SPATIAL SNOWFALL DISTRIBUTIONS IN WINTER STORMS IN COLORADO

by

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ABSTRACT

Snowfall data from storms in Denver and Colorado Springs, Colorado, are used to confirm the finding from previous studies that snowstorms in Denver are characteristically distinct from snowstorms in Colorado Springs. From analyses of storms in these two cities during the period 1972 to 1992, storm-total snowfall at the sites is found to be inversely related; that is, heavy snowfall at Denver is usually associated with relatively light snowfall at Colorado Springs, and vice versa. Hourly liquid precipitation data from a set of several stations in Colorado are totaled over the lifetime of 17 major storms in Denver and 11 in Colorado Springs. Plots of these totals demonstrate that precipitation during major Denver storms is concentrated on the eastern plains of Colorado, while precipitation during major Colorado Springs storms shows large amounts west of the Continental Divide. These spatial distributions are compared to composite maps of storm circulation produced by Mahoney et al (1994), which exhibit strong low-level cyclogenesis in the lee of the Rocky Mountains in the Denver storms and low-level cyclogenesis west of the mountains in the Colorado Springs storms.

INTRODUCTION

In previous work we have presented evidence for significant differences between the synoptic-scale meteorological setting associated with heavy snowfall in Denver, Colorado, and that associated with heavy snowfall in Colorado Springs, Colorado (Mahoney, 1992; Mahoney and Brown, 1992; Mahoney et al, 1994). These differences are something of a surprise, since both cities are located along the eastern slopes of the Rockies less than 100 km apart (Fig. 1). Mahoney et al. (1994) hypothesize that they arise due to interactions between the synoptic-scale flow and mesoscale terrain features. For instance, the Palmer Divide, a relatively shallow east-to-west-oriented ridge that separates Denver and Colorado (Fig. 1), provides the greatest chance for upslope flow in Denver under a synoptic regime of low-level northeasterlies and in Colorado Springs under a southeasterly regime.

Here, we address a more basic question: Are there in fact fundamental differences between the magnitudes and spatial distributions of the actual snowfall produced by Denver and Colorado Springs storms? Experience suggests that there is. For instance, a snowstorm on 9 March 1992 absolutely clobbered Denver but had very little affect on Colorado Springs and other points south. Conversely, a storm in 1987 left almost 33 cm (13 in) of snow beginning on March 15 in Colorado Springs but less than 5 cm (2 in) in Denver. Indeed, it is commonly supposed that there are synoptic patterns that lead to a Denver storm, and others that foretell a Springs storm, but few that produce heavy snowfall at both locations.

We propose to confirm this anecdotal evidence by quantitatively analyzing hourly precipitation gage observations from Colorado and snowfall records from Denver and Colorado Springs. Our principal objective is to determine if there are repetitive snowfall characteristics discernible in a twenty-year record of Denver snowstorms that are demonstrably different from those observed in Colorado Springs storms during the same period.

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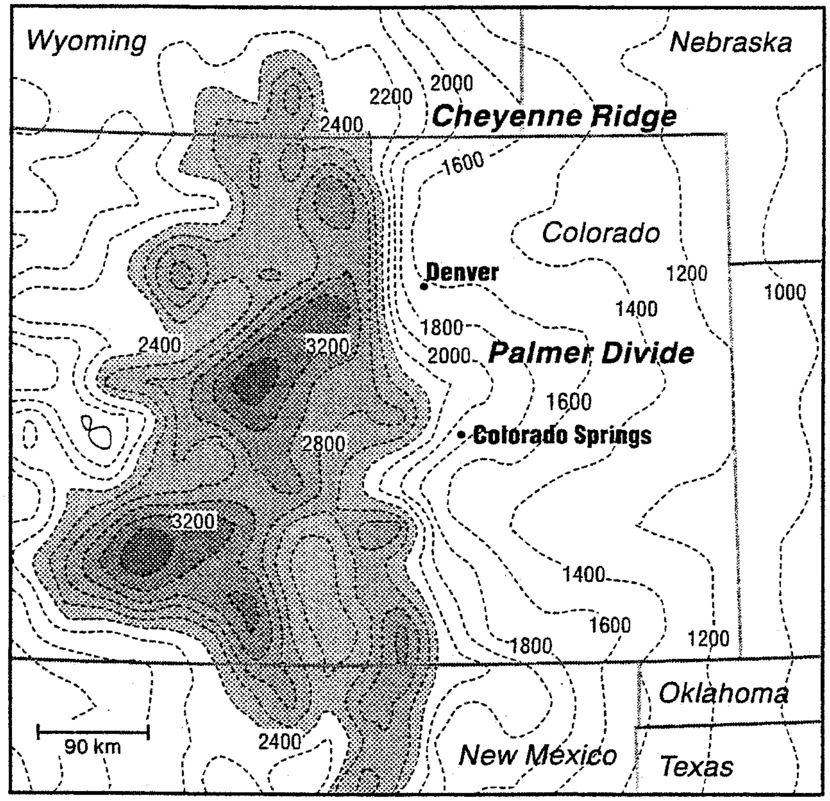

Figure 1. Terrain features of the Colorado Rocky Mountains. Elevation contours are labeled in m.

Data and Methodology

In order to compare the magnitude of snowfall in Denver storms with concurrent Colorado Springs snowfall and vice-versa for Colorado Springs storms, 6-hourly snowfall observations at National Weather Service Offices in Denver and Colorado Springs have been assembled and tabulated. In addition to providing the primary snowfall data for this study, storm snowfall totals based on these observations were also used to define sets of storms of various intensity.

The determination of spatial distributions of snowfall, however, required observations with reasonable spatial density across Colorado. Since actual snowfall measurements from other locations were not readily available, we chose to utilize observations from the Hourly Precipitation Dataset (HPD) obtained from the National Climatic Data Center (NCDC) in Asheville, NC. Fig. 2, which shows precipitation observations for a Colorado Springs storm in March 1987, demonstrates that available HPD sites provide a good picture of the distribution of precipitation in Colorado. Although these data provide only snow-water equivalent (SWE) measurements, not the actual snowfall depth, they still are very useful in showing precipitation variability in space as well as in relative magnitude.

Using storm-total snowfall at Denver and Colorado Springs, we have identified sets of snowstorms of various intensity. The most general set used is a set of storms that produced at least 10.2 cm (4 in) of snow in either Denver or Colorado Springs. Our primary sets, however, were one that included storms that produced at least 20.3 cm (8 in) of snow in Denver, and one that included storms that produced at least that amount in Colorado Springs. Since our intention was to illustrate significant differences between major storms in the two locations, we have applied the further criterion that snowfall in Denver storms must be at least twice as great as accompanying Colorado Springs snowfall (vice versa for Colorado Springs storms). These two criteria resulted in the identification of 17 storms in Denver during the period of 1972-92 and 11 storms in Colorado Springs during the same period. Eight storms that produced heavy snowfall in one of the cities were excluded by the second criterion. A detailed description of the selection process and a full listing of the storms selected can be found in Mahoney et al (1994).

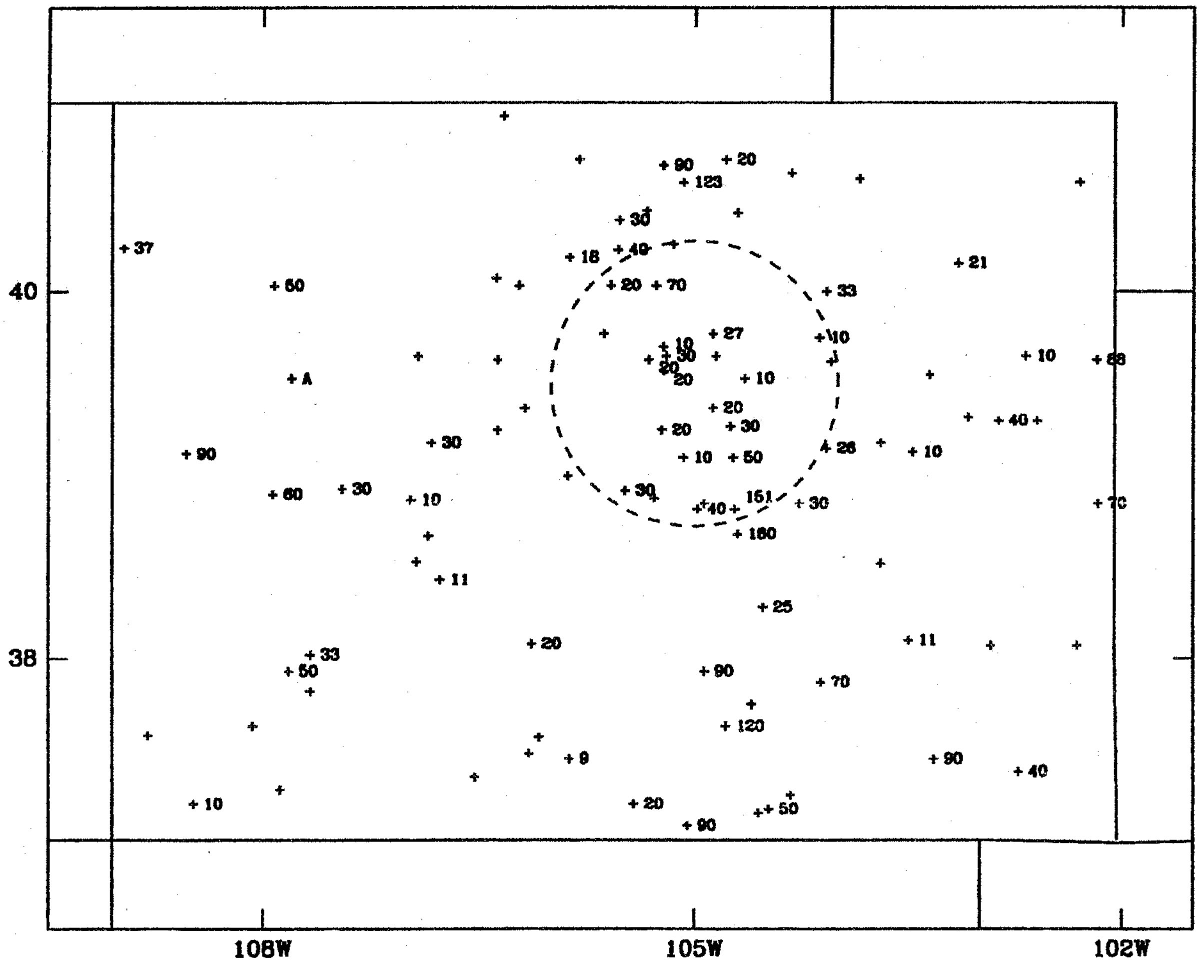

Figure 2. Precipitation (rain and/or snow-water equivalent) for the Colorado Springs storm during the period 15 March 1987 to 17 March 1987 at HPD observing sites in Colorado. Values are in hundredths of inches; to convert to mm, multiply by 0.254. The site label 'A' indicates that hourly observations were accumulated at that site for periods longer than 1 hr.

As in Mahoney and Brown (1992) and Mahoney et al (1994), analyses were devised to describe the essential and recurring characteristics of Denver and Colorado Springs storms. The principal analysis procedure was a composite representation of snowfall in Colorado assembled from observations made in the individual storms of each set. In the two previous studies, observations composited were atmospheric soundings; here, they are snowfall reports and SWE observations made at Colorado HPD sites. We interpret these composite representations as "typical" (mean or median) snowfall patterns for the two storm types.

Results

Differences in storm-total snowfall between Denver and Colorado Springs

Our first objective was to confirm that Denver and Colorado Springs storms are inherently different. In support of this objective, we use actual snowfall observations made at the Weather Service Offices in Denver and Colorado Springs to show that heavy snowfall in Denver is most often accompanied by relatively light snowfall in Colorado Springs, and vice versa. The scatterplot in Fig. 3 is based on snowfall values from both of the cities during periods of at least 10 cm snowfall at either one of them. If storms in one city had no affect on the other, all points would fall along the two axes. Conversely, if Denver and Colorado Springs storms were essentially the same, then it might be expected (given the two cities' proximity) that heavy snowfall in Denver or Colorado Springs would commonly result in heavy snowfall in the other city as well. In this latter case, the points on Fig. 3 would cluster along the one-to-one line connecting the lower left and upper right corners of the plot.

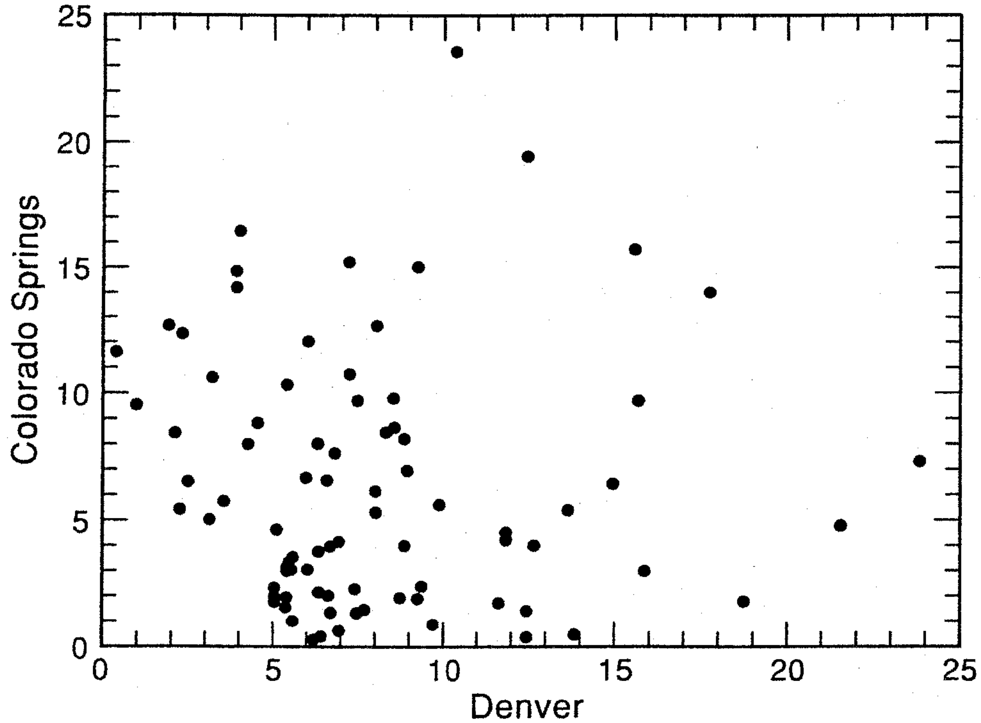

Figure 3. Scatterplot of storm-total snowfall in Denver and Colorado Springs for storms which produced at least 10 cm (4 in) of snowfall in at least one of the two cities.

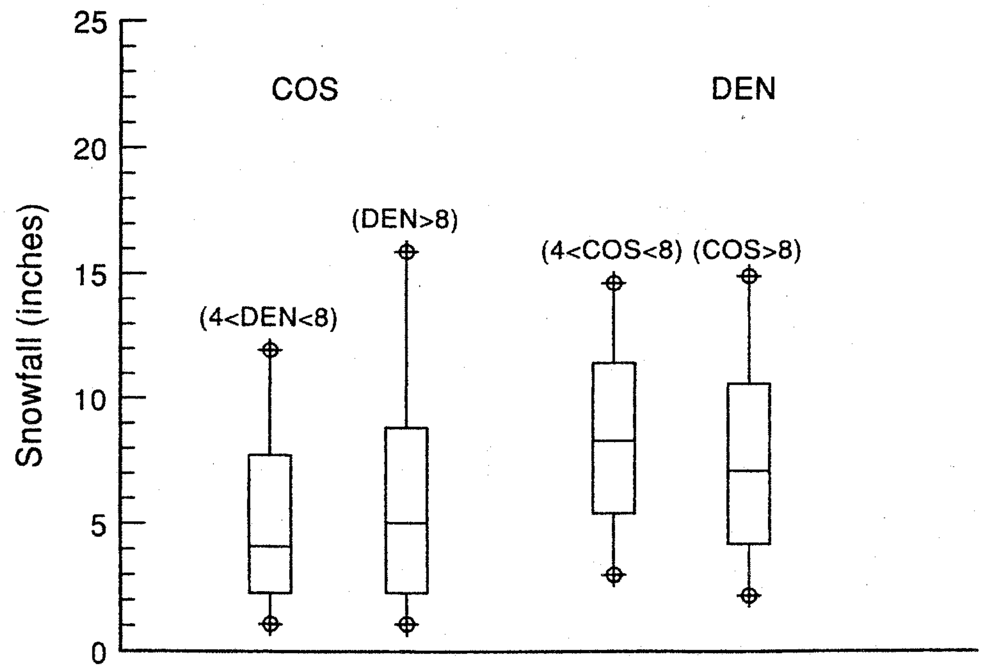

Figure 4. Boxplots displaying the distribution of storm-total snowfall in Colorado Springs during Denver storms (left pair of boxplots) and in Denver during Colorado Springs storms (right pair of boxplots). Two intensities of storms are indicated for each pair. The middle line of each boxplot denotes the median snowfall, the bottom and top of each box are the 25th and 75th percentile, respectively, and the bottom and top crosshairs are the 10th and 90th percentiles.

Inspection of Fig. 3 reveals an apparent tendency for a sparsity of points along the one-to-one line, leaving the impression of a substantial "flip-flop" in snowfall between the cities. To subjectively confirm this impression, we display in Fig. 4 boxplots of the distribution of snowfall values for two categories of Denver and Colorado snowfall totals: light (between 10 and 20 cm) and heavy (greater than 20 cm). If snowfall in Denver and Colorado Springs were closely correlated, the median of the boxplots should be roughly the same as the median value of the accompanying snowfall in the other city. The boxplots for Denver storms show a considerably different result: median snowfall in Colorado Springs for both storm categories is less than half of that expected if the two locations were perfectly correlated. The light snowfall boxplot for the set of Colorado Springs storms reveals a median snowfall in Denver that is about the same as the median Colorado Springs snowfall during these light Colorado Springs storms. However, comparison with the other boxplot of the pair (the heavy snowfall category for Colorado Springs) shows that the median Denver snowfall in heavy Colorado Springs storms is actually less than the median Denver snowfall during light Colorado Springs storms. This result would be difficult to explain if Denver and Colorado storms were inherently the same kind of system. Thus, both pairs of boxplots support the contention that heavy snowfall occurs in different storms in Denver and Colorado Springs.

Spatial precipitation distributions in Denver and Colorado Springs Storms

A basic finding from Mahoney et al (1994) is show in Fig 5. Clearly, low-level cyclogenesis in the set of Denver storms differs significantly from cyclogenesis in the Colorado Springs storm, the former being primarily a phenomenon of the eastern Colorado plains while the latter tends to produce cyclogenesis west of the Continental Divide. Given the relatively short distance between Denver and Colorado Springs and the similar location of the two cities relative to the largest of the regional terrain features (the Rocky Mountains), one would not intuitively expect to find a difference of this magnitude.

The clarity of the difference between the preferred region of cyclogenesis in the two sets of storms suggests that a precipitation analysis should also show spatial differences. To confirm this, we would like to be able to create contoured maps of composite precipitation in the Denver storms to be compared with similar maps in the Colorado Springs storms. Unfortunately, the relatively small set of storms in each set, difficulties with observations of snowfall inherent in the HPD, changes in station location during the period of storm sampling, and other data problems all conspire to render impossible the level of detail required for such a contour map.

As the next best possible analysis, we have determined stations in relevant locations across Colorado which sample all or most of the storms and also generally produce good observations. These stations are indicated in Fig. 6. The pair of numbers plotted at each station show the median SWE for all Denver storms (left) and for all Colorado Springs storms (in parenthesis). For instance, 2.62 cm (1.03 in) of liquid precipitation fell in Denver in a typical Denver storm, while 2.29 cm (.9 in) fell in Colorado Springs during a typical Colorado Springs storm. At the outlying sites, a large left number generally indicates a station whose storm-total precipitation varies most closely with Denver, while a large number in parentheses indicates a station whose storm precipitation is more closely related to Colorado Springs.

Examination of the fields of SWE values shows, as expected, that Colorado Springs generally has much lighter snowfall than Denver during Denver storms, and vice versa. Another pattern also is clear: sites on the eastern plains vary more closely with Denver, and stations west of the Continental Divide vary more closely with Colorado Springs. For instance, Seibert (labeled 70(20)) appears to be a Denver site while Grand Junction (10(39)) appears to be more closely related to Colorado Springs. These two stations are almost equidistant from Denver and Colorado Springs, effectively ruling out proximity as a determining factor.

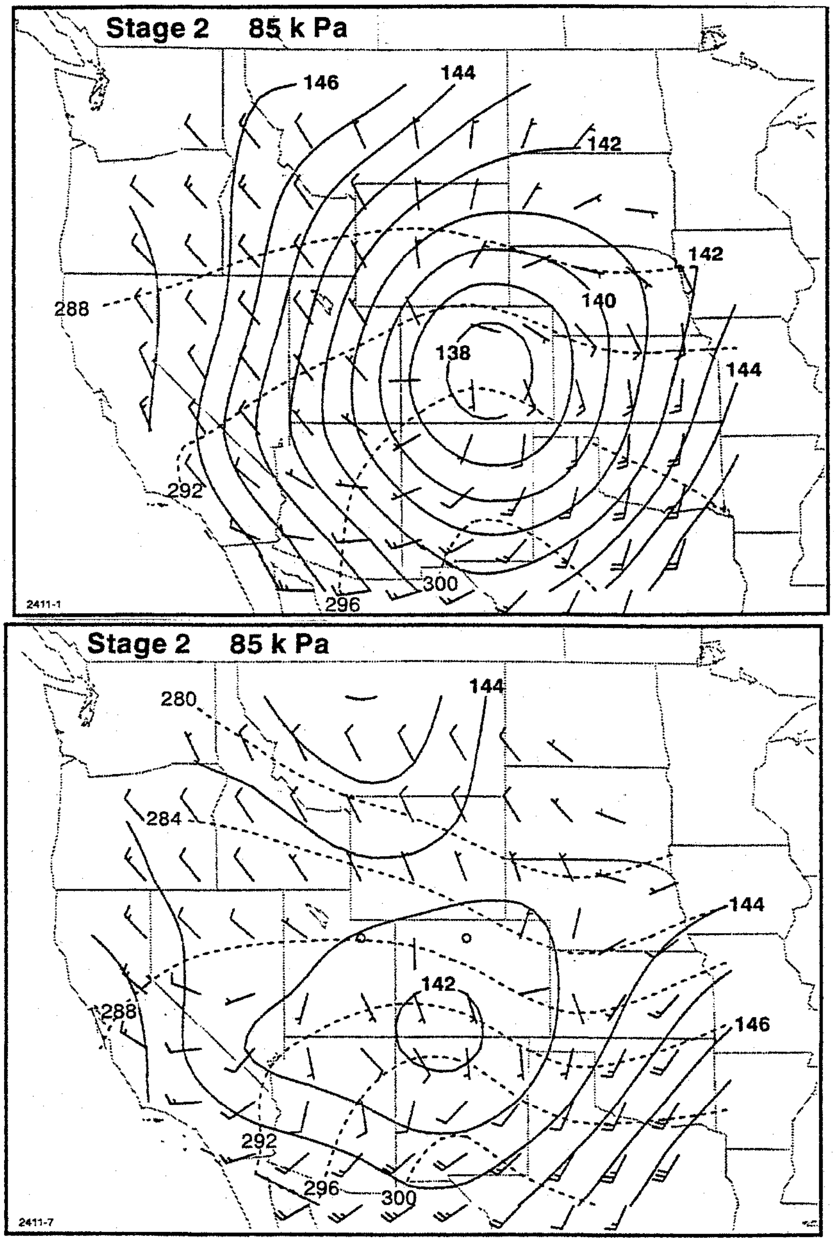

Figure 5. Composite representation of 85 kpa geopotentials (solid contours; units labeled in dm), potential temperature (dashed contours; units labeled in K), and winds for (top) Denver storms and (bottom) Colorado Springs storms (from Mahoney et al, 1994). Both plots were assembled from radiosonde data acquired at the synoptic observation time closest to the commencement of snow (Stage 2).

CONCLUSIONS

By analysing Denver and Colorado Springs storm-total snowfall, and storm-total precipitation at other HPD sites in Colorado, we have been able to confirm two characteristics that distinguish snowstorms at the two cities from each other: first, that there is a strong tendency for Denver storms to be duds in Colorado Springs (and the reverse for Colorado Storms), and second, that Denver storms are largely eastern plains storms while Colorado Springs storms more seriously effect the intermountain region to the west. The first of these results is at least partly caused by the east-west oriented Palmer Divide located between the cities. As discussed in the Introduction, this ridge has the effect of maximizing upslope snowfall in Denver under northeast near-surface flow and in Colorado Springs under southeast flow.

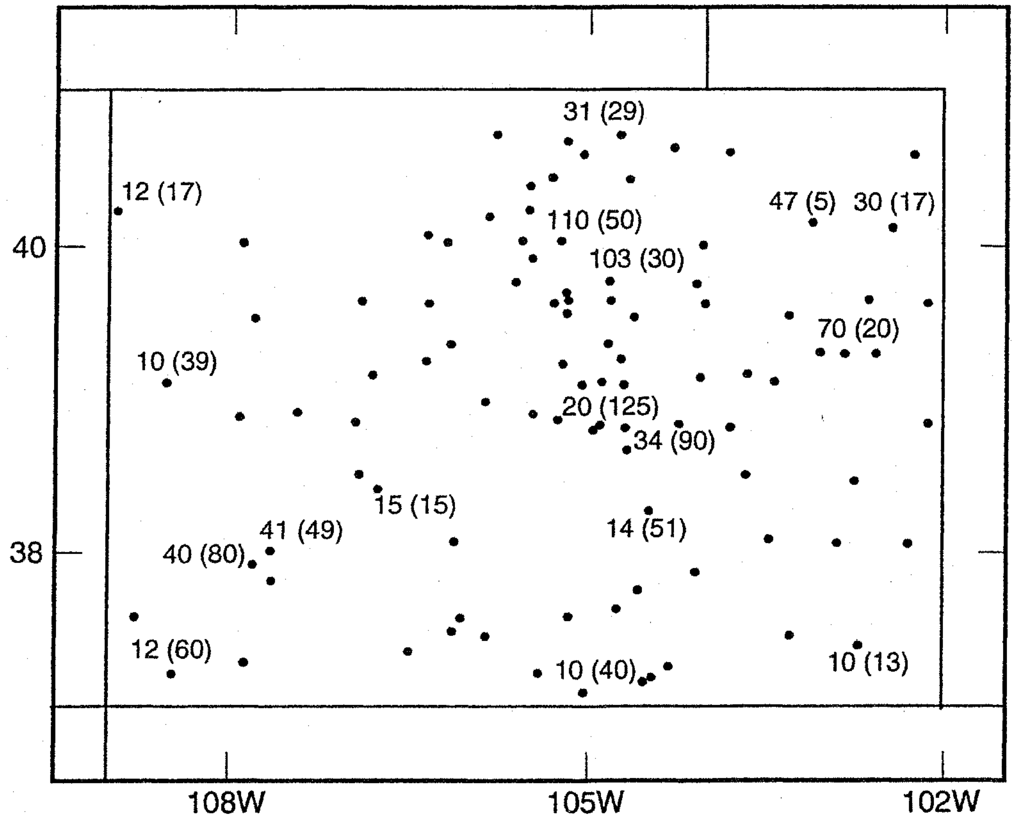

Figure 6. Median storm-total precipitation in hundredths of inches at selected HPD sites for Denver storms (left number of each pair) and Colorado Springs storms (parenthesized number).

The second result is also partially explainable by this argument. In the low-level flow indicated for Denver storms by Fig. 5, for instance, it is easy to see that northeasterly flow might dominate the Front Range. A low in south central Colorado, on the other hand (as in the Colorado Springs composite), could drive low level flow from the southeast. It is interesting to note, in this regard, that in the Fort Collins region (labeled 31(29)), located south of another east-west ridge (the Cheyenne Ridge; see Fig. 1) in much the same relative position as Colorado Springs, Colorado Springs storms typically produce very nearly the same amount of SWE as do Denver storms. Based only on proximity, one would expect Fort Collins snowfall to track Denver snowfall most closely; apparently local terrain is also exerting a strong influence on precipitation at Fort Collins.

REFERENCES

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