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WEAK UPPER-LEVEL DIVERGENCE AND ITS ROLE IN ORGANIZING MESOSCALE CONVECTIVE STORMS ALONG THE ARIZONA MONSOON MOISTURE BOUNDARY

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Introduction

The term "The Arizona monsoon" brings to mind a warm, humid season filled with numerous thunder and lightning displays, and the periodic flash floods, high winds, small tornadoes, large hail, and massive dust storms.

The severe thunderstorm season associated with the Arizona monsoon is unique nationally due to the unusual length of time or seasonal window for possible severe weather. Severe thunderstorm potential in Arizona normally exists for two months, from mid-July through mid-September, or for the duration of the monsoon.

The Arizona monsoon is characterized by a seasonal wind shift from weak, dry lower-tropospheric westerly winds to a moist southerly flow during July and August. The moisture source originates from the Gulf of Mexico and Gulf of California, which slowly circulates and deepens over the mountains and high plateaus of northern Mexico, then subsequently advects northward into Arizona.

The most perplexing part of the Arizona monsoon is the inability to forecast organized convective outbreaks, especially severe weather producing mesoscale convective systems (MCSs). Unlike the central and eastern sections of the nation, where detectable wind shear environments provide reasonable forecasts of severe thunderstorms, seasonal light winds aloft and the absence of vertical shear preclude forecasting organized storms in Arizona. Unstable warm, moist environments diagnosed daily by convective programs seem useful to determine only where general thunderstorms will develop and move. Although general pulse thunderstorms can occasionally produce bursts of severe weather, forecasting the severe long-lasting (2-4 h) MCS event remains elusive.

In recent years, weather researchers have shown considerable interest in the Arizona monsoon. Collaborative efforts by the National Severe Storms Laboratory (NSSL) and the university community in 1990 led to the Southwest Area Monsoon Project (SWAMP), and another SWAMP effort which occurred in 1993. Both projects were designed to investigate many facets of the monsoon, including mechanisms responsible for organized storm development and severe weather.

Recently, Arizona forecasters have noticed that some organized severe convective storms develop when weak upper-level divergence moves over the low-level monsoon moisture boundary.

Definition of an Operational Monsoon Moisture Boundary

Relatively high amounts of moisture are drawn into Arizona during the monsoon. Daily analyses have revealed that, under an average July/August temperature sounding (environmental temperatures under a subtropical high pressure system change very little during these warm months), an 850 mb dew-point temperature of 8°C is a threshold low-level moisture value needed to minimally produce convective available potential energy (CAPE) on the soundings. 850 mb dew-point temperatures exceeding 8° C produce greater amounts of CAPE. Although the 850 mb pressure level is below the mountains of central Arizona, it is favored because: 1) observed and forecast data are readily available at this level; 2) the highest values of low-level moisture for southern and western Arizona, where most organized storms occur, are located closer to 850 mb than 700 mb (see Fig. 1); 3) high 850 mb dew-point temperatures typically reflect high moisture values several thousand feet above and below this level; and 4) the 8°C dew-point temperature is operationally useful. Therefore, the 8°C 850 mb dew-point temperature is used to outline the leading edge of a moist CAPE producing air mass, operationally defined as the monsoon moisture boundary.

The operational monsoon moisture boundary is routinely plotted to: 1) locate statewide shifts in the boundary (Figs. 3a, 5a, 7a); and 2) qualitatively estimate the boundary slope. The slope of the monsoon moisture boundary varies daily and can change from a gentle slope (as inferred by loosely spaced 850 mb dew-point temperatures), to a steep slope (Fig. 1) (tightly compacted dew-point temperature gradients). (Note: The moisture boundary cross-section in Fig. 1 is too time consuming to be routinely plotted manually; however, it can now be quickly analyzed by PCGRIDS). High equivalent potential temperature (Θ_e) air feeding into building convection and focused along the monsoon moisture boundary gradient can contribute to the development of large multicellular thunderstorms, if upper-level forcing such as divergence is available.

Upper-Level Divergence

The southwest corner of the U.S., including Arizona, is subject to periods of confluent flow at and above the 300 mb level from the west and south. Confluent flow, as weak as it sometimes appears, can produce upper level divergence fields necessary to support and sustain large severe convective storms.

Confluent winds aloft, normally anticyclonic in Arizona, are typically associated with areas of wind maxima or jet streaks. Upward vertical motion, produced largely by the wind divergence component (changes in wind speed and wind direction are two essential components of the total divergence field), can develop in the right-rear entrance region of the jet streak. [A recent Western Region Technical Attachment (February 1993) discussed and illustrated vertical motion areas associated with anti-cyclonically curved jet maxima (Fig. 2), which has application in Arizona].

The two most recognizable upper-level wind patterns which produce divergence in Arizona are deformation zones (Fig. 7b), and confluent flow along the western flank of a subtropical high pressure system (Fig. 3c). The wind speed divergence component located in the right-rear entrance region of the jet streak is often associated with upward vertical motion sufficiently strong enough to: 1) erode high static stability, which can reduce or kill thunderstorm potential even under a high CAPE air mass; 2) modify upper-level lapse rates to increase instability; and 3) mechanically transport moisture through the exhaustive effects at the top of thunderstorms through air mass acceleration near the jet streak.

Examples of Organized Convection

July 26, 1991 (Figs. 3 and 4)

The monsoon moisture boundary at 850 mb was located in southeast Arizona. Flow at 500 mb was light northwesterly, with a weak positive tilt 300 mb short wave trough moving through the state. A 300 mb divergence field was diagnosed southwest of Tucson. Corresponding satellite pictures at 2231 UTC and 0300 UTC (Figs. 4a and 4b) show convection had organized along the monsoon moisture boundary, and under the area of divergence.

August 9, 1991 (Figs. 5 and 6)

The monsoon moisture boundary at 850 mb was again located across southeast Arizona. The mid-level flow was characteristically weak around a 500 mb high pressure system located in Nevada. Upper-level winds at 300 mb showed an apparent area of wind divergence in east central and southeast Arizona. Satellite pictures at 2131 UTC, 2231 UTC, and 2331 UTC (Figs. 6a-c) showed convection initially organized over east central Arizona along the moisture boundary and under an area of divergence located diagonally across the state. Deep convection subsequently propagated or built back toward the southwest.

September 3, 1990 (Fig. 7)

The monsoon moisture boundary had shifted northwestward to Las Vegas. A 300 mb deformation zone had developed over the southwest U.S. with the axis of dilatation located in western Arizona. A weak 300 mb divergence field was diagnosed across the entire state. Figure 7c lists the various types of severe weather warnings issued for Arizona.

Conclusions

Upper-level divergence sometimes associated with the right rear entrance region of an anti-cyclonically curved jet streak, or wind maxima play a critical role in organizing large convective outbreaks along the monsoon moisture boundary. This concept has been successfully used to forecast several regional Arizona severe thunderstorm outbreaks using FD wind forecasts and the FDPAP diagnostic program. However, more investigation is needed to document additional cases, and to develop a proven forecast technique. New PCGRIDS diagnostics technology can help with additional research to: 1) locate an optimum pressure level if necessary to redefine the monsoon moisture boundary, including the significance of its vertical slope; and 2) look at an array of upper-level fields such as layered static stability, Q-vectors, and layered Q-vector divergence to establish reliable indicators of severe thunderstorm support.

References

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Moore, J.T., and G.E. VanKnowe, 1992: The Effect of Jet-Streak Curvature on Kinematic Fields. *Mon. Wea. Rev.*, 120, 2429-2441.

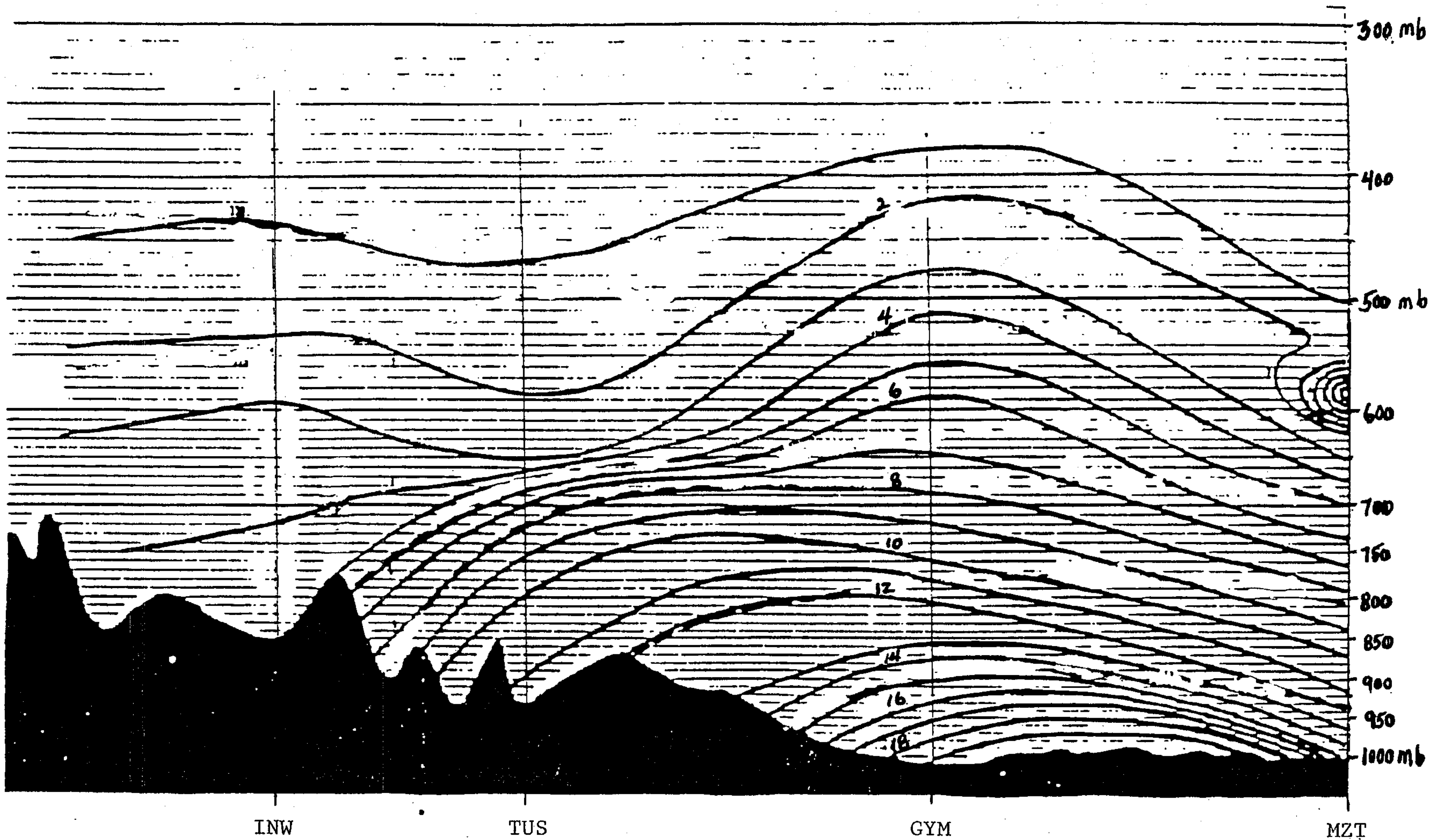
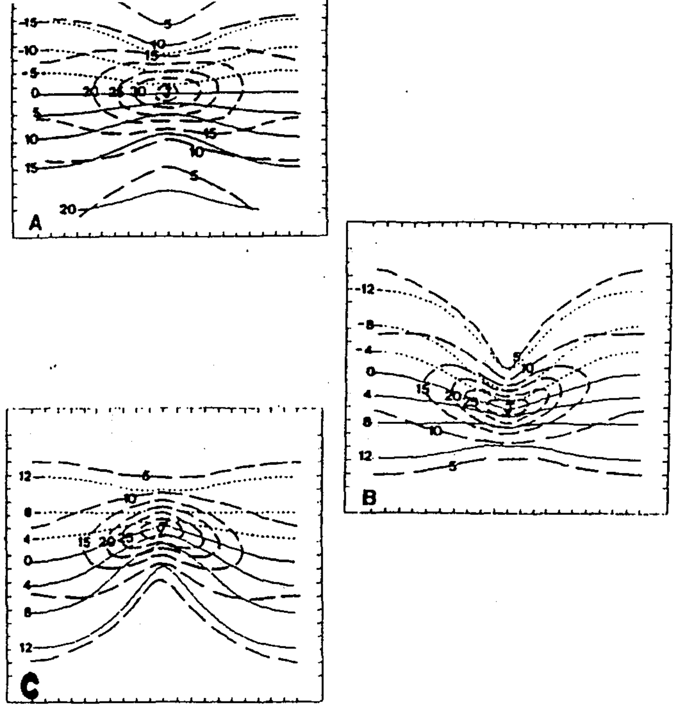
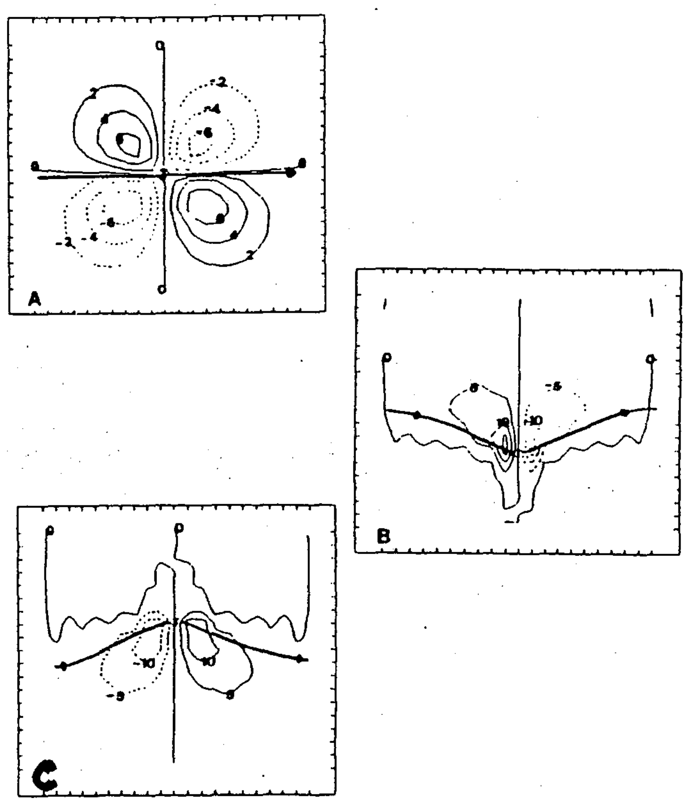


Fig. 1 North-South Cross Section of Dewpoint Temperatures (°C) from Winslow (INW) to Mazatlan (MZT) 1200Z 13 July 1972



Streamfunction values (10^6 m^2 s^{-1}), small dashed (negative values) and solid (positive values) lines, and isotachs (m s^{-1}, thick dashed lines) for (a) straight-line jet, (b) cyclonically curved jet, and (c) anticyclonically curved jet. Here J marks the jet core. All values are for the initial time at 400 mb. (From Moore and VanKnowe, 1992).



Vertical motion at 600 mb ($10^{-1}\mu b$ s^{-1} for all figures) at initial time for (a) straight-line jet, (b) cyclonically curved jet, and (c) anticyclonically curved jet. Here J marks the jet core and the thick black line is the jet axis. (From Moore and VanKnowe, 1992).

Fig. 2

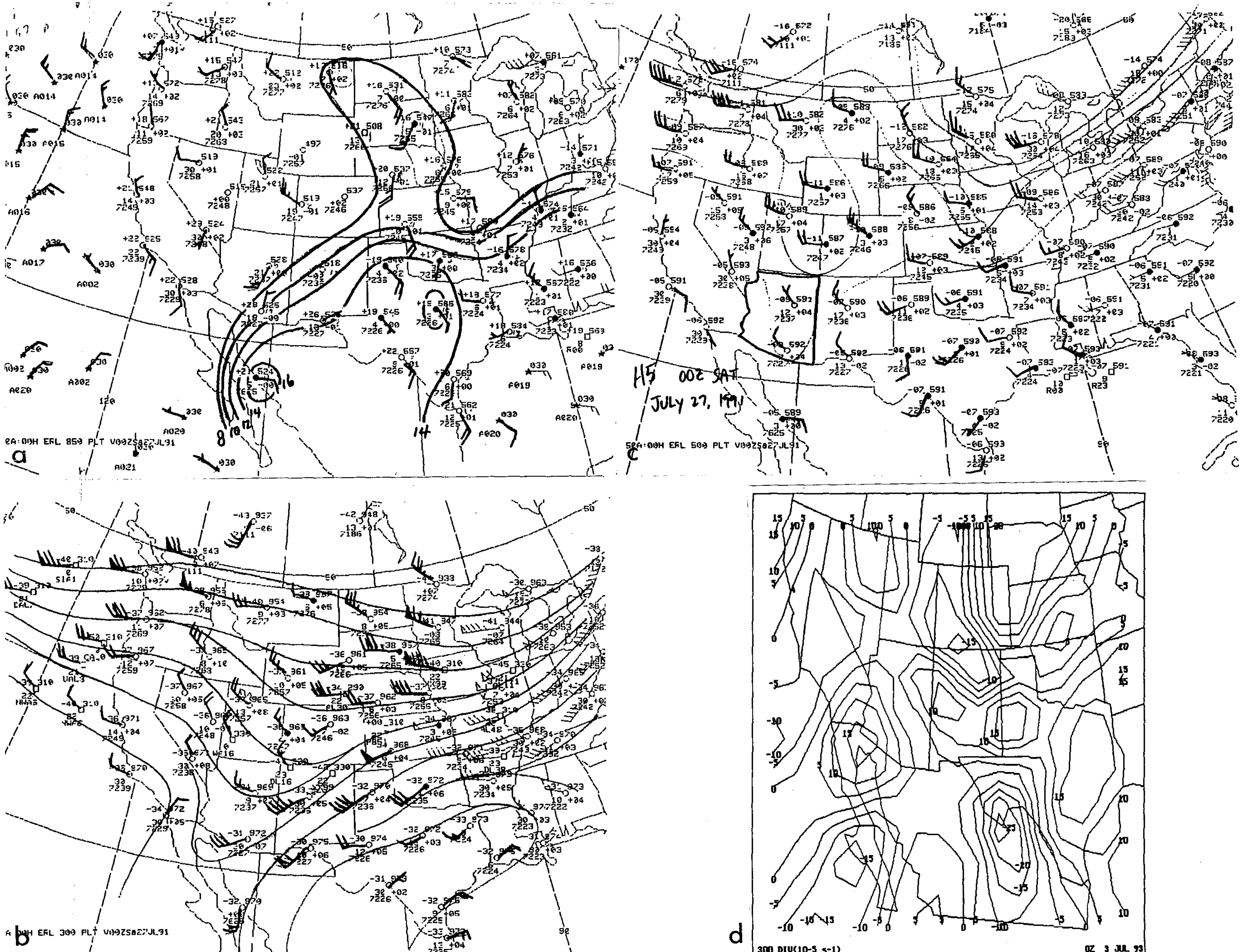


Fig. 3 Analyses for 0000 UTC 27 July 1991 at a) 850 mb, b) 300 mb, and c) 500 mb. 300 mb divergence (positive contours) for 0000 UTC 27 July 1991.

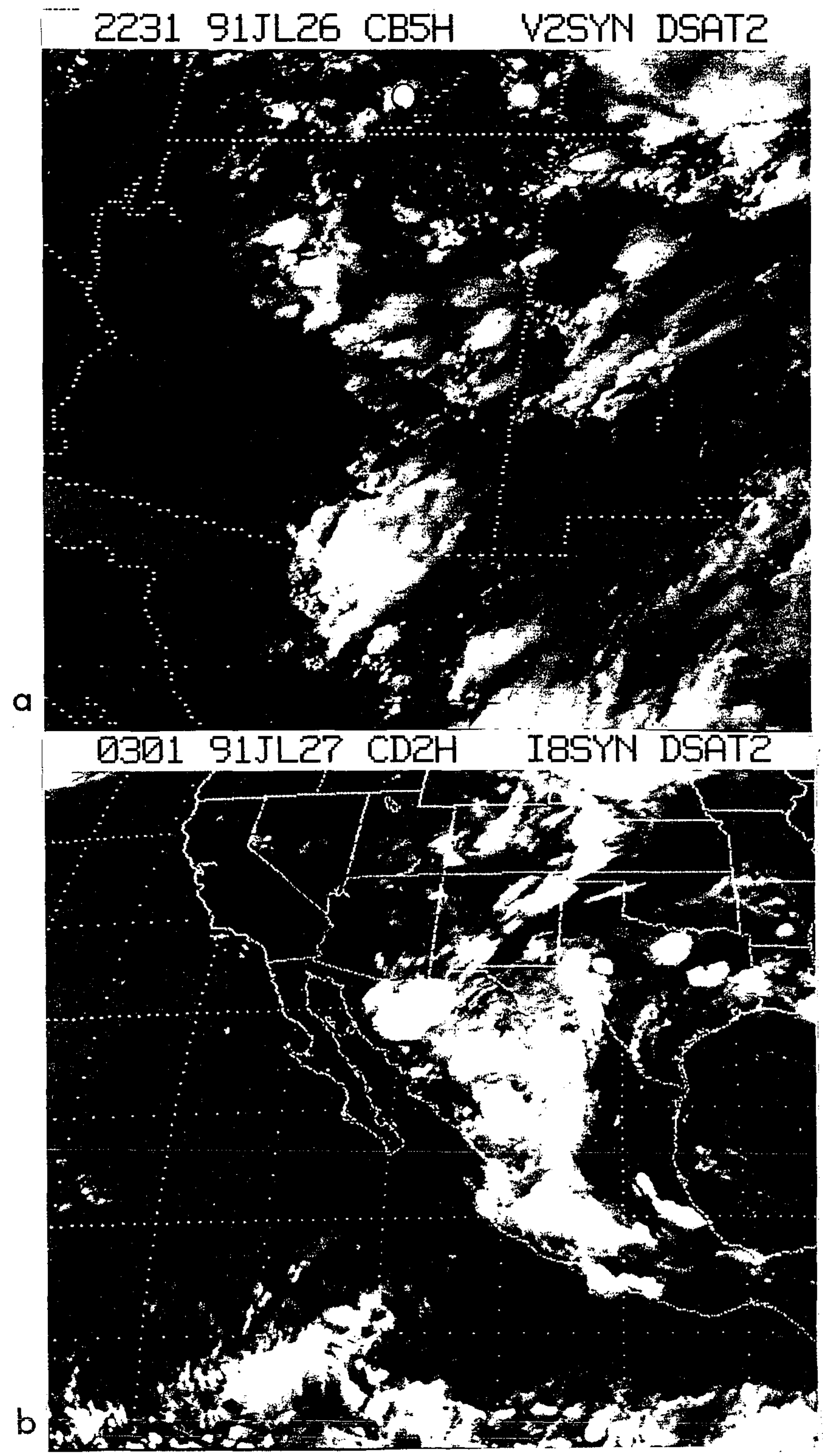


Fig. 4 a) Visible satellite imagery at 2231 UTC 26 July 1991 and b) infrared satellite imagery at 0301 UTC 27 July 27.

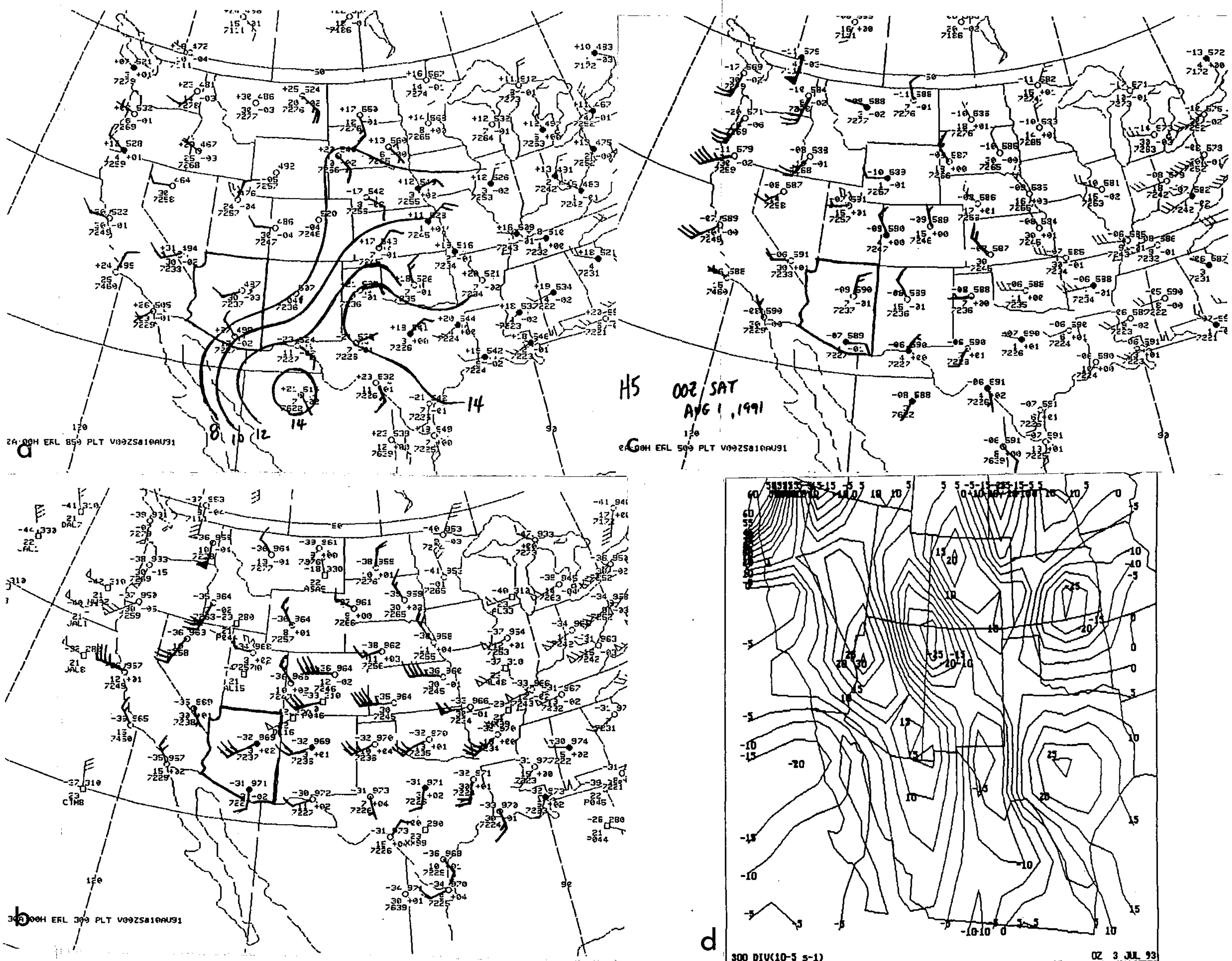


Fig. 5 Analyses for 0000 UTC 10 August 1991 at a) 850 mb, b) 300 mb, and c) 500 mb. 300 mb divergence (positive contours) for 0000 UTC 10 August 1991.

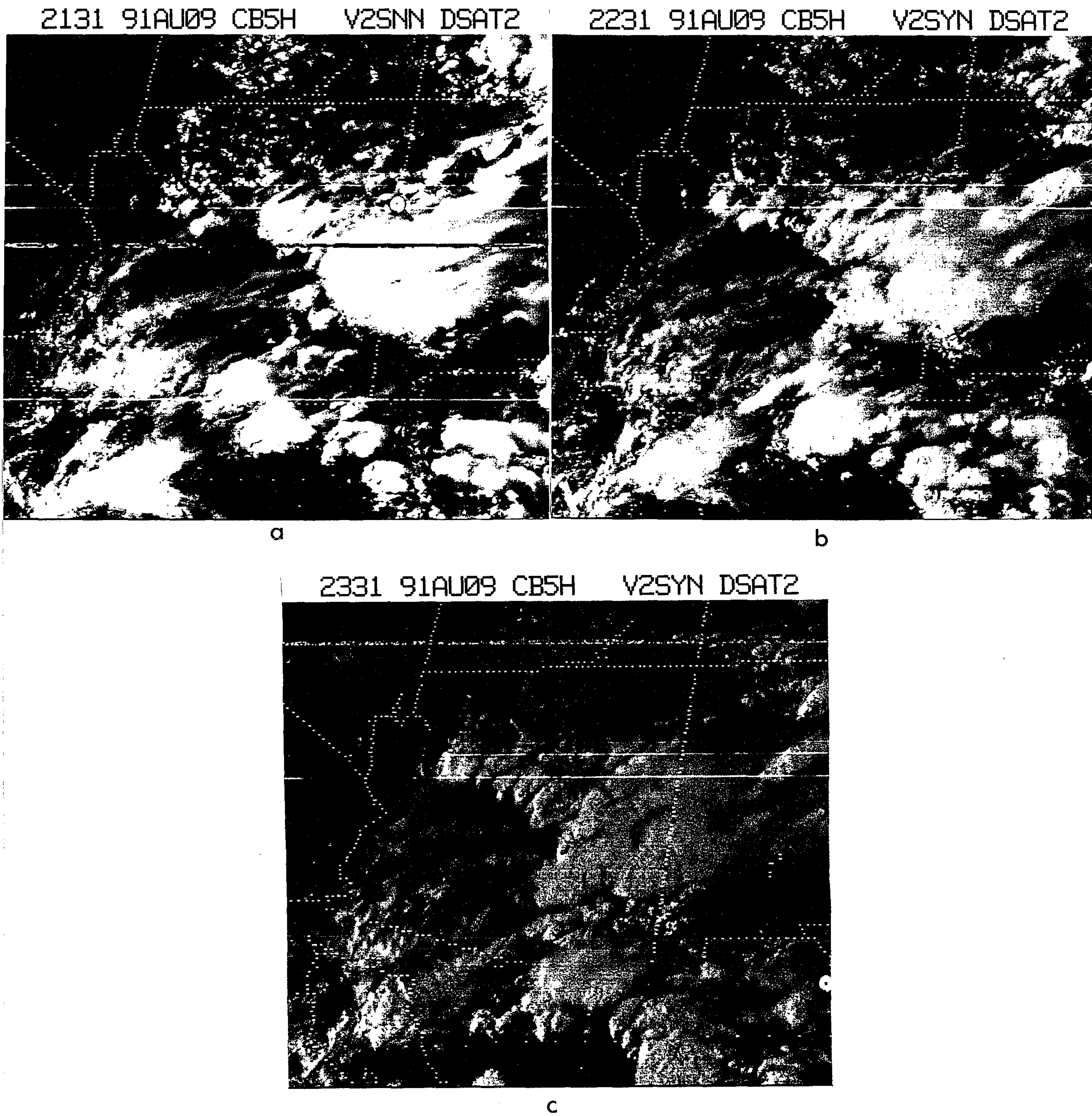
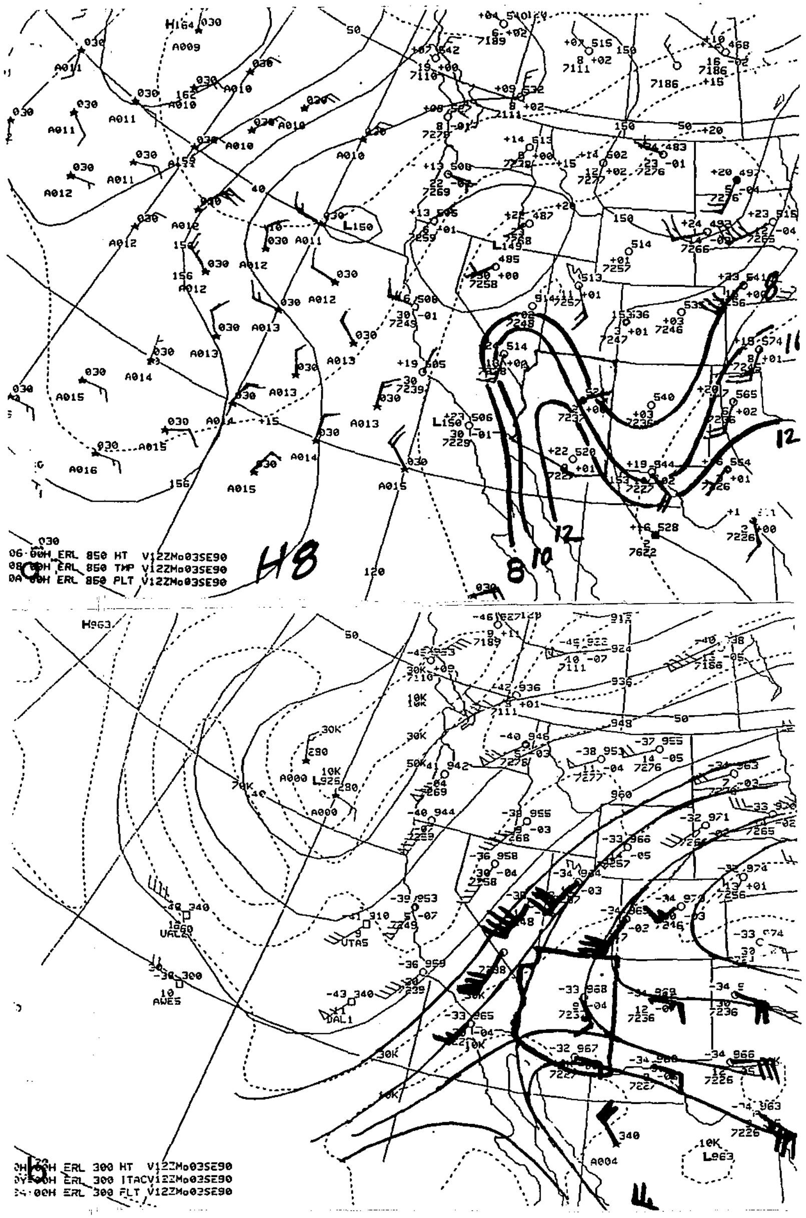


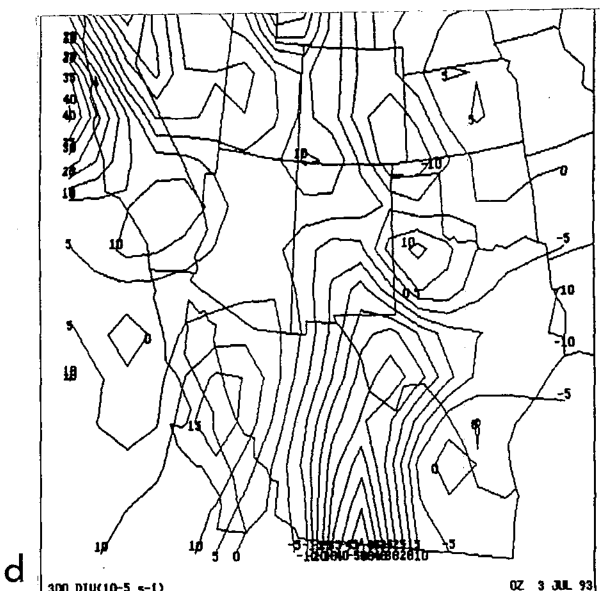
Fig. 6 a) Visible satellite imagery at 2131 UTC, b) 2231 UTC, and c) 2331 UTC 10 August 1991.



The sequence of severe weather events that day are chronicled below:

Time		Type Warning	Location	Office involved
500	am	SPS	Entire State	(WSFO PHX)
1215	pm	FFA	Entire State	(WSFO PHX)
122	pm	SVR/FFW	Mohave County	(WSFO PHX)
131	pm	SVR	Eastern Pima Co.	(WSO TUS)
138	pm	SVR/FFW	Southern Yuma Co.	(WSO YUM)
148	pm	SVR Tstm Watch #719	SW Qtr AZ	(SELS)
218	pm	SVR/FFW	Western Pima Co.	(WSO TUS)
341	pm	SVR/FFW	La Paz/Eastern Yuma Co.	(WSO YUM)
431	pm	SVR/FFW	All Yuma Co.	(WSO YUM)
445	pm	SVR	Northern Maricopa Co.	(WSFO PHX)
518	pm	TOR	N Central Maricopa Co.	(WSFO PHX)

c



d

Fig. 7 Analyses for 1200 UTC 3 September 1990 at a) 850 mb and b) 300 mb; c) Warnings issued; and d) 300 mb divergence (positive contours) for 1200 UTC 3 September.