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Terrain Influences on Precipitation in the Intermountain West as Related to Synoptic Situations

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ABSTRACT

Precipitation in the Wasatch Front area of northwest Utah was analyzed with regard to different storm types. It was found that precipitation associated with "cold lows" aloft was relatively greater at valley than at mountain stations when compared with cold or warm frontal precipitation. Also the precipitation profile across the mountain range differed with "cold low" and "non-cold low" type storms. The probable causes of these differences are discussed.

1. Introduction

The Wasatch Front area of northwest Utah (Fig. 1) is an excellent region for studying terrain influences on precipitation as the mountain range is nearly orthogonal to the general storm paths during the winter season, and forms a rather solid block to air flow from the west. In addition to terrain effects, the type of storm is of considerable importance in determining the areal distribution of precipitation. Precipitation patterns for storms over a period of several years were reviewed to determine if the distribution could be related to synoptic situations. The survey of the distributions and synoptic situations showed that the lower elevation stations generally received relatively greater amounts of precipitation in comparison with higher stations when a "cold low" was observed on the upper air charts.

2. Classification of storms

Storms with upper air "cold lows" in the intermountain region are usually associated with large-scale upward vertical motion, while other storm types may or may not have such large-scale lifting. A division of storms on the basis of the presence or absence of a "cold low" aloft may be used to segregate precipitation into that which is derived primarily from large-scale vertical motion and that which is induced principally by other factors, such as orographic or frontal lifting. Closed lows on the 500-mb constant pressure chart, at the latitude of northern Utah, are nearly always associated with a pool of colder air, and such lows are commonly referred to as "cold lows." An example of a typical "cold low" is shown on the 500-mb chart for 1200 GMT 9 October 1960 (Fig. 2). A storm was classified as a "cold low" type if during the precipitation period a closed 200-ft contour appeared on the 500-mb chart with a center located between the Continental Divide on the east and the Sierra-Cascades on the west, and between 35 and 45N.

3. Precipitation profiles

If precipitation distribution varies with the different storm types, this variation should be evident in average profiles of precipitation over the mountain range. Five stations ranging in location from the Salt Lake Valley, over the Wasatch Range and down to the valley on the eastern side were selected for use in defining the precipitation profiles. Fig. 3 shows a schematic topography profile across the Wasatch Mountains near Salt Lake City, Utah. Precipitation during the months of October through April for the four-year period, October 1953 to April 1957, for the five selected stations shown in Fig. 1 was separated on the basis of the two storm types, "cold low" and "non-cold low." A tabulation of the observed precipitation for each station for the 4-yr period is shown in Table 1. Ratios of the total precipitation for each station as compared with that for Salt Lake City (SLC) are also given. Similar data for two other 4-yr winter periods (October 1947 to April 1953 and October 1957 to April 1961) were computed and are shown in Table 1. The ratios for the two additional 4-yr periods were found to be well correlated with those for the 1953–57 period. The average ratios for the entire 12-yr period are shown in Table 1 and are plotted as precipitation profiles on Fig. 3.

The ratio of Silver Lake Brighton precipitation to that of Salt Lake City varies considerably during the winter season, with the lowest ratios for the months of October and April and the highest ratios during the mid-

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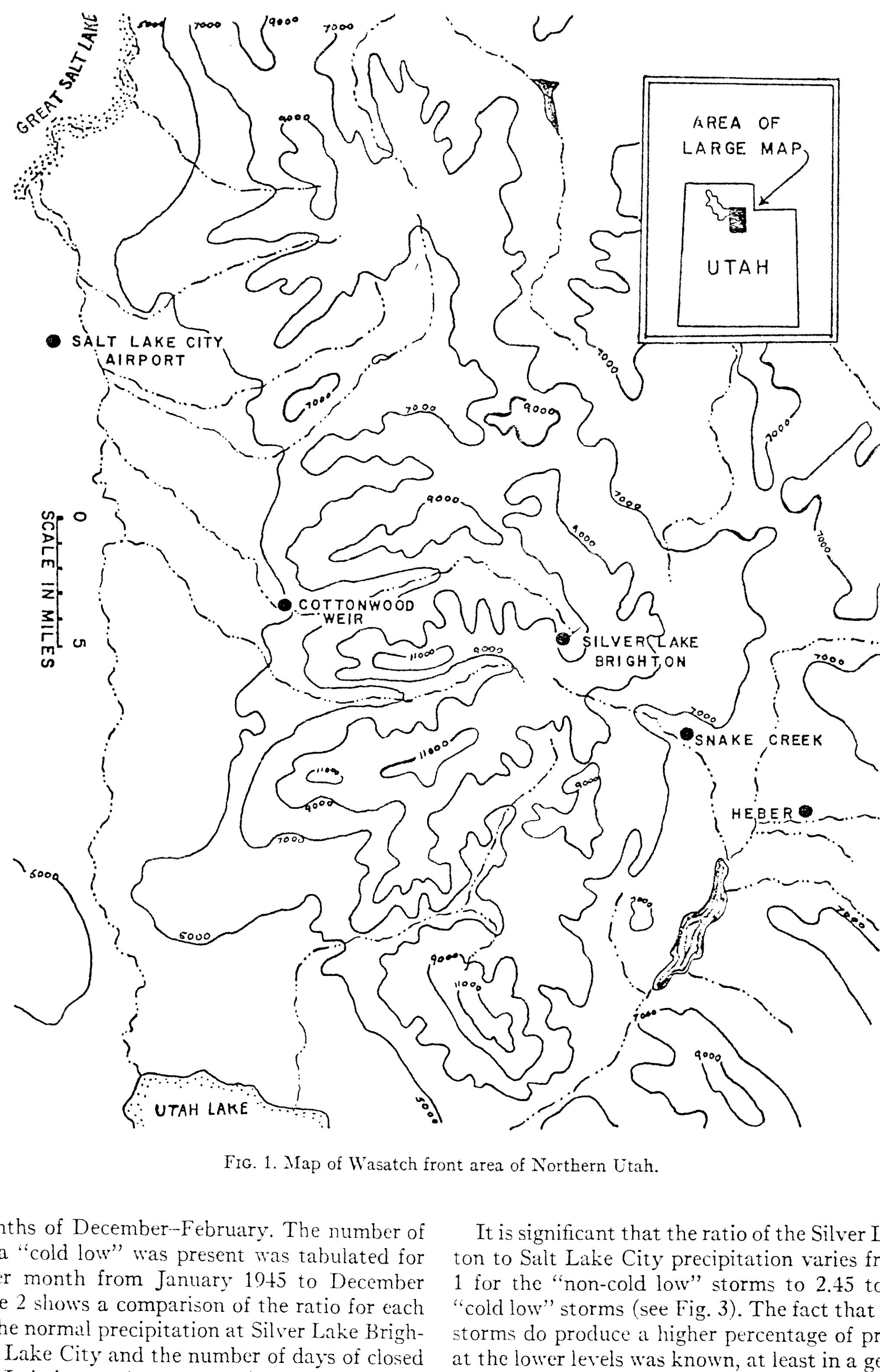

FIG. 1. Map of Wasatch front area of Northern Utah.

winter months of December–February. The number of days that a "cold low" was present was tabulated for each winter month from January 1945 to December 1960. Table 2 shows a comparison of the ratio for each month of the normal precipitation at Silver Lake Brighton to Salt Lake City and the number of days of closed lows aloft. It is interesting to note (Fig. 4) that there is an inverse relationship between curves of these data, which is in agreement with the findings for the two storm types.

It is significant that the ratio of the Silver Lake Brighton to Salt Lake City precipitation varies from 3.75 to 1 for the "non-cold low" storms to 2.45 to 1 for the "cold low" storms (see Fig. 3). The fact that "cold low" storms do produce a higher percentage of precipitation at the lower levels was known, at least in a general way, prior to the study. A second finding, which was not generally known, is that the precipitation ratio in the lee of the mountain range (as indicated by the Heber data) is less than unity for "cold low" storms but

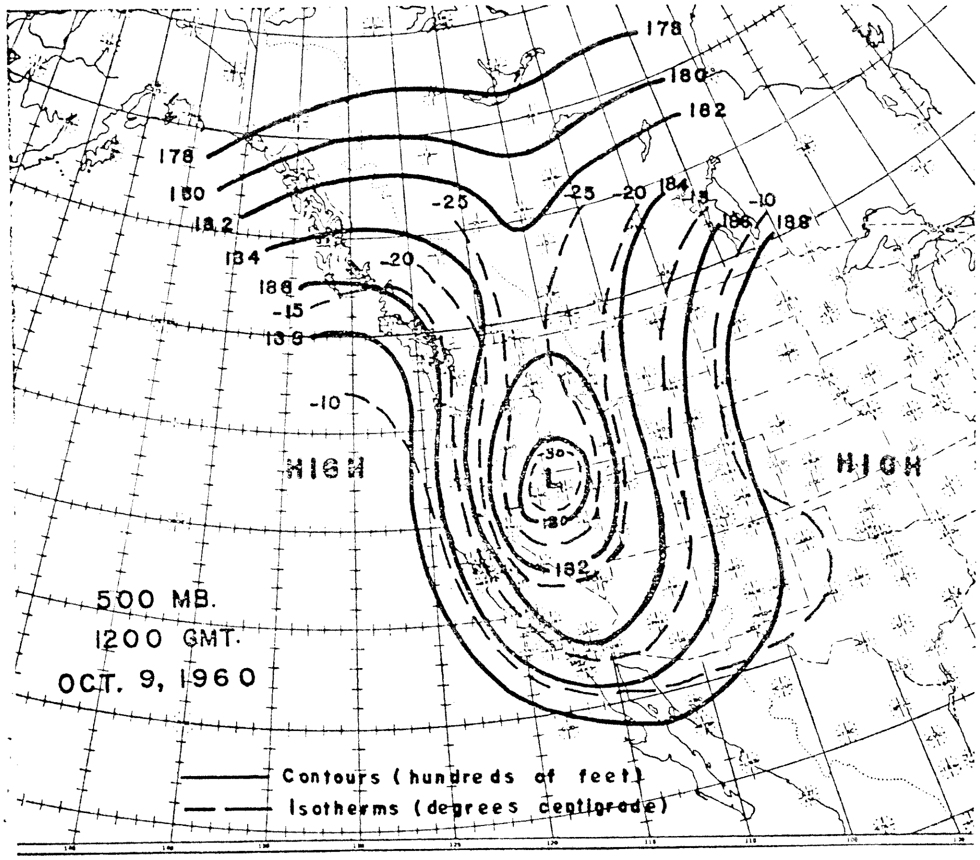

FIG. 2. 500-mb chart for 1200 GMT 9 October 1960.

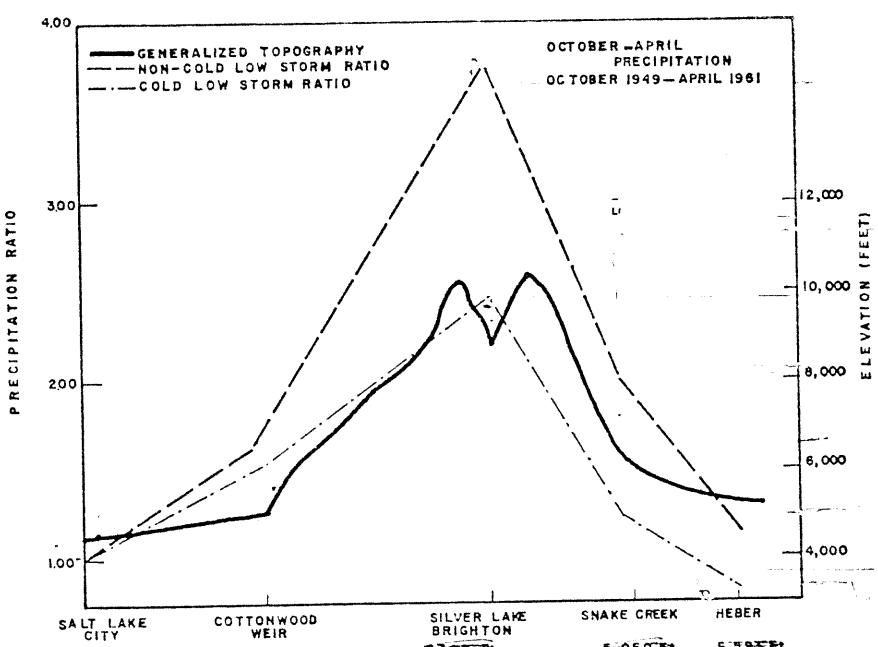

FIG. 3. Schematic diagram of topography, and precipitation profiles ("cold low" and "non-cold low") across Wasatch Mountains near Salt Lake City, Utah.

TABLE 1. October–April precipitation.

	Cold lows					Non-cold lows				
Four year periods	Salt Lake City WBAS	Cotton-wood Weir	Silver Lake Brighton	Snake Creek	Heber	Salt Lake City WBAS	Cotton-wood Weir	Silver Lake Brighton	Snake Creek	Heber
1953–57										
Total precip.	9.78	16.68	21.63	10.53	7.50	13.48	22.87	54.33	26.03	16.19
Ratio to SLC	1.00	1.71	2.21	1.08	0.77	1.00	1.70	4.03	1.93	1.20
1949–53										
Total precip.	14.07	22.03	34.26	19.26	11.96	30.26	46.98	109.09	64.87	38.44
Ratio to SLC	1.00	1.57	2.43	1.37	0.85	1.00	1.55	3.63	2.14	1.27
1957–61										
Total precip.	12.84	17.49	33.99	15.76	10.84	21.91	38.33	82.49	39.63	22.54
Ratio to SLC	1.00	1.36	2.65	1.23	0.84	1.00	1.75	3.76	1.81	1.03
Twelve year period										
1949–61										
Total precip.	36.69	56.20	89.88	45.55	30.30	65.65	108.18	245.91	130.53	77.17
Ratio to SLC	1.00	1.53	2.45	1.24	0.83	1.00	1.65	3.75	1.99	1.18

greater than unity for "non-cold low" precipitation occurrence.

4. Additional storm classification

Following the profile study where the precipitation was separated into two catagories, further studies were made to determine if additional storm classifications might be of value. For this portion of the study only the ratio of Silver Lake Brighton precipitation to that of Salt Lake City was used. This analysis was made for the winter season for the period October 1953 through April 1959. Only precipitation occurring during storms of at least 0.40 inch at Silver Lake Brighton or Salt Lake City in a 48-hr period was included. No change was made in the classification of the "cold low" storms. The "non-cold low" storms were divided into three groups based on the predominant synoptic stiuation associated with each storm. The classifications were:

(1) overruning warm air, including cases both with and without a definite surface warm front;
(2) precipitation following a cold front; and
(3) miscellaneous.

Miscellaneous includes all precipitation that could not be definitely associated with (1) or (2) above. This would include air-mass showers, precipitation in moist currents that could not be called either pre-warm frontal or post-cold frontal, and precipitation with occlusions that were not definitely of the warm or cold type.

Fig. 5 is a bar graph showing the Silver Lake Brighton-Salt Lake City precipitation ratio for each of the four storm types. The number of occurrences of each storm type is given on the bar graph. Cold front precipitation is by far the most frequent type during the winter season in the area. The precipitation ratio for the "cold low" storms was found to be near 2 to 1 as previously determined in the profile analysis. The average ratio for the warm front overrunning storms was near $5\frac{1}{2}$ to 1, and for the cold front storms slightly over 7 to 1. For the miscellaneous storms it was nearly 9 to 1. "Cold low" formations over the western plateau are usually the result of strong baroclinic situations, with pronounced deepening of an upper air trough as it moves in from the west coast. This is associated with marked cold air advection and generally strong northwest winds aloft along the Pacific Coast with the build-up of a pronounced high pressure ridge in the eastern Pacific. There is usually strong vorticity advection with

TABLE 2. Comparison of monthly precipitation normals with frequency of cold lows aloft.

	Months						
	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Silver Lake Brighton monthly normals[1]	2.91	4.28	5.25	5.15	5.27	5.42	3.85
Salt Lake City WBAS monthly normals[1]	1.15	1.30	1.24	1.35	1.18	1.56	1.76
Ratio monthly normals Silver Lake to Salt Lake City	2.53	3.29	4.23	3.81	4.47	3.47	2.19
Number of days with closed cold lows aloft[2]	66	43	37	38	54	53	83

[1] For period 1931–1960.
[2] Total for period 1945–1960. All days with cold lows aloft and not limited to days with precipitation.

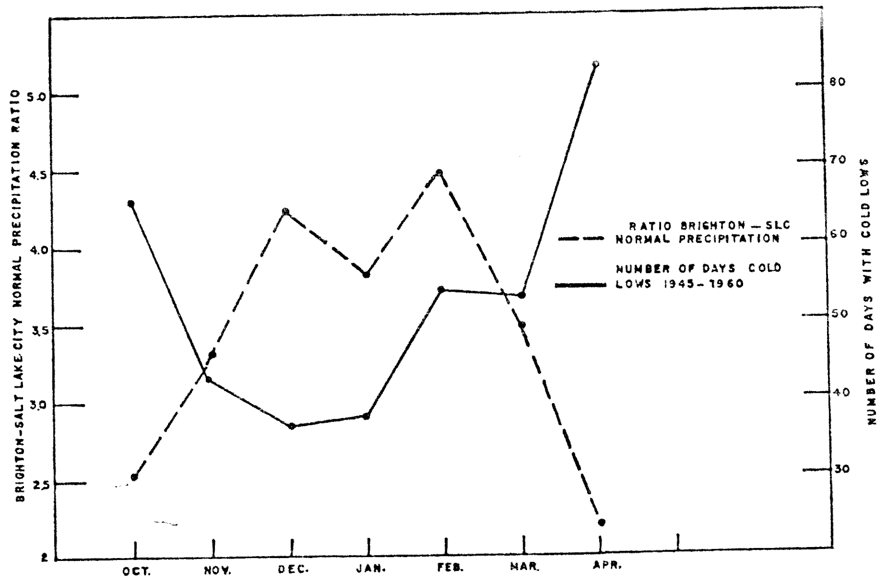

FIG. 4. Ratio of monthly normal precipitation, Silver Lake Brighton to Salt Lake City, and number of days with cold lows over plateau.

developments of this type, resulting in pronounced large-scale upward vertical motion. Thus, with "cold low" type storms, precipitation may result with relatively little dependence on orographic lifting, as compared to other storm types, and the precipitation ratio, mountain to valley stations, is relatively small.

The standard deviations, as computed for the individual storm totals for each group, are shown by arrows in Fig. 5. Deviations are quite large for the cold front and miscellaneous types, but very small for the "cold low" type. The large standard deviation for the cold front storms is probably related to the variation in the direction and speed of the upper winds associated with cold fronts of different orientation.

5. Additional studies

The storm classifications used in this study are quite general and the results can only be applied in a broad sense. For the past several years work has been progressing on a more detailed study relating upper air parameters to the 12-hourly precipitation amounts for the Wasatch Front area. Preliminary results of these detailed studies show that the best correlated parameters are those of upper air wind speed and direction, and indices representing air-mass stability. The objective of the detailed studies is to determine if a better classification may be developed using the upper air parameters and numerical values of vorticity advection and large-scale vertical motion. Elliott and Shaffer (1962) have made a detailed study of some of these relationships for the southwest coast of the United States.

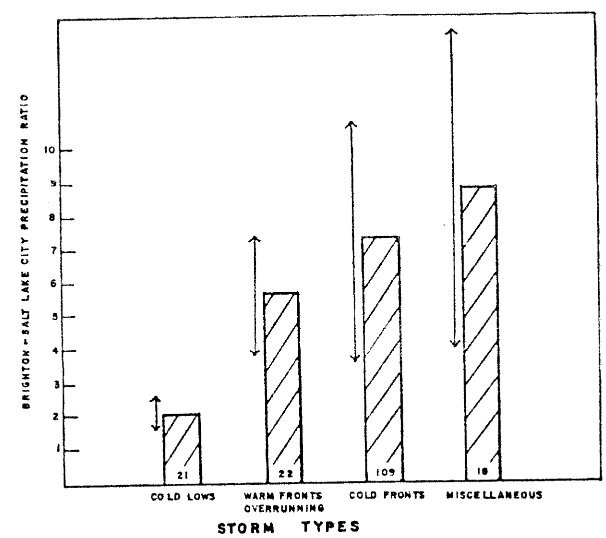

FIG. 5. Ratio of Silver Lake Brighton to Salt Lake City precipitation for different storm types. The number of cases for each type is shown at the bottom of the respective bars. Arrows to left of the bars show standard deviation.

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REFERENCE

Elliott, R. D., and R. W. Shaffer, 1962: The development of quantitative relationships between orographic precipitation and air-mass parameters for use in forecasting and cloud seeding evaluation.