ANALYSIS OF HOURLY THUNDERSTORM DATA AT SALT LAKE CITY

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Abstract

Convection is an important source of precipitation in the Great Basin. This is particularly true during the warm season when a monsoonal circulation evolves northward from Old Mexico into the western states. Distributions of thunderstorm occurrence at the Salt Lake International Airport in daily, monthly and seasonal time frames were investigated using reports of audible thunder. Variabilities can be attributed to synoptic systems, insolation, the proximity of water and elevated terrain as well as advective processes.

1. Introduction

Thunderstorm distributions have been widely studied. They have often focused on particular by-products such as flash floods and hail; causative relationships like low level jets and sea breezes; or particular source regions such as mountainous terrain. Convection is a complex process influenced by synoptic and mesoscale features, solar insolation, land/water interactions, terrain and static stability of the airmass.

The southeast shore of the Great Salt Lake is unique in that convection is influenced by a variety of forcing functions, some dependent upon time of year while others on the physical setting of the lake itself. To gain some insight into mechanisms for thunderstorm occurrence at the Salt Lake City International Airport (SLC) and, in general, the southeast shore of the Great Salt Lake (GSL), a tabulation was made of the hours for which thunder was reported at the WSFO SLC station. We can determine the expected diurnal influences. We can also hypothesize about other processes which result in daily, monthly or seasonal patterns.

This study will summarize the variations in observed thunderstorm activity at SLC using monthly-by-hour, hourly-by-month and seasonal stratifications. The effects of local and regional factors will also be discussed.

Because of the dependence of this study on the *audible* nature of thunder reports, the results are only valid for the area along the southeast shore of the GSL in the vicinity of SLC. Many aspects, however, may be applicable to adjoining lower valley locations. The results are very likely not applicable to the surrounding mountainous terrain. The occurrence of precipitation was not considered in this study.

2. Terrain and Climatological Features

SLC is located near the southeast shore of the GSL at an elevation of approximately 1288/m MSL (Fig. 1). Depending upon lake elevation, SLC averages between 8 and 10 km from the water's edge, although lowland swamp is somewhat closer. The GSL is in northwest Utah, in the northeast extremity of what is generally known as the Great Basin. The lake is shallow (average depth 4.5–6 m) and large (120 km × 60 km). Water temperature varies from the upper 30s in December–January to low 70s°F during July–August (it never freezes due to high salt content). A north-south mountain barrier parallels the eastern shoreline and borders the adjoining Salt Lake Valley. Average ridge elevation is 2500–3000 m. Lowlands around the lake to the west and south average 1300–1400 m. Two smaller mountain ranges (the Oquirrh and Standsbury) begin near the south shore and extend southward. Ridges along these ranges average 2500m. Synoptic-scale events in the area are influenced by the size of the water body, daily/seasonal temperature variability and geography.

In a broader view, meteorological regimes over much of the interior western U.S. are seasonally well-defined and

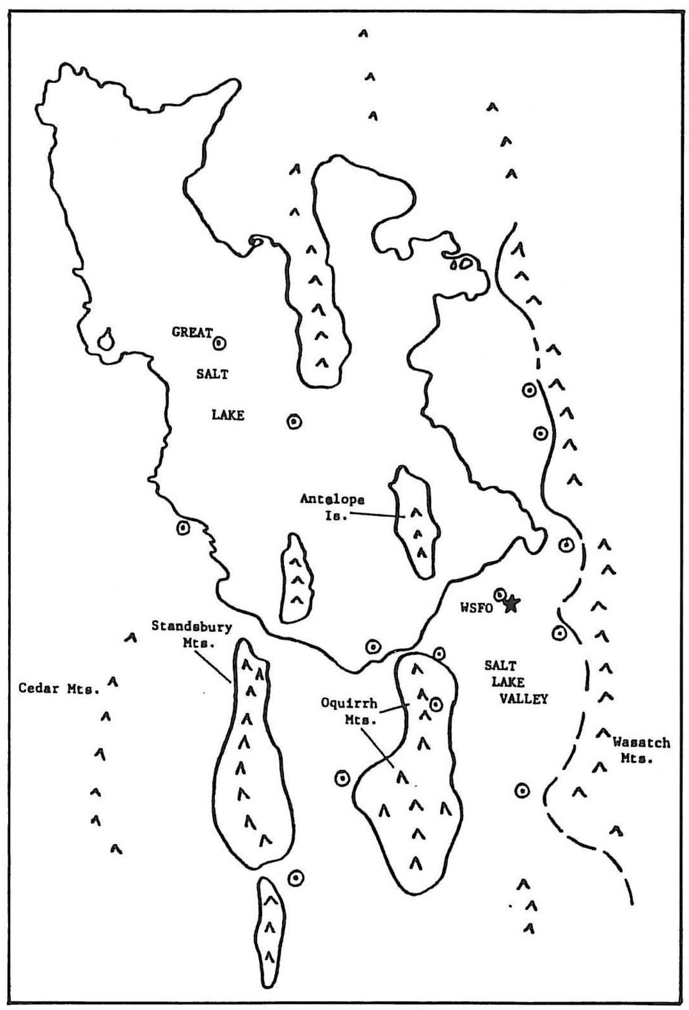

Fig. 1. Geographical features in the immediate area of WSFO Salt Lake City. ⊙ denotes approximate location of wind observations used in Figure 5.

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are controlled by the north-south migration of the mean jet stream. Intense surface heating of the elevated interior plateau in summer creates a mean monsoonal circulation, whereby moisture is drawn north from western Old Mexico and adjacent coastal waters through Arizona into the Great Basin. Winter months exhibit the effects of the migratory westerlies. Transition between these two extremes also has marked delineation. A minimum in precipitation probabilities is a climatological fact at SLC during the last few days of June, first half of July, and the first half of October (Figgins and Smith, 1989).

3. Data and Analyses

Tabulation was made for hours during which thunder was observed at the National Weather Service office at SLC for the 22-year period from 1965 through 1986. Data were taken from standard NWS observation form WBAN 10 B, Columns 82–88. Beginning and ending times of H$\pm$5 minutes were ignored in an attempt to avoid a common bias of observers to conveniently begin and end thunder on the hour. This data set includes the two driest years of record since 1929 (beginning of modern records) and the seven wettest, making it representative of climatological extremes.

Figure 2 shows the monthly variability of thunderstorm occurrence for each hour (note the vertical scale difference for 0000–1200 LST). During the predawn hours (0000–0600 LST) the peak month of thunderstorm activity is August followed closely by September. These two months maintain a remarkably uniform level of activity while others vary considerably. The next six hours (0600–1200 LST) are a minimum in the diurnal cycle. August and September show a relative maxima until 1000 LST, however, reflecting the end of nocturnal activity during those months. By 1100–1200 LST a rapid rise in occurrence is noted in May though September as an initial response to more intense surface heating.

Afternoon hours (1200–1800 LST) truly reflect the effects of the summer heat. July is climatologically the hottest month of the year in SLC and the atmosphere responds well with the greatest concentration of reports during the afternoon hours. The summer (June, July, August) peak is carried over into the 1800–2400 LST period as well.

Figure 3 shows the hourly variability of thunderstorm occurrence for each of the 12 months (note the vertical scale difference for May–September). January exhibits minimal convective activity although a distinct morning bias is evident, as 64% of all occurrences fall between 0500–1200 LST. The limited number of instances do not allow for reliable conclusions. This bias was reversed in February and March as focus shifts toward the evening hours. As spring yields to summer, the concentration of activity during afternoon and evening hours becomes striking. By June a strong diurnal trend is apparent between 1400–2100 LST. July follows suit, but a decay in this simple pattern sets in during August and September. These months still have the expected afternoon peak due to diurnal heating but the predawn hours also show an increased affinity for convection. This is particularly evident in September where predawn activity is stronger *relative* to afternoon activity. Convection tails off rapidly in October and is minimal during November and December.

Figure 4 displays the hourly variation of thunderstorm occurrence by season (note vertical scale difference in June–July–August panel). The monthly groupings were made to conform more closely to climatology. The winter period (December–January–February) seems to have rather uniform distribution except for a slight preference toward late afternoon. The number of events is low, however, and statistical significance is questionable. Spring (March–April–May) reveals a strong increase in convection which is highly weighted toward the maximum daytime heating, peaking at 1500 LST. Similar results are found during the warmest portion of the year (June–July–August). Here, mid-afternoon maxima declines only slowly until 2100 LST. Autumn (September–October–November) reveals a more uniform pattern as the differential between nocturnal and late afternoon activity becomes less pronounced. The peak in thunderstorms has also shifted to 1900 LST (on average), perhaps reflecting a longer period of heating needed to generate convective development.

4. Discussion

Forcing mechanisms for convection in the eastern Great Basin and the vicinity of the Great Salt Lake include synoptic and mesoscale features, seasonal factors such as solar insolation, moisture influx from the southwest monsoon, topography and associated diurnal wind flows.

Astling (1984, 1987) analyzed the diurnal wind regimes over adjacent areas of the GSL. He noted that the GSL acted as a heat source at night, conducive to convergent drainage, and as a heat sink during the day, providing divergent flow off the water. The effect at SLC, along the southeast shore, is to show a dominant southeast surface wind component toward the lake during the majority of the day while a "lake-breeze" regime often prevails during the midday and afternoon hours (Fig. 5). See Figure 1 for approximate locations of data points for this analysis. Magnitude of these daily reversals is dependent upon time of year and synoptic events.

The relationship between topographically induced convergence and hourly precipitation frequencies during February and July/August is seen in Figure 6 (from Astling 1984). Thunderstorms are a subset of general precipitation and their variation should be reflected in these graphs. For the sake of discussion the SLC "point" divergence calculation is assumed to be representative of the southeast shore of the GSL. During February, a maximum of convergence toward the GSL occurs about 0800 LST. This corresponds well with a peak in precipitation frequency and is reflected in the thunderstorm count (Fig. 3b). It is during the predawn hours that land/water contrasts are greatest and drainage flows peak. Another winter precipitation extreme is seen after 1800 LST and is more convective in nature as implied by a greater thunderstorm frequency. It opposes the trend in boundary layer convergence (Fig. 6, top dashed) and implies that these events may be more dependent upon synoptic forcing with late day frontal passages.

Summer patterns of precipitation and divergence relate well also in Figure 6. The early morning winter relative maximum in convergence (0800 LST) is a relative minimum during summer. The lake is not as much of a convergent force (heat source) since the predawn land-water contrasts during the height of the warm season are significantly reduced from that of winter. Because most rainfall during July/August is convective, the correlation between Figure 6 and Figure 3-g, h is very close.

During January a statistically insignificant frequency of thunder was observed. This can be a persistently stagnant time of year for SLC as an anticyclone often dominates the Great Basin. However, those events which do occur in association with frontal passages are likely linked to some extent to cold advective outbreaks over the relatively warm unfrozen water. A local SLC study indicates a temperature difference of 17–23°C between the 700-mb temperature and that of the water surface during the winter months is optimum to induce convective overturning given low enough airmass static stability and moisture availability (Carpenter, 1985).

By February and March (Fig. 3-b, c) the synoptic pace quickens as north–south baroclinicity increases. Convection during the latter half of the day (1200–0000 LST) dominates. The afternoon and evening maximum reflects convective motions associated with migratory frontal systems combining with diurnal heating. A smaller predawn peak during

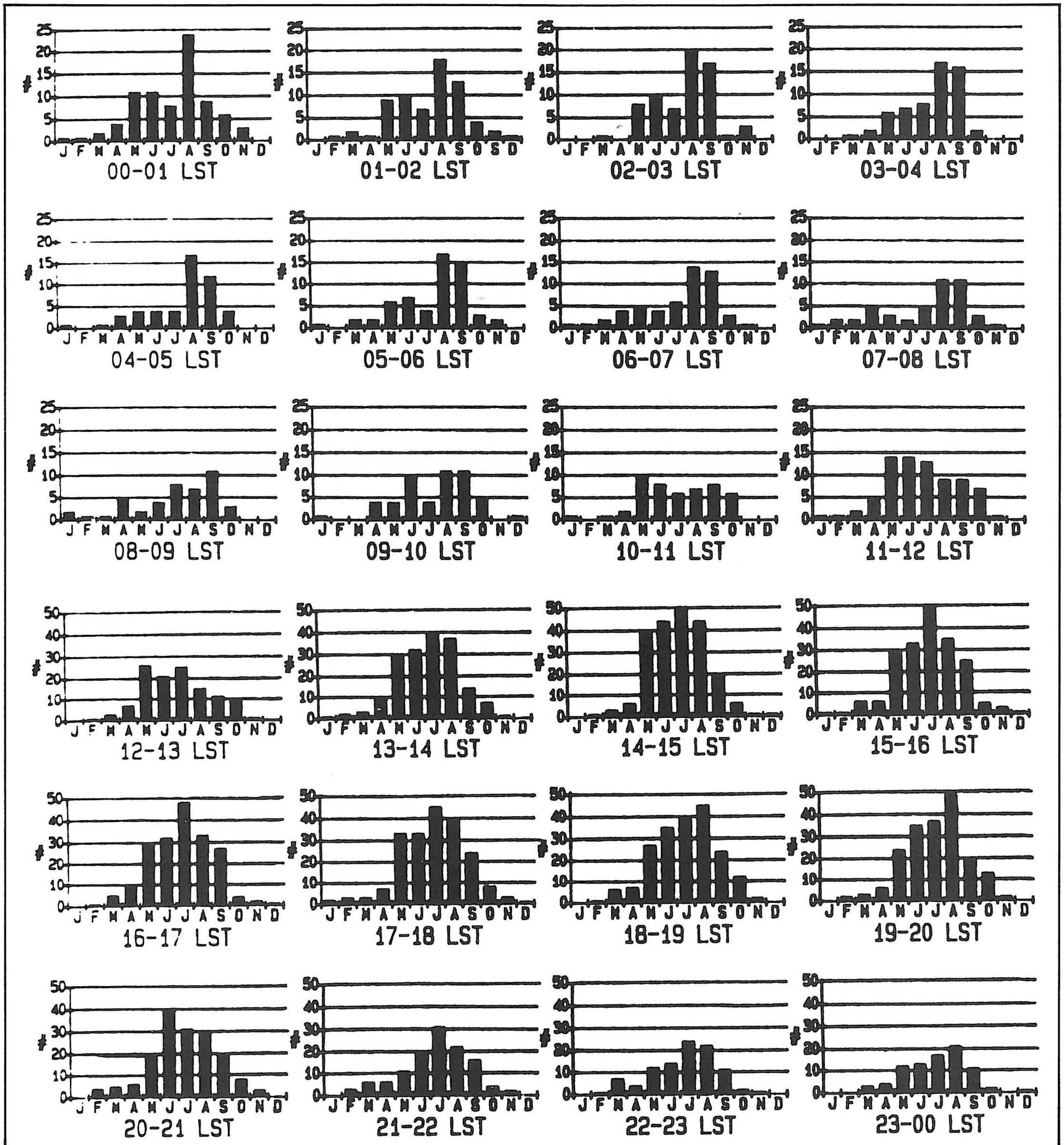

Fig. 2. Monthly variation of thunderstorm distribution by hour. Note the difference in vertical scale between 0000–1200 LST and 1200–0000 LST.

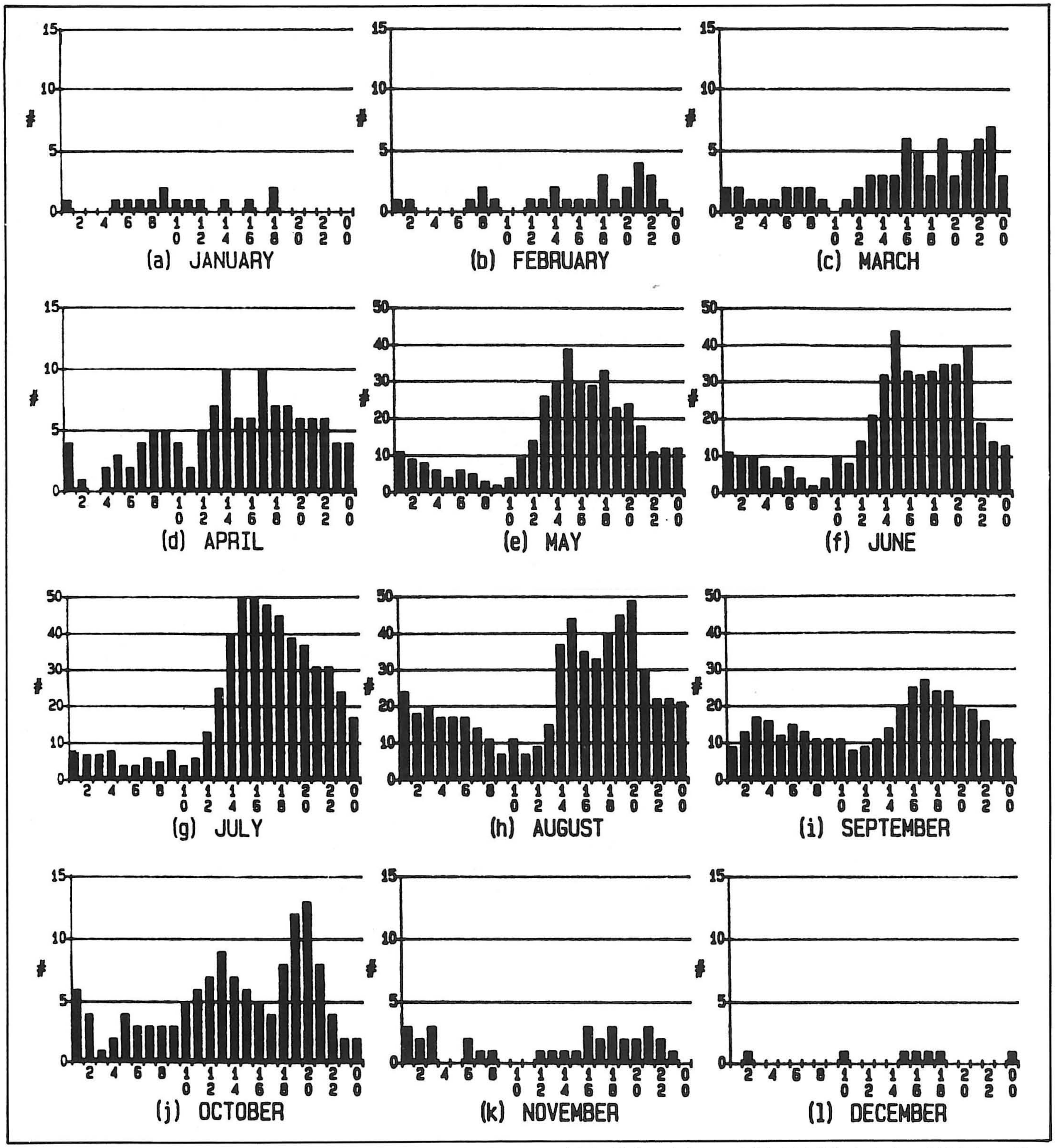

Fig. 3. Hourly variation of thunderstorm distribution by month. Times are LST with hourly interval (00–01 LST) plotted as 01 LST etc. Note vertical scale differences May through September.

this period may be partially attributed to boundary layer convergence and cold advection processes similar to January.

The spring months (April, May and June) exhibit strong diurnal tendencies signaling the increased importance of insolation as the prime convective forcing function. The sunrise peak of February/March is weakly carried over into April but disappears thereafter.

The strongest diurnal cycle occurs during July. Surface heating is most intense at this time, migratory fronts are

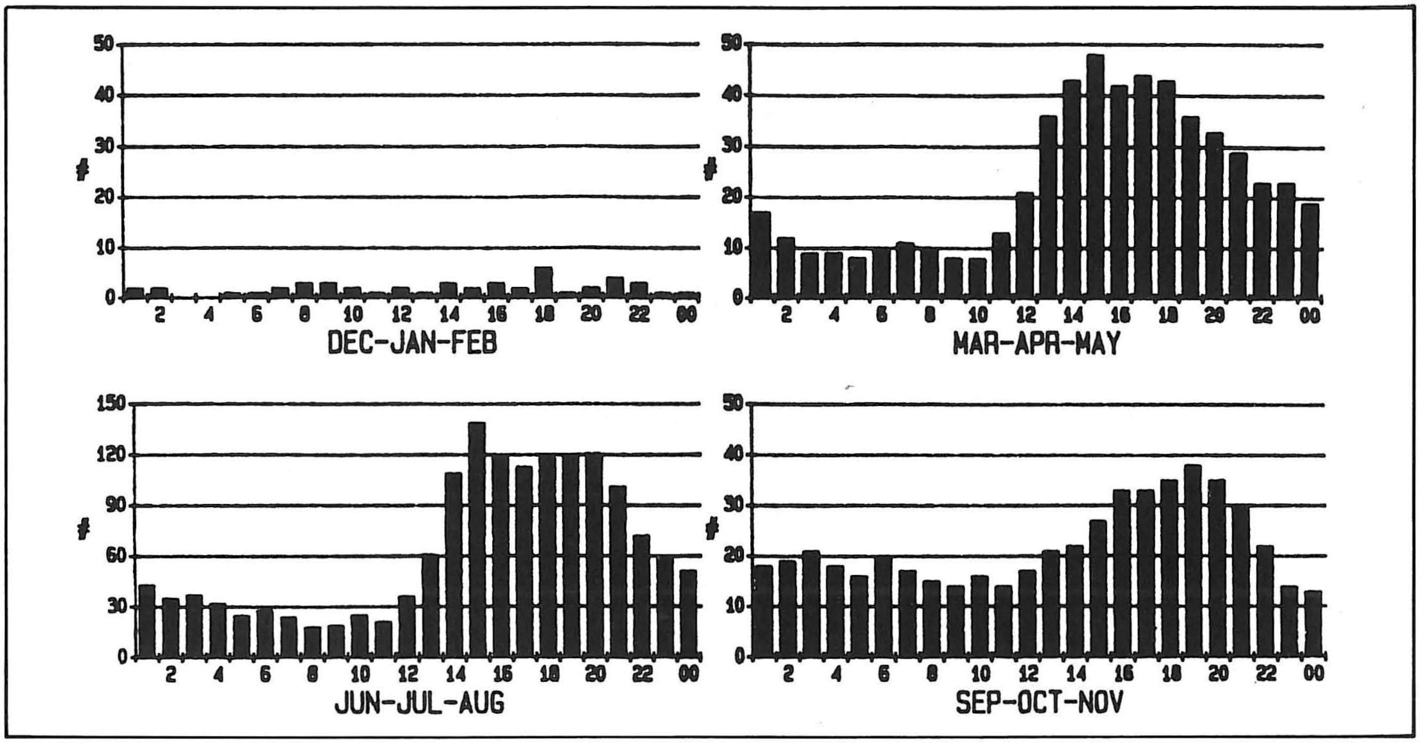

Fig. 4. Seasonal variation of thunderstorm distribution. Times are LST with interval (00–01 LST) plotted as 01 LST etc. Seasons are adjusted to reflect local climatology. Note vertical scale difference Jun–Jul–Aug panel.

minimal and moisture flux from the monsoonal circulation has, on average, begun by the second half of the month. Activity is most characteristic of "airmass" convection.

The waning months of summer (August, September) introduce other components which influence the convective cycle. Hourly profiles (Fig. 3-h, i) retain an afternoon maximum but also show a pronounced early morning relative (0000–0600 LST) bias. To account for this nocturnal activity we must first consider the normal drainage flows toward the lake (Fig. 5, bottom sequence). In itself, the drainage flow pattern does not appear sufficient to account for the late summer activity, since June and July show no such distinct tendency. However, during August and early September radiational cooling of surrounding deserts is increasing while the water body loses heat only slowly. Thus an increased thermal gradient enhances stronger convergent boundary layer fluxes. This is augmented by canyon downslope breezes along the east shores. Further, moisture of tropical origin is at its peak during the latter portion of the summer, providing fuel for convective processes when static stabilities are low enough.

A number of months, particularly June, August and October, show twin peaks of activity, (1300–1500 LST) and (1900–2100 LST). These likely reflect the local and non-local origins of convection affecting the Salt Lake Valley. The absence of this configuration during July may be partially attributed to the overpowering diurnal influence of solar heating masking other effects. It's apparent absence in September during the time of this study is unknown.

The first peak represents thunderstorms which form over the nearby Oquirrh Mountains. Studies of convection in the Colorado Rockies have shown that cells are induced by an elevated heat source and topographical updrafts form over mountainous terrain, then drift away over valley locations. The proximity of SLC to the Oquirrh Range suggests that thunder would be detected soon after the activity had formed and before the storms moved very far from their generation zone.

The second peak is indicative of cells which form over eastern and central Nevada or southwest Utah then advect northeastward during the afternoon. A southwesterly flow aloft is the preferred regime over the eastern Great Basin during June–October. NWS Western Region Tech Attachments 74-14, 74-21 (1974) and 73-39 (1973) detail favored 500-mb patterns during June, August and October. These thunderstorms can be associated with mesoscale disturbances or develop diurnally over mountainous terrain of Nevada. They then propagate northeastward reaching the SLC area during the late afternoon or early evening hours.

Figures 7a and b are satellite photographs that illustrate how this dual maxima can occur. At 282116 UTC (1416 LST) active convection was in progress in the vicinity of SLC. It was at least partially initiated by a short wave moving northeastward across south central Nevada. The height lines are 500-mb data valid at 290000 UTC, about 3 hours after the image. By 290146 UTC (1846 LST) the thunderstorms directly associated with the upper air disturbance are about to enter the Salt Lake Valley. These impulses in a southwest flow aloft are not uncommon in the eastern great basin during the summer season. The synoptic environment is in agreement with the Type 1 flash flood pattern identified by Maddox *et al.* (1980).

The frequency of convection drops off rapidly during the autumn months. October retains a strong multiple peak. Weighting toward the late afternoon hours suggest a strc g dependence upon daytime heating. The dual maxima may again reflect the some influence of an upstream origin. Early season cold outbreaks over a still warm GSL probably contribute to some of the post midnight count in October and November.

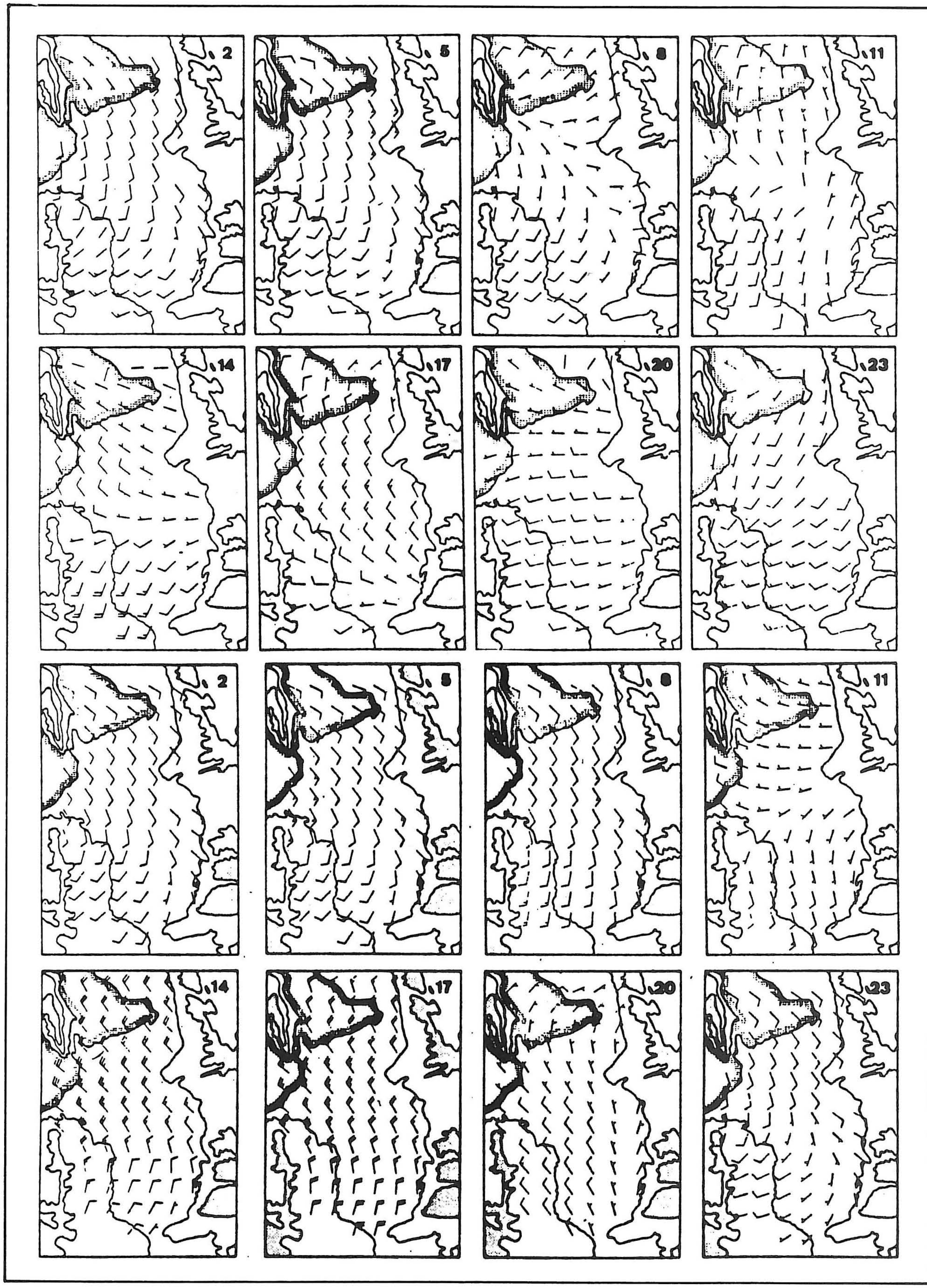

Fig. 5. Objective analysis of hourly-averaged winds from stations in and around the Salt Lake Valley (See Fig. 1). *Top two* rows are winter, *bottom two* are summer. Times are LST in 3 hourly intervals. Grid size 5 km. Full barb is 1 m/s (2 kt) (after Astling, 1984).

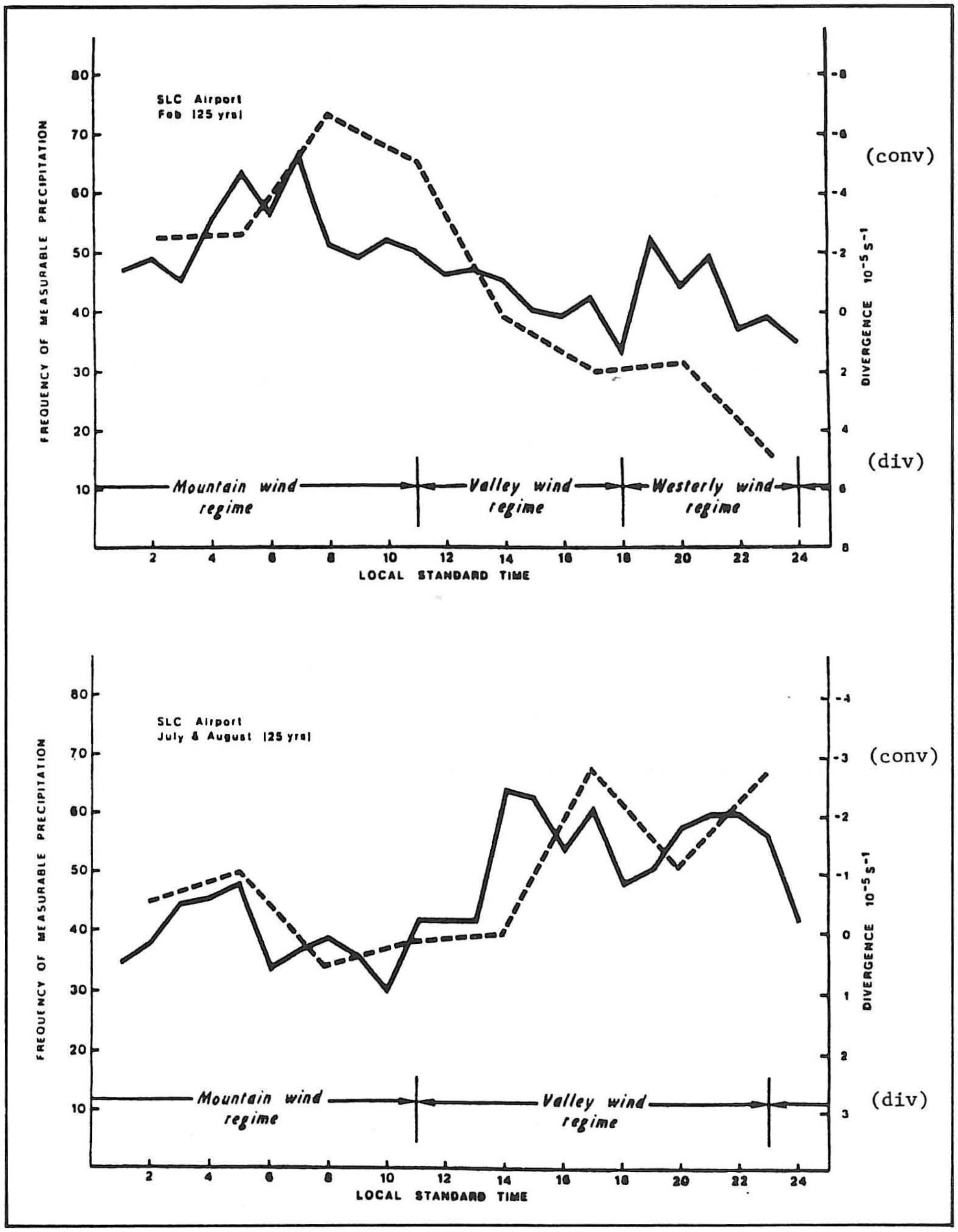

Fig. 6. Hourly frequency of measurable precipitation (solid line) at SLC for February (top) and July/August (bottom) for a 25 year period. Three-hourly averaged wind divergence at SLC is dashed line (after Astling, 1984).

5. Conclusion

The environs of the Great Salt Lake are unique in that a large water body is isolated in a desert-mountain setting. The lake is large enough to influence mesoscale circulations and climatology over adjacent areas. Location of a long term meteorological observational site along the south shore of the GSL allows these effects to be studied and hypotheses made regarding thunderstorm formation.

Hourly observations of thunderstorm occurrence at SLC during a 22-year period (1965–1986) were tabulated. Variations in daily, monthly and seasonal counts suggest that a range of forcing mechanisms can be identified. Insolation and synoptic disturbances are the most important macro components. Detailed analysis of secondary peaks (day and night) indicate that boundary layer convergence toward the GSL, differential land/water heating or cooling as well as source regions for formation are all important contributors.

While the scope of this study included extremes of dry and wet years, a longer time frame may be necessary to verify the hypotheses developed here. Also, breaking the data set up into above average (wet) and below average (dry) years may suggest mechanisms which predominate during those regimes. No consideration was given to the occurrence of precipitation. High-based "dry" thunderstorms are not uncommon in this area. Perhaps factoring this element out or considering it separately would also lead to alternate conclusions regarding the convective regime at SLC.

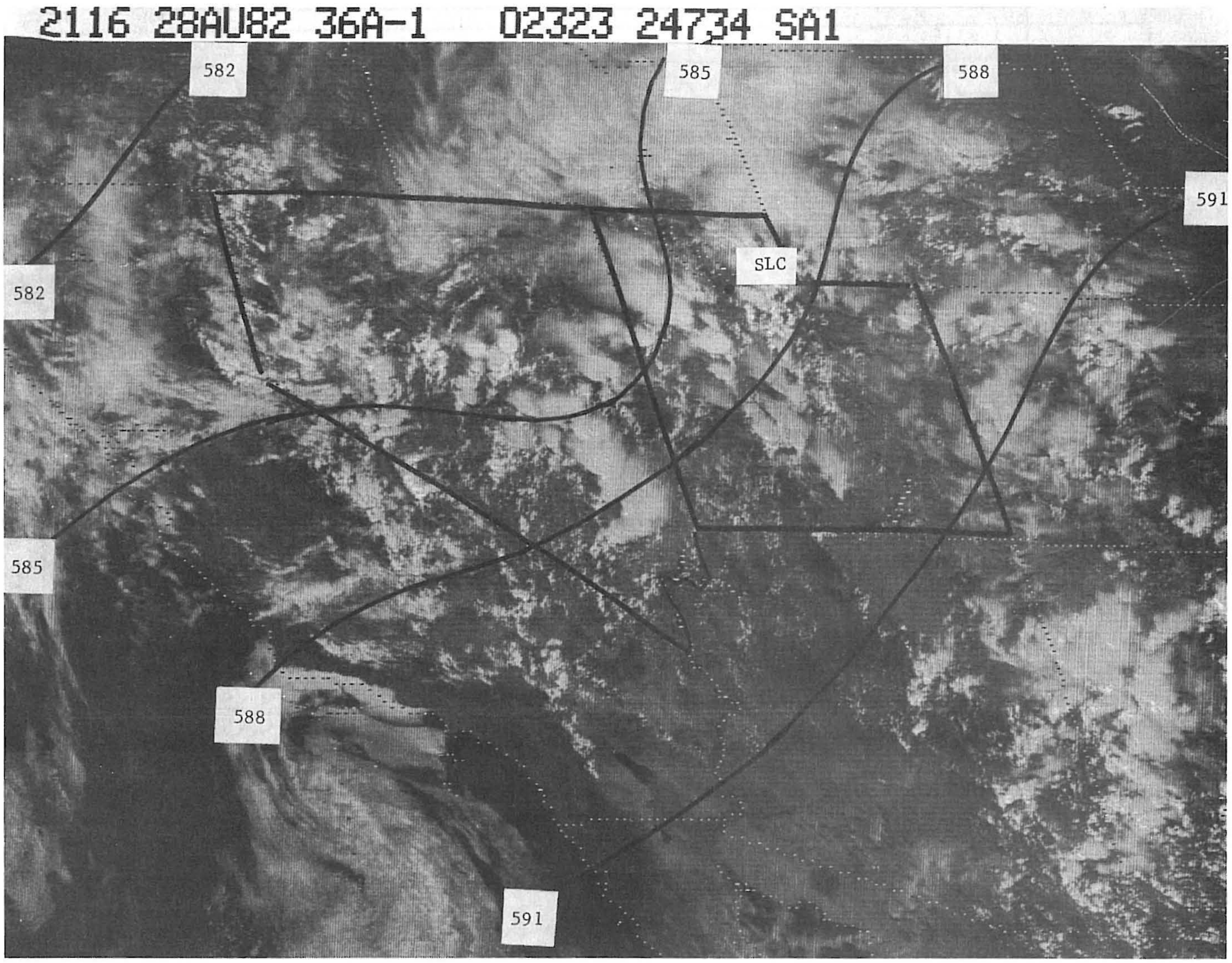

Fig. 7a. Example of dual origin of convection for SLC. Mid afternoon photo shows thunderstorms in northwest Utah breaking out ahead of a short wave disturbance moving northeastward from south central Nevada. 500-mb height contours for 290000 UTC are overlaid. Thunder would likely be reported at about this time as convection is initially aided by local mountain ranges (see Fig 7b).

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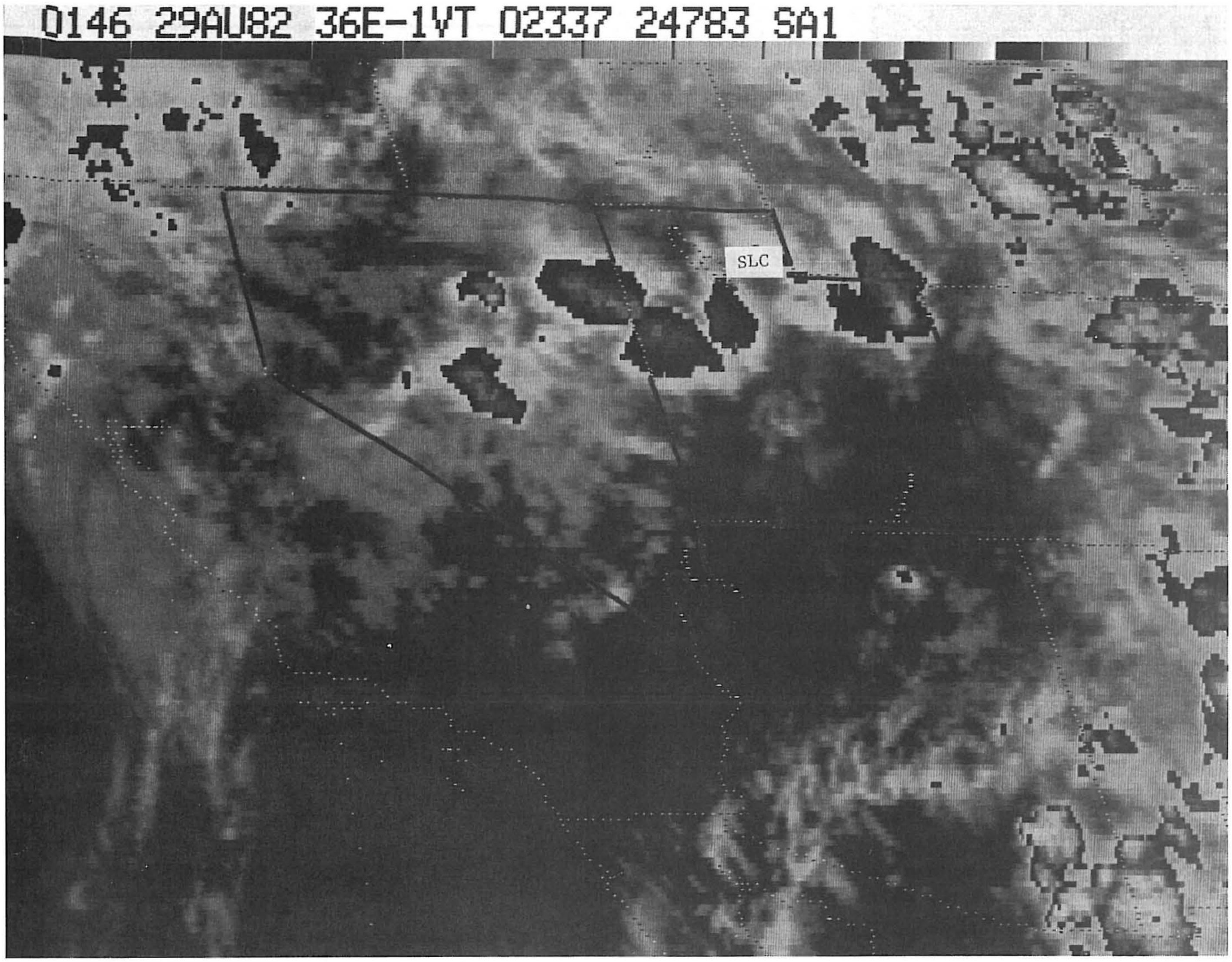

Fig. 7b. A second round of thunder is in progress at SLC as convection associated with the short wave trough itself reaches northwest Utah.