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FRONTAL RETARDATION LEADING TO THE DEVELOPMENT OF THE 9 JULY 1995 OREGON SUPERCELL

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Abstract

Between 6 and 9 July 1995, an outbreak of severe weather occurred throughout the Pacific Northwest. The culminating event of this period took place on 9 July with the development of a single HP supercell along the east slopes of the Oregon Cascades. The supercell proceeded to move northeast through north central Oregon and into eastern Washington producing wind gusts of 70 mph, softball size hail and torrential rainfall that led to flash flooding. An estimated 50 million dollars worth of damage occurred to property and crops. Storms of this magnitude are rare in the Pacific Northwest. This Technical Attachment will discuss the synoptic conditions leading up to this event and the important role that frontal retardation played.

Introduction

Severe convective weather in the Pacific Northwest rarely reaches the magnitude of severe weather in other parts of the country. Nonetheless, severe weather events do occur in the Pacific Northwest and have been well documented in a study by Evenson and Johns (1995). Evenson and Johns identified two types of synoptic weather patterns that produce severe weather in the Pacific Northwest. These severe weather patterns are based largely upon a synoptic scale trough moving into the Pacific Northwest. The first synoptic weather pattern, which Evenson and Johns referred to as "Pattern A", is based upon a negative tilted 500 mb trough moving into the Pacific Northwest (Fig. 1). The other pattern, "Pattern B", is based upon the passage of a 500 mb trough axis through the Pacific Northwest. Out of 26 severe weather events studied from 1955 to 1993, Evenson and Johns determined that 21 events fell into Pattern A, while 5 were categorized as Pattern B. In NOAA Technical Memorandum, NWS WR-237, Evenson and Johns (1996) categorized the July 1995 Pacific Northwest severe weather outbreak as a typical Pattern A event. A case study such as Evenson and Johns provide a sound meteorological theory for severe weather development. However, the location and development of convection depends on more than just the synoptic weather pattern alone. The interaction of synoptic weather features with terrain needs to be examined closely to get a clear picture of how and why this supercell developed on 9 July.

The Synoptic Scale Pattern

The beginning of this synoptic weather pattern started during the first week of July. A developing trough dropped southwest out of western Canada and stalled off the West Coast through 8 July. This allowed moisture from the desert Southwest to begin advecting northward. Upper-air soundings from Spokane and Boise (Fig. 3) at 0000 UTC and 1200 UTC of 6 July shows the increase of moisture between 700 and 500 mb. This led to the development of isolated high based thunderstorms from 6 July through the 8th which produced damaging dry microburst winds. However, in time these storms helped mix the mid-level moisture downward, moistening the lower levels of the atmosphere. This will be shown in later soundings. By the morning of 9 July, the synoptic weather pattern (Fig. 2) closely matched that of Pattern A (Fig. 1) from Evenson and Johns. A negative tilted trough was set to pivot into the Pacific Northwest accompanied by a 500 mb jet cutting across the front and diffluent flow ahead of the front.

9 July Conditions

Analysis of morning data and 1200 UTC model output from 9 July show many instability factors in place for another day of convection across the Pacific Northwest. An 850 mb equivalent potential temperature ridge over eastern Oregon indicated a deep layer of moisture in place which was needed to produce convection (Fig. 4). This was also detected in the Boise sounding where the surface theta-E value of 336 Kelvin remained basically unchanged in the vertical to near 700 mb. Lifted Indices from the Spokane and Boise soundings (Fig. 6) indicates how unstable the atmosphere was at 1200 UTC with Boise at -2°C and a +2°C at Spokane. Modifying the Boise sounding to reflect forecasted conditions over eastern Oregon provided Convective Available Potential Energy (CAPE) values near 2500 J/kg and a Lifted Index of -10°C. This came very close to the observed 10 July 0000 UTC Boise sounding which had a Lifted Index of -9°C. The 1200 UTC hodograph from Boise showed vertical speed shear conducive to supercell development with helicity values from the surface to 3 km of 222 m2/s2.

At the surface, a thermal trough extended north from California into central Oregon further adding to the instability of the lower atmosphere by providing dry adiabatic lapse rates near the surface. Figure 7 shows the thermal trough with the approaching cold frontal positions at 1500 UTC. Also noticeable were the high dew point temperatures in the upper 50s to lower 60s over eastern Oregon and the Columbia Basin. The thermal trough also aided in advecting moist low-level air towards the Cascades and providing a source of low-level convergence. This can be seen in the Eta 1200 UTC forecast boundary layer moisture flux convergence field valid at 1800 UTC (Fig. 5).

The southwest to northeast oriented jet was also important in the development of convection. A 100 knot jet maximum at 300 mb was crossing over the front in the vicinity of the Oregon Cascades by mid-morning. The resulting indirect circulation provided additional upward motion in the form of ageostrophic divergence over central Oregon. The 250 mb ageostrophic divergence and 850 mb convergence can be seen in the six hour forecast from the 1200 UTC Eta (Fig. 8). Thus, the overall synoptic pattern on 9 July indicates that thunderstorm activity was likely once again over eastern Oregon and Washington with some potential of severe weather including supercells.

Mesoscale Features

Mesoscale meteorology is based upon the interaction of terrain with synoptic scale weather patterns. Doswell (1987) stated that the magnitude of synoptic scale lift (on the order of a few centimeters per second) is simply too small and slow to produce needed lift for convection in a reasonable amount of time. Furthermore, to initiate deep convection, some degree of mesoscale lift is needed to aid the large-scale synoptic lift. Doswell (1987) defined mesoscale processes as those which cannot be understood without considering large-scale and microscale processes. Having looked at the synoptic pattern, we must now look at how it interacted with the local terrain on 9 July to provide an understanding of how and where the supercell developed.

Because model terrain representation depends on model resolution, large-scale models do a poor job of representing the terrain of the Pacific Northwest particularly the Cascade Mountain Range. Unfortunately, at the time of this occurrence, the 40 km Eta was the highest resolution model that was available to the Pendleton office for this study. The Cascade Range averages a height of five to six thousand feet with several peaks over ten thousand feet. The average horizontal width of the Cascades is 60 to 100 miles. The Cascade Mountain Range serves as an effective natural barrier separating the coastal marine climate of the Pacific Northwest coast from the inland Continental Steppe Region of eastern Oregon and Washington. However, due to the model's need for terrain smoothing characteristics, the Cascade Range is poorly represented. Instead, the model's terrain is distinguished by more of a continual elevation rise from the West Coast to the Rocky Mountains. Only now are finer resolution models becoming available, such as the Eta 29 km, Eta 10 km, and the Regional Spectral model, which are capable of distinguishing the height of the Cascades and the depth of the Columbia Basin. It is the interaction of synoptic scale features such as fronts with terrain like the Cascades that need to be considered to understand mesoscale meteorology in the Pacific Northwest. In the case of 9 July, the approaching fronts interaction with the Cascades led to a case of frontal retardation.

Frontal retardation (Schumacher, et al. 1992) depends largely on an approaching front's orientation to a mountain range as well as the width and height of the range. The ideal frontal retardation case would be a front approaching nearly parallel to a mountain range.

Schumacher, et al. (1992) theorized that the portion of the front near the earth's surface slows as it approaches a mountain, while the upper-level portion of the front, free of friction, continues to progress over the mountain (Fig. 9). The result is a folded front in the vertical as the advancing low-level cold air is partially blocked by the mountain, thus slowing its progression. Even though the large-scale models have difficulty representing the Cascades, the models did show indications of frontal retardation occurring. A west to east cross section through Oregon (Fig. 10), of Potential Temperature at 1200 UTC compared to the six hour forecast valid at 1800 UTC, shows that the slope of the front increased as it moved over the mountain range. This was also an indication of frontogenesis further enhancing the mesoscale lift in the area. The same cross section using Equivalent Potential Temperature (Fig. 10a) at 1200 UTC compared to the six hour forecast showed that cool dry air aloft moving over the warm moist air east of the Cascades aided in the destabilization of the atmosphere.

The 1930 UTC satellite picture on July 9 (Fig. 11) shows the supercell near the north Oregon border. Cloud cover associated with the cold front covers western Oregon, while east of the Cascades it was mostly clear. This allowed maximum solar heating east of the Cascades to increase the thermal gradient along the front. As the upper portion of the front, and the associated cooler dry air, worked its way over the Cascades, the atmosphere east of the mountains began destabilizing. This key interaction of the front with the Cascade Mountains initiated the convection along the east slopes of the Cascades. Around 1830 UTC, the Portland Doppler radar started detecting the increased convective activity (Fig. 12) caused by the frontal retardation along the east slopes of the Cascades. The radar tracked the cell that eventually developed into a supercell as it moved through the lower Columbia Basin (Fig. 12a).

Once the supercell developed, it became isolated and appeared to modify its surroundings becoming the dominant cell in the Columbia Basin (Fig. 12a). This was likely due to two events. First, the capping inversion was likely broken by the initial convection of the "soon to be" supercell. In a supercell environment, the breaking of the cap concentrates the released CAPE into a limited area. In this case, it appears that the energy was focused into one storm. Second, the intense vertical updrafts and gust fronts of a supercell can have dramatic effects within the storm and its immediate environment. Such influences can suppress new convection in the Region (Doswell III, 1985). Storm motion from the 9 July 1200 UTC Boise sounding indicated a north northeast storm movement. This moved the supercell away from the Cascades into the main axis of the Theta-E ridge and the high surface dew points. Only later, as the supercell dissipated over southeast Washington, did any additional thunderstorms develop from the outflow boundaries. Some of these thunderstorms became severe, however, none reached the same severity as the Oregon supercell.

Summary

There had been several days of isolated thunderstorm activity in the Pacific Northwest leading up to the supercell event. This thunderstorm activity was due to the large-scale synoptic weather pattern that had stalled over the Region through the first week of July. On 9 July, the pattern began to change as the stalled trough off the West Coast moved northeast pushing the cold front onshore. The front came inland and encountered the Cascade Mountain Range at a nearly parallel angle creating the frontal retardation. With the upper portion of the front moving freely over the mountains, the atmosphere quickly became unstable along the east slopes. This initiated convection along the east slopes of the Cascades, where the potential for severe thunderstorms existed due to the environment created by the synoptic weather pattern over the previous few days. Eventually, one of the thunderstorms developed into a supercell as it moved into the moist and unstable airmass in the Columbia Basin. The degree to which frontal retardation occurs with each front will differ depending on many factors. Also, the development of convection due to frontal retardation will differ in each case depending on environmental conditions.

The importance of mesoscale meteorology cannot be overstated especially in the western United States where highly variable terrain heavily influences local weather. Staudenmaier recently illustrated this with several examples using the new Eta 10 model (1997). He showed how the finer terrain resolution of a mesoscale model handled small weather perturbations caused by the terrain in portions of the Pacific Northwest. As the new mesoscale models come forth, they are making it possible to further understand the interaction of fronts with terrain such as the Cascades. This will enable forecasters to gain a better understanding of how terrain interacts with the synoptic weather patterns and improve local forecasting. Further studies using mesoscale models to assess past frontal retardation events are needed to predict future events, and these studies will be possible now that mesoscale models are coming into operational use.

Acknowledgments

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References

Evenson, E.C. & R.H. Johns, 1995: Climatological and synoptic aspects of severe weather development in the northwestern United States. *Wea. Forecasting*, **9**, 265-278.

_____, _____, 1996: The 6th July and 9th July 1995 severe weather events in the northwestern United States: Recent examples. *1996 NOAA Technical Memorandum NWS WR-237.*

Doswell, C.A.III, 1987: The distinction between large scale and mesoscale contribution to severe weather. *Wea. Forecasting*, **7**, 588-612.

Schumacher, P.N., D.J. Knight, & L.F. Bosart, 1990: Frontal retardation along the Appalachian mountains. Fifth conference on mesoscale processes, 175-176.

Doswell, C.A.III, 1985: The operational meteorology of convective weather volume II: Storm scale analysis. *NOAA Technical Memorandum ELR ESG-15.*

Staudenmaier, M.J,. 1997: Why is high resolution important in the West? An early look at the Eta-10 model. *WR Technical Attachment 97-03.*

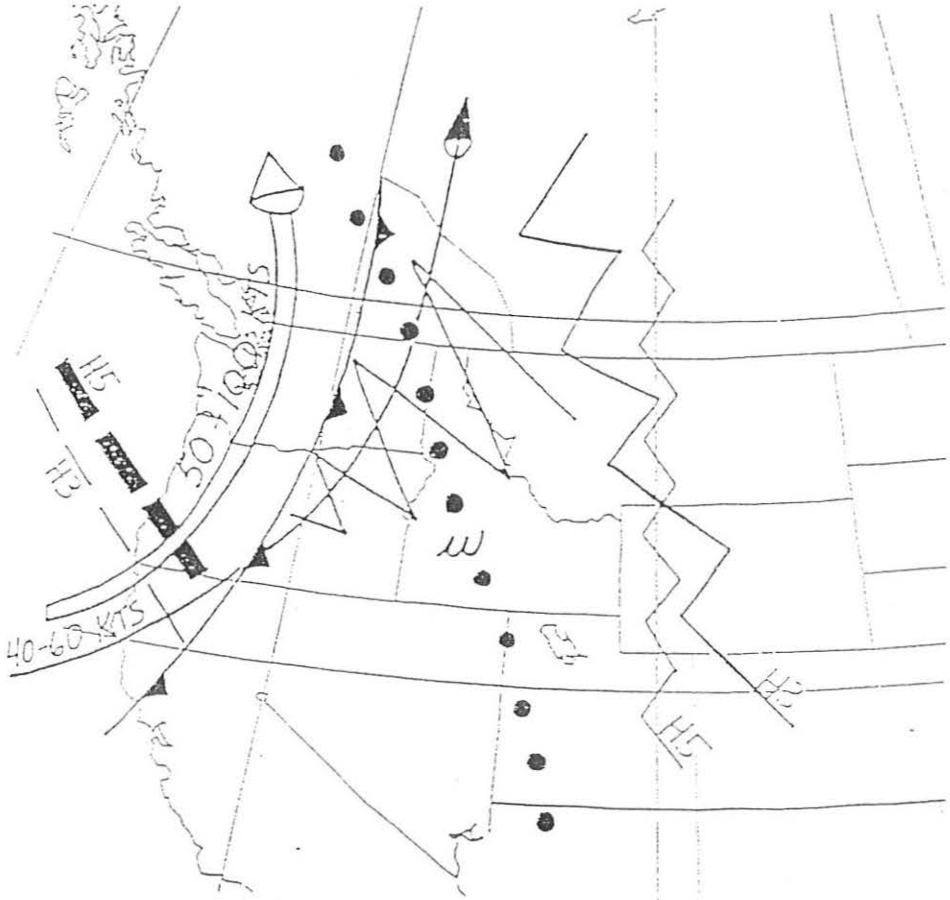


Figure 1

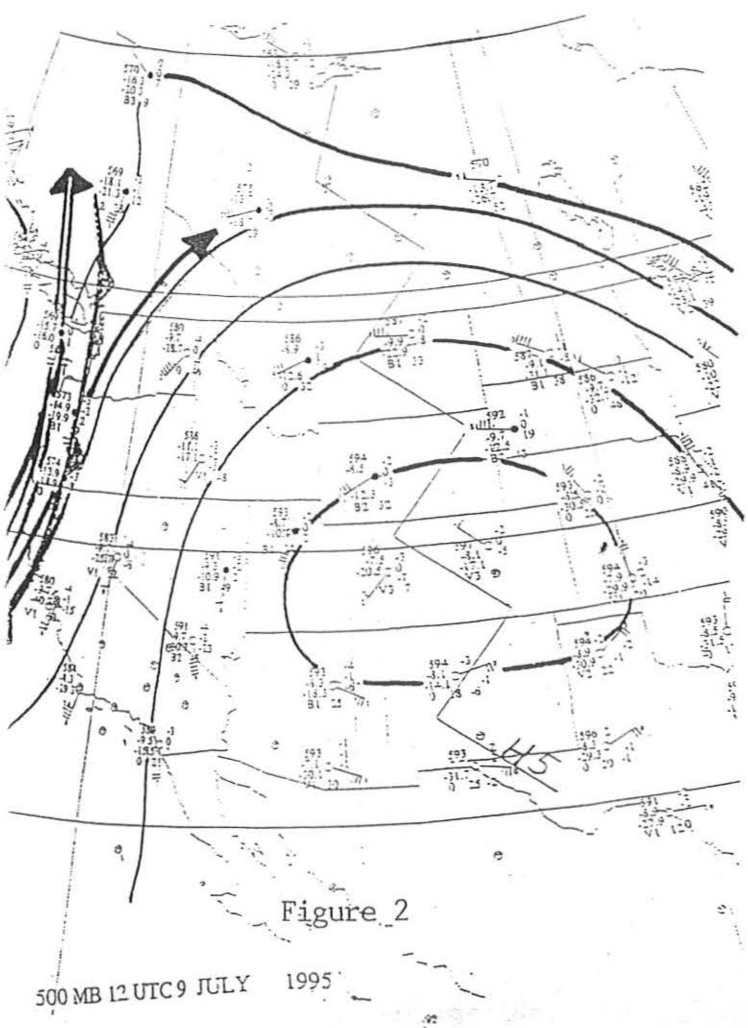
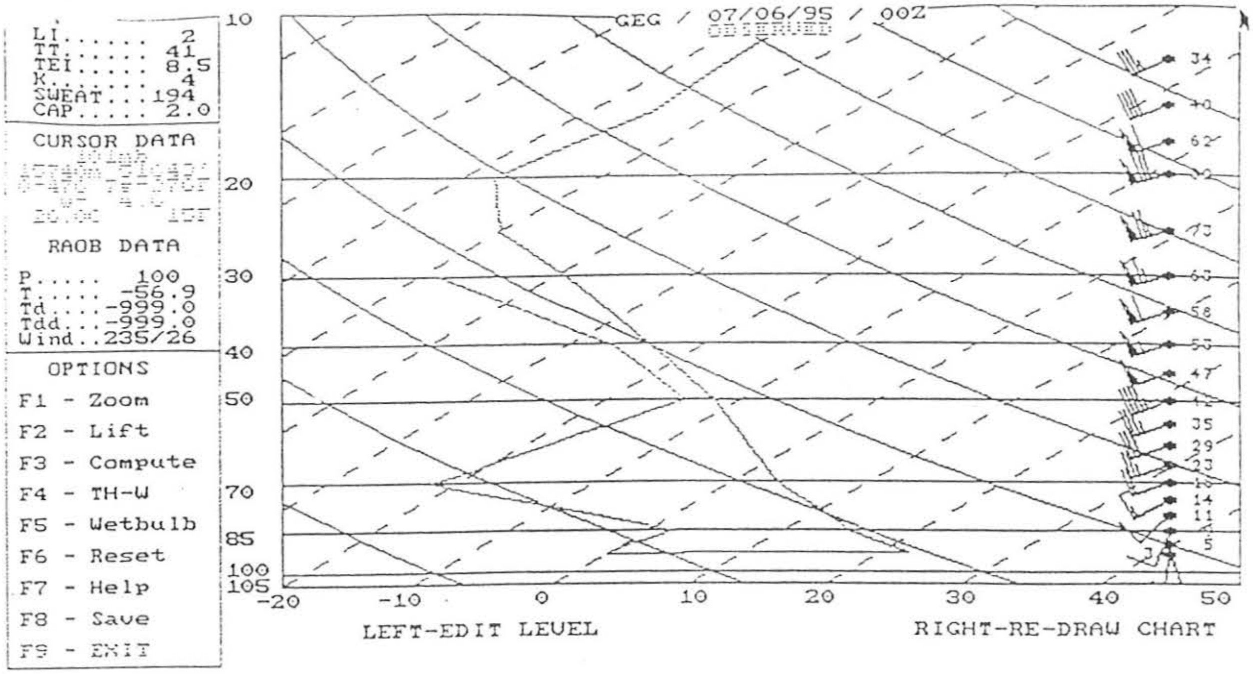


Figure 1 Composite chart for Pattern A severe weather events by Evenson and Johns. Frontal boundary is position of 700 mb front. Jet's are shown at 500 mb (thin arrow) and 300 mb (thick arrow). H5 and H3 trough position (dashed lines) and ridge (zigzag lines). 850 mb thermal ridge (dotted line) and difluent flow aloft ahead of front (zigzag line).

Figure 2 Synoptic pattern on the morning of July 9th 1995 closely matching that of Pattern A in figure 1.



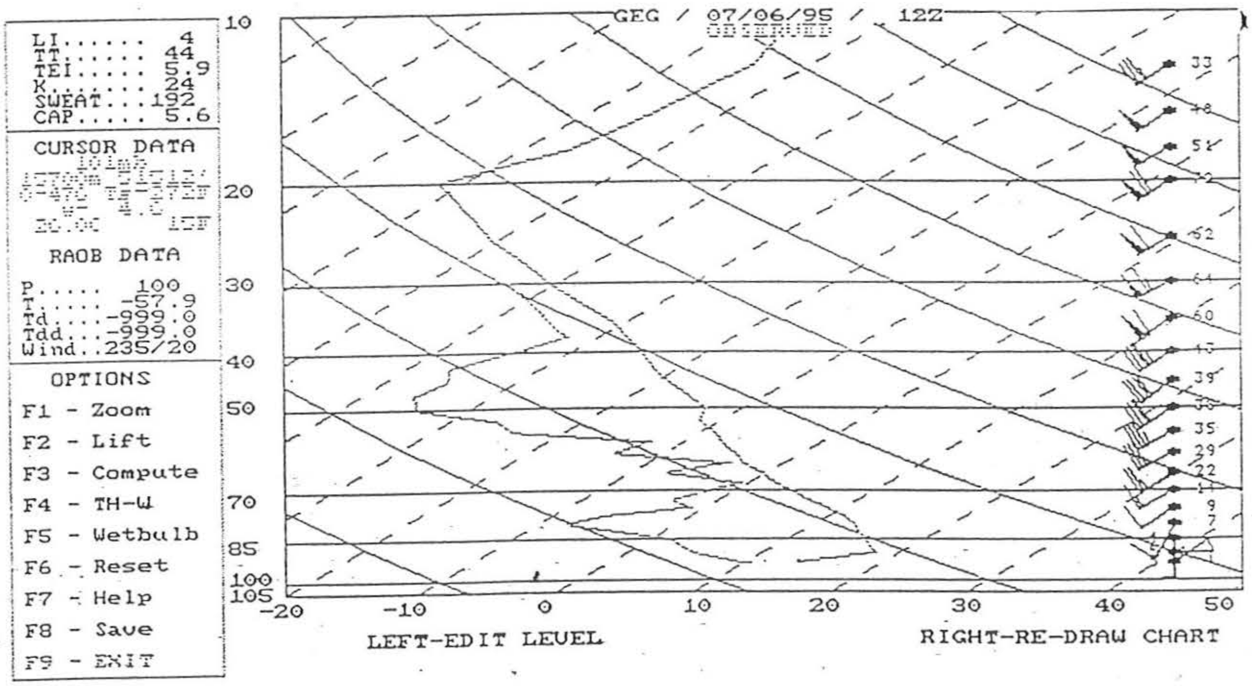
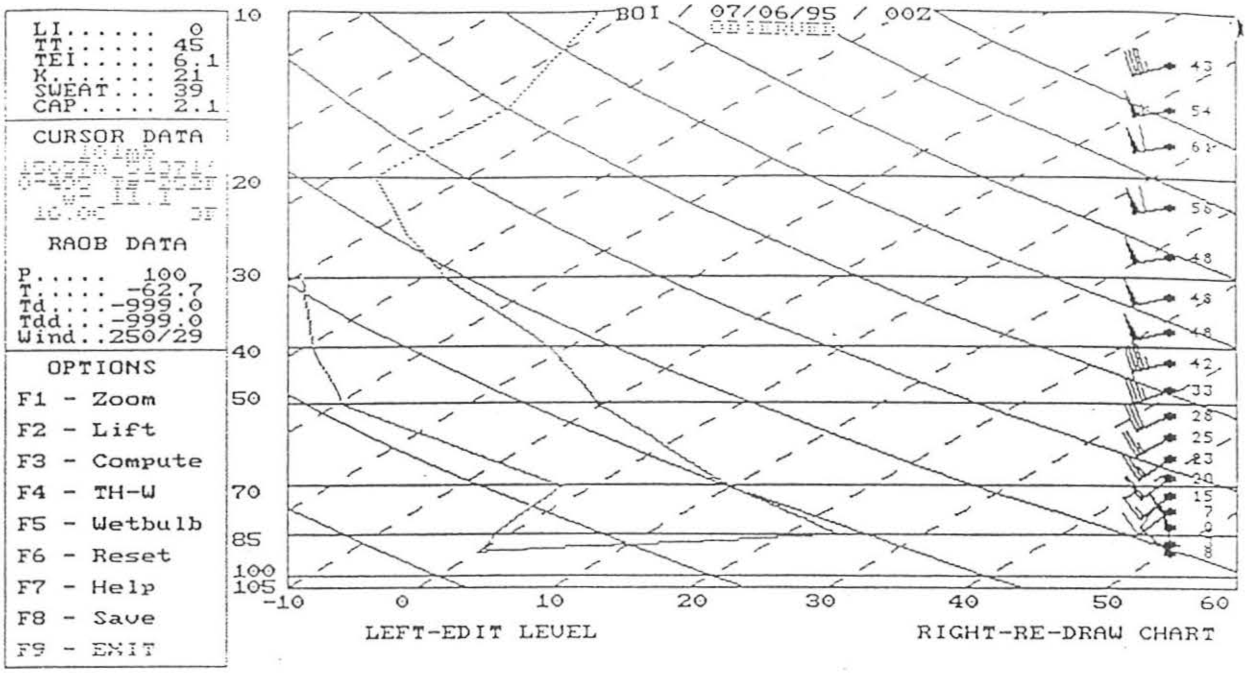


Figure 3

0000 and 1200 UTC July 6th, 1995 soundings for Spokane and Boise (next page).



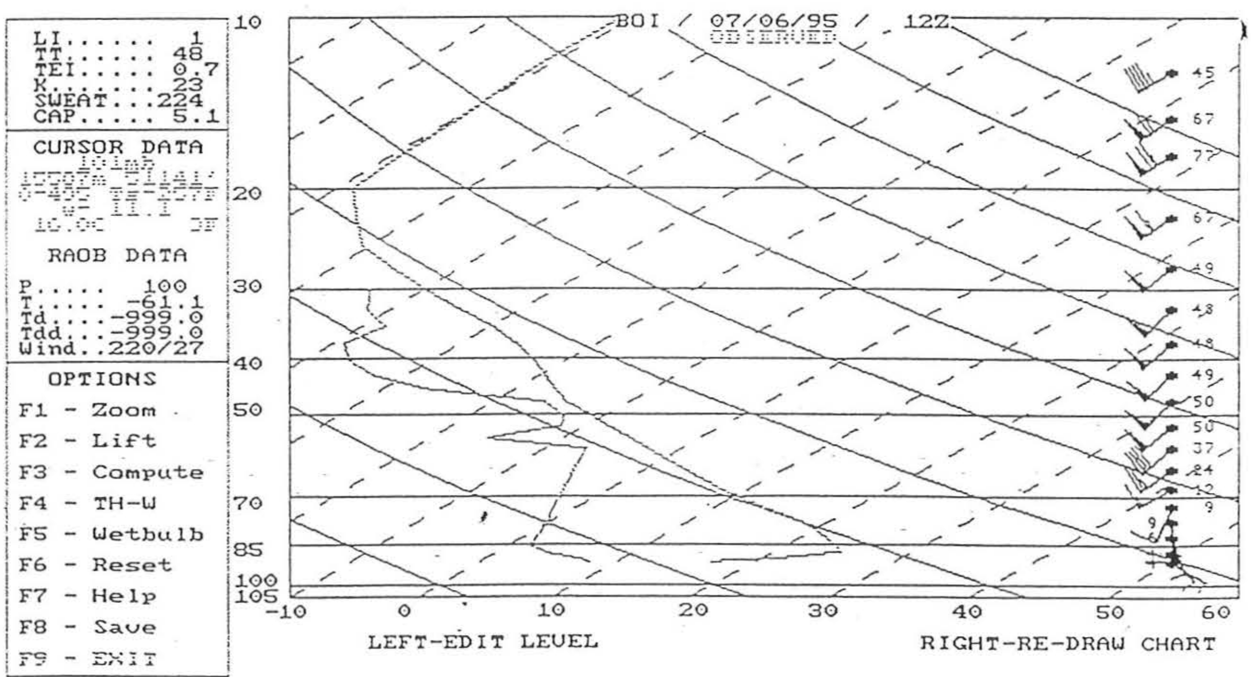


Figure 3

Boise soundings.

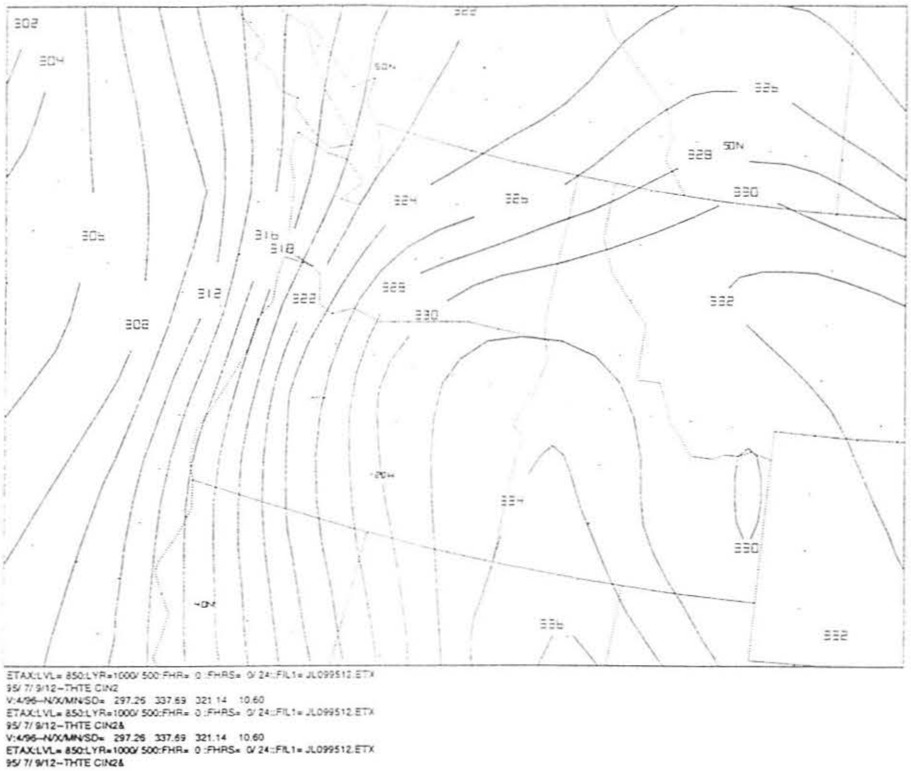


Figure 4

Eta analysis of the 850 mb Theta-E valid 1200 UTC July 9th, 1995.

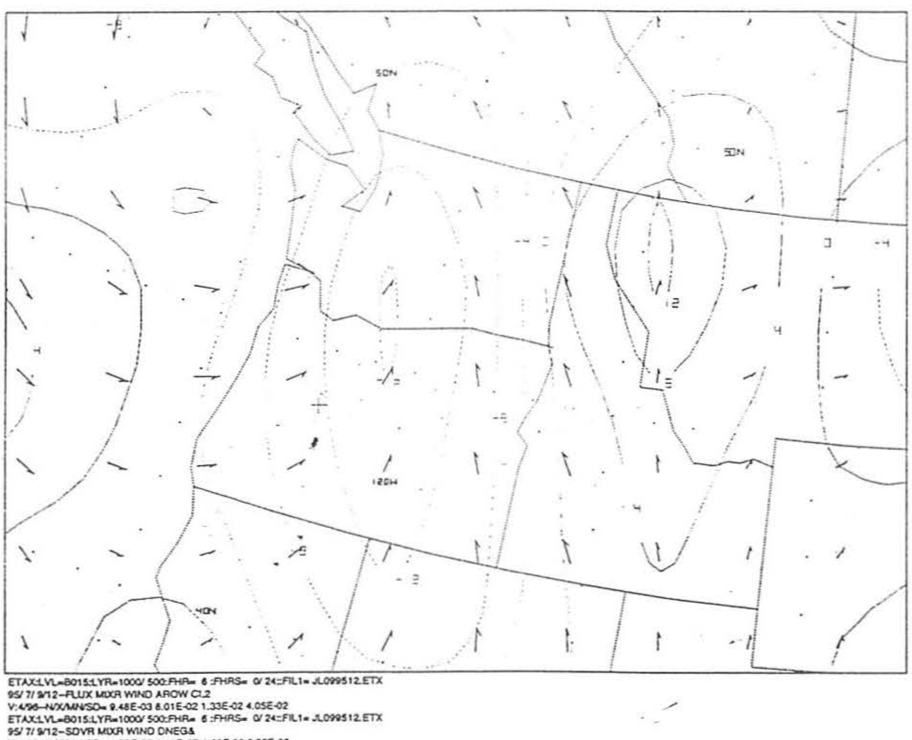
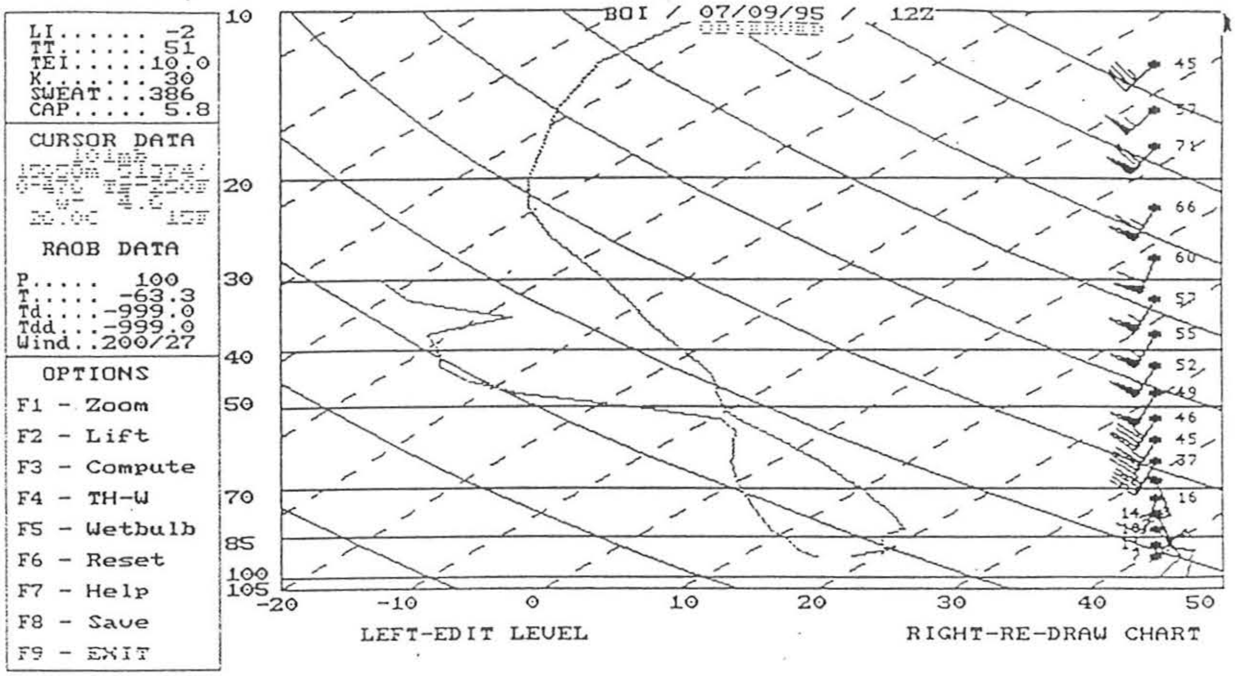


Figure 5

Eta 6-hour forecast of Boundary Layer moisture flux convergence, valid 1800 UTC July 9th, 1995. Dashed line represents convergence.



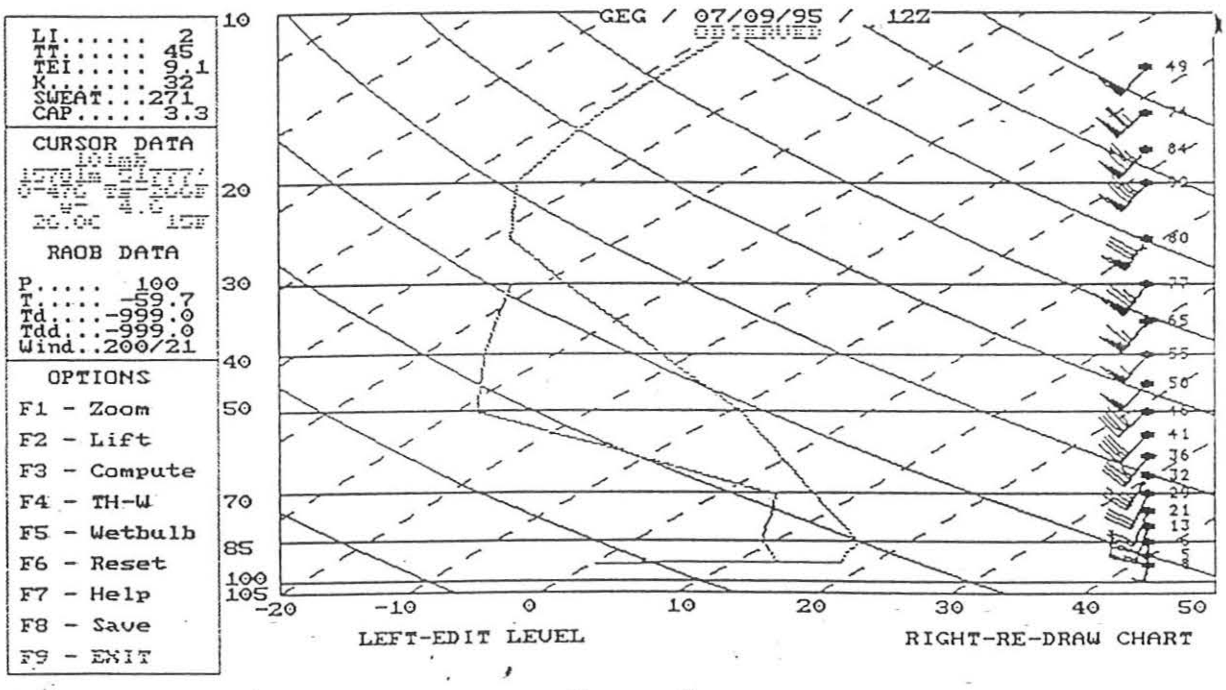


Figure 6

1200 UTC soundings from Boise (top) and Spokane (bottom) on July 9th, 1995.

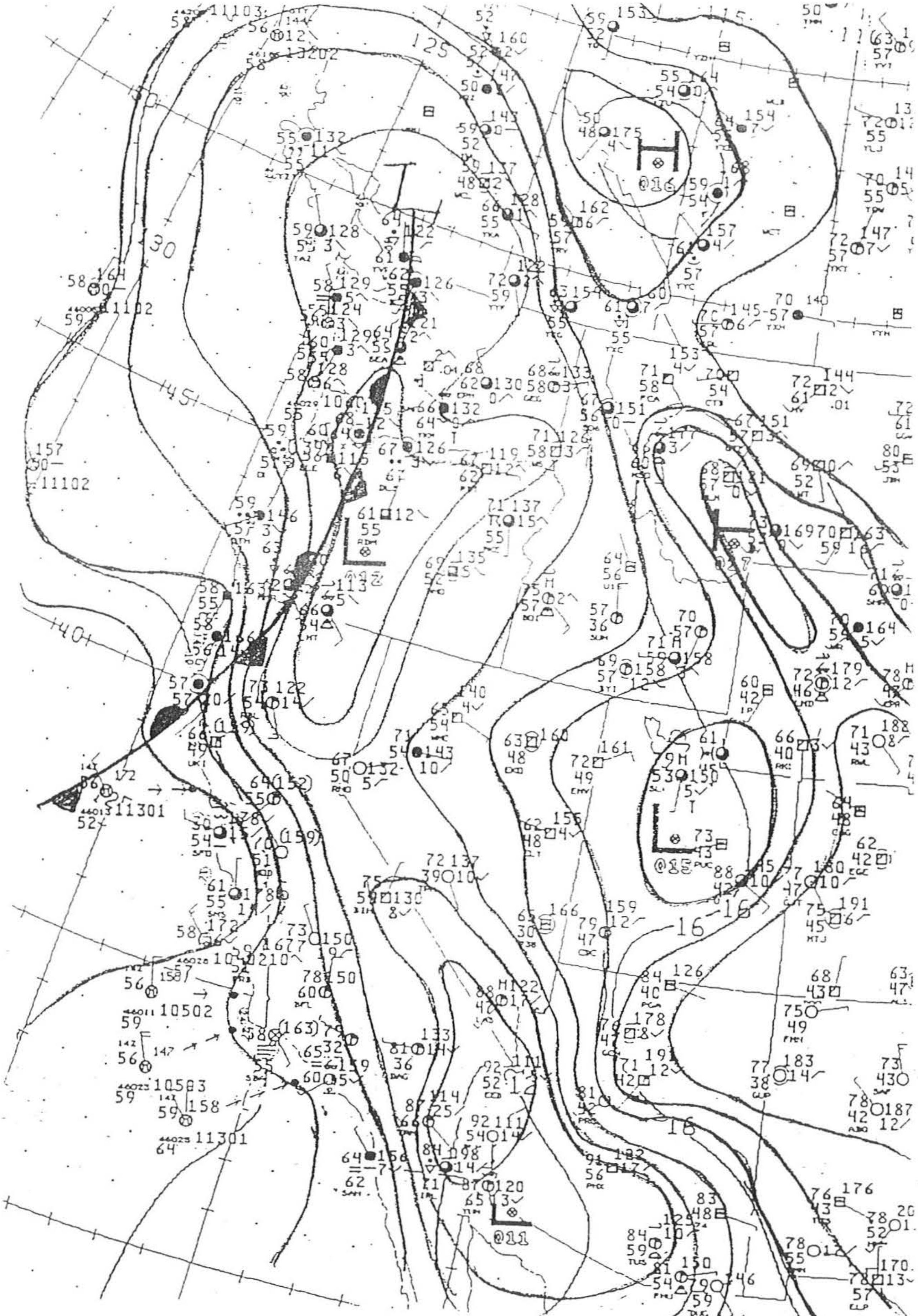


Figure 7

Surface observations and SLP analysis at 1500 UTC on July 9th, 1995. The Thermal trough extends from California into central Oregon.

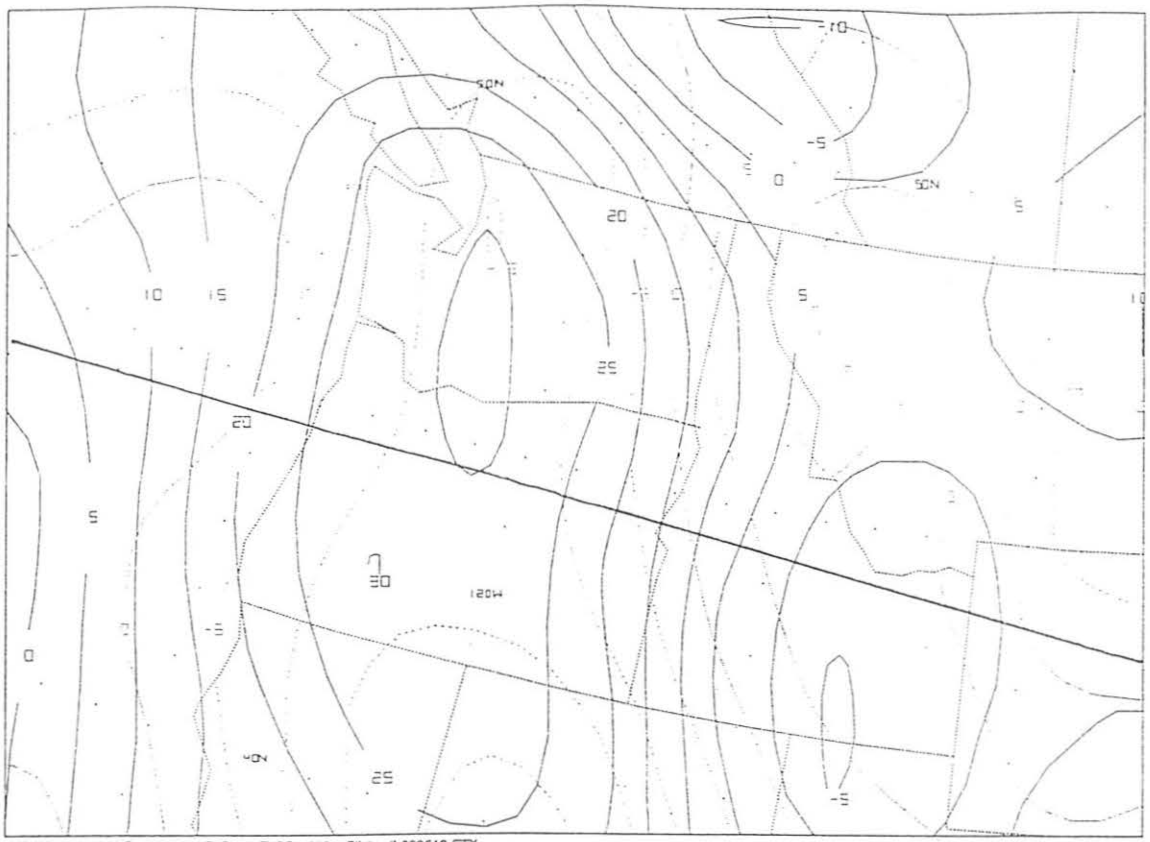


Figure 8

Eta 6-hour forecast of 250 mb Ageostropic divergence (solid) and 850 mb Ageostropic convergence (dashed), valid at 1800 UTC July 9th, 1995.

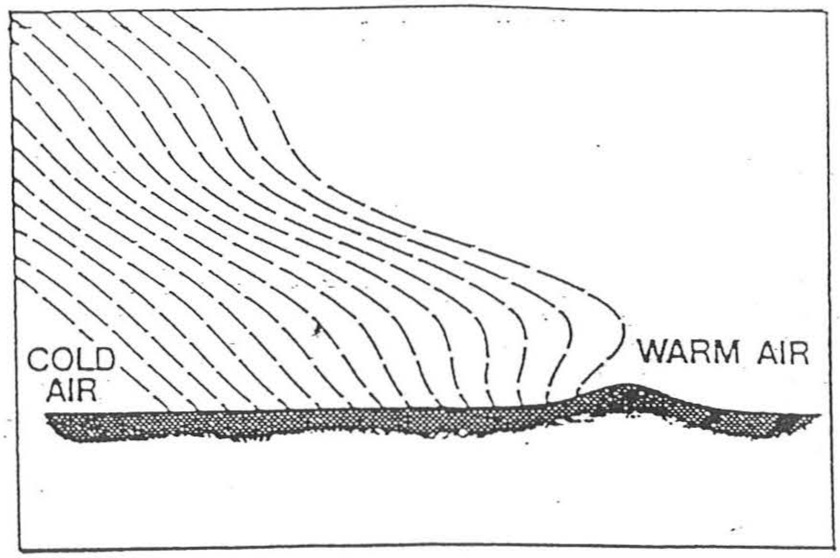
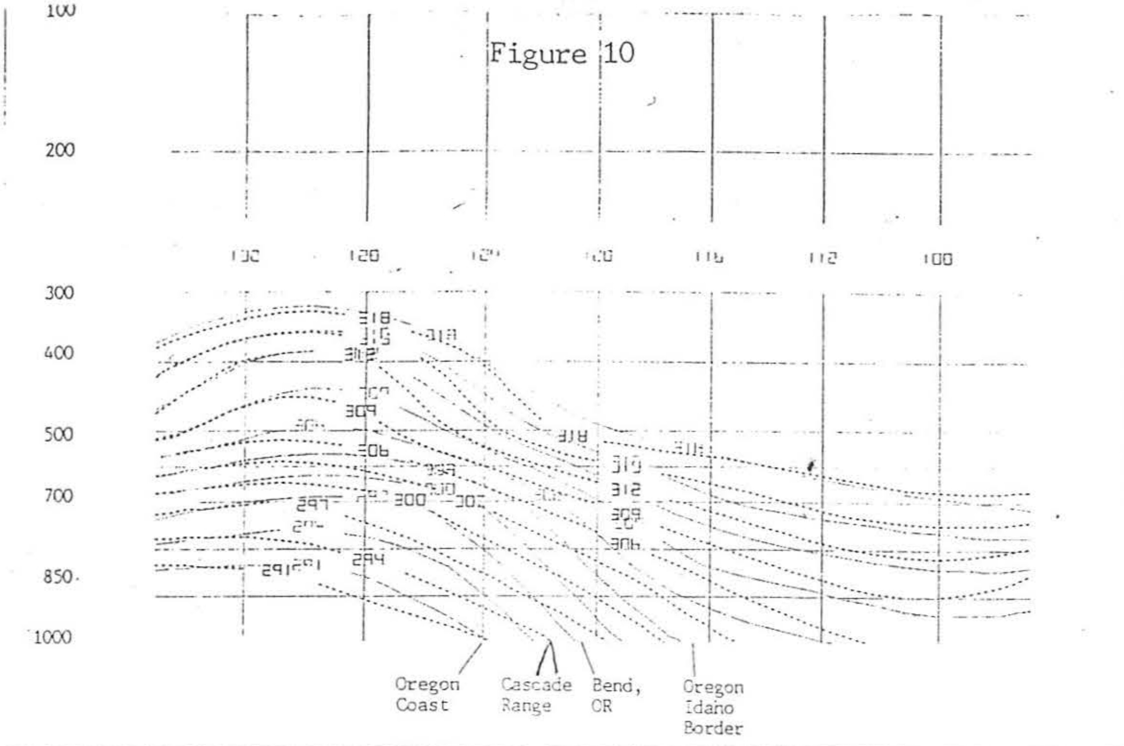
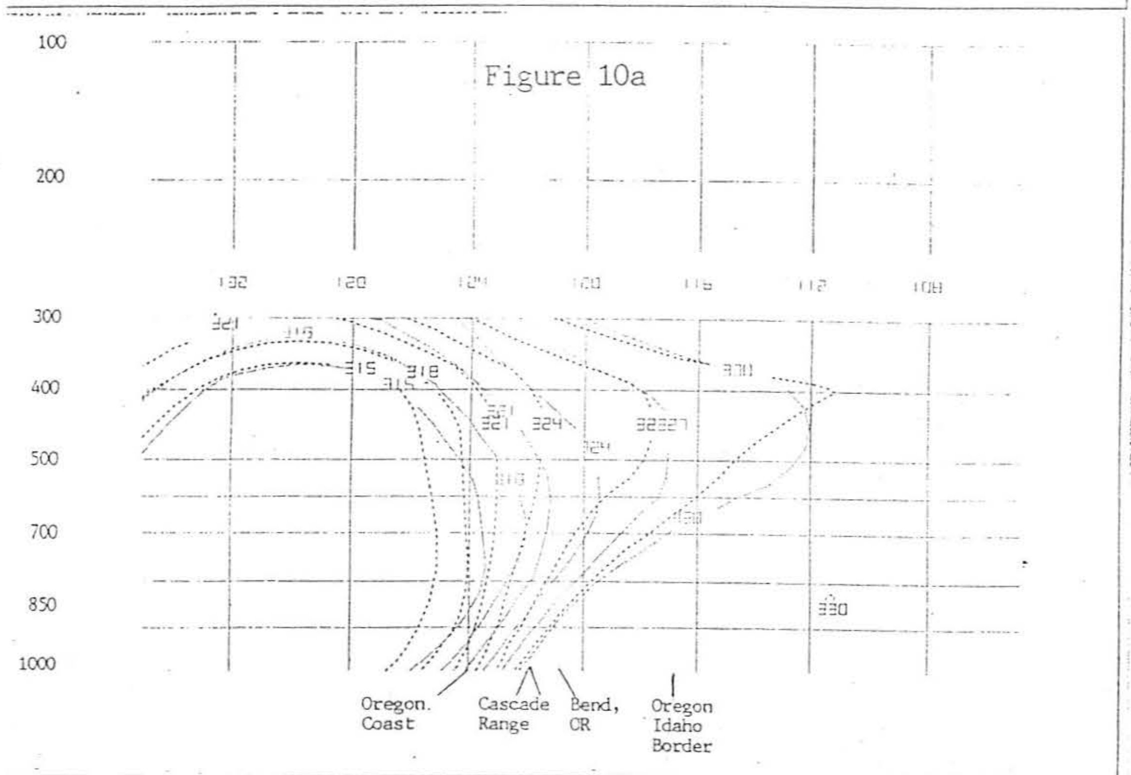


Figure 9

Figure 5. Distortion of a cold front (dashed lines) approaching a mountain range by retarding the low-level stable airflow as it is pushed up the slope. The cold front starts at the left of the figure and proceeds toward the mountain range; positions are at hourly intervals. [From Smith, (1982).]





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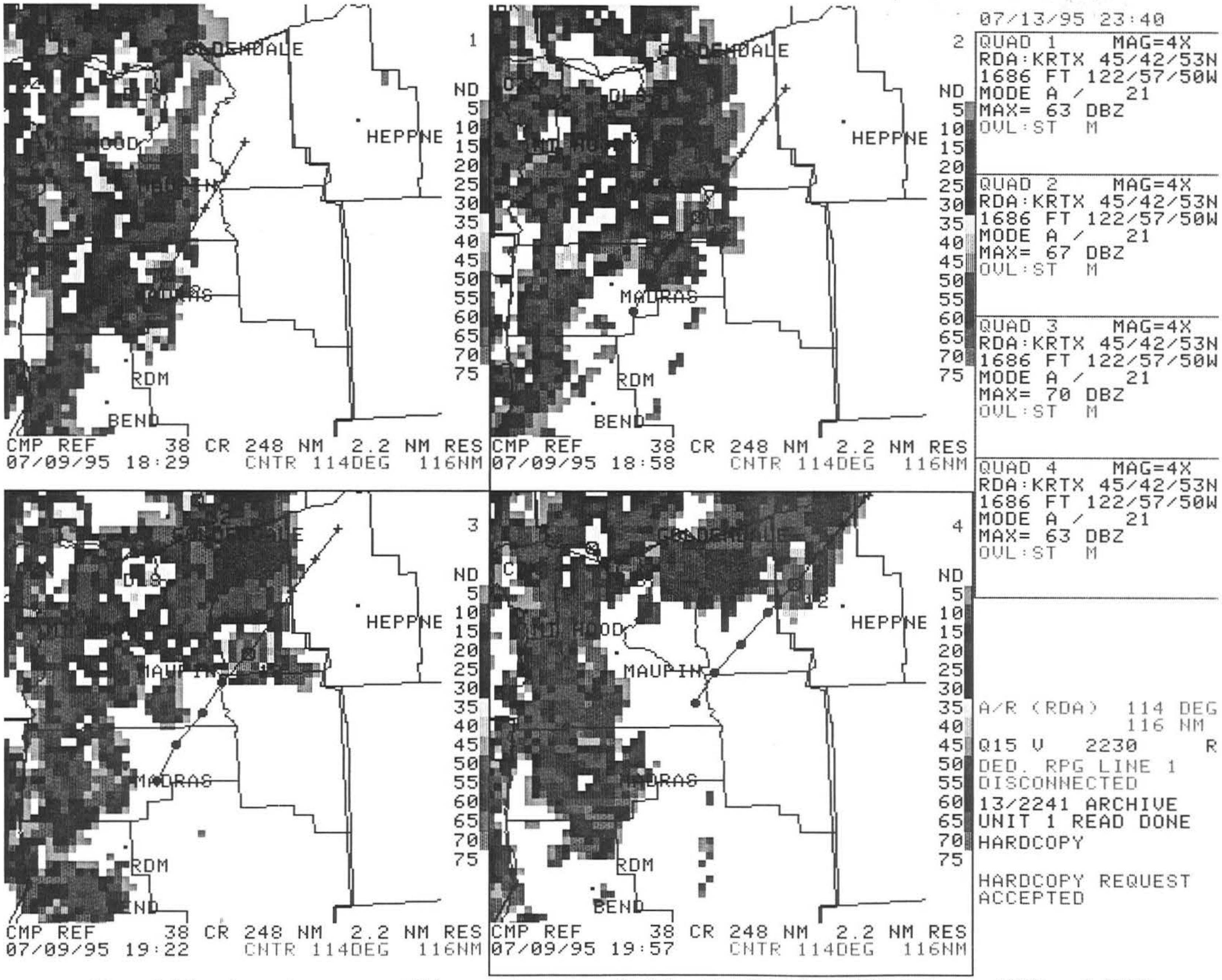
Eta west to east cross sections of Theta (figure 10) and Theta-E (figure 10a). Theta analysis (dashed lines) and 6-hour forecast (solid lines) valid at 1800 UTC July 9th, 1995. Theta-E analysis (dashed lines) and 6-hour forecast (solid lines) valid at 1800 UTC July 9th, 1995. See figure 8 for cross section path through Oregon.

Figure 11

1930 UTC visible satellite picture on July 9th, 1995. The supercell (near center) is approaching the north Oregon border. At 1950 UTC, baseball size hail and torrential rainfall struck Hermiston. Also evident is the supercell's isolation from other convection still occurring near the Cascade mountains.

Figure 12



Fiures 12 and 12a show the supercell's track as tracked by the Portland 88D between 1830 and 2115z. The cell is tracking northeast at 35 knots and away from the convection over the Cascade mountains. This storm motion was into the heart of the Theta-E ridge. Unfortunately, the Pendleton radar had not been installed at the time of this event.

Figure 12a

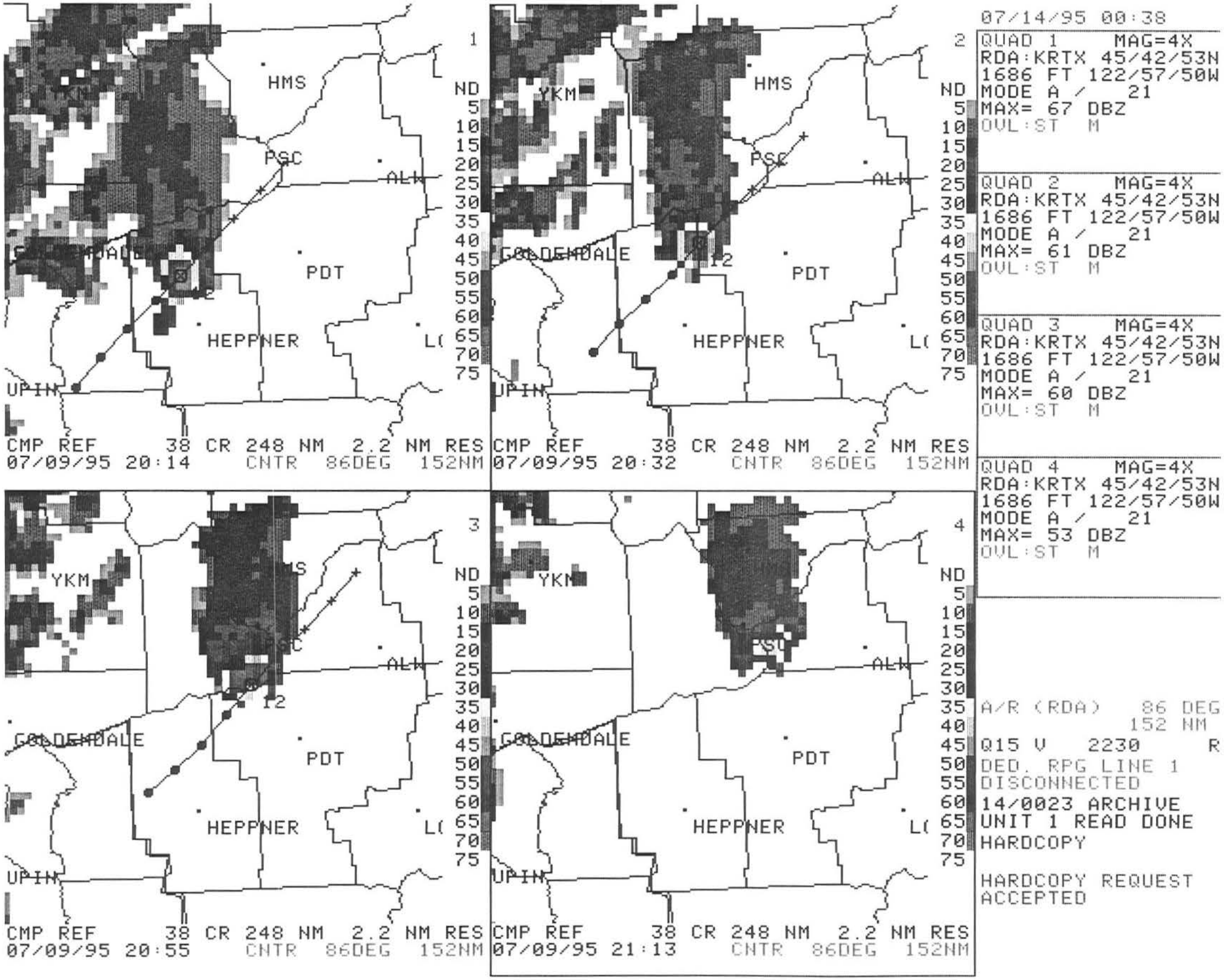


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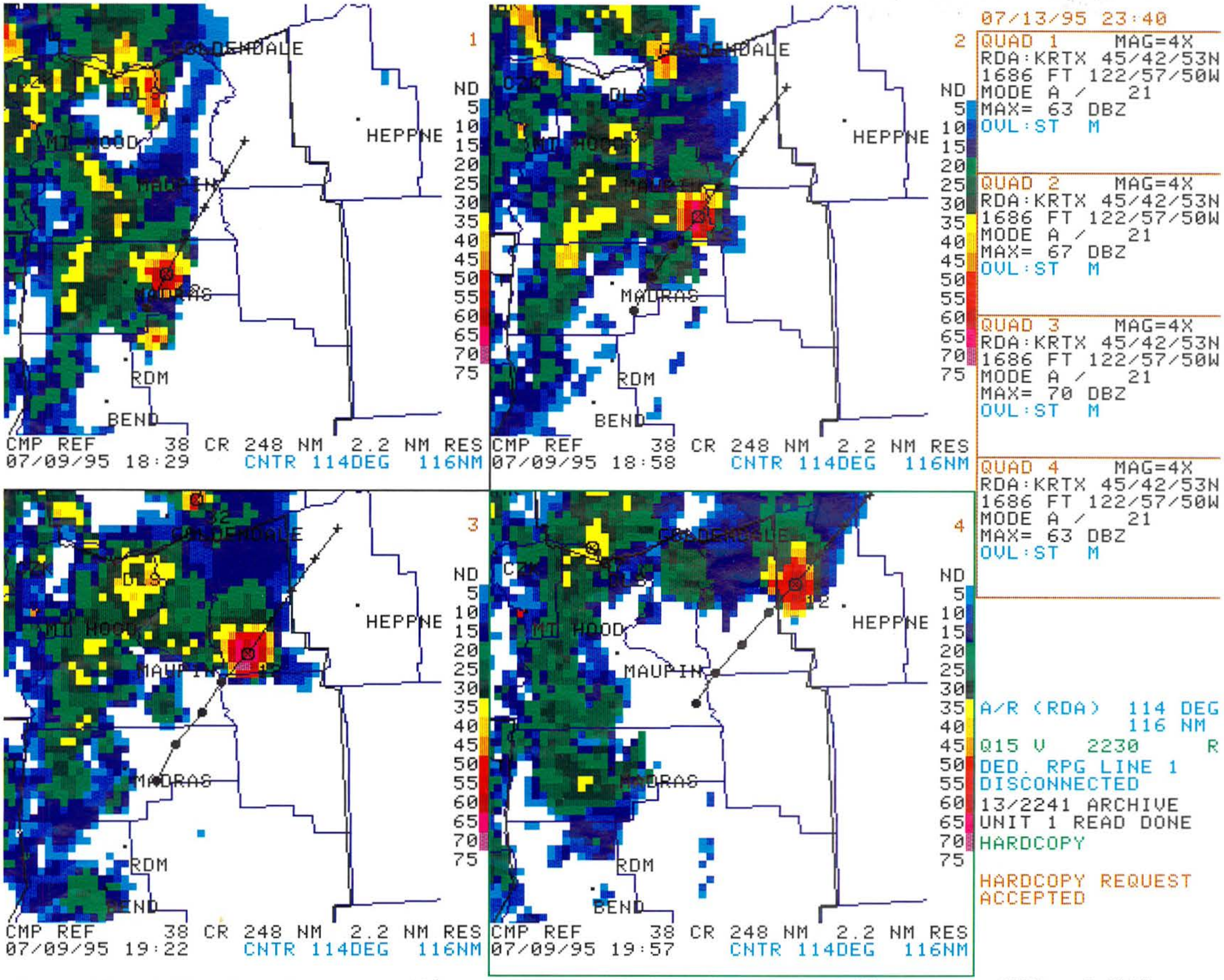
Figure 12



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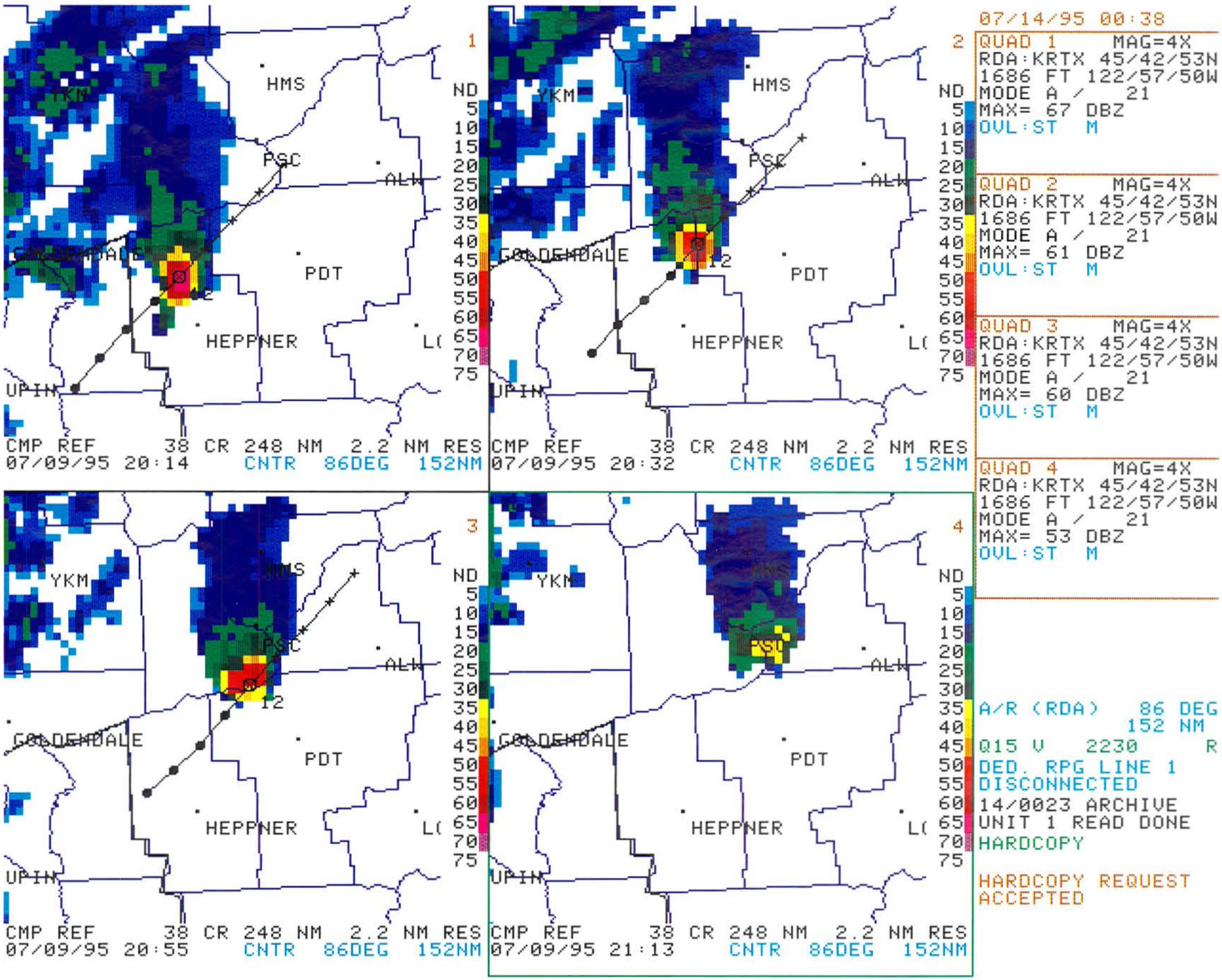
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