A WES Examination of the Environment of the 10-11 September 2002 Severe Weather Outbreak

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Introduction

Northern Arizona's most significant severe weather outbreak in recent history struck on 10-11 September 2002. The conditions that led to this outbreak were typical for the transition period between the North American Monsoon and the more baroclinic fall season. During this brief transition period, typically occurring in early to mid September, baroclinic systems move far enough southward to bring strong deep-layer shear and moderate dynamics to Arizona, which interact with the abundant low-level monsoonal moisture still in place. This combination can lead to significant outbreaks of severe thunderstorms and flash flooding.

A WES case study was developed which focused on some of the synoptic- and meso-scale mechanisms that produced an environment conducive to both severe weather and flash flooding. The environment was supportive of stronger severe thunderstorms in the western portion of the CWA, while an environment supporting training of echoes and higher precipitation efficiency existed across eastern portions. Thirty three warnings and advisories were issued during this event, with the majority of the severe thunderstorms occurring from Flagstaff westward and the majority of the flash flooding occurring east of Flagstaff. This paper will discuss some of the important features of the large scale environment which were addressed in the WES case study.

Synoptic Situation

A water vapor loop from 1200 UTC 10 September 2002 through 0000 UTC 11 September (Fig. 1) indicated the general synoptic situation. A strong 500 mb trough was located off the California/Mexico coast with a large plume of moisture streaming northward across the eastern portion of Arizona and much of New Mexico. Deep convection, identified with the color enhancement on the images, developed along the western edge of the moisture plume. Dry air aloft moving in from the southwest was also apparent in the water vapor imagery.

The 1200 UTC Flagstaff sounding (Fig. 2a) indicated a profile conducive to severe weather potential with an AWIPS predicted lifted index of -3.8 0C and 830 J/kg of CAPE. Although AWIPS derived values usually are too high for Flagstaff, these values seem appropriate for this case, based on modifications to the sounding made using afternoon temperature and dewpoint temperature values. The 0-6 km shear profile indicated an environment that supported cell splitting along with a general storm movement to the north at around 20 kt. The precipitable water value of 0.74" - along with the significant storm motion - indicated that flash flood potential would be low that day from Flagstaff west, although some training of echoes could be anticipated. The Eta model sounding is shown in Figure 2b. The Eta model did a fair job of representing the synoptic environment and was used to examine the eastern CWA storm environment. Using the Eta model soundings, an environment much more conducive to flash flooding with precipitable water values around one inch, less shear, and a much 'thinner' CAPE profile was indicated across the eastern CWA. It has been documented that long "skinny" CAPE profiles represent the potential for slower updraft acceleration, longer droplet residence time, better condensate production, and taller thunderstorms which enhance precipitation efficiency (COMAP lecture notes). Therefore, based on both the observed and predicted environmental conditions, severe weather potential, with large hail and possible supercells, was indicated from a Grand Canyon to Flagstaff to Payson line westward, with a higher potential for flash flooding east of this line.

Inertial Instability

Examination of the water vapor imagery at 1200 UTC along with 400-200 mb absolute vorticity from the Eta model indicated that the plume of moisture advecting northward around the Southern Plains high pressure system had low values of absolute vorticity associated with it. WFO Flagstaff has noted a tendency for convection to be more vigorous and longer-lived in areas with low values of upper-tropospheric absolute vorticity. Research has shown that many MCCs and MCSs have been observed to form in environments where the isentropic absolute vorticity have values near zero, resulting in regions with weak inertial stability or even inertial instability (Blanchard 1998). According to this paper, a region favored for weak inertial stability is just equatorward of a westerly jet maximum where anticyclonic shear is large. Another favored region is in a subsynoptic-scale ridge with large anticyclonic curvature. Figure 3 indicates both these areas. Examination of the synoptic environment of 10-11 September indicated that the deepest and most vigorous convection occurred on the equatorward side of a 30-40 kt jet streak in an area of low absolute vorticity aloft (Fig 4). This matched the idealized southern location shown in Figure 3.

Examination for areas with low inertial stability is useful because it has been shown to indicate areas where convection may remain more vigorous and deep, and also where it may linger longest during the night when other forcing mechanisms are not present to sustain convection beyond sunset. According to Blanchard (1998), equilibrium level outflow in an inertially stable situation is constrained to flow downstream in a channeled flow. In the inertially unstable case, it is not constrained, resulting in more divergent outflow (Fig. 5). If the environment has both weak inertial stability (or inertial instability) and convective instability, then the divergent outflow from upright convection can exploit the weak restoring force and therefore be stronger and more persistent than otherwise. Numerical models can diagnose and forecast regions of weak inertial stability. However, numerical models tend to remove any large instabilities, so it has been found that absolute vorticity values below 4X10-5 s-1 seem to work best. Although we cannot show isentropic absolute vorticity in AWIPS at this time, using 400-200 mb absolute vorticity seems to work well as a proxy. Figure 6 shows the radar imagery and 400-200 mb absolute vorticity at 0000 UTC, indicating that echoes in the eastern CWA had much broader, well-developed anvils, compared to western echoes. Although difficult to show with one image, the storms in the eastern CWA developed much broader anvils than across the western CWA throughout the entire event, with the 400-200 mb absolute vorticity indicating a plausible relationship to the cause.

Overview of Event

Widely scattered convection developed early across central portions of the CWA on the morning of 10 September. By 1800 UTC, convection was occurring across the entire CWA, with the first severe thunderstorm warning issued at 1927 UTC for one inch hail. Splitting supercells began developing over the northwest portion of the CWA around 2000 UTC with several warnings issued. A strong supercell developed just east of Flagstaff around 2130 UTC, passing over the community of Doney Park. This storm featured a well-defined three-body scatter spike (Lemon 1998) indicating a strong possibility of large hail (Fig. 7). Two inch diameter hail was reported with this storm. Additional severe thunderstorms continued to develop throughout the afternoon, along with flash flood producing thunderstorms.

At 2344 UTC, a severe thunderstorm warning was issued for the area around St. Johns in the eastern CWA for a rapidly developing supercell. This supercell was moving northward into the Little Colorado River Valley (LCRV) and into much deeper low-level easterly flow. This easterly flow had been predicted to develop by the 1200 UTC run of the Eta model. As this storm moved into the LCRV and into the higher helicity environment, the mesocyclone strengthened significantly, prompting the only Tornado Warning of the event (Fig. 8). No reports of tornadoes were received, however golfball-sized hail was reported with the storm as it passed over a highway. Of the 21 severe weather warnings issued during this weather event, 17 out of 21 (81%) occurred west of a line from Grand Canyon to Flagstaff to Payson. Of the 12 flood-related advisories and warnings issued, 10 out of 12 (83%) occurred east of this line.

Discussion

During 10-11 September 2002, a strong baroclinic system was moving into the southwest United States and interacting with an environment that featured increasing moisture to the east across Arizona. The interaction of cooling temperatures aloft, strong synoptic forcing, a shear profile that supported storm splitting and supercells, along with large values of low-level moisture created an environment supportive of severe thunderstorms with a large hail threat across western portions of the CWA. Further east, deeper moisture and weaker shear created an environment more supportive of training echoes and flash flooding. Weak inertial stability across the eastern CWA allowed storms to exploit the weak restoring force and generate stronger and more persistent secondary circulations than in the west. With a thinner CAPE profile, these storms were more precipitation efficient with the result of numerous flash floods across this area. In-depth examination of the storm environment for this case was fundamental in anticipating the differing nature of the environment and being prepared for the events that occurred.

Acknowledgments

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References

Blanchard, D.O., W.R. Cotton, and J.M. Brown, 1998: Mesoscale circulation growth under conditions of weak inertial instability. Mon. Wea. Rev., 126, 118-140.

Lemon, L.R., 1998: The Radar "Three-Body Scatter Spike": An Operational Large-Hail Signature. Wea. Forecasting, 13, 327-340.

Figure 1

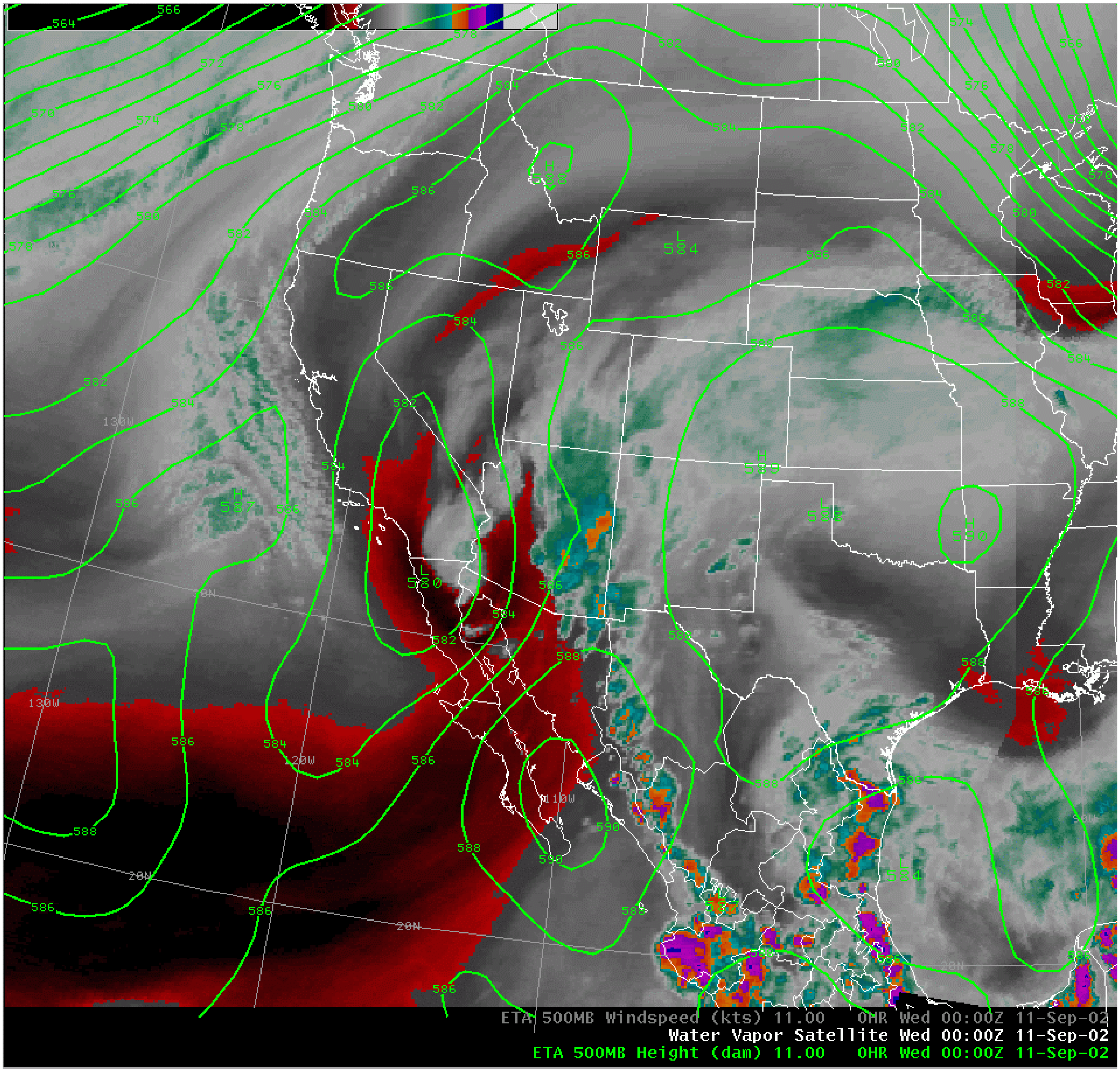

ETA 500MB Windspeed (kts) 11.00 0HR Wed 00:00Z 11-Sep-02
Water Vapor Satellite Wed 00:00Z 11-Sep-02
ETA 500MB Height (dam) 11.00 0HR Wed 00:00Z 11-Sep-02

Figure 2a

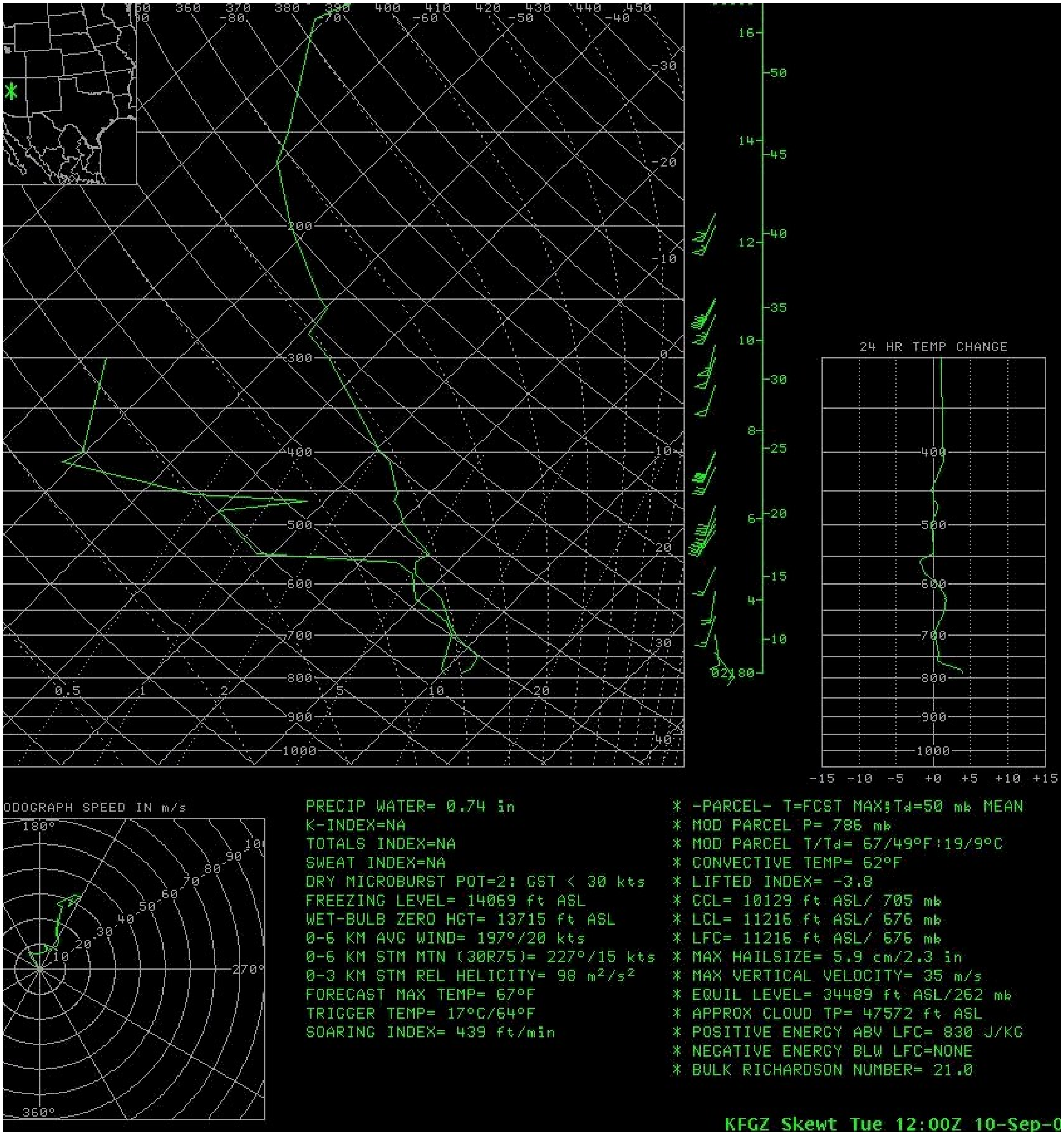

PRECIP WATER= 0.74 in
K-INDEX=NA
TOTALS INDEX=NA
SWEAT INDEX=NA
DRY MICROBURST POT=2: GST < 30 kts
FREEZING LEVEL= 14069 ft ASL
WET-BULB ZERO HGT= 13715 ft ASL
0-6 KM AVG WIND= 197°/20 kts
0-6 KM STM MTN (30R75)= 227°/15 kts
0-3 KM STM REL HELICITY= 98 m²/s²
FORECAST MAX TEMP= 67°F
TRIGGER TEMP= 17°C/64°F
SOARING INDEX= 439 ft/min
* -PARCEL- T=FCST MAX;Td=50 mb MEAN
* MOD PARCEL P= 786 mb
* MOD PARCEL T/Td= 67/49°F:19/9°C
* CONVECTIVE TEMP= 62°F
* LIFTED INDEX= -3.8
* CCL= 10129 ft ASL/ 705 mb
* LCL= 11216 ft ASL/ 676 mb
* LFC= 11216 ft ASL/ 676 mb
* MAX HAILSIZE= 5.9 cm/2.3 in
* MAX VERTICAL VELOCITY= 35 m/s
* EQUIL LEVEL= 34489 ft ASL/262 mb
* APPROX CLOUD TP= 47572 ft ASL
* POSITIVE ENERGY ABV LFC= 830 J/KG
* NEGATIVE ENERGY BLW LFC=NONE
* BULK RICHARDSON NUMBER= 21.0
24 HR TEMP CHANGE
ODOGRAPH SPEED IN m/s
KFGZ Skewt Tue 12:00Z 10-Sep-0

Figure 2b

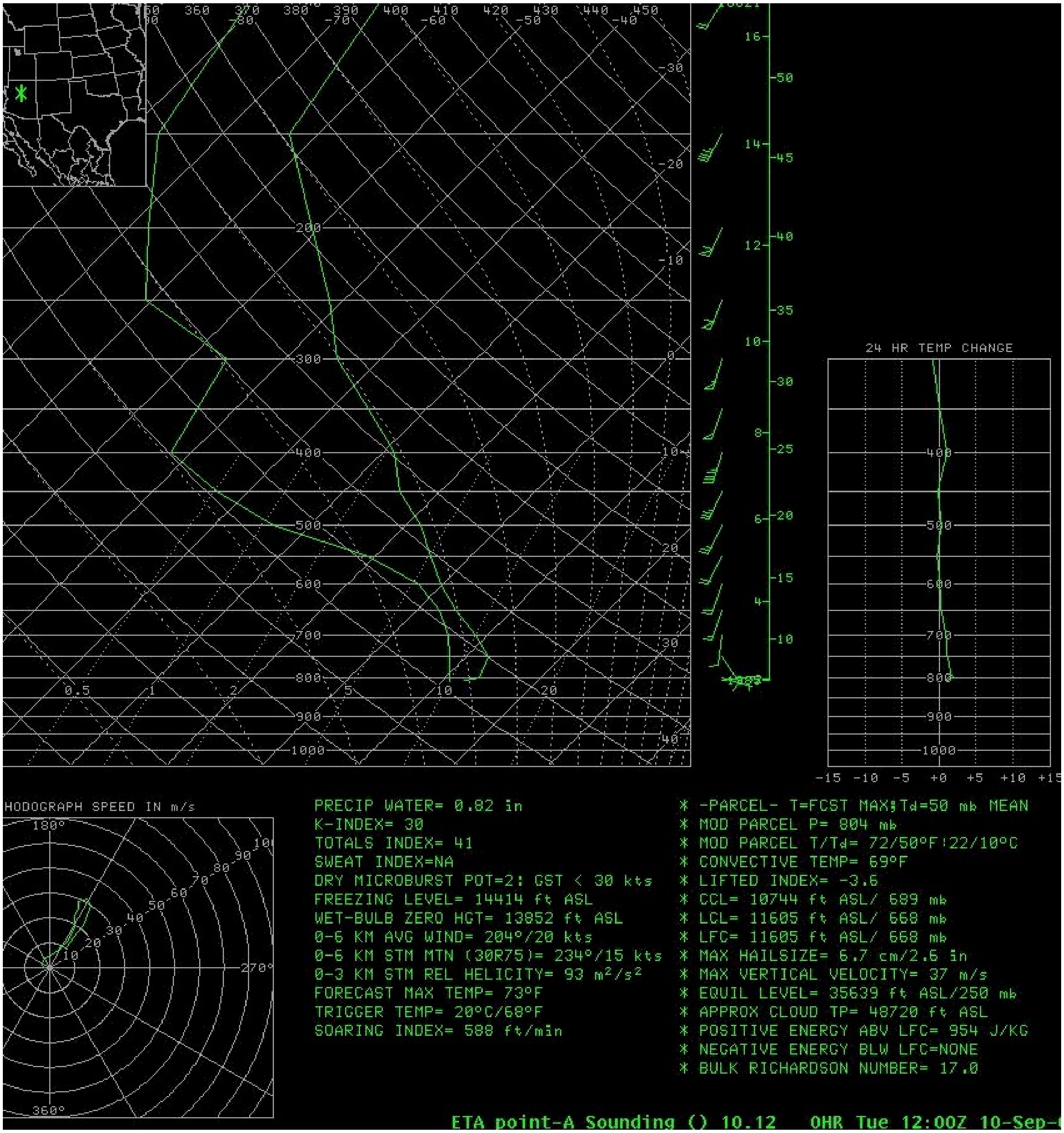

24 HR TEMP CHANGE
HODOGRAPH SPEED IN m/s
PRECIP WATER= 0.82 in
K-INDEX= 30
TOTALS INDEX= 41
SWEAT INDEX=NA
DRY MICROBURST POT=2: GST < 30 kts
FREEZING LEVEL= 14414 ft ASL
WET-BULB ZERO HGT= 13852 ft ASL
0-6 KM AVG WIND= 204°/20 kts
0-6 KM STM MTN (30R75)= 234°/15 kts
0-3 KM STM REL HELICITY= 93 m²/s²
FORECAST MAX TEMP= 73°F
TRIGGER TEMP= 20°C/68°F
SOARING INDEX= 588 ft/min
* -PARCEL- T=FCST MAX;Td=50 mb MEAN
* MOD PARCEL P= 804 mb
* MOD PARCEL T/Td= 72/50°F:22/10°C
* CONVECTIVE TEMP= 69°F
* LIFTED INDEX= -3.6
* CCL= 10744 ft ASL/ 689 mb
* LCL= 11605 ft ASL/ 668 mb
* LFC= 11605 ft ASL/ 668 mb
* MAX HAILSIZE= 6.7 cm/2.6 in
* MAX VERTICAL VELOCITY= 37 m/s
* EQUIL LEVEL= 35639 ft ASL/250 mb
* APPROX CLOUD TP= 48720 ft ASL
* POSITIVE ENERGY ABV LFC= 954 J/KG
* NEGATIVE ENERGY BLW LFC=NONE
* BULK RICHARDSON NUMBER= 17.0
ETA point-A Sounding () 10.12 OHR Tue 12:00Z 10-Sep-

Figure 3

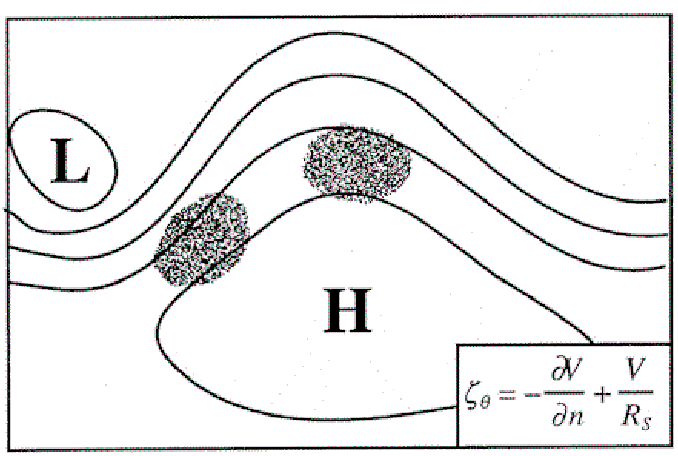

L
H
$\zeta_\theta = -\frac{\partial V}{\partial n} + \frac{V}{R_S}$

Figure 4

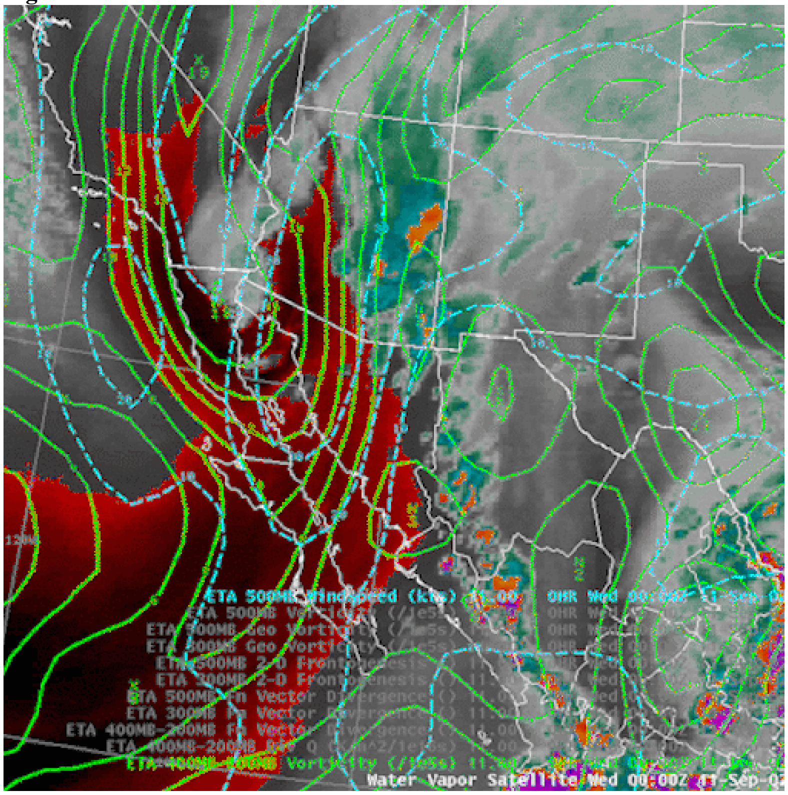


Figure 5

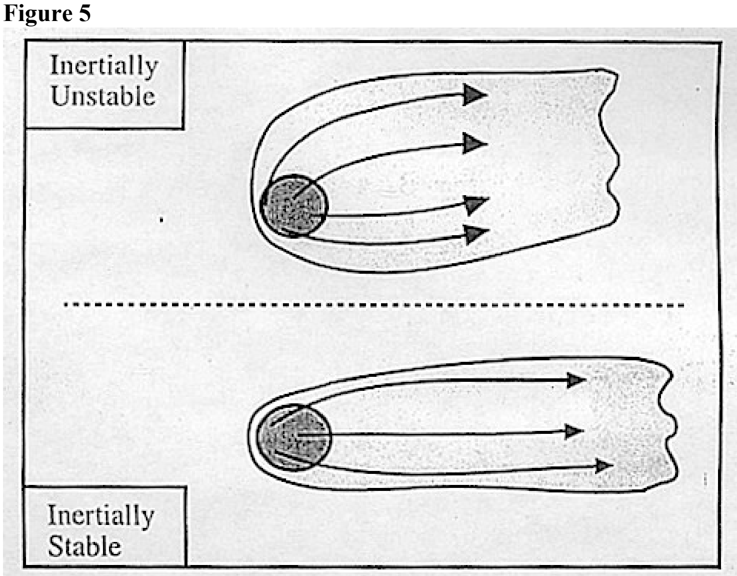


Figure 6

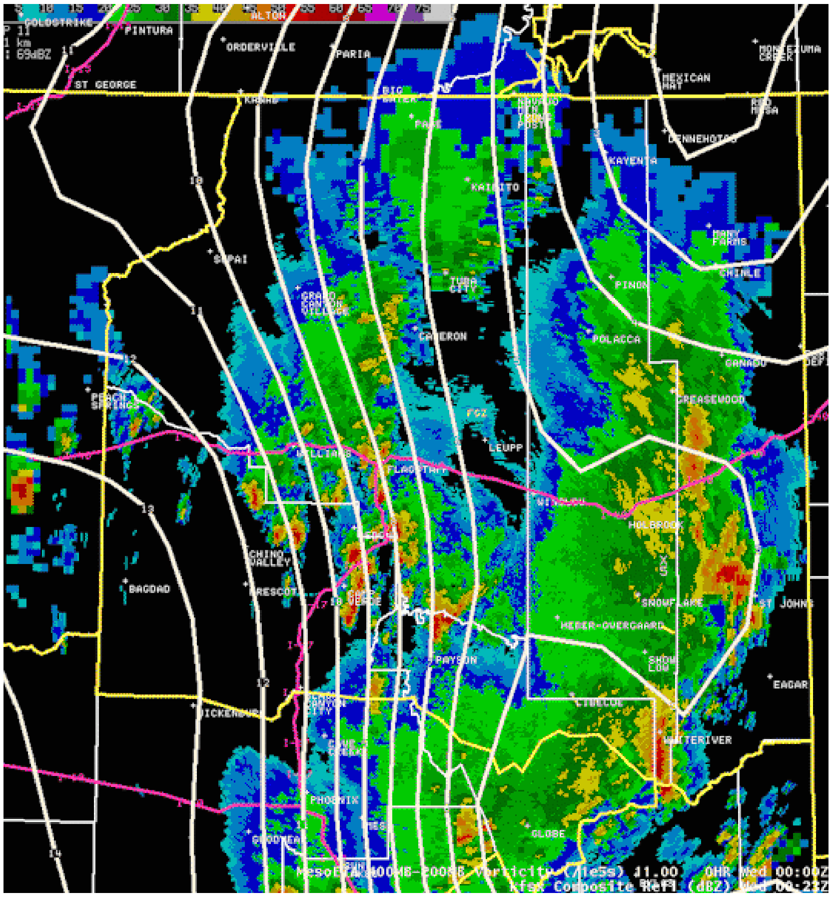


Figure 7

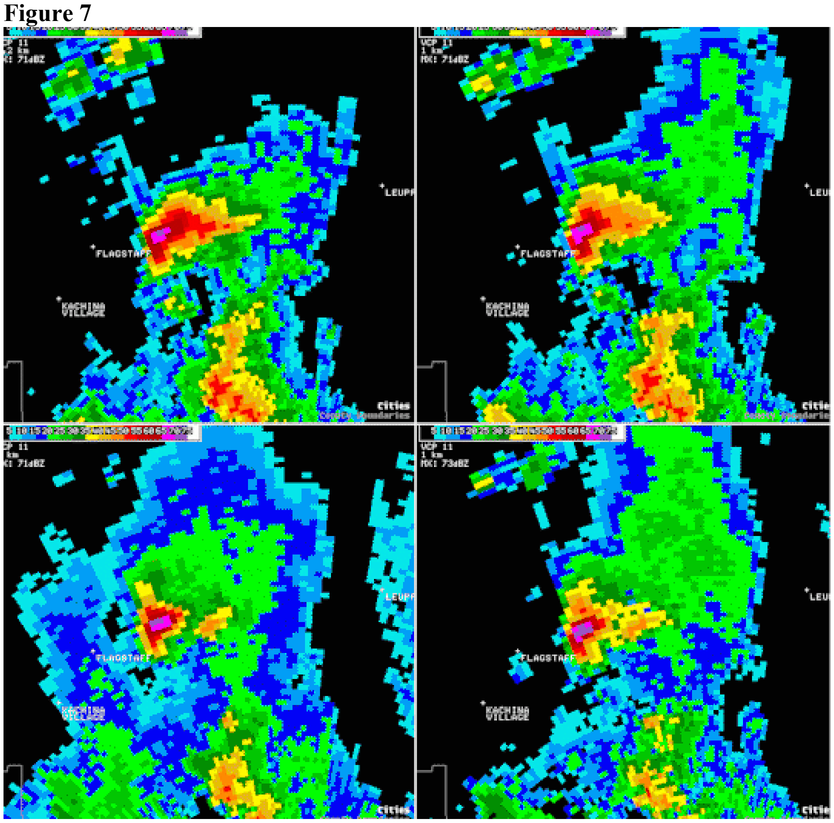
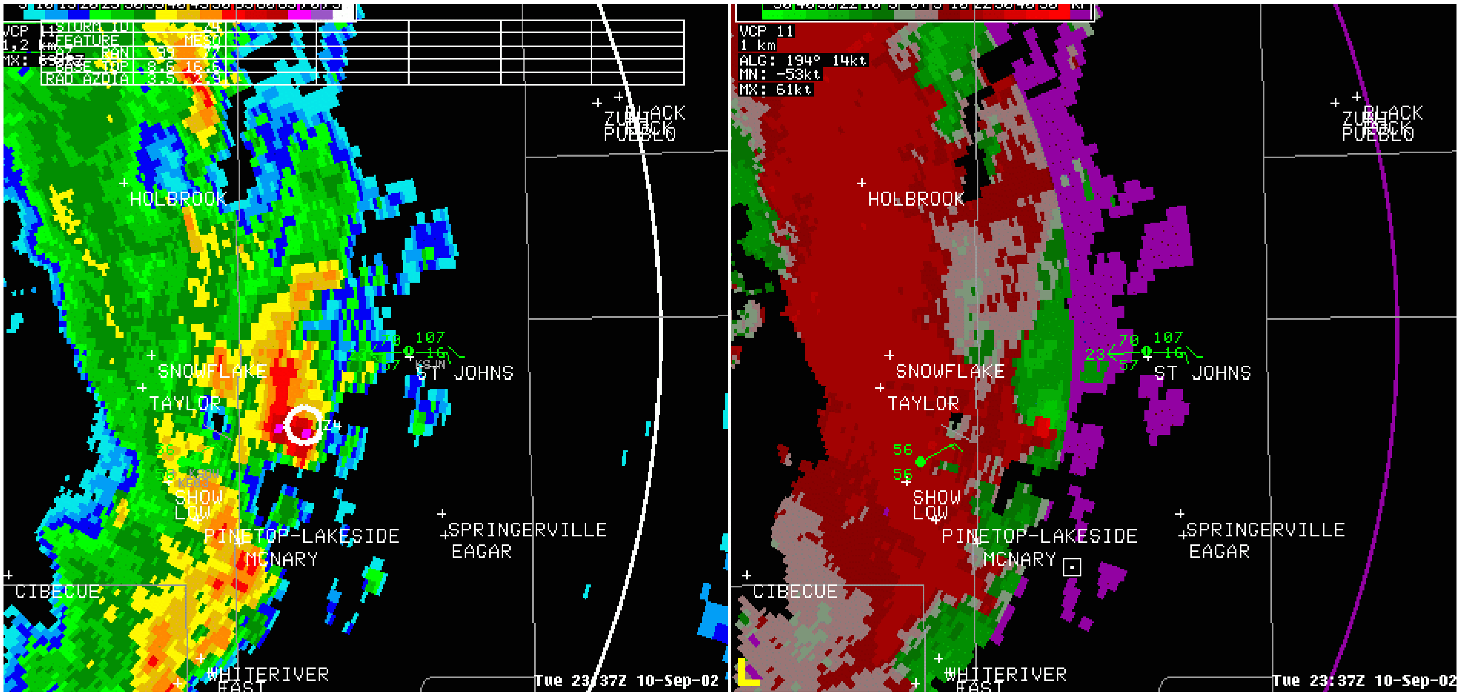


Figure 8


HOLBROOK
SNOWFLAKE
TAYLOR
SHOW LOW
PINETOP-LAKESIDE
MCNARY
SPRINGERVILLE
EAGAR
ST JOHNS
CIBECUE
WHITERIVER
Tue 23:37Z 10-Sep-02
VCP 11
1 km
ALG: 194° 14kt
MN: -53kt
MX: 61kt
HOLBROOK
SNOWFLAKE
TAYLOR
SHOW LOW
PINETOP-LAKESIDE
MCNARY
SPRINGERVILLE
EAGAR
ST JOHNS
CIBECUE
WHITERIVER
Tue 23:37Z 10-Sep-02