication in the variation of the wind field. Thus the variation in the vertical motion from that implied by the catalogue type can be deduced. This deviation is easily determined by subtracting the catalogue map height values from the actual values at various stations.

The amount of atmospheric moisture is dependent on the air temperature. The higher the temperature, the greater the potential for moisture content. Since the 1000-500 mb thickness is also dependent on the mean air temperature, it gives an indication of potential atmospheric moisture content. This parameter is easily obtained from the upper air observations and, as a conservative property, is relatively easy to predict.

By using map typing, pattern deviation and 500-1000 mb thickness, a set of correlation tables were established to correlate the snowfall amounts with the observed data for each map type. These tables were developed using two years' data (360 cases).

The Forecast

The forecast is based on data obtained from the numerical weather prediction charts. The 500 mb height data and 1000-500 mb thickness data is entered into a computer programme which does the map typing and gives the forecast based on the established tables. The forecasts are issued daily at 0600 and 1500 MST from 15 November to 30 April. By using the 48-hour prognostic charts, a forecast for up to 75 hours can be produced.

Forecast Verification

The verification of last winter's forecasts is shown in Fig. 4. Fifty-five percent of the forecasts were completely accurate. However, when the ranges adjacent to the 100% accurate diagonal are included as accurate, the accuracy improves to 89%. This inclusion is reasonable as, in many cases, the snowfall was only 1 cm into the next ranges. Last winter the correlation tables were modified to forecast the 5 cm ranges instead of the random established initially.

Future Work

The main goal is to produce a forecast that is both timely and accurate and meets the requirements of the Warden Service. Presently, after four years, data are available for 721 cases. As more data become available, the correlation tables will be updated and refined. Also, experiments using more 500 mb data for map typing and raising the threshold correlation coefficient are in progress.

In this study, the 500 mb level was used because the catalogue of 500 mb maps was already established. Also, when the study commenced, 700 mb numerical prognostic charts for 36 and 48 hours were not available to the forecast offices. It would be useful to develop a 700 mb map catalogue since the 700 mb level is close to the level of maximum vertical velocity.

This technique will be expanded to other areas such as Parker Ridge and Marmot Basin. It is anticipated that forecasts for longer periods will eventually be possible.

ACKNOWLEDGEMENTS

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References

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Discussion

FITZGERALD: The Weather Service at the Salt Lake City Airport furnishes us with wind speeds, wind directions, and temperature at the 700 mb level. To what elevation level does this correspond?

DALY: The 700 mb level may vary from 2800 to 3200 meters, but in the winter it usually remains between 2800 and 3000 m.

PERLA: Ken Daly is tackling a difficult problem - precipitation forecasting on the downwind side of a chain of mountains. It is commendable that he has done as well as he has.

DALY: Yes, we have certain problems getting data on conditions in the Interior of British Columbia. There is no midnight shift at Revelstoke or Banff, and we have to produce a 6:00 a.m. forecast without input data from interior stations.

TABLE 1

Number of Occurrences of 500 mb Map Types and Snowfall November - April 1972 - 1976.

500 mb Map Type	Occurrences	Snowfall Occurrences 0-2	3-7	8-12	13-17	18-12	23-27	28-32	>32 c
1	158	54	56	25	13	4	2	2	2
2	108	62	26	10	1	3	5		1
3	22	9	6	7					
4	19	12	3	3				1	
5	14	11	2	1					
6	14	10	3	1					
7	1	1							
8	45	22	18	4	1				
9	2	2							
10	14	14							
11	62	25	19	9	6	2			1
12	2	1		1					
13	1	1							
14	38	28	5	4		1			
15	3	2	1						
16	19	16	3						
17	5	5							
18	4	2	2						
19	9	6	1	1	1				
20	9	9							
21	1	1							
22	2	1	1						
23	5	5							
24	0								
25	21	16	3	2					
26	3	1	2						
27	0								
28	4	4							
29	10	10							
30	4	4							
31	0								
32	10	10							
33	8	6	2						
34	0								
35	2	2							
U	102	91	7	2	1				1
Total	721	443	160	70	23	10	7	3	5

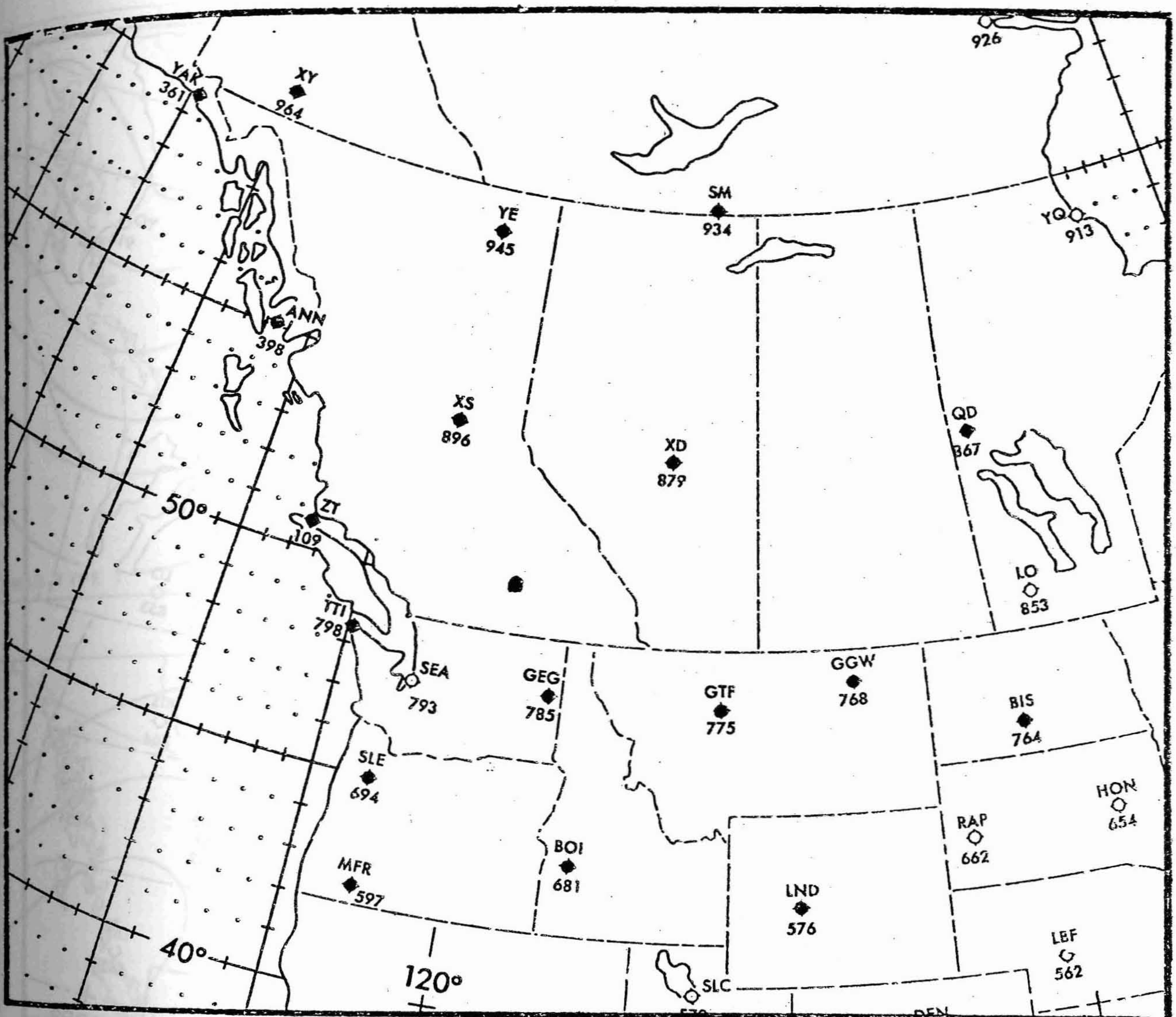

FIGURE 1 UPPER AIR STATIONS FROM WHICH DATA ARE OBTAINED FOR USE IN THE 500 mb MAP TYPING PROGRAM IN THE ALBERTA WEATHER OFFICE.

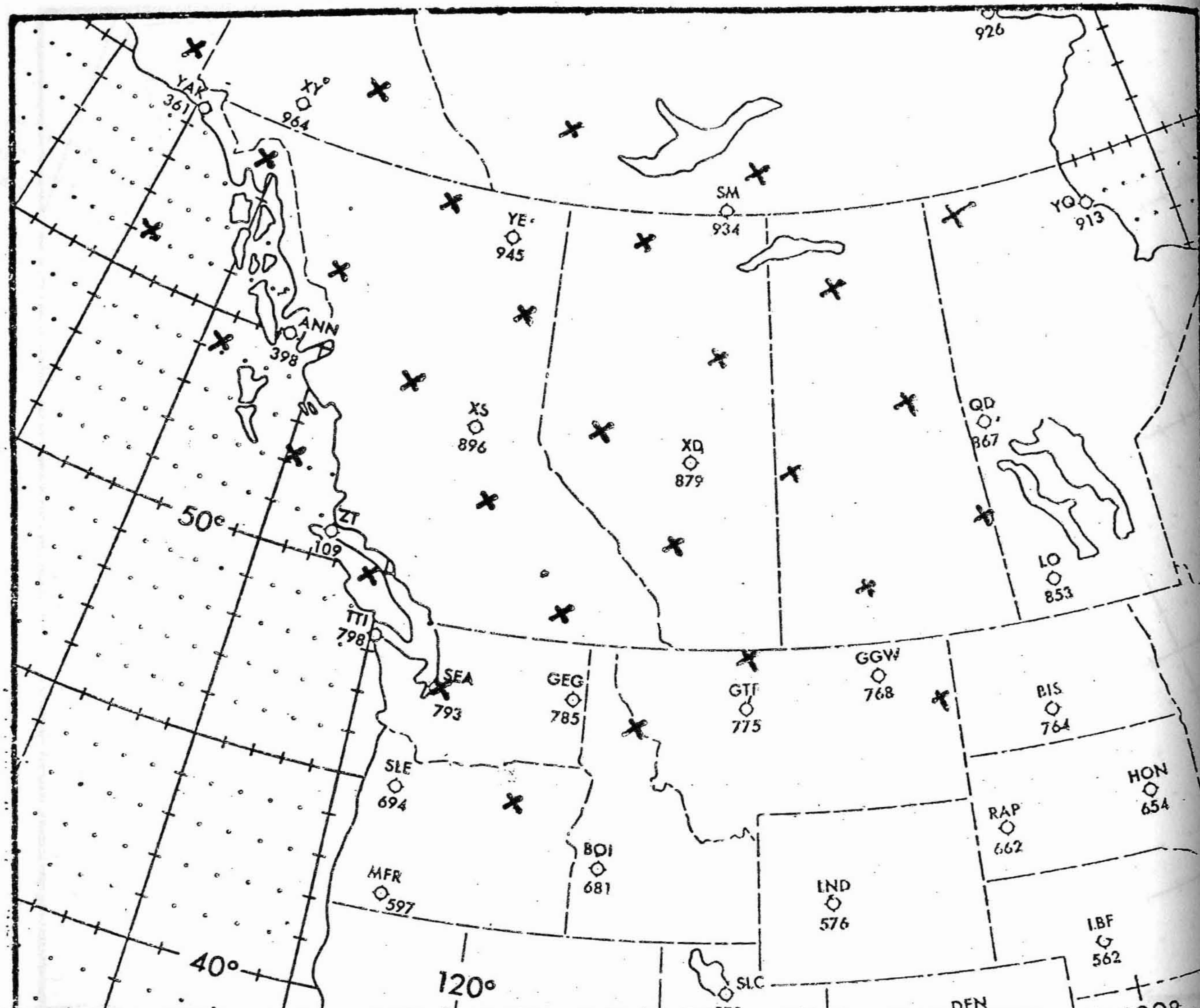

FIGURE 2 NUMERICAL WEATHER PREDICTION (NWP) GRID POINTS. GRID LENGTH IS 381 km. THE QUANTITATIVE PRECIPITATION FORECAST GRID LENGTH IS ONE-HALF THE NWP GRID LENGTH

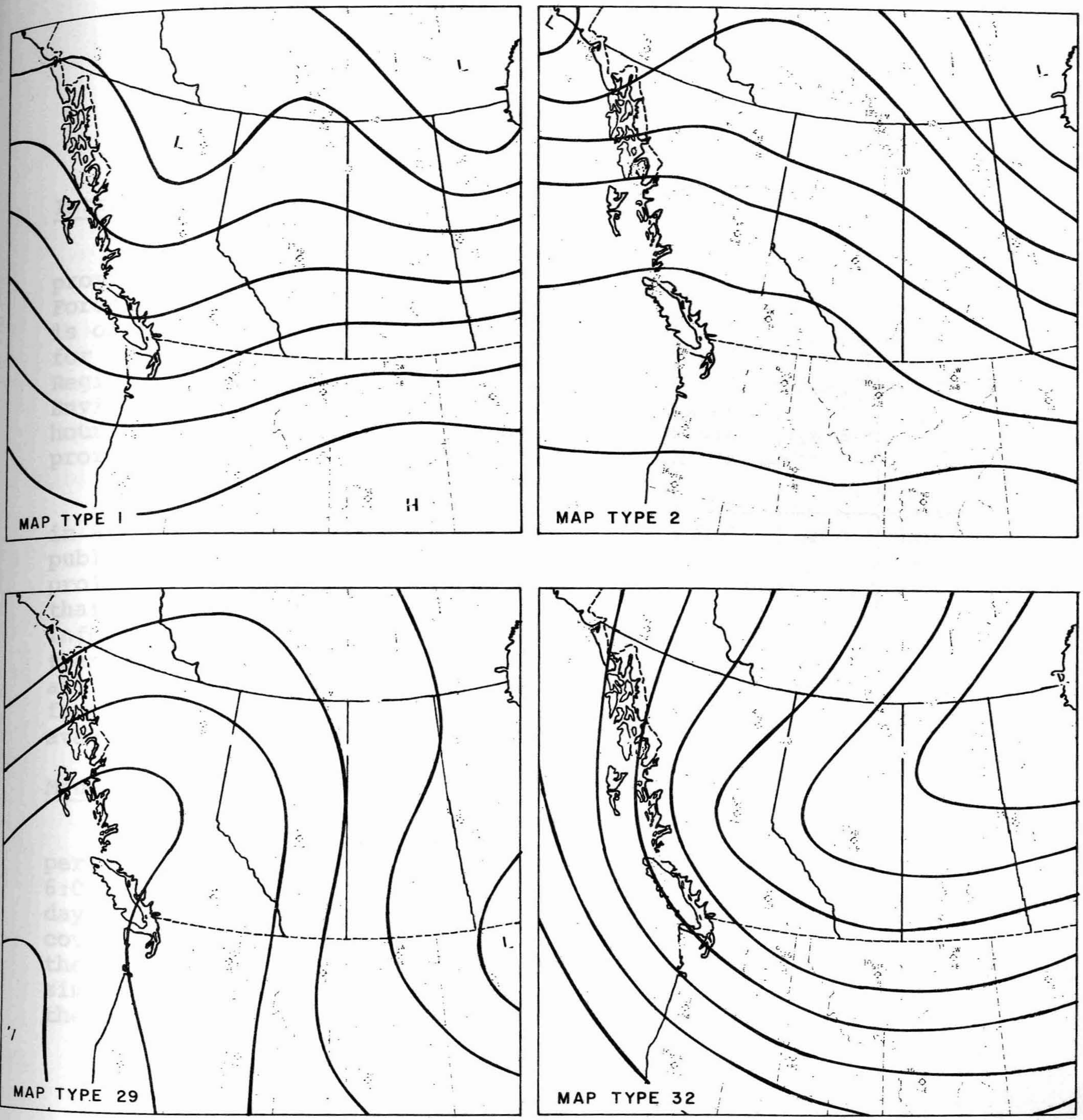

FIGURE 3 FOUR EXAMPLES OF 500 mb MAP PATTERNS. TYPES 1 AND 2 PRODUCE 0 TO MORE THAN 25 cm OF SNOW IN TWENTY-FOUR HOURS. TYPES 29 AND 32 PRODUCE LESS THAN 2 cm

FORECASTS OF SNOW	OCCURRENCES OF SNOW CM								
	0-2	3-7	8-12	13-17	18-22	23-27	28-32	> 32	TOTAL
0-2	76	21	3						100
3-7	20	10	8	1	1				40
8-12	5	5	5	2		1		1	19
13-17	1	1	1			2			5
18-22	1		1		1				3
23-27									
28-32									
> 32									
TOTAL	103	37	18	3	2	3		1	167

Percentage Correct — 55 %
Percentage Correct combined with adjacent ranges — 89 %

FIGURE 4 VERIFICATION OF SNOWFALL FORECASTS WINTER 1975-76. OCCURRENCES ALONG DIAGONAL LINE INDICATE 100% ACCURACY. OCCURRENCES TO THE UPPER RIGHT OF THE DIAGONAL LINE SHOW LOW FORECAST BIAS, WHILE THOSE TO THE LOWER LEFT SHOW HIGH BIAS