

## Comment on: "A Study of 30 Years of July and August Hourly Precipitation Data for Omaha, Nebraska"

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Sangster (1989) considers several aspects of the well-known problems of documenting and understanding the nocturnal character of summer precipitation over the Plains states of the central United States (e.g., Kincer 1916; Wallace 1975). The problem is important since we still do not understand well the interplay of large and mesoscale processes that leads to nighttime thunderstorms and widespread rains over the Plains. The accurate prediction of them remains elusive. Sangster's article presents an interesting and careful documentation of the nocturnal character, especially of significant rainfall amounts of summer rains (July and August) at Omaha, Nebraska (a station with a long observation record also located in the area experiencing the most pronounced nocturnal precipitation signals, e.g., Balling 1986; see Fig. 1). However, we feel that some statements made by the author are not well-founded and wish to stimulate discussion of several issues with the readership of *Weather and Forecasting*.

Sangster reviews studies of nighttime thunderstorms in this region of the country by Means (1944) and casts doubt upon the soundness of the procedures employed. Briefly, Means (1944 and 1952) had determined that substantial warm temperature advection (indicated by "cross patterns" in mean monthly height and temperature contours, see Fig. 2) appeared to be occurring over the region frequented by nighttime thunderstorms. He came to several important conclusions. Most prominent was his finding that differential thermal advection, particularly the low level warm component, could be acting to destabilize the atmosphere during the nighttime over the Plains. Indeed, in the conclusions of his 1952 paper he stated that, "Underrunning' associated with low-level jets deserves the attention of forecasters along with the possibly too-frequently-used frontal concept 'overrunning.'" Little attention apparently was paid to this suggestion until the work of Carlson and Ludlum (1968) documented

the importance of this type of differential advection in the development of severe thunderstorm environments. Means further made the case that the low-level jet played an important role in establishing the thermodynamic environments conducive to Plains thunderstorms. Finally, Means concluded that the semi-permanent presence of warm air over the elevated terrain of the southwest during summer played an important role in establishing the "cross patterns" so apparent in the monthly mean charts (again, refer to the chart reproduced in Fig. 2).

Sangster feels that Means' monthly charts are "unconvincing" because, "The existence of isobar-isotherm cross patterns on mean charts indicates that vertical motion and/or diabatic effects are important, since the local rate of temperature change averaged over a period of a month or so is small." However, the fact that the cross patterns are so pronounced leads us to feel that Means' charts capture important aspects of the forcing for the Plains' nighttime maxima of thunderstorms and precipitation. If the average charts indicate repetitive quasi-geostrophic forcing for upward motion, i.e., the "cross patterns," the local rates of temperature change should remain small, because the cooling associated with the upward motion would nearly balance the warming due to horizontal advection. Since the cross patterns are so pronounced, we feel that Means' charts did indeed capture important aspects of the background setting, and associated forcing for upward motion, that lead to Plains' thunderstorms and precipitation in the summertime.

We admit that it would have been useful if Means' charts were for specific times during the day rather than longterm averages. But the signal is very strong and it reinforces the importance of diabatic heating to the west over the mountains. Preferential warm advection regions (i.e., areas of recurrent quasi-geostrophic forcing of upward vertical motion) are therefore tied to the zone downwind of the mountains. Sangster chooses to emphasize the destabilization aspects of Means' arguments and takes the position that they are further flawed since upward lifting, in addition to instability,

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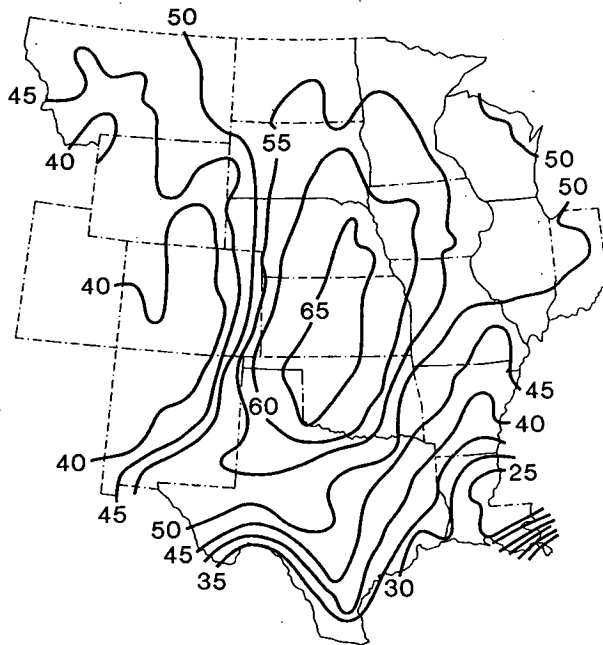


FIG. 1. Frequency of nocturnal (8 pm to 8 am) precipitation events of greater than 2.54 mm/h for June and July 1948-1983 (from Balling 1986).

is required to cause thunderstorms. However, given the advantage of a quasi-geostrophic perspective, the reader is struck by the obvious association between Means' "cross patterns," their associated forcing for upward motion, and the region experiencing nocturnal storm activity. The moist instability available to support thunderstorm development probably varies more day-to-day than does the large-scale forcing for upward motion.

It is well-established that the organized mesoscale convective systems that frequent the area of nighttime rains are also nocturnal in character, and are strongly associated with regions of pronounced warm advection in the lower troposphere, below about 600 to 700 mb. (The interested reader may refer to Maddox 1983; Rodgers et al. 1985; Fritsch et al. 1986; McAnelly and Cotton 1986; Augustine and Howard 1988; and Cotton and McAnelly 1989 for detailed discussions of the environmental, climatological, and precipitation character of central United States mesoscale convective systems.) We are puzzled therefore as to why Sangster considers the diagnosis of low level tropospheric warm advection to be "... a forecaster's crutch." We consider it to be a critical diagnostic tool for refining the convective forecast, particularly during the warm season. Thunderstorms are more likely to occur in an environment characterized by moist instability, within regions of upward large-scale vertical motion (see the discussions regarding the use of diagnosed warm advection to help delineate thunderstorm forecast regions in Maddox and Doswell 1982). The differences be-

tween a tool and a crutch are substantial; "crutch" implies an aide or rule of thumb applied with little understanding or documented physical basis. Use of quasi-geostrophic theory to improve or refine one's forecast represents application of a powerful, well-documented forecasting tool!

We agree that the pronounced low-level diurnal wind oscillations over the Plains also play an important role in the development of nighttime storms (e.g., Blackadar 1957; Pitchford and London 1962; Bonner 1966). However, Means succinctly pointed out that the processes of elevated heating, development of nocturnal jets, persistent warm advection, and thermodynamic destabilization are all closely interrelated. We agree that improved understanding of these processes is required if we are to resolve the central United States nighttime thunderstorm paradox. Improved representation and resolution of boundary layer, radiation, and turbulent processes in operational numerical forecast models probably would improve numerical predictions of all types of precipitation; explicit prediction of thunderstorms in operational forecast models likely remains a number of years in the future.

We have prepared several simple analyses to help the reader to evaluate the work of Means. The July hourly precipitation records for Omaha were used for

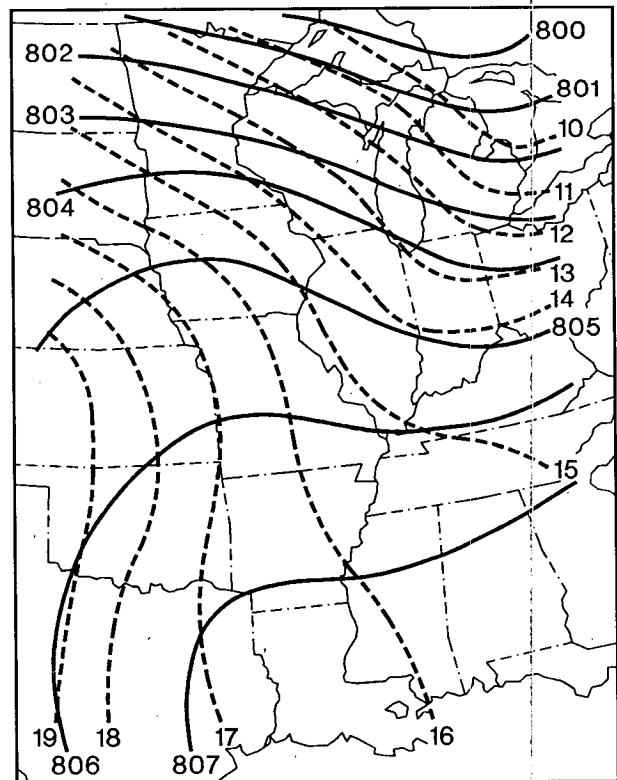


FIG. 2. Mean 2000 m chart for July 1939-1944. Dashed lines are isotherms ( $^{\circ}\text{C}$ ) and solid lines are isobars (mb). Chart is from Means (1952).

the period 1958–1987 to identify nocturnal rain events that produced at least 0.25 inches of rainfall. We restricted our attention to rain events that commenced between 0000 UTC and 1200 UTC and ended by 1800 UTC. During the 30-year period examined, 67 such nighttime precipitation events were identified (the frequency of occurrence of such events in July is thus slightly more than 7%). Composite maps of the 850- and 700-mb charts for 0000 UTC preceding the nighttime rain event, and for 1200 UTC the next morning, were prepared by averaging the pressure level data for surrounding upper air stations for all of the events. The resultant charts (Figs. 3 and 4) represent average conditions associated with significant nighttime rains at Omaha during the month of July. At 0000 UTC prior to the nighttime rains, the 850-mb (Fig. 3a) height

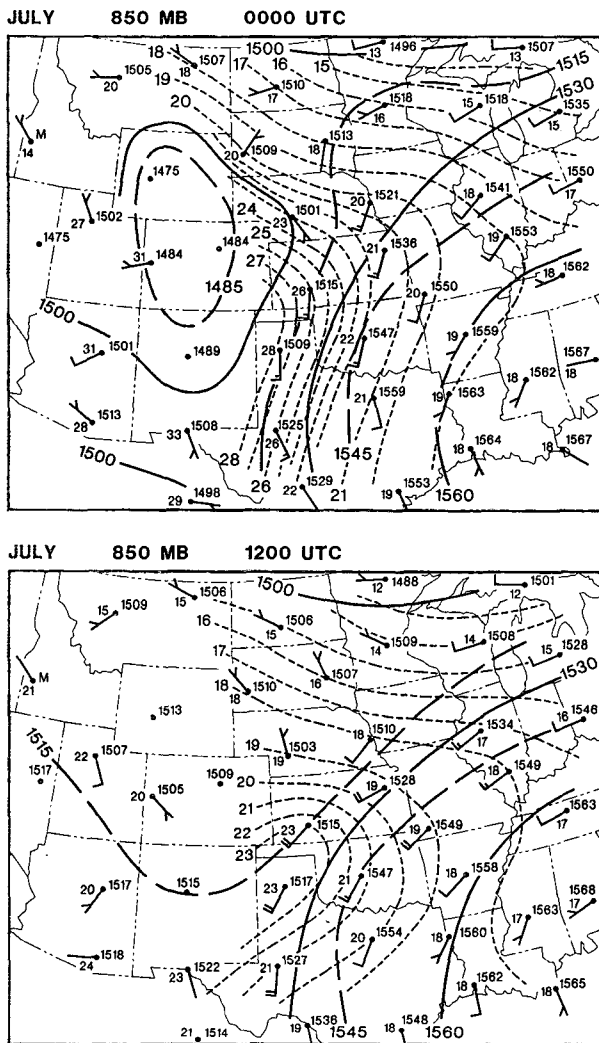


FIG. 3. (a) Mean 850-mb chart for 0000 UTC preceding 67 nocturnal rain events at Omaha, Nebraska. Height contours (m) are solid lines and dashed lines are isotherms ( $^{\circ}\text{C}$ ). (b) Same analysis fields for 1200 UTC the next morning.

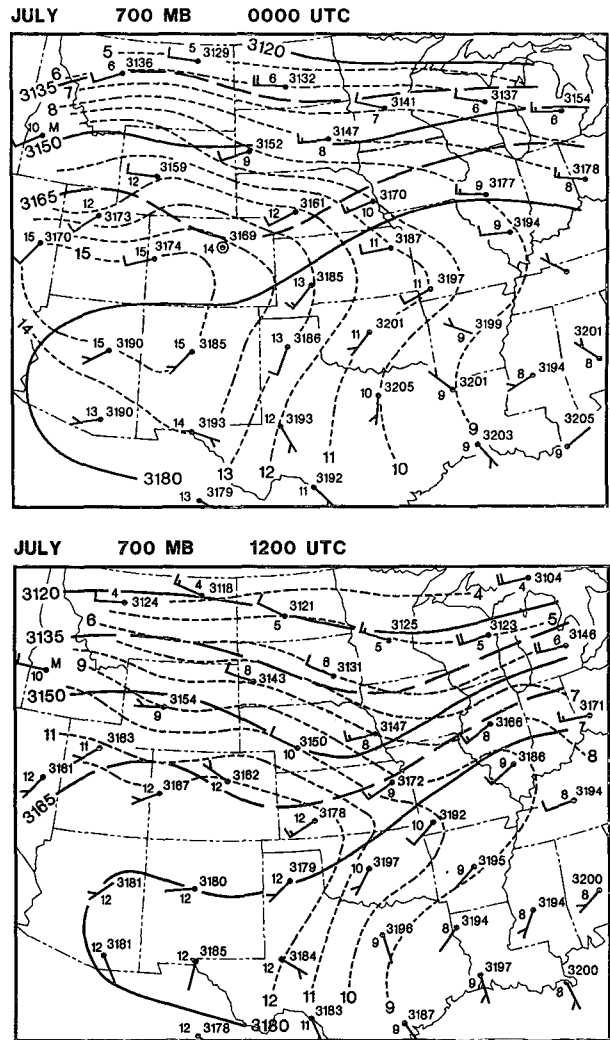


FIG. 4. (a) Mean 700-mb chart for 0000 UTC preceding 67 nocturnal rain events at Omaha, Nebraska. Details as in Fig. 3a. Same analysis fields for 1200 UTC the next morning. Shaded area is the region where average relative humidities have increased by more than 10% during the time between analyses.

gradient associated with the mean, southerly low-level jet is apparent over the Plains along the western periphery of the subtropical high. The winds appear to be sub-geostrophic because they have a component directed toward lower heights to the west at a number of stations. The overall patterns at both 0000 and 1200 UTC (Figs. 3a and b) are remarkably like Means' chart shown in Fig. 2, with warm advection present from Kansas and Nebraska eastward to the Great Lakes area (note that Means' charts are constant height analyses and are thus not directly comparable to these constant pressure charts). The 850-mb analysis for 1200 UTC (Fig. 3b) illustrates several important aspects of the nocturnal rain setting for Omaha. Marked diurnal cooling has occurred over the high Plains and inter-

mountain west and the height gradients over the Plains appear slightly weaker. However, the low-level jet is now much more distinct in the observed winds from west Texas to northern Illinois. The morning winds also appear to be more nearly geostrophic. The region of pronounced warm advection is tied directly to this jet and obviously has its roots in the plume of warm air from the southwest. Even though warm advection has been indicated for 12 h over a large area, temperatures have cooled at almost all locations, indicating the effects of both diabatic cooling and upward motion.

The corresponding analyses for 700 mb are shown in Fig. 4. At 0000 UTC, pronounced warm advection is present from the Colorado Rockies eastward to northern Illinois, again illustrating the important role of the elevated heat source over the western mountains in maintaining the persistent warm advection pattern. By morning, temperatures again have decreased over the entire domain, but relative humidity has increased substantially from southeastern South Dakota and eastern Nebraska to Northern Illinois (i.e., over the region where nocturnal convection has presumably occurred frequently enough to influence the averages strongly). This pattern appears to bring nighttime rains to a fairly substantial mesoscale region that encompasses much of the corn belt.

Finally, it is curious that in the mean for these 67 cases, an afternoon short-wave trough to the immediate lee of the western mountains amplifies during the night and appears to become directly coupled with the nocturnal rain event. This may be the result of important interactions between the elevated heat source, its intense diurnal character, the background large-scale flow, and embedded precipitation systems. However, it could also reflect a necessary and recurrent feature of the large-scale setting for July rains at Omaha.

In summary, we do not agree with Sangster that Means' results were flawed but we do agree wholeheartedly that the meteorology that produces the nocturnal rainfall maximum over the central United States is intriguing and worthy of more detailed investigation. The simple analyses shown above support these conclusions.

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