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A NORTHERN UTAH SOAKER!

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I. INTRODUCTION

A cold short-wave feature that had been poised over the eastern Pacific for several days moved eastward to the coast of northern California and southern Oregon on October 24, 1989, and into the western Great Basin by 12Z on October 25. Although locally heavy rains resulted from thunderstorms in northern California, rain amounts elsewhere were generally meager, ranging from 0.15 inches in southern Idaho to 0.50 inches locally in central Nevada. However, when this system moved into the eastern Great Basin, the storm underwent cyclogenesis and produced moderate to heavy rains along with embedded thunderstorms. The heaviest rain occurred from central Utah to extreme southern Idaho, where rain amounts generally were 0.75 to 1.50 inches, with over 2.00 inches reported locally. This rain event was clearly underforecast by the NGM; the 24-hour quantitative precipitation forecast (QPF) predicted 0.18 inches at Salt Lake City. Why did cyclogenesis occur over this part of the Great Basin, why was the QPF so low in face of apparent strong dynamics, and could cyclogenesis and a better QPF have been forecast from a subjective point of view? This paper will examine these questions in some detail.

II. STORM SYNOPSIS

During the last week of October 1989, a ridge dominated the eastern half of North America while the long-wave trough resided over the western half of the continent and the eastern Pacific (east of 150° W). On October 24, a 500 mb short-wave trough with a closed circulation of its own, but still within the flow of the westerlies, moved east to just off the southern Oregon coast (Fig. 1a). This system continued moving due east, reaching extreme south central Oregon by 12Z on October 25 (Fig. 1b). Within this system were unseasonably cold 500 mb temperatures, with -28°C reported at Medford and -26°C at Oakland (Fig. 1b). Between 12Z on October 25 and 00Z on October 26, the short-wave trough moved southeastward into central Nevada in response to the decreasing wavelength between it and an upstream short-wave trough over the Gulf of Alaska that dropped into the western portion of the overall long-wave trough position (Fig. 1c). Although this paper focuses on the short-wave trough entering the Great Basin, it should be kept in mind that this trough was being influenced by the upstream trough. The 24-hour 500 mb height change chart clearly identifies this wavetrain propagation by the large rise/fall couplet valid at 00Z on October 25 (Fig. 1d). Note that very minimal height changes are shown over the eastern half of the country, indicating that the ridge position was holding firmly over the Mississippi Valley.

The 300 mb analysis for 12Z on October 25 identifies at least two distinct jet streaks greater than 90 kt associated with the closed circulation short-wave trough over northern California: (1) one moving southward on the west side of the trough and (2) a possible couplet of jet maxima rounding the base and heading northeastward (Fig. 2a). The separate jet maximum on the west side of the trough was of importance because it suggested that the trough could potentially deepen before being accelerated northeastward by the upstream trough. Figure 2b, valid at 00Z on October 26, indicates that the 300 mb center did, in fact, deepen and move into north central Nevada. For the following 12 hours, winds greater than 70 kt remained on the west-southwest side of the trough, while the jet segment on the east side of the trough weakened. The net result was a transition from a slightly positively-tilted trough at 300 mb at 00Z on October 26 to a slightly negatively-tilted trough by 12Z on October 26 (Fig. 2c). The other jet segment or possible jet couplet is discussed below in the satellite interpretation section of this paper.

In spite of 12- to 24-hour forecasts of strong dynamics at 500 mb (Figs. 3c and 3d)(i.e, a vorticity maximum of at least 22 x 10^{-5} s^{-1} rotating through a slightly negatively-tilted trough) and the favorable jet configurations at 300 mb, the NGM failed to develop cyclogenesis over Nevada. At 12Z on October 25 the 500 mb wind at Mercury, NV was about 215 degrees at greater than 50 kt, a sign that conditions were becoming favorable for cyclogenesis downwind of the Sierra-Nevada mountain range. This formation typically occurs along a frontal boundary that extends northeastward, parallel to the 500 mb flow, as was seen here on the 12Z surface chart for October 25 (Fig. 7). Note how the October 25 18Z analysis (Fig. 7) differs significantly from the 24-hour forecast valid 00Z on October 26 (Fig. 5a). The 12-hour forecast improves with a secondary low over northern Utah, but it's forecast to be too far east and not strong enough (Fig. 5b). The importance of this cyclogenesis is that it significantly strengthens the baroclinic zone at the surface by retarding the eastward progression of the pre-existing frontal boundary north of the point of formation. Since the NGM did not indicate strong Nevada cyclogenesis and subsequent low pressure development at the surface, the upward vertical velocities due to secondary circulations (i.e., advective vorticity changes and divergence) were not incorporated into the forecast. The poor forecast of strong upward vertical motions characteristically associated with rapid cyclogenesis appears to be the main reason why the QPF for Salt Lake City was so low, a meager 0.18 inches. However, other factors such as moisture availability within this storm and an understanding of the computations behind the analyses and forecasted NGM relative humidity (RH) fields need to be examined before a full conclusion can be made.

In the post-processed output of the NGM, the mean relative humidity is defined by the weighted mean of the relative humidities in the bottom nine layers of the model (from the earth's surface up to 472 mb when the surface pressure is 1000 mb), where the relative thickness of the layers is used as the weighting function (Hoke et al, 1989). Since the layers are nearly twice as thick near 500 mb than at the surface, it follows that the upper layers carry twice as much weight as the lower layers. It has been generally accepted that this method does not capture the true moisture content of the atmosphere in the NGM's 700 mb height and relative humidity panel. Consequently, it typically takes the NGM 12 to 24 hours through an inherent "spin up" to generate a more reliable RH forecast. To discard the possibility that the NGM precipitation forecast in this storm was meager due to the so-called "spin up" delay, the 24- to 48-hour QPF generated 24 hours earlier at 12Z on October 24 was examined (Fig. 8a). Note that only 0.05 inches was forecast between 24 and 48 hours. It is apparent then that "spin up" delays were not the main reason for a low QPF.

Knowing that the NGM does not have a reliable RH analysis, it follows that a better tool for obtaining the initial moisture content of the atmosphere is the "average relative humidity (sfc to 500 mb)" depiction (Fig. 6b). Note that there is an analyzed >90% RH contour that is not featured on the NGM analysis (Fig. 4a). The soundings from Winnemucca and Boise (Figs. 6c and 6d) support this very moist atmosphere of >90% RH. Figure 4a also shows that the NGM's RH >70%

area was much less extensive than the actual area. During the following 12 hours, the NGM enlarged the RH >70% area by expanding it southeastward into western Utah and northward into western Montana (Fig. 4b). An area of >90% was introduced, but it was located in central Idaho and not in Nevada where one might expect it to develop due to cyclogenesis. However, the 24-hour forecast valid at 12Z on October 26 appears to hint at some kind of development in the eastern Great Basin by introducing a small pocket of RH >90% between Salt Lake City and Wyoming (Fig. 4c). Figure 8b indicates that this RH >90% area of the R2 level moved over Salt Lake City between the 12- and 24-hour forecasts respectively, valid at 00Z and 12Z on October 26. This forecast feature is subtle, yet important. Given the fact that the NGM was forecasting relative humidities >90% and a QPF of 0.18 inches through 24 hours (Fig. 8b) without clearly identifying cyclogenesis as occurring over Nevada, the operational forecaster should have asked what the RH and resulting QPF would be with cyclogenesis.

A reasonable response to the above question would be to adjust the precipitation forecasts upward for Salt Lake City. One method to determine how much of an adjustment to make in the precipitation forecast might be to look at the amount of precipitation that occurred during the previous 24 hours across the western Great Basin and California (Fig. 6a). Rain amounts generally were less then 0.50 inches, although there were exceptions. For example, in California, Redding and Red Bluff reported 1.41 and 3.36 inches, respectively. These impressive amounts revealed how much moisture was potentially available, especially in the convectively unstable regions of the cold 500 mb low and the vicinity of the vorticity maximum. Considering that cyclogenesis was likely to occur over the Great Basin between 12Z on October 25 and 12Z on October 26, a forecast for much heavier precipitation (in the neighborhood of 0.50 to 1.00 inch for eastern Nevada and Northern Utah) might have been a good first guess. Determination of time and place of anticipated heavy rain could have been aided by a continuous examination of the satellite images as the day progressed.

III. SATELLITE DISCUSSION

The use of satellite images was probably the most important tool in tracking the storm system as it moved into the Great Basin. The 6.7-μm water vapor imagery for 13Z on October 25 (Fig. 9) shows a clearly-defined, elliptical dark area extending from coastal California to roughly 34°N and 125°W. The dark area behind the baroclinic cloud band (a result of sinking motion) is a first clue of deepening or cyclogenesis (Smigielski and Ellrod, 1986). By 16Z, (Fig. 10), the darkening and broadening of the initial dark band over southern California continued, which was reflective of the mid-level drying caused by subsidence. This expanse of the dry slot is also a strong indicator of cyclogenesis frequently observed by Smigielski and Ellrod (1986). By 19Z (Fig. 11), an apparent mid-level moisture band developed just ahead of the dark band near Las Vegas, NV. It then spread northward, reaching to higher levels over the next 6 hours as indicated by the increasing brightness on the water vapor imagery for 01Z on October 26 (Fig. 12).

This moisture organization was in response to the rising/sinking couplet of the thermally indirect circulation associated with the exit region of the jet (Weldon, 1983). A close examination of the 300 mb chart for 12Z on October 25 (Fig. 2a) indicates that there were possibly two jet segments in the jet streak located between the base of the trough and Montana. I have assumed that the downstream segment was the region from

Ely, NV to central Montana and the upstream segment was from Edwards AFB, CA southwest to the base of the trough. This delineation is based on the slightly lower wind speed of 85 kt at Mercury, NV. The downstream segment has the characteristics of a "channeled" jet in that the 500 and 300 mb jet maxima and the vorticity lobe axis (not necessarily the vorticity isopleths) are typically parallel to the height contours, streamlines, 1000-500 mb thickness isopleths, and isotherms (Weldon, 1979). Their existence establishes the well-defined back edge of a cirrus shield, as is clearly identifiable on Figure 13. On the other hand, the upstream jet segment has the characteristics of an "advection" jet in that the vorticity lobe axis is not parallel to the winds, but instead crosses the streamlines and height contours at significant angles (Weldon, 1979). This lobe of vorticity axis was analyzed at 12Z on October 25 (Fig. 3a) and was forecast to intensify by 00Z on October 26 (Fig. 3b). This strong positive vorticity advection (PVA) resulted in cyclogenesis and hence the rapid cloud development across southern Nevada near Las Vegas (Figs. 14 and 15). The combination of the PVA aloft and the surface frontogenesis produced strong upward vertical motions, allowing thunderstorms to blossom rapidly between 18 and 21Z. Surface observations from southern Nevada and Cedar City, UT reflected these developments with rapid pressure falls and reports of cumulonimbus and thunder. By 22Z on October 25 (Fig. 16), a comma cloud signature had developed over southwest Utah and the adjacent region of Nevada, indicating that the cyclogenesis process was possibly developing a secondary low near Caliente, NV (P38 on Fig. 7). The explosive nature of this system was an indicator that it was going to be the focal point for the weather imminent in central and northern Utah. This storm system reached maturity between 03Z and 06Z on October 26, with a well defined comma cloud signature and a dry tongue protruding northward along the Nevada-Utah border (not shown).

The storm produced much needed precipitation across the west central and northern third of Utah, with many areas receiving over 1.00 inch. Figure 17 summarizes the reported rainfall amounts for central and northern Utah. Most of the precipitation occurred between 22Z on October 25 and 06Z on October 26, although another period of precipitation occurred along the Wasatch Mountains between 09Z and 15Z on October 26 as the 700 mb flow became northwest. This second period of precipitation was likely mesoscale in nature, resulting from orographic lifting of the moist air mass with northwest winds.

IV. SUMMARY AND CONCLUSIONS

An overview of this storm suggests that several integral components all came together over the Great Basin on October 25 to produce a significant synoptic scale rain event. Although the NGM model indicated that this storm would have good dynamic support and the surface to 500 mb RH analysis indicated the availability of substantial moisture, the NGM failed to produce a high enough QPF, even after a 12-hour "spin up" time. The forecaster's dilemma was to determine which parameters were being forecast most accurately. Among the important questions to be considered by the forecaster were: Would cyclogenesis occur over Nevada? If plenty of moisture was available, how much of an adjustment to the QPF should be made to account for cyclogenesis acting on the moist atmosphere?

A first glance at the 500 and 300 mb levels indicates that the most important dynamic features were strong PVA embedded in southwest flow across the Sierra-Nevada mountain range. This combination of PVA embedded within southwest winds resulted in rapid cyclogenesis over southern Nevada that later moved northeast along the pre-existing frontal boundary across west central and northern Utah. Other important features included the cold 500 mb temperatures and the abundance of maritime moisture within the original short-wave trough. In addition to these more obvious features, there were two subtle features that played important roles in maintaining the overall storm strength and possible development. The first was the upstream short-wave trough over the Gulf of Alaska. As it moved down the backside of the long-wave trough, it acted as a "kicker" to the primary system, not allowing it to stall over California. The second, was the 90 kt plus jet on the southwest flank of the primary short-wave trough at 12Z on October 25 that directed the core of the system farther south.

With a knowledge of the existing strong dynamics shown by the analysis for 12Z on October 25 and the potential dynamics thereafter, the forecaster's main concern was how much precipitation could be rung out of the atmosphere if cyclogenesis took place. Upstream rainfall amounts for the previous 24 hours were generally unimpressive, with less than 0.50 inches at most locations. However, there were reports of 1.41 and 3.36 inches at two different observation sites in northern California, which indicated the potential for heavy rainfall with this storm. This vital information and the extremely moist 12Z soundings from Winnemucca and Boise were significant indicators that the computer guidance was deficient in the QPF department even without considering the effects of cyclogenesis acting on the moist atmosphere. The NGM's failure to forecast cyclogenesis over Nevada was the crux of the entire forecast.

Satellite pictures not only aided in following the progress of the storm, they identified the location of the "advection" jet maximum and, therefore, the region in which cyclogenesis was most likely to occur. Continued enhancement of the cloud signature over southern Nevada by 20Z on October 25 suggests that the location and strength of the vorticity maximum forecast by the NGM were on track. Strong thunderstorms developed under the favored left-front quadrant of the jet maximum as it sped across southern Nevada into southern Utah. This embedded convection spread northward along the cold front, which moved much more slowly across the northern half of Utah as the tilt of the trough became slightly negative. In doing so, the northern half of Utah remained in a favorable location for upward vertical motions for an extended period of time. As a result, the rain continued for 10 to 16 hours, producing widespread amounts of 0.75 to 1.50 inches. Also, up to 3 inches of snow accumulated in parts of the Salt Lake City Valley early on October 26 as the flow at 700 mb became northwest with the passage of the 700 mb low.

In conclusion, it is imperative from an operational forecaster's point of view that the computer models' guidance be used as exactly that-- "guidance". Constructive analyses of available data can help determine if the models have a good handle on the overall storm system, and this information can be combined with the guidance, experience, and intuition to generate a worthy forecast. As seen in this case study, there were many so-called "hand writings on the wall" at least 12 hours prior to the storm reaching Utah. These indicators, along with the Nevada cyclogenesis, all argued for a substantial rain event and should have been recognized as such. Therefore, when the NGM and/or LFM (which forecast similar 500 mb dynamics and a slightly higher QPF for this case) produce meager objective precipitation forecasts in the face of storm characteristics as described above, the forecaster's subjective intuition should prevail over the computer QPF guidance.

V. ACKNOWLEDGMENTS

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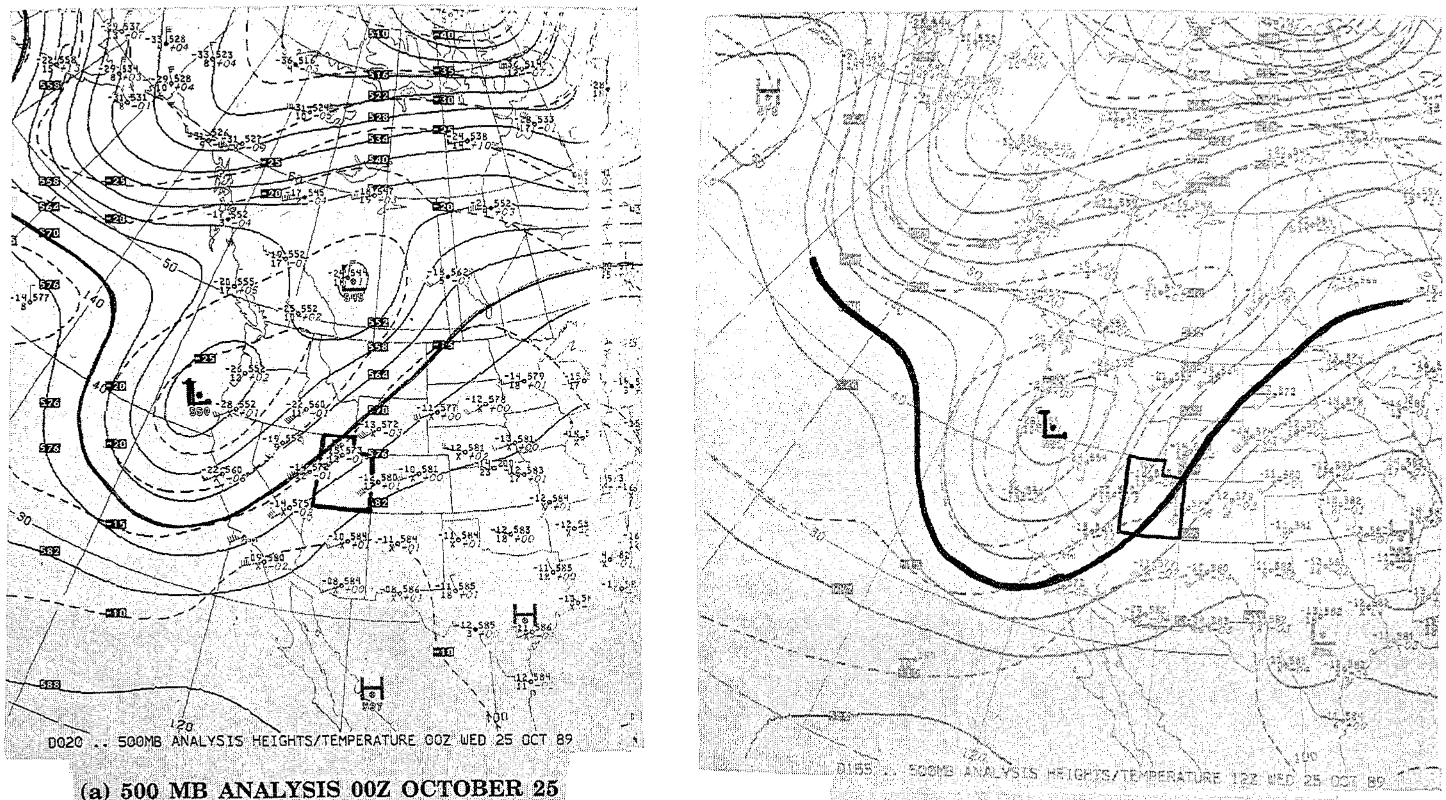
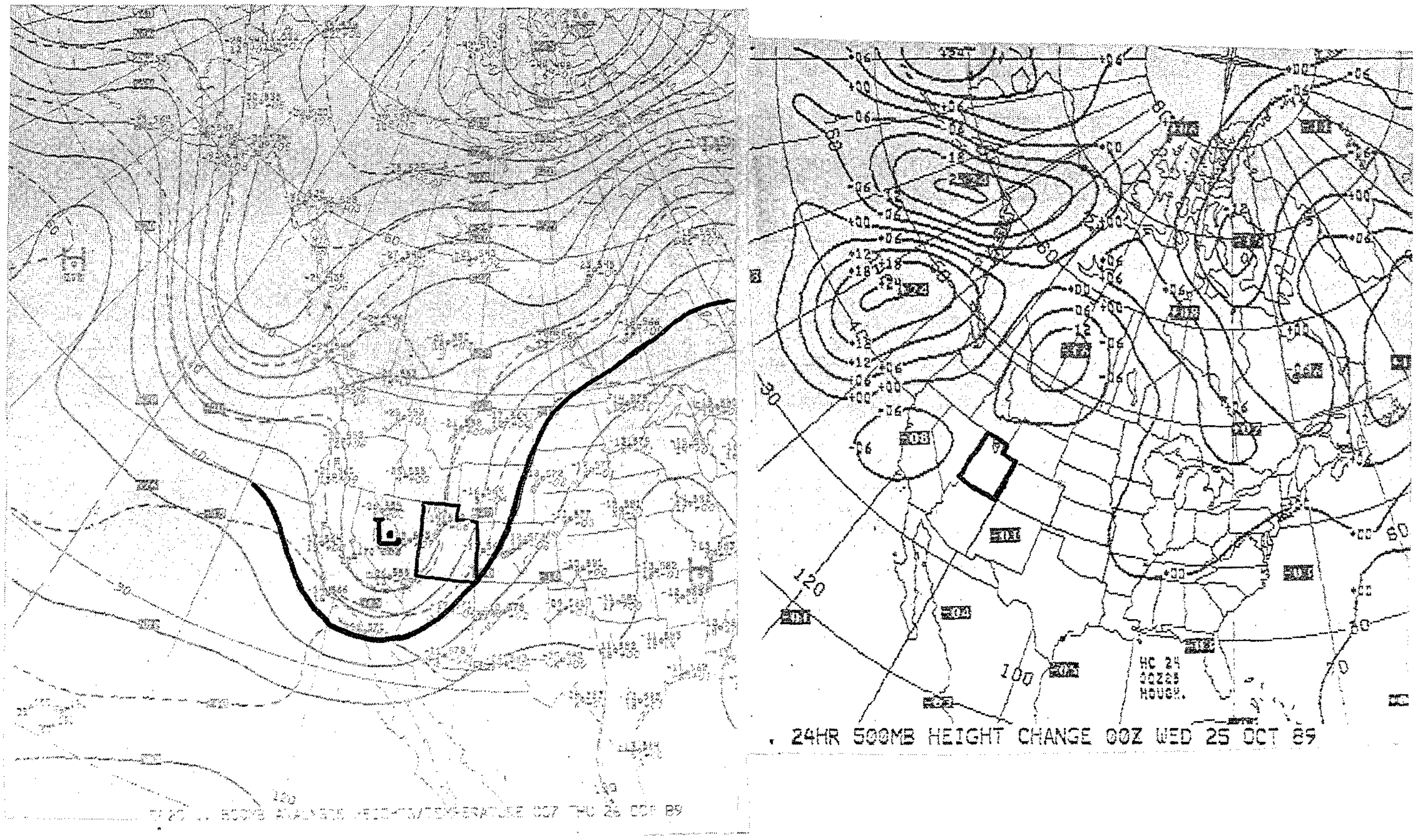
FIGURE 1



(a) 500 MB ANALYSIS 00Z OCTOBER 25

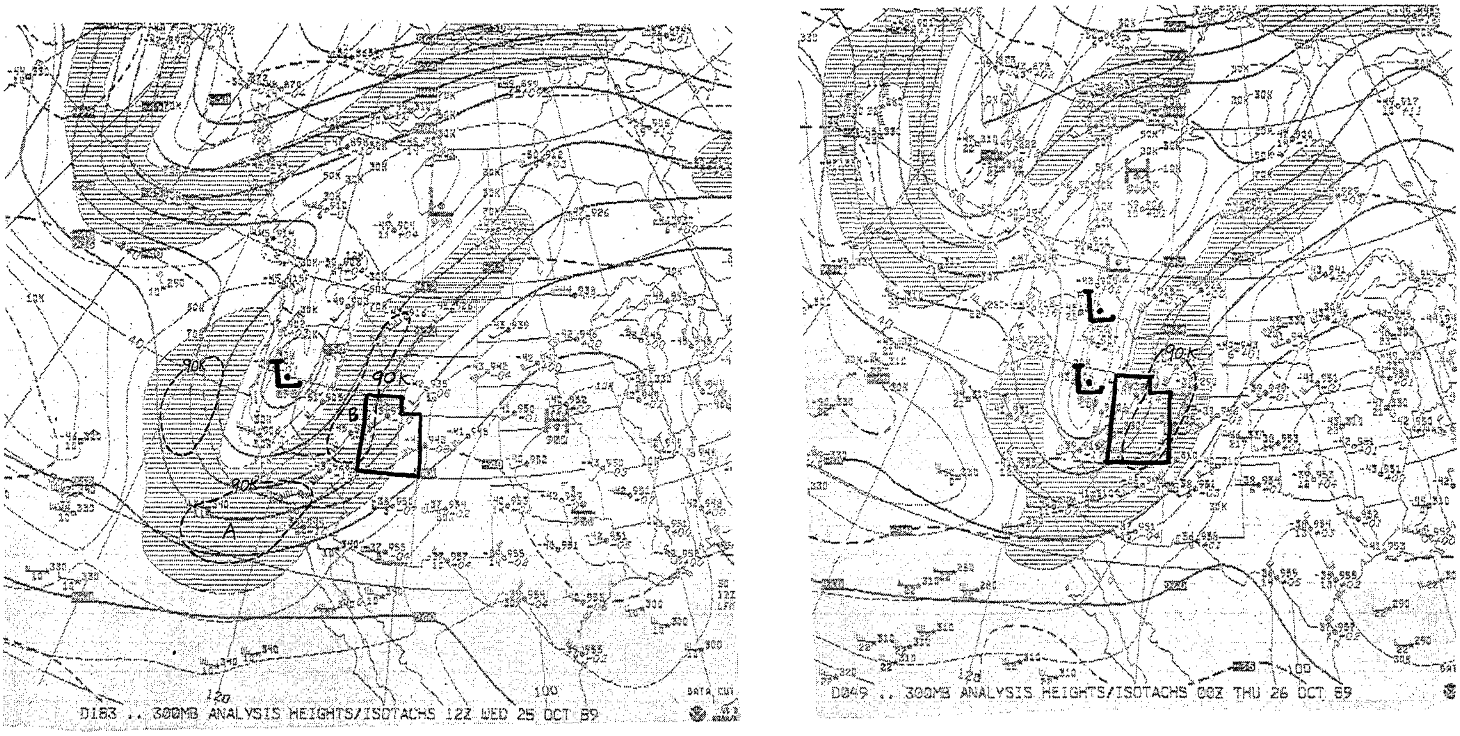
(b) 500 MB ANALYSIS 12Z OCTOBER 25



(c) 500 MB ANALYSIS 00Z OCTOBER 26

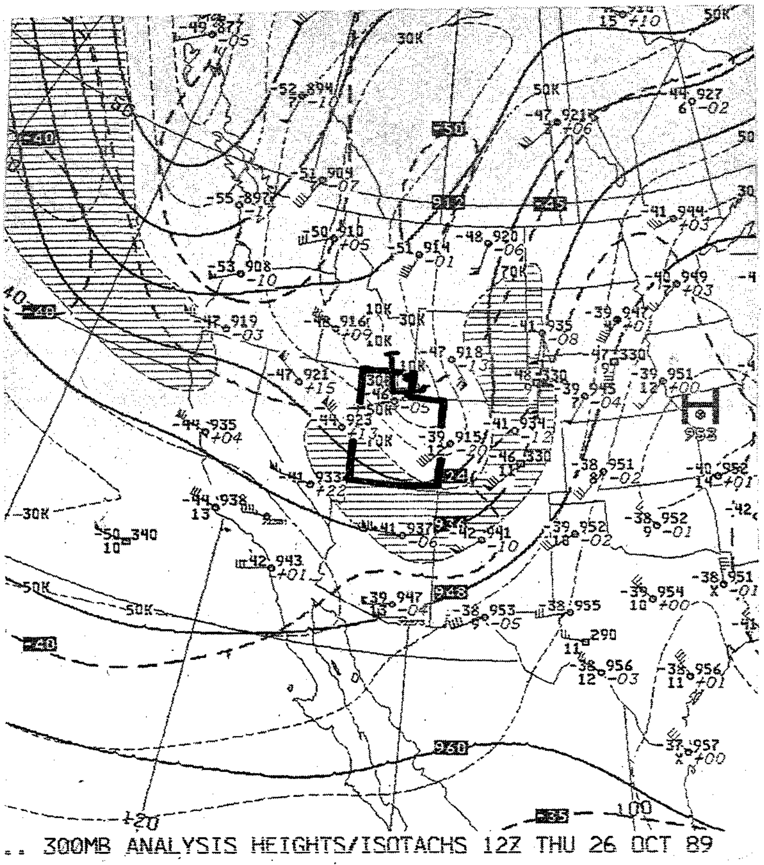
(d) 24 HR 500 MB HEIGHT CHANGE
00Z OCTOBER 25

FIGURE 2



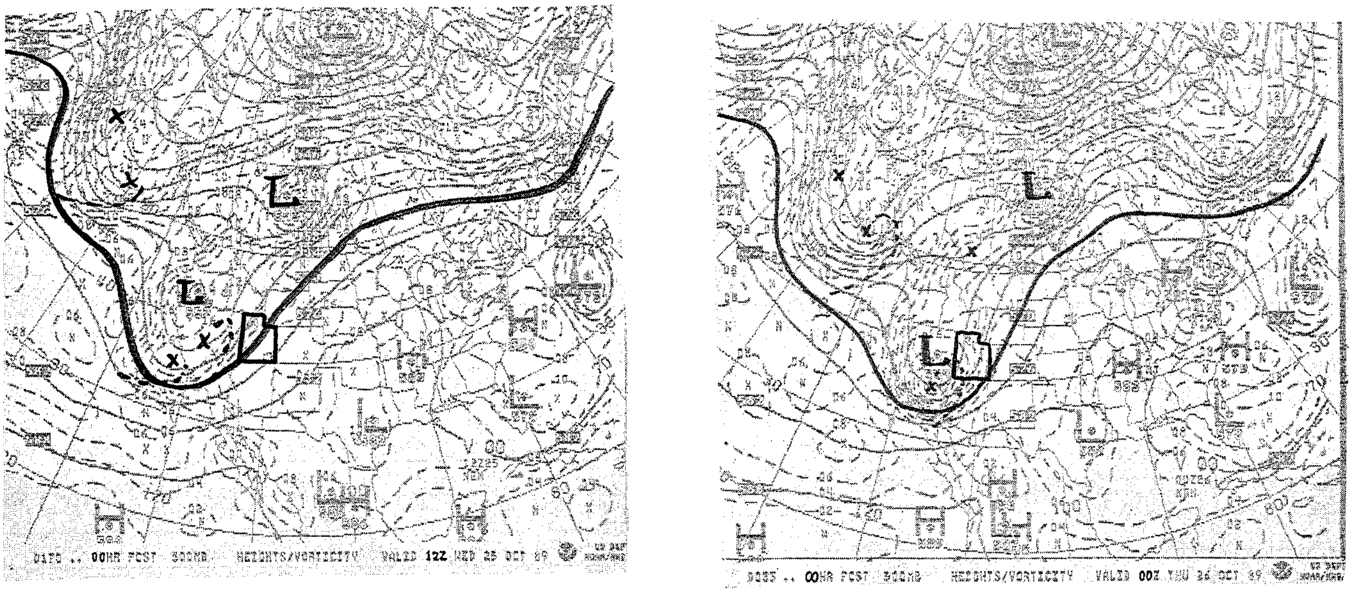
(a) 300 MB ANALYSIS 12Z OCTOBER 25
Jet segment "A" is an "advection" jet.
Jet segment "B" is a "channeled" jet.

(b) 300 MB ANALYSIS 00Z OCTOBER 26



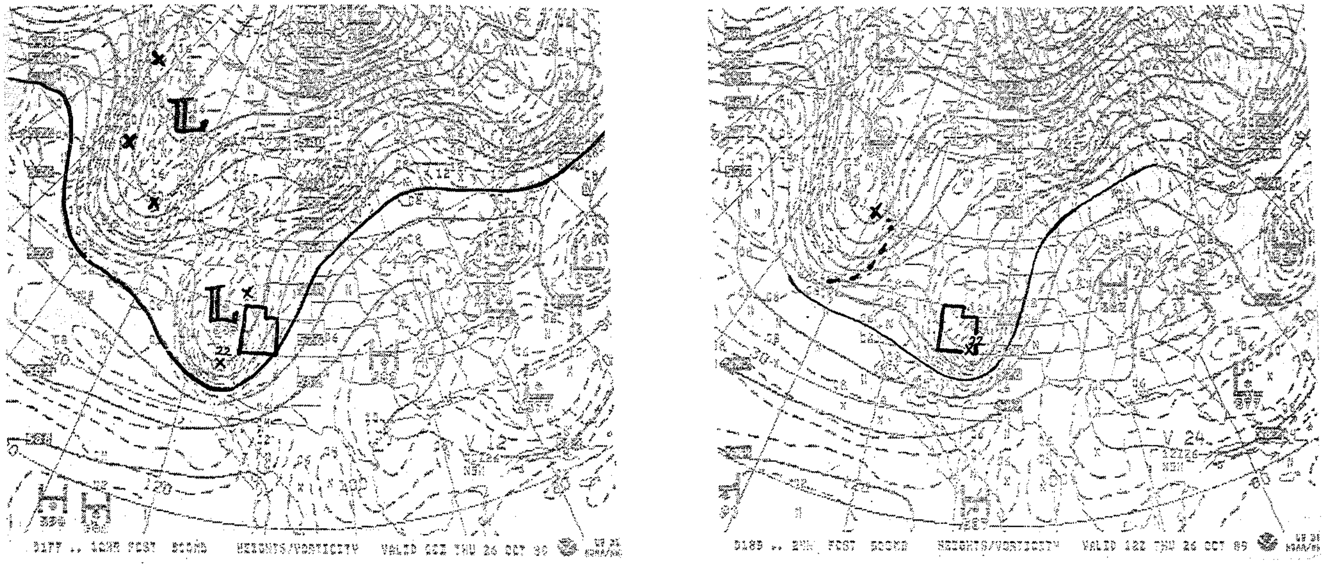
(c) 300 MB ANALYSIS 12Z OCTOBER 26

FIGURE 3
The highlighted vorticity lobe on Figures 3a and 3b
is associated with the 300 mb "advection" jet.



(a) 500 MB ANALYSIS HEIGHTS/VORTICITY
VALID 12z OCTOBER 25

(b) 500 MB ANALYSIS HEIGHTS/VORTICITY
VALID 00Z OCTOBER 26

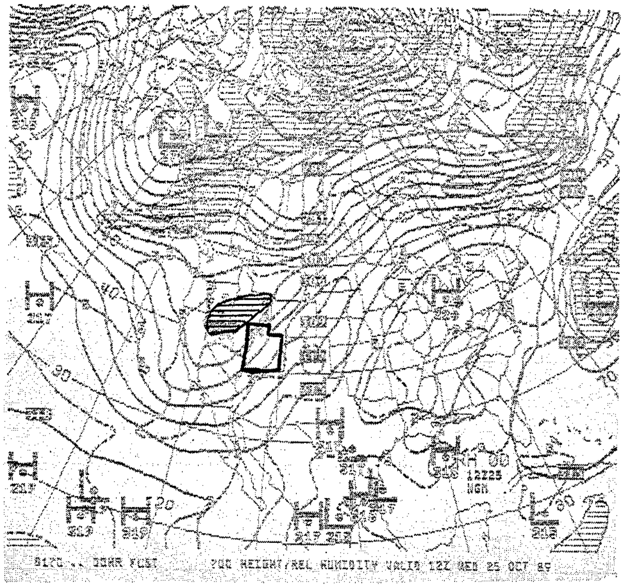


(c) 500 MB NGM 12-HR FCST HGTS/VORTICITY
VALID 00Z OCTOBER 26

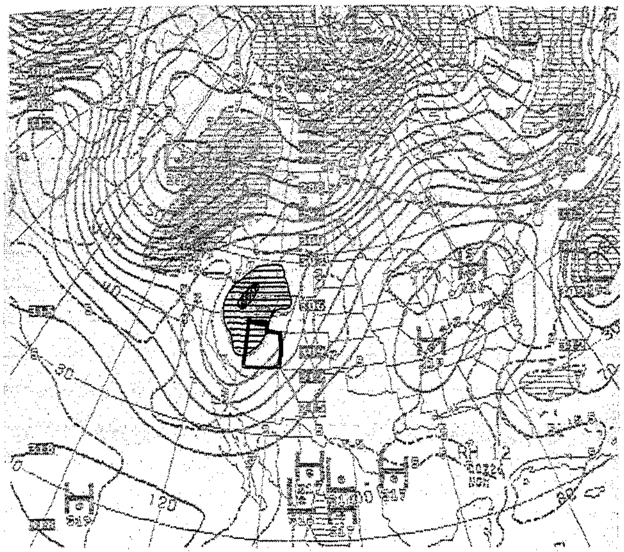
(d) 500 MB NGM 24-HR FCST HGTS/VORTICITY
VALID 12Z OCTOBER 26

FIGURE 4

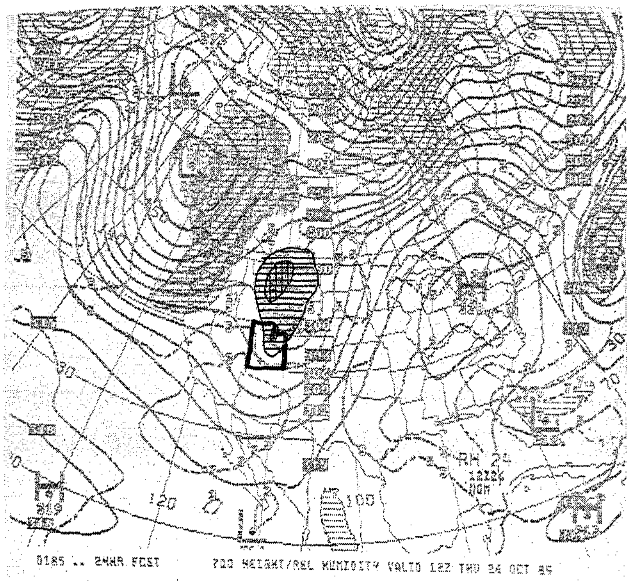
Figures 4a, 4b, and 4c are the NGM's 12Z October 25 analysis, 12-hour forecast, and 24-hour forecast of the 700 mb height and relative humidity fields. The highlighted area with horizontal lines represents ≥70% RH and the cross-hatched area represents ≥90% RH.



(a) 700 MB ANALYSIS HGTS/RH VALID 12Z OCTOBER 25

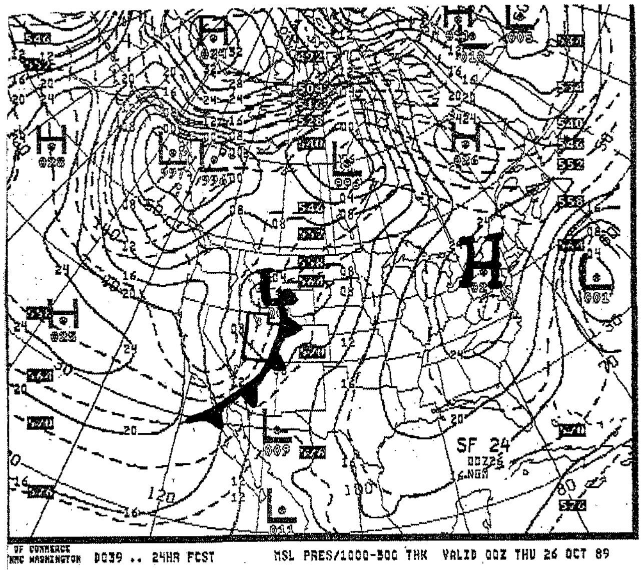


(b) 700 MB NGM 12-HR FCST HGTS/RH VALID 00Z OCTOBER 26

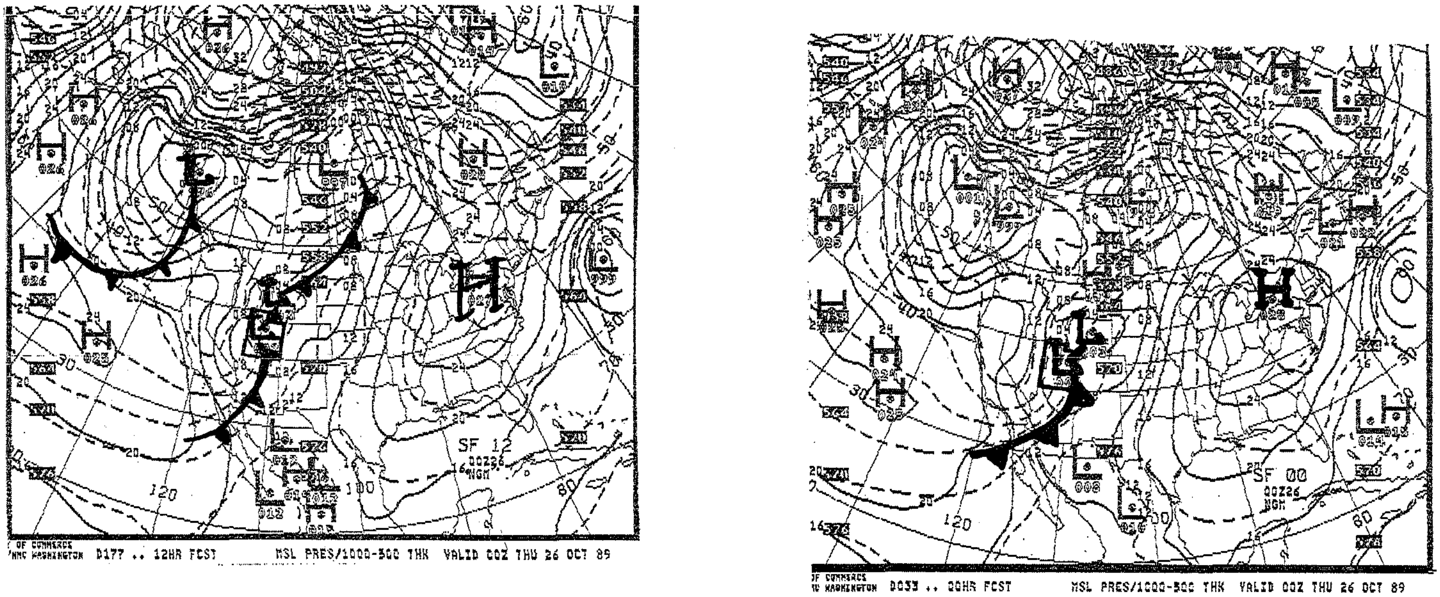


(c) 700 MB NGM 24-HR FCST HGTS/RH VALID 12Z OCTOBER 26

FIGURE 5



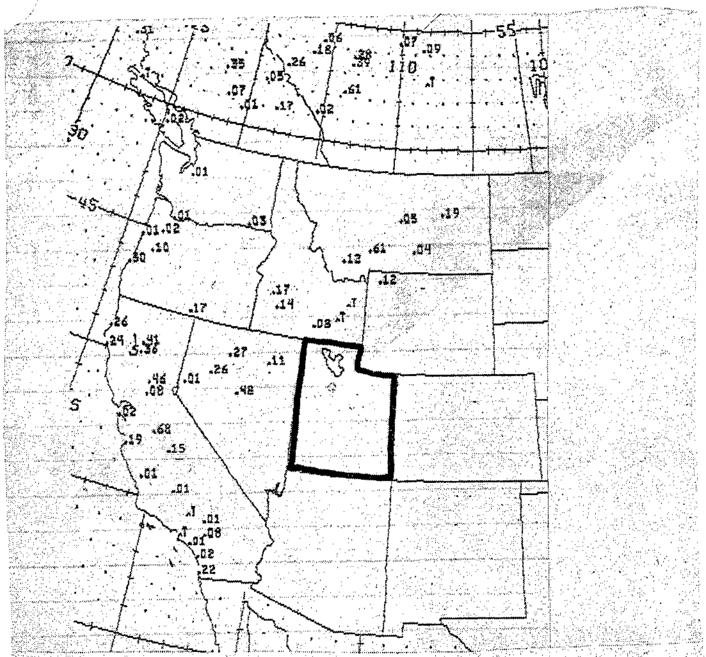
(a) NGM 24-HR FCST MSL PRES/THKNS VALID 00Z OCTOBER 26



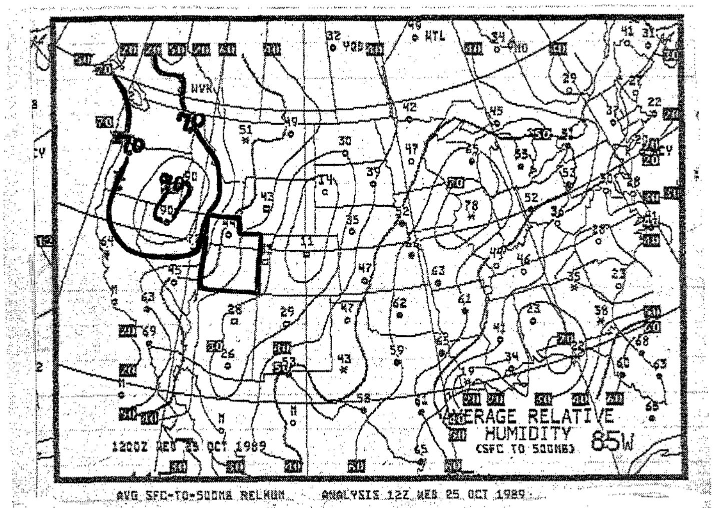
(b) NGM 12-HR FCST MSL PRES/THKNS VALID 00Z OCTOBER 26

(c) NGM ANALYSIS MSL PRES/THKNS VALID 00Z OCTOBER 26

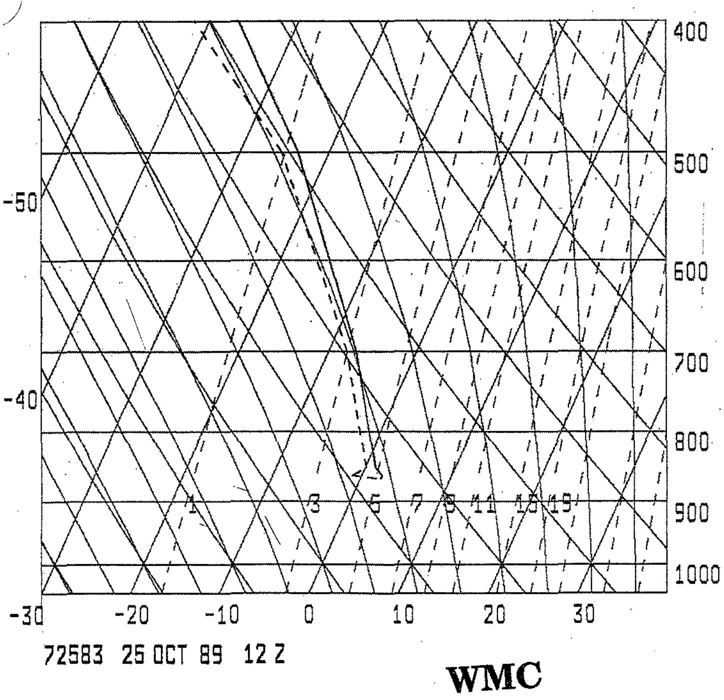
FIGURE 6



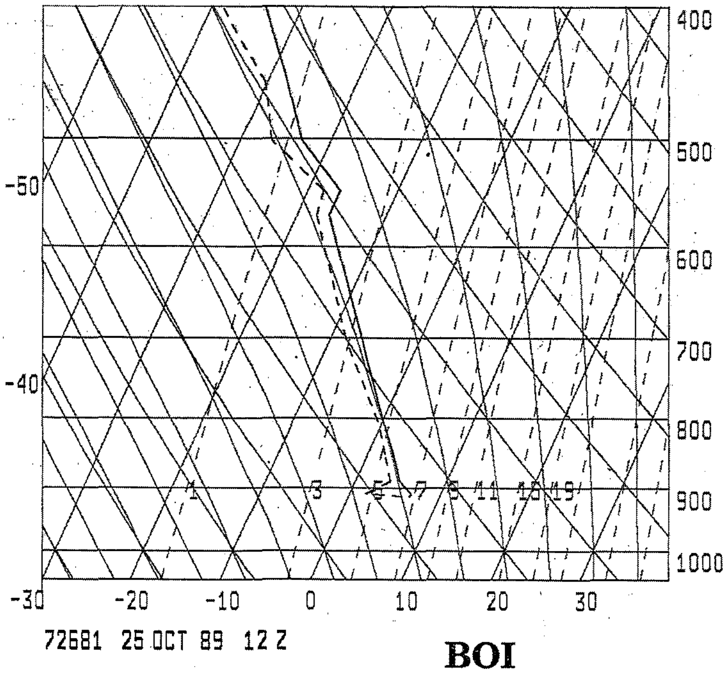
(a) OBSERVED 24-HR RAINFALL VALID 12Z OCTOBER 25. [NOTE THE TWO IMPRESSIVE RAINFALL REPORTS FROM RED BLUFF AND REDDING, CA.]



(b) MEAN RH FROM SFC TO 500 MB VALID 12Z OCTOBER 25.



(c) SOUNDING FOR WINNEMUCCA, NV



(d) SOUNDING FOR BOISE, ID

FIGURE 7.

Combined surface analysis for 12Z and 18Z on October 25 '89.

The conventional cold front symbol attached to the low labeled "A" is the 12Z position. Note the slow movement of the low from "A" position at 12Z to the "B" position at 18Z. The heavy dashed line represents the cold front at 18Z. The low labeled "C" is the approximate position of a secondary wave formation.

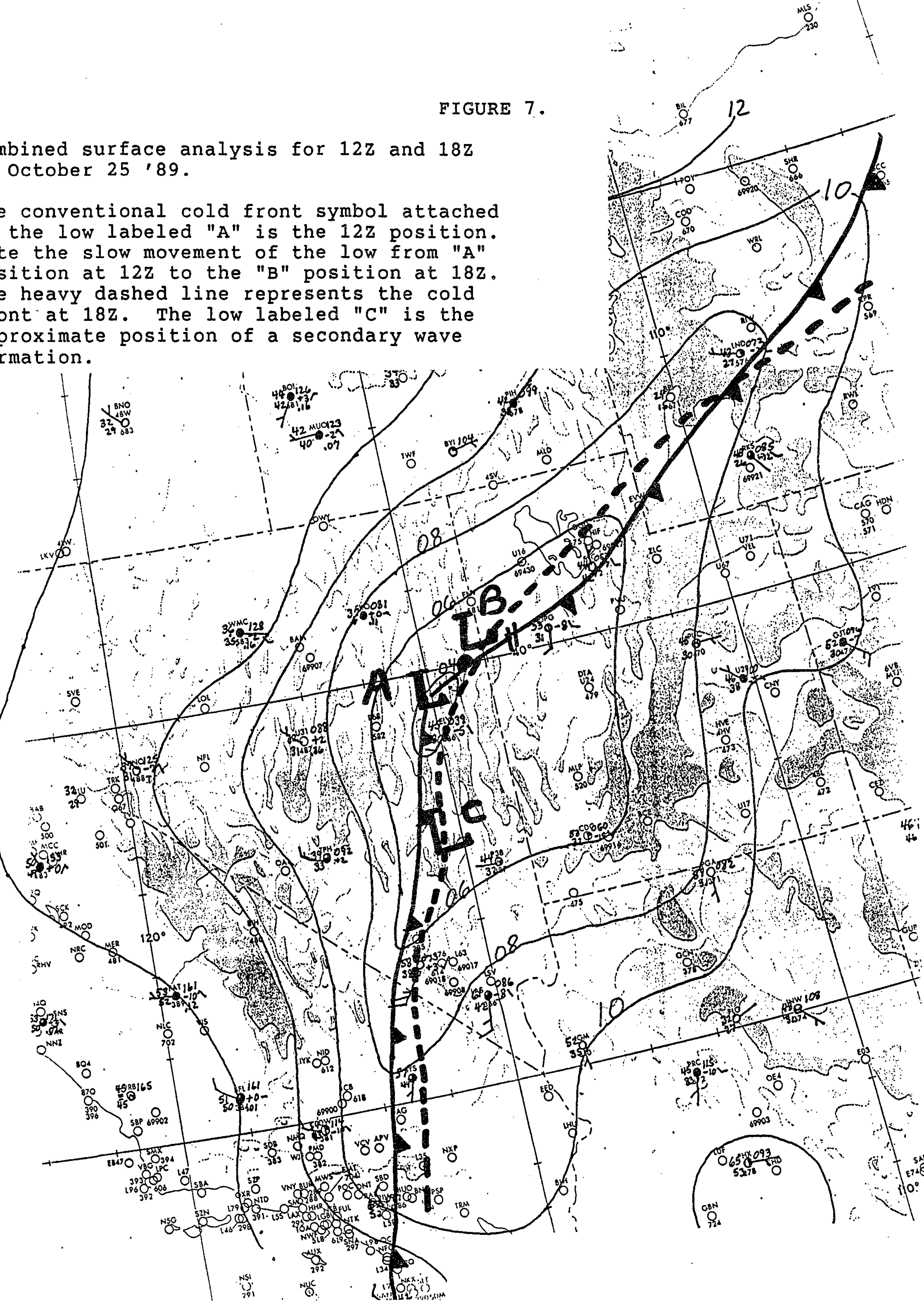
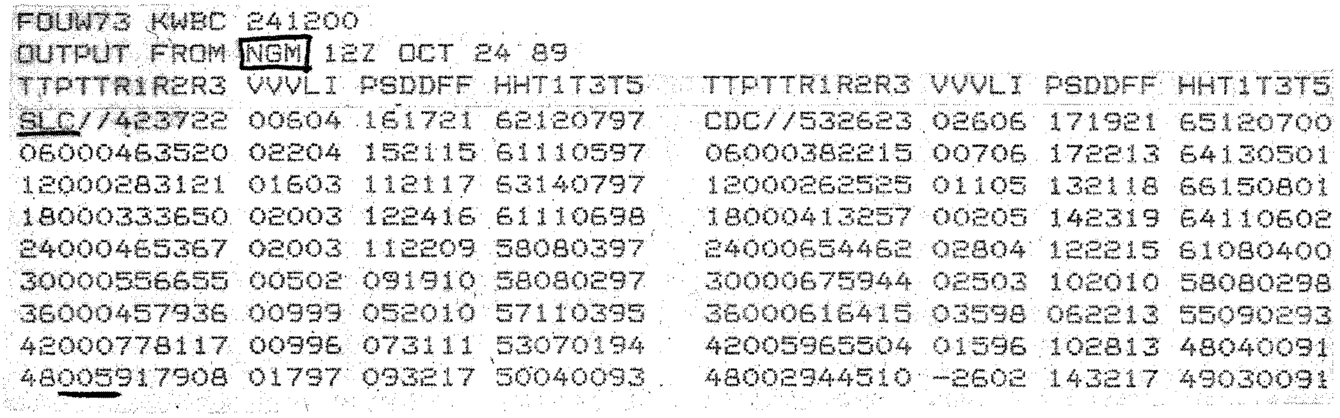
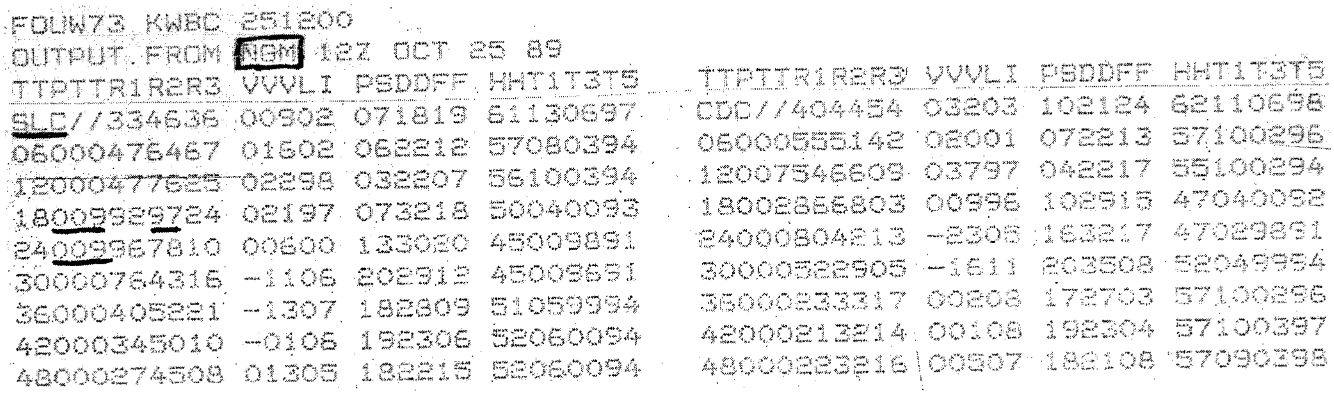


FIGURE 8



```
FOUW73 KWBC 241200
OUTPUT FROM NGM 12Z OCT 24 89
TTPTTR1R2R3 VVVLI PSDDFF HHT1T3T5   TTPTTR1R2R3 VVVLI PSDDFF HHT1T3T5
SLC//423722 00604 161721 62120797   CDC//532623 02606 171921 65120700
06000463520 02204 152115 61110597   06000382215 00706 172213 64130501
12000283121 01603 112117 63140797   12000262525 01105 132118 66150801
18000333650 02003 122416 61110698   18000413257 00205 142319 64110602
24000465367 02003 112209 58080397   24000654462 02804 122215 61080400
30000556655 00502 091910 58080297   30000675944 02503 102010 58080298
36000457936 00999 052010 57110395   36000616415 03598 062213 55090293
42000778117 00996 073111 53070194   42005965504 01596 102813 48040091
48005917908 01797 093217 50040093   48002944510 -2602 143217 49030091
```

(a) NGM OUTPUT FOR SALT LAKE CITY FROM THE 12Z OCTOBER 24 RUN. NOTE THAT 0.05 INCHES WAS FORECAST BY THIS PARTICULAR RUN FOR THE LAST 6 HOURS OF THE 48 HOUR FORECAST PERIOD.



```
FOUW73 KWBC 251200
OUTPUT FROM NGM 12Z OCT 25 89
TTPTTR1R2R3 VVVLI PSDDFF HHT1T3T5   TTPTTR1R2R3 VVVLI PSDDFF HHT1T3T5
SLC//334636 00902 071819 61130697   CDC//404454 03203 102124 62110698
06000476467 01602 062212 57080394   06000555142 02001 072213 57100296
12000477625 02298 032207 56100394   12007546609 03797 042217 55100294
18009929724 02197 073218 50040093   18002866803 00996 102915 47040092
24009967810 00600 133020 45009891   24000804213 -2306 163217 47029891
30000764316 -1106 202912 45009651   30000522905 -1611 203508 52049954
36000405221 -1307 182809 51059994   36000233317 00208 172703 57100296
42000345010 -0106 192306 52060094   42000213214 00108 192304 57100397
48000274508 01305 182215 52060094   48000223216 00507 182108 57090298
```

(b) NGM OUTPUT FOR SALT LAKE CITY FROM THE 12Z OCTOBER 25 RUN. THIS RUN OF THE NGM FORECAST 0.18 INCHES FOR A 12 HOUR PERIOD, WHICH WAS STILL MUCH TOO LOW. NOTE ALSO THE HIGHER RELATIVE HUMIDITIES FORECAST BY THIS RUN FOR THE LOWEST 2 LAYERS.

FIGURE 9 Note the dark area from southern Calif. to 130·W.

FIGURE 10 Note that the dark area enlarged and moved across southern Calif.

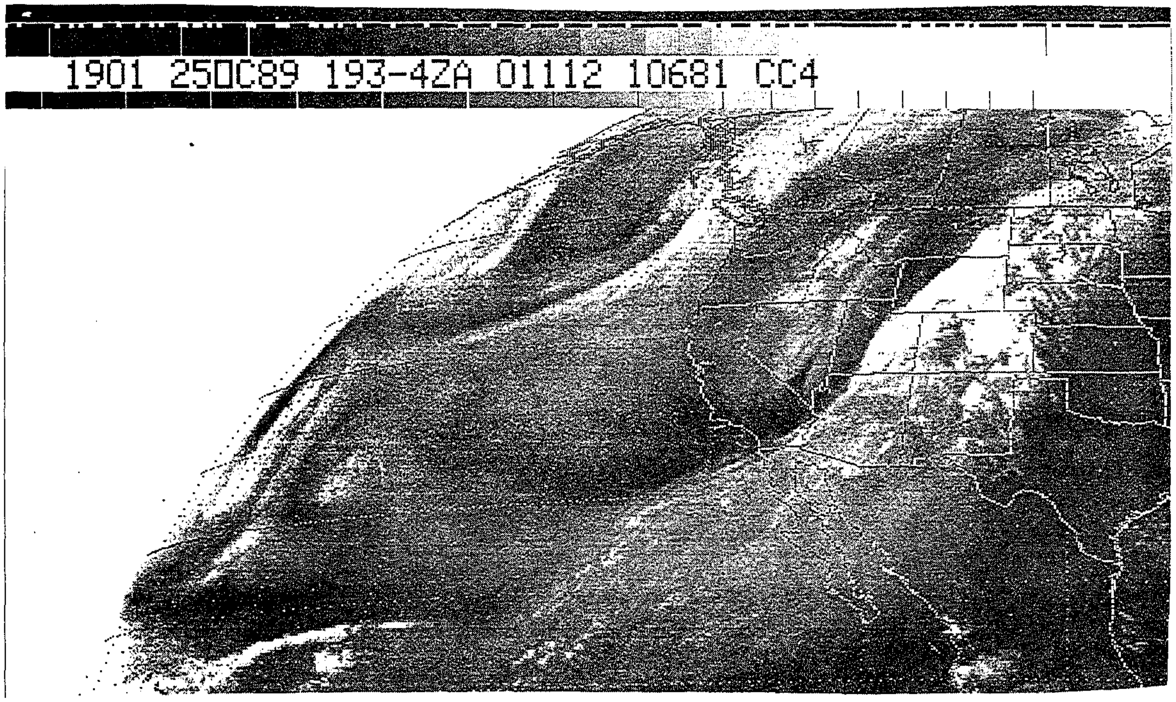


FIGURE 11

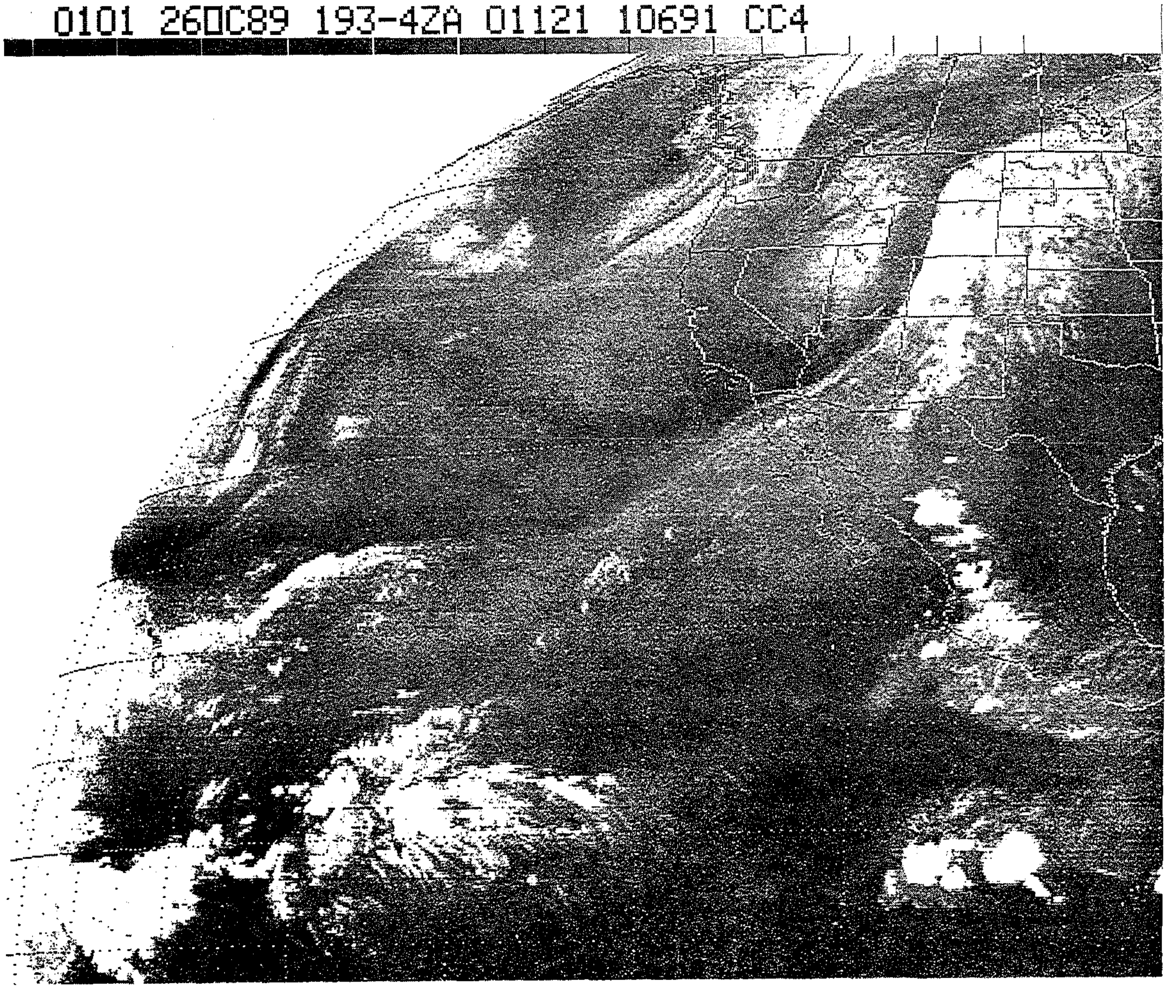


FIGURE 12

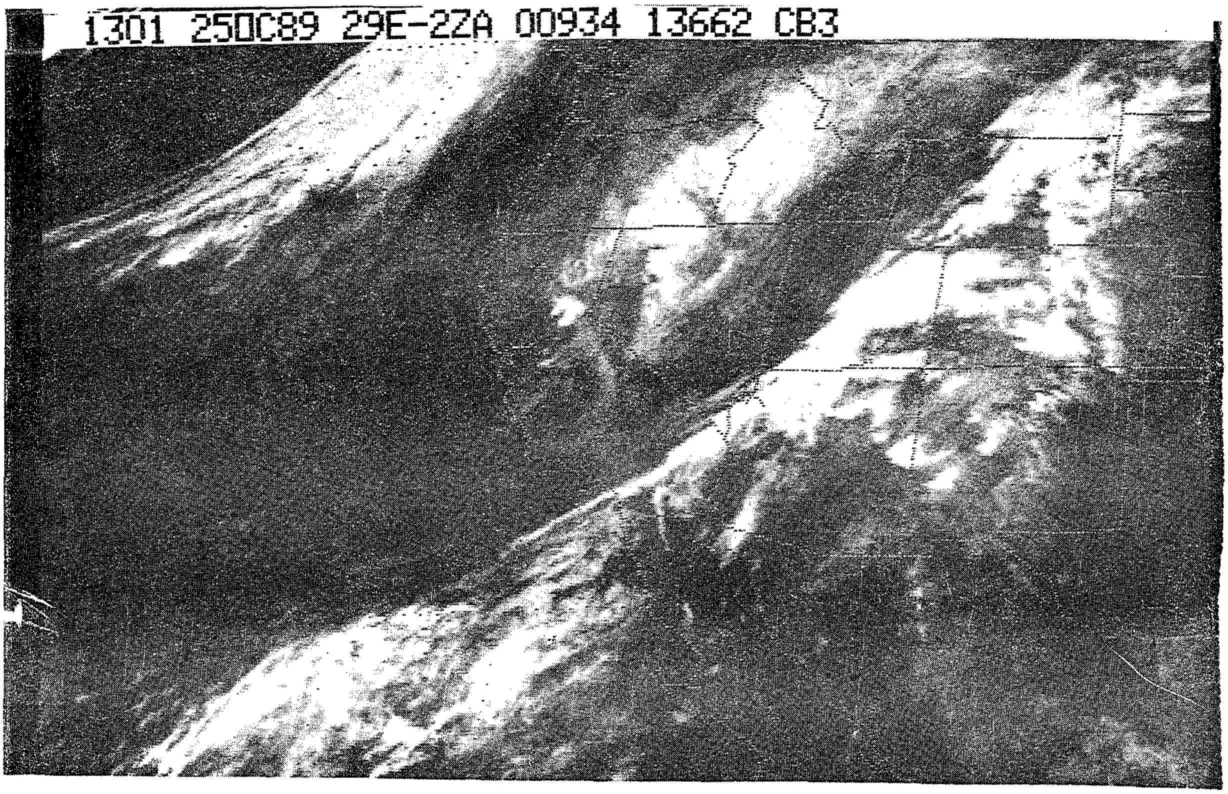


FIGURE 13

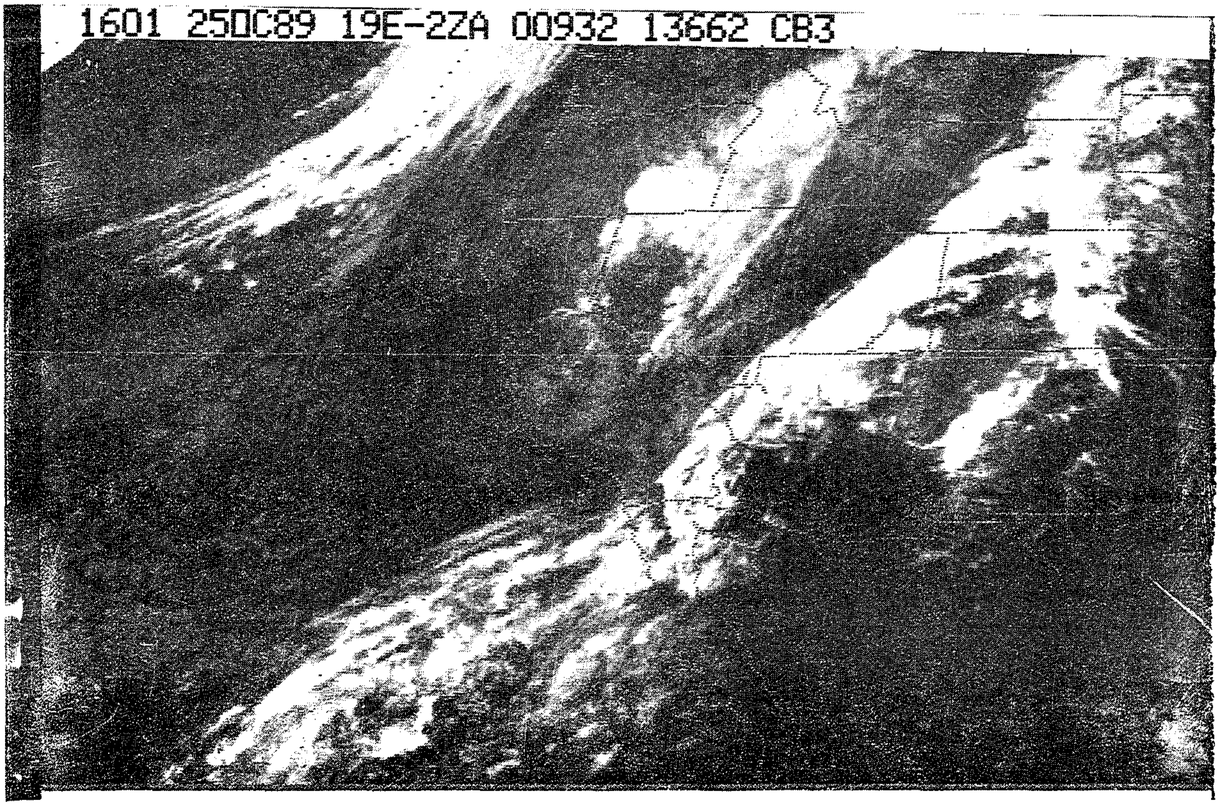


FIGURE 14

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