Western Region Technical Attachment
89-24
August 22, 1989

Frontal Characteristics of the Arizona Monsoon Boundary

[Editor's note: The following Technical Attachment is a summary of an article by Thomas C. Adang and Robert L. Gall (from the University of Arizona) entitled "Structure and Dynamics of the Arizona Monsoon Boundary", which appeared in the July 1989 issue of Monthly Weather Review. The article contains some interesting information about the similarities between the Arizona Monsoon Boundary and midlatitude frontal boundaries.]

Early in the summer, usually between late June and early July, the southwestern U.S. experiences a change in air mass from continental tropical to maritime tropical, which generally lasts through September. This change in air mass is due to a northward shift in the subtropical surface ridge from Mexico to north of Arizona. The result is a shift in the direction of the prevailing winds from westerly to southeasterly. This seasonal change in wind direction satisfies the standard definition of a monsoon circulation. During the season when much of Arizona is under the influence of the warm, moist air mass (about three months) Tucson averages more rainfall (5.91") than during the remainder of the year (5.18"). Figure 1 shows the mean streamline analysis (from Bryson and Hare, 1974) for the month of August in which it is apparent there is a boundary separating generally northwesterly flow from southeasterly flow. The northwesterly flow is dry since its ultimate source is the cold Pacific Ocean, while the southeasterly flow is very moist, having come from the warm Gulf of Mexico. Data that Adang and Gall have collected suggest this boundary is a little farther to the west than shown in Figure 1.

The onset of the monsoon at Tucson in 1984 was analyzed using RAOB data (winds, moisture, and temperature), satellite imagery, and surface pressure. Mean soundings (not shown) were constructed for before and after the monsoon onset. The major changes after the onset were a significant increase in moisture at all levels, and a temperature lapse rate that was slightly more stable (closer to moist-adiabatic). Time-height cross-sections (not shown) constructed from the RAOB data show that the onset of the monsoon was quite distinct, somewhat like the passage of a midlatitude front. There was a sharp increase in mixing ratio in the lower levels, a well-defined shift in wind direction at all levels, and a distinct surface pressure fall followed by a pressure rise as the monsoon boundary passed through Tucson. It is obvious from their data that there was a distinct air mass change.

The monsoon boundary was examined more closely in August of 1985 using cross-sections provided by the Fleet Numerical Oceanography Center (FNOC). They were constructed using conventional RAOB data and soundings from satellite data. The cross-sections are all generally perpendicular to the monsoon boundary. Figure 2 is a water vapor image at 2330 UTC 1 August 1985 which shows the boundary in Arizona separating the dry air mass (dark) from the moist air mass (brighter). Figure 3 is a cross-section from roughly the same time as the satellite image, and runs approximately from San Diego to the western Gulf of Mexico. The monsoon boundary is roughly at the center of the figure. The top part (a) shows that there is a sharp boundary between southwesterly winds to the west and southeasterly winds to the east. There is also a strong gradient of moisture (mixing ratio values) at the boundary. The edge of the moisture at 400 mb in the cross-section compares well with the location of the boundary on the water vapor image. The deformation axis along the boundary apparently helps to maintain the sharp moisture gradient and forces the ageostrophic circulation shown in the bottom part of Figure 3 (b). The circulation is such that there is rising motion on the moist side and sinking motion on the dry side.

A composite cross-section was constructed for 11 days in August 1985 from the same data provided by FNOC. The composite confirmed the ageostrophic circulation about the boundary as seen in the single cross-section. Winds, including the ageostrophic circulation, were found to be roughly one fourth as strong as typical midlatitude fronts. The temperature gradient across the monsoon boundary was about one third the value of a typical frontal boundary. However, it was noted that in some cases the temperature gradient approached the strength of typical midlatitude fronts. Furthermore, the bulk of the temperature gradient from the composite cross-section was found on the cool side of the boundary (the boundary is defined as the axis where the across-boundary wind component goes to zero), which is also found with midlatitude fronts. Equivalent potential temperatures were found to be higher on the moist side, which means the moist side is potentially warmer than the dry side. However, the actual surface temperature may not change much across the boundary. The ageostrophic circulation around the boundary is therefore a direct circulation.

Cloud-to-ground lightning strike locations are also a good indicator of the monsoon boundary position. Figure 4 shows ground strike locations in a two and a half hour period on 23 July 1985, with the approximate monsoon boundary position (inferred from water vapor imagery) overlaid. Thunderstorm clusters are apparent to the east, and right up to the edge, of the moisture boundary.

Conclusions: Time-height cross-sections constructed from RAOB data in 1984 and the composite 11-day cross-sections constructed from RAOB and satellite data in 1985 are nearly identical. Similarities in the wind, moisture, and temperature fields indicate that the Arizona Monsoon Boundary is a consistent feature each season. Furthermore, the deformation axis, moisture boundary, ageostrophic circulation, and temperature gradient at the surface all indicate that the boundary is much like a midlatitude frontal boundary, though not as strong. [Note: There are also many similarities to the dryline of the Southern Plains in terms of the moisture and temperature fields as well as the three-dimensional wind structure. For a detailed discussion of the dryline structure, see the 1974 article by J. Schaefer entitled "The Life Cycle of the Dryline" which appeared in Volume 13 of the Journal of Applied Meteorology.] The authors also speculate on the possibility that disturbances could develop along the boundary, much like with midlatitude frontal systems, and play a significant role on the weather in the southwestern U.S. The composite wind shears suggest that the boundary may be unstable to both barotropic and baroclinic processes. Cyclonic development has been known to occur along the boundary.

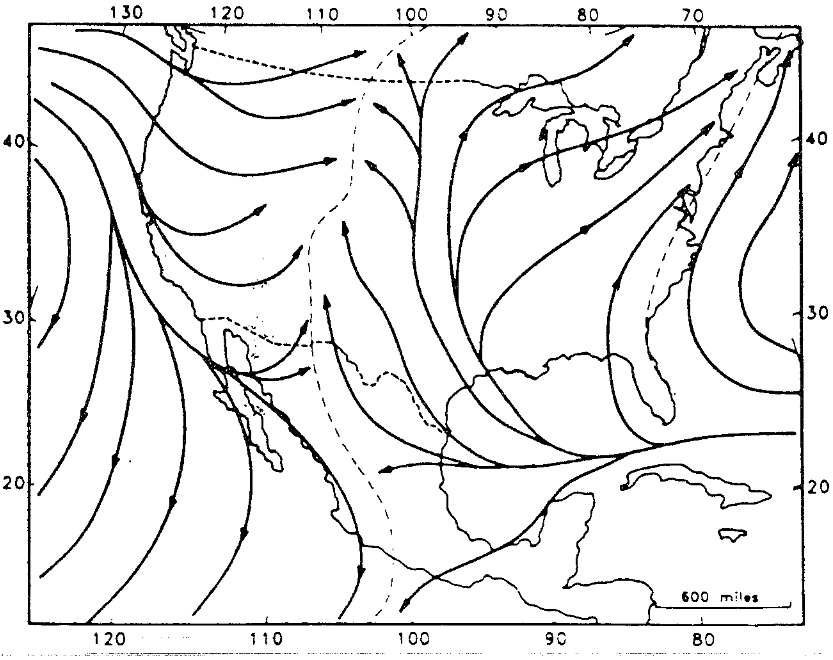

FIG. 1. Mean streamline analysis for August (after Bryson and Hare 1974).

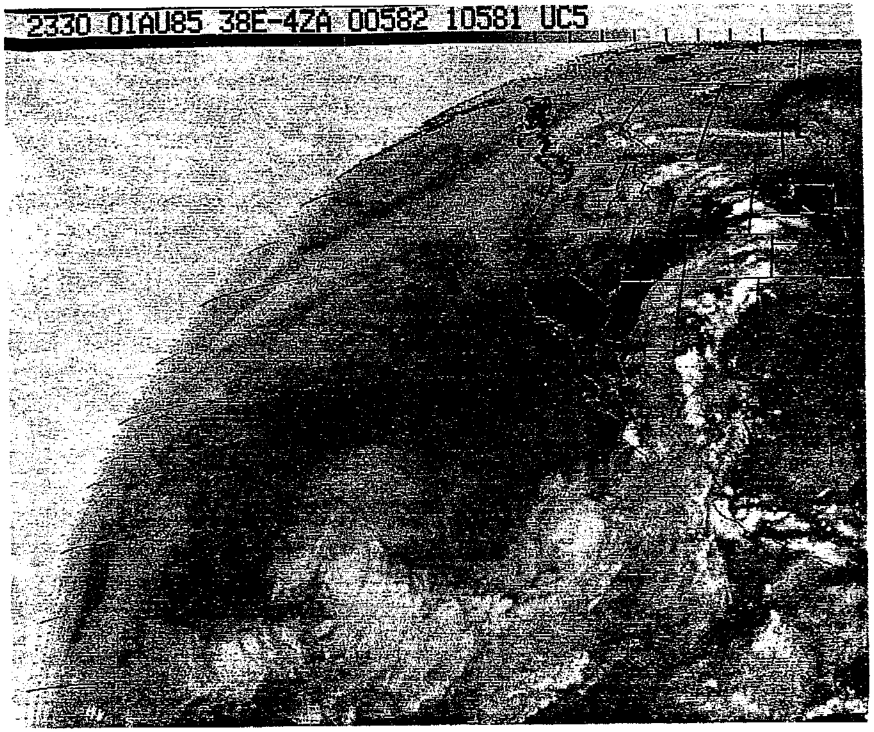

Figure 2

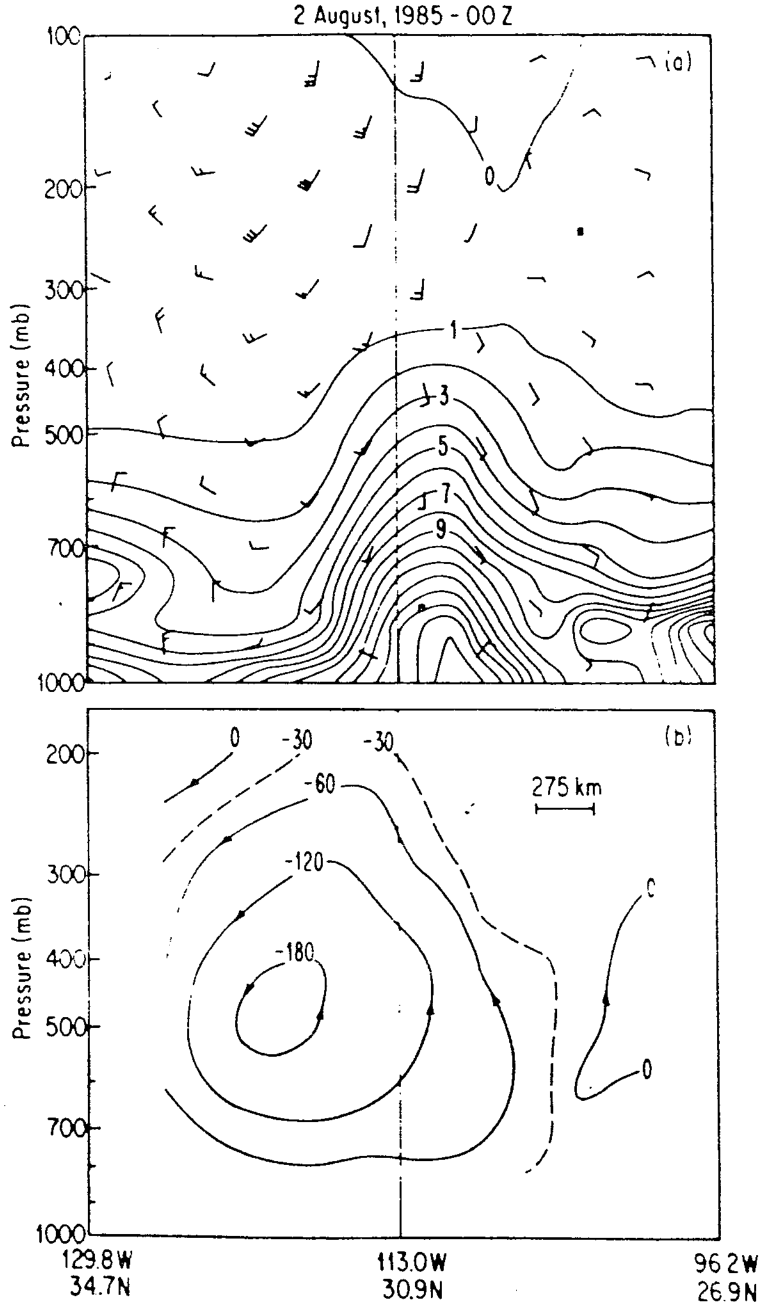

Figure 3

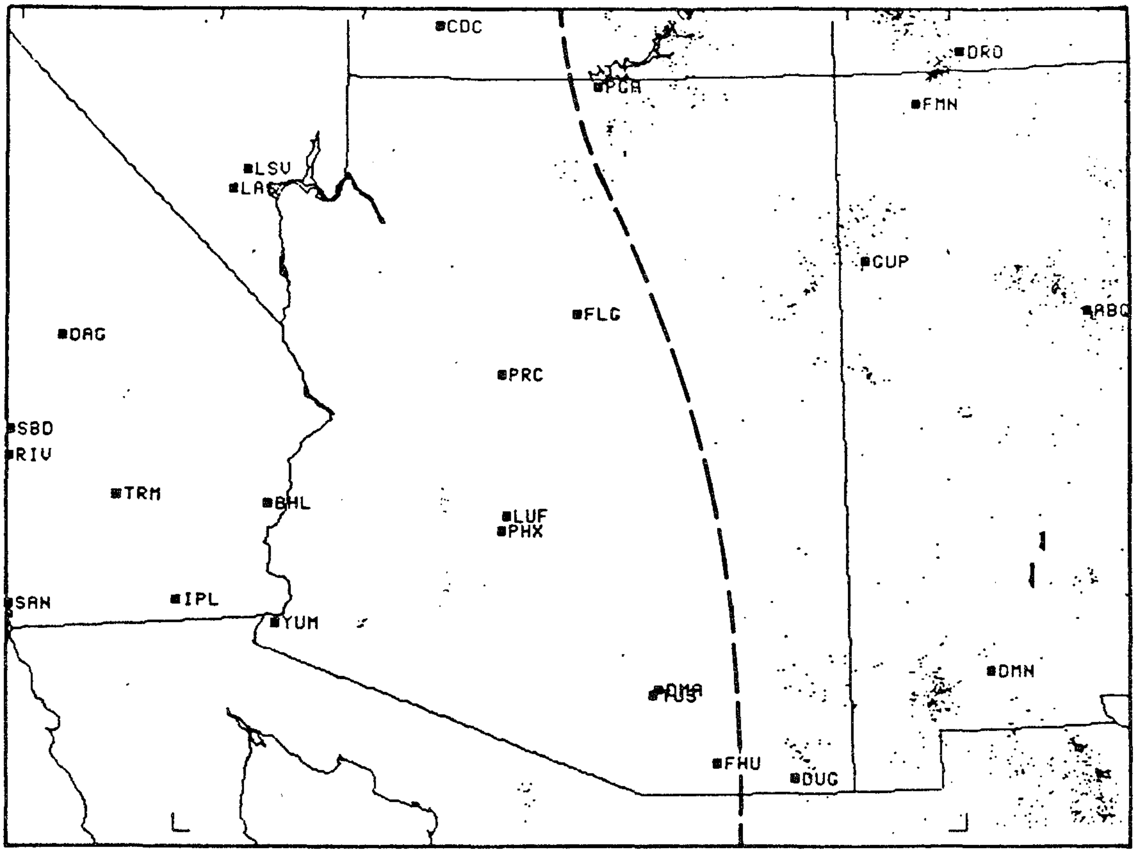

FIG. 12. Cloud-to-ground lightning-strike locations (dots) for 0000–0238 UTC 23 July 1985. Dashed line denotes approximate location of monsoon boundary at that time, inferred from GOES 6.7 μm imagery.

Figure 4