WESTERN REGION TECHNICAL ATTACHMENT
NO. 98-38
OCTOBER 27, 1998

THE NORTHERN ARIZONA SNOWSTORM OF 12-14 JANUARY 1997: A MODEL SIMULATION

Mike Staudenmaier, Jr. and Kenneth Wallingford
NWSO Flagstaff Arizona

Introduction

Major winter storms are fairly common in the high country of northern Arizona. The city of Flagstaff, for example, is located at approximately 7000 feet MSL on Arizona's western Mogollon Rim. Flagstaff averages 109 inches of snowfall each winter. On 12-14 January 1997, a major winter storm struck northern Arizona. This storm had serious impacts on the region and will be remembered by many as one of the worst winter storms to hit this area.

The storm lasted over 36 hours and came in two distinct waves, the first beginning around 0000 UTC 13 January. When the snow ended around 1200 UTC 14 January, snowfall totals at Flagstaff exceeded 30 inches with some unofficial observations of nearly six feet of snow along the Mogollon Rim (Fig. 1). In addition to the heavy snowfall, strong winds produced near zero visibilities and snow drifts from six to ten feet high. Many roads, including portions of Interstates 17 and 40, were closed for over 40 hours, stranding many motorists. Several NWS employees were stranded at the office, remaining on duty for over 40 hours. In some areas, power and phone services were lost for up to five days.

This Technical Attachment will examine the synoptic situation and then discuss the results of running a mesoscale model simulation on this event. It will be shown that the model simulation was able to add useful information to that which was available to the forecaster via nationally created numerical guidance. However, the model did have some problems handling this situation, which will also be discussed.

Model Description

The model used to simulate this powerful winter storm was the nonhydrostatic version of the Penn State/NCAR Mesoscale Model (MM5V2.7). Model physics included the MRF PBL scheme, explicit moisture with simplified ice physics, Kain-Fritsch cumulus parameterization, and the radiative upper boundary condition (Dudhia, 1993).

The model domain for the simulation consisted of a 45 km horizontal resolution outer grid covering much of the western United States, a 15 km horizontal resolution middle grid, and a 5 km horizontal resolution inner nest centered near the city of Flagstaff, Arizona (Fig. 2). This model run was comprised of 27 vertical layers and was run on a Hewlett Packard C-160 machine. The run took 30 hours to complete the 36 hour simulation.

The model was initialized at 0000 UTC 13 January 1997 using initial data and boundary conditions derived from the Eta-48 model. The Eta-48 model was selected for initialization, as it was the operational model of choice as the event was occurring, and verified best. The MM5 was run out to 1200 UTC 14 January 1997, capturing the main portions of this powerful winter storm.

Synoptic Overview And Diagnosis of Eta-48 Model

At 1200 UTC 12 January, a large closed upper low was centered over the Great Basin region at 500 mb with a large, positively-tilted blocking ridge extending from the eastern Pacific northeastward across western Canada (Fig. 3). This large upper low was an extension of a deep trough of low pressure which extended from Hudson Bay southwestward across the Northern Plains and into the Rockies.

By 0000 UTC 13 January, this southern branch short wave was located nearer to Arizona with a corresponding increase in vertical forcing reflected in the forecast 700 mb omega fields. Light snow had fallen across much of the Western Mogollon Rim, including Flagstaff, for much of 12 January, however there was little accumulation by evening. This snow was primarily the result of weak dynamics and strong southwesterly upslope flow onto the Rim. Snowfall increased significantly after 0000 UTC 13 January, in response to the increasing vertical forcing and continued strong southwesterly upslope flow.

From 0000 UTC through 1200 UTC 13 January, the Eta-48 forecast strong upward vertical forcing to continue as the first short wave rotated through the region and combined with strong southwesterly upslope flow. Heavy snow developed during the night and gradually spread eastward along the Mogollon Rim. By 1200 UTC, 10-12 inches of new snow had fallen in and around the Flagstaff area.

At 1200 UTC 13 January, the 500 mb upper low was forecast to be over northwestern Nevada with the first short wave exiting the region and another rotating around the western side of this system across eastern California (Fig. 4). The Eta-48 forecast this second short wave to be weaker than the first and track across northern Arizona after 0000 UTC 14 January. As a result, the 700 mb omega fields from 1200 UTC 13 January through 1200 UTC 14 January, yielded gradually weaker vertical velocity fields over the Rim, with the focus of best forcing shifting eastward during this time.

This appears to have been the only error of this Eta-48 model run. In actuality, the precipitation ended completely from west to east after 1200 UTC 13 January, with some clearing actually occurring between 1200 and 1800 UTC. Precipitation redeveloped later in the day as the second short wave moved into northern Arizona. This second short wave was much stronger than the first, and brought the worst weather of this storm to the region.

Heavy snow and strong winds were commonplace across the high country of northern Arizona after 0000 UTC 14 January, especially over the Rim. Travel was brought to a standstill and by 1200 UTC, another 15-20 inches had fallen, bringing the storm total to 24-30 inches for the Flagstaff area. Precipitation tapered off from the west to east after 1200 UTC 14 January, as this last short wave moved out of the region.

Although the Eta-48 model erred in the strength of the second short wave and the break that would occur in between, the 36 hour total precipitation field (Fig. 5) was very good. Note the maxima of 2.5-3.0 inches depicted over central Arizona. There is remarkable correlation between this maxima and the heaviest snowfall reports which occurred over the central Rim (Fig. 1). These amounts are quite consistent with the 17:1 snow to liquid conversion which was found for this event.

Results of the MM5 Simulation

Of greatest concern for the forecasters during this event was the amount of snowfall accumulation which would occur over northern Arizona. The Eta-48 model forecast a maximum of close to 3.0 inches of precipitation over portions of the central Mogollon Rim. Figure 6 shows the accumulated 36 hour precipitation from the MM5 model along with reported snowfall amounts. Two separate bullseyes of greater than 3.5 inches of precipitation are located along the central Mogollon Rim with a much better delineated axis and gradient. Using a 17:1 ratio for snowfall leads to amounts very close to the 60 inches recorded. Other notable details in the MM5 output are higher maxima on the Kaibab Plateau, around the Flagstaff region, and in the northeast plateaus of Arizona. This amount of detail was not available in any other operational numerical guidance at that time.

Another factor of this storm were the strong winds associated with it. The MM5 run had much more detail in both surface wind fields and winds aloft. This can be attributed to resolution of both topographical features and more gridpoints with which to plot the wind field. Because of the varied terrain in Arizona, high resolution models are needed to even attempt to represent an accurate wind flow. This was made very apparent in this model run, as southwest winds aloft translated to southeast winds over the deserts and the Little Colorado River Basin due to orographic effects (Fig. 7).

A surprising feature of this model run was the generation of three distinct mountain waves generated off the San Francisco Peaks (near Flagstaff), the Kaibab Plateau (north of the Grand Canyon), and the Black Mesa (in northeastern Arizona). These three locations are in mostly unpopulated areas, making it nearly impossible to verify if the waves did develop on this date. However, signatures of mountain waves and lee waves have been seen numerous times on satellite imagery, and occasionally a report of abnormally high surface winds or turbulence aloft will be reported to the NWS office from one of these locations. Research done during the 1995 Arizona Program showed numerous occasions of topographically induced, storm-embedded gravity and mountain waves developing (Klimowski et al., 1998). Thus, it is entirely possible that mountain waves may have developed on this day and contributed to some of the stronger surface winds that were reported.

A cross section (Fig. 8) from Chino Valley to the southwest of the San Francisco Peaks to Hotevilla to the northeast, revealed one example of a mountain wave in the potential temperature field along with strong downward motion downstream of the San Francisco Peaks. An upward motion field existed further downstream. Figure 9 shows the same cross section, but indicated significant drying occurring downstream of the mountains, even in the area of strong rising motion as indicated in the previous cross section. Winds also indicated some downward momentum transfer, with stronger surface winds being located along the downwind side of the mountain and a decrease in windspeeds further downwind of the mountain wave in the 650-400 mb layer.

Because of the original error in the Eta-48 forecast of the vertical motion continuing between the two short waves, and with the second short wave being forecast to be weaker than reality, the MM5 run also suffered from this bias due to the boundary conditions forcing the model solution. The MM5 simulation had continuous snow throughout the 36 hour forecast, with no break in between short waves as seen in reality. Thus, without the lull in precipitation, along with having a weaker second short wave, it appears that the MM5 run would have overforecasted snowfall everywhere had it had 'perfect' boundary conditions.

Discussion and Conclusions

Results indicate that this MM5 simulation was able to successfully capture some of the features observed during the 12-14 January 1997 snowstorm, along with indicating a few features that could only be guessed at based on the sparse data network over northern Arizona. Observed and simulated snow amounts were collocated very well, although the model appeared to over-produced amounts in some locations. Additionally, the model generated precipitation every hour over the Rim, as opposed to showing the break in the precipitation which occurred in reality between the two short waves.

The model produced distinct mountain waves, which cannot be verified. However, based on local reports along with satellite detection of this phenomena occurring at other times, it is entirely likely that mountain waves did develop during this and possibly many precipitation events over northern Arizona. More modeling will have to be done in order to qualify this statement.

It is obvious to the authors, along with the staff at NWSO Flagstaff, that the interpretation of mesoscale model guidance is extremely difficult at this time. Model-generated fields appear to look very believable, and are very easy to take as fact. In reality however, models have a difficult time with the exact details of a meteorological situation, and this must be remembered by the meteorologist viewing the data. In this particular case, the spatial resolution of the precipitation field would have been extremely useful for the forecast of this event. However, snowfall amounts and duration of the event would have been overforecast in some locations. The wind fields were generally good, and thus would have given forecasters a bit more information for aviation and public forecasts as well. As an aside, had the MM5 model guidance been available in three or six hour output, as opposed to hourly, and the model had correctly predicted the break in the precipitation, it still may not have been seen by the forecaster. This has direct implications in how operational model information is packaged and sent out to the field, and what we can really expect from future nationally run operational mesoscale models. Hourly output is vital for getting the most information from any high resolution model.

Since any mesoscale model is only as good as the initial guess and boundary conditions which drive it, it is important for a meteorologist to know if the information going into a mesoscale model is accurate. With numerical model guidance in the field still generally available only in six hour intervals and not even at the native grid resolution, it is very hard for a forecaster to make this important decision. In this case, even with a simulation that far surpassed forecasters typical expectations, the mesoscale run had errors not only due to biases in the MM5 model itself, but also from the Eta-48 model which drives the model simulation. Thus, not only do the mesoscale model biases affect the forecast (the actual biases of the MM5 aren't even really known), but also the forecaster has to be able to label the accuracy of the first guess and boundary conditions that are forecast, which are never known until after the event has passed.

Even with these problems, mesoscale models have a place in the operational NWS office. Model placement of precipitation, near surface wind flow patterns, and mountain waves are only three features which are very dependent on model resolution. For northern Arizona, it is clear that horizontal resolution approaching a few kilometers is necessary to capture many of the subtleties of weather phenomena which occur. Unfortunately at this time, it is nearly impossible for a local NWS office to create MM5 output at 5 km resolution over an entire CWFA the size of NWSO Flagstaff in a timely manner, without compromising the size of the outer domains to the point of having the boundary conditions impact the forecast soon into the model run. However, as hardware and computer speed continues to advance, it is likely that in the not too distant future, high resolution model runs such as this can be performed on a daily basis, with output available to the forecaster in hourly intervals as needed.

Until that time, the MM5 can still be a powerful 'post-mortem' tool in the local NWS office for diagnosing storm structure, examining local topographical impacts on synoptic and mesoscale weather systems, and learning more about the subtleties of a CWFA. It also can quickly show the difficulties in interpretation of numerical model forecasts, especially as they get to higher resolutions and resolve many features which look inherently believable. Many more cases will need to be run at this office in order to get a better idea of the value of a mesoscale model, and how to derive the most information from it in the most intelligent manner.

Acknowledgments

The authors wish to thank David Bright of NWSO Tucson and James Nelson, Jr. of NWSFO Salt Lake City/Western Region Scientific Services Division for their assistance in the set-up of the model at NWSO Flagstaff. The initial Eta data set was obtained from COMET.

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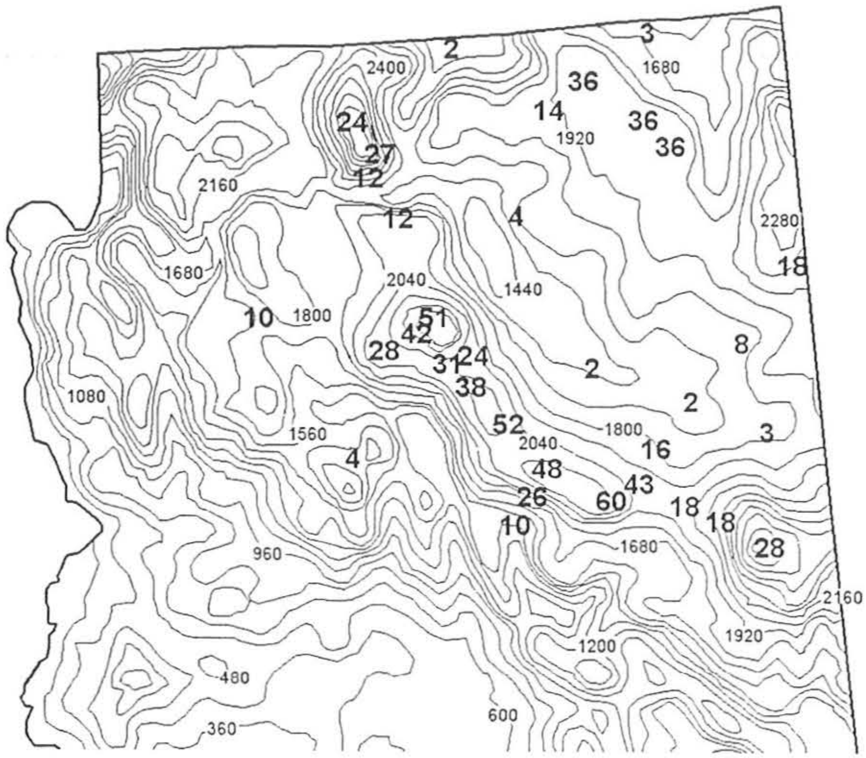


Figure 1: A map of northern Arizona showing topography (solid contours) and snowfall totals for the 12-14 January 1997 snowstorm.

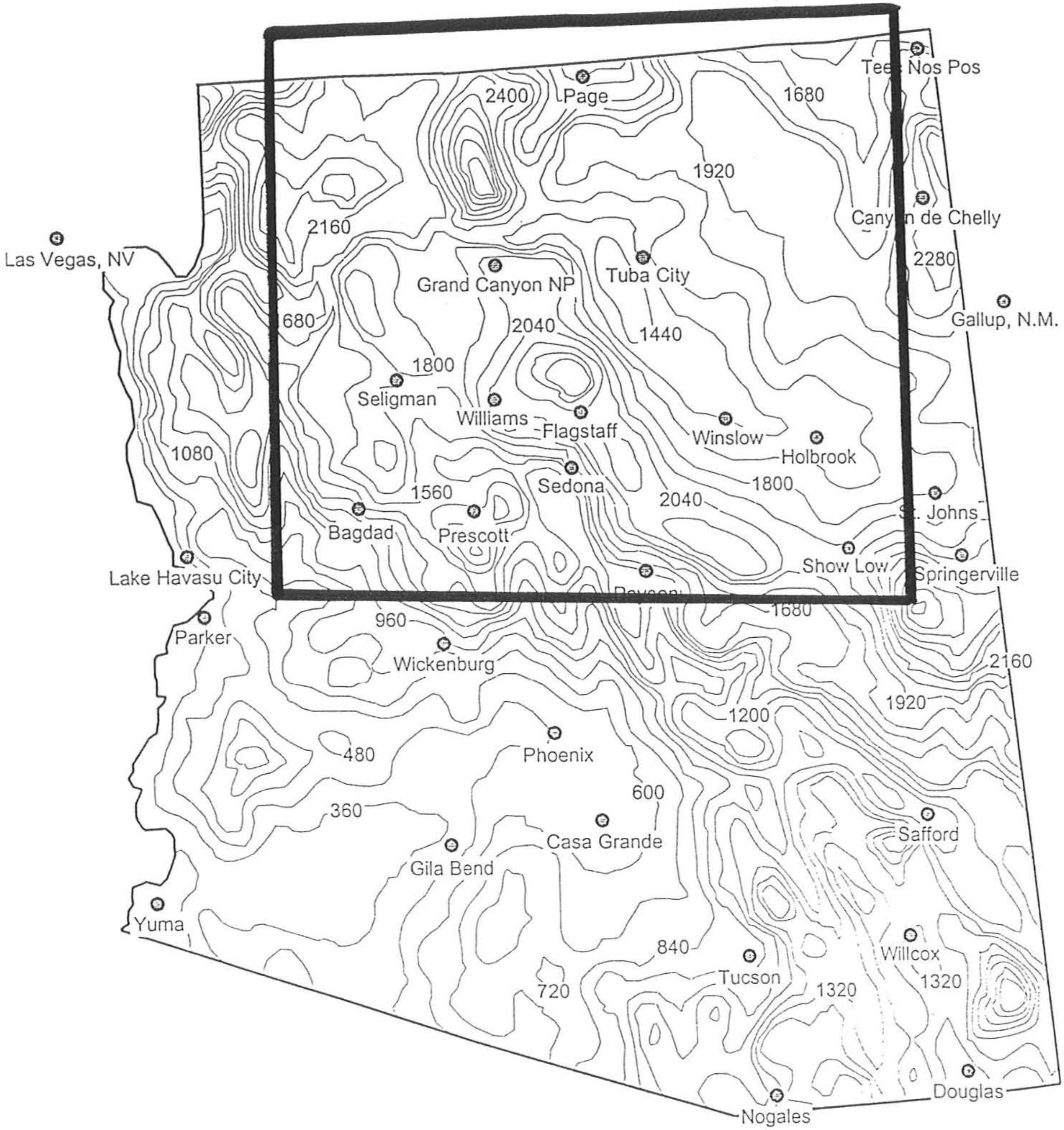


Figure 2: A map of northern Arizona showing topography (solid contours), city locations, and the outline of the 5 km horizontal resolution inner nest of the MM5 model, covering much of the NWSO Flagstaff CWFA (heavy solid lines).

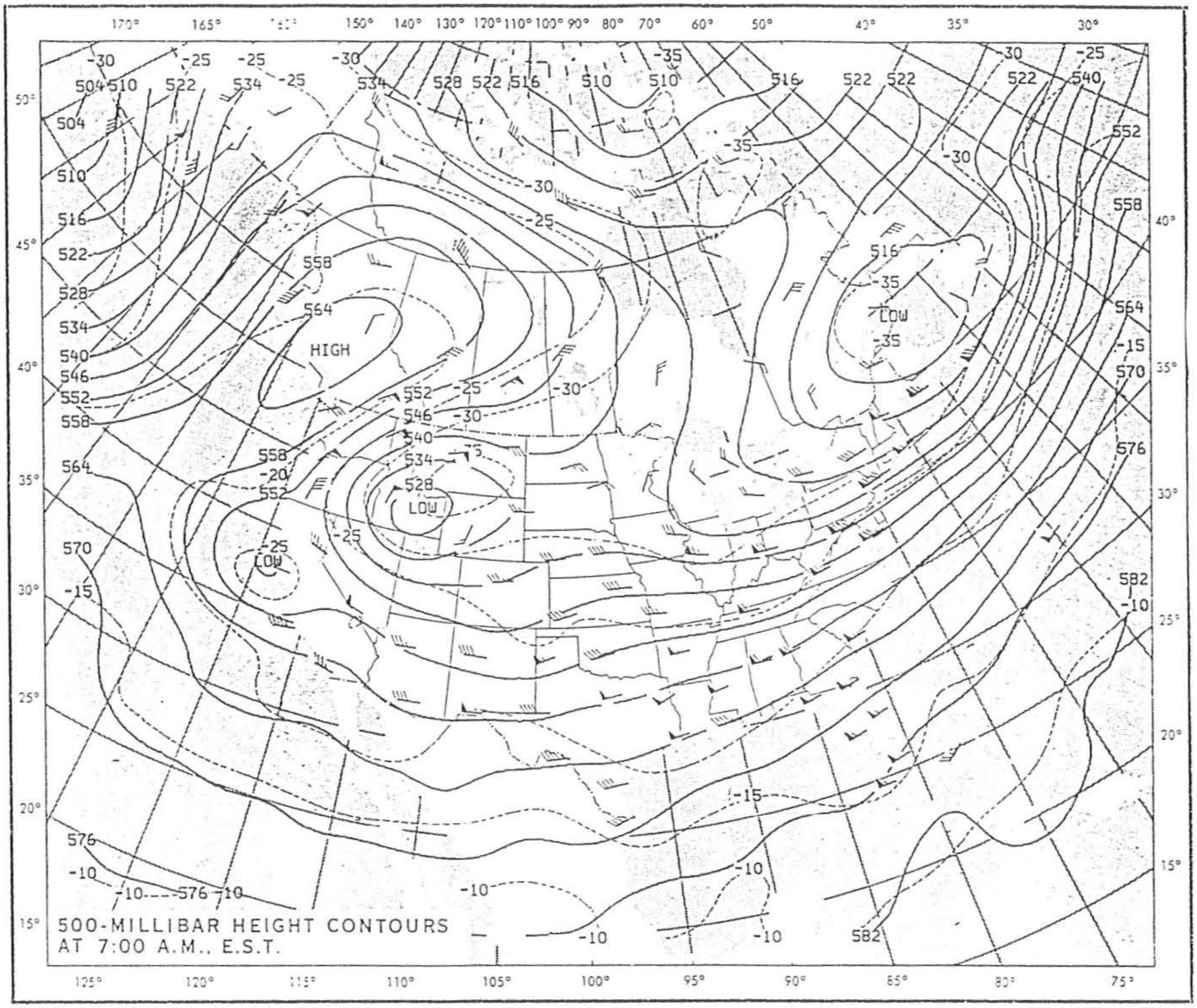
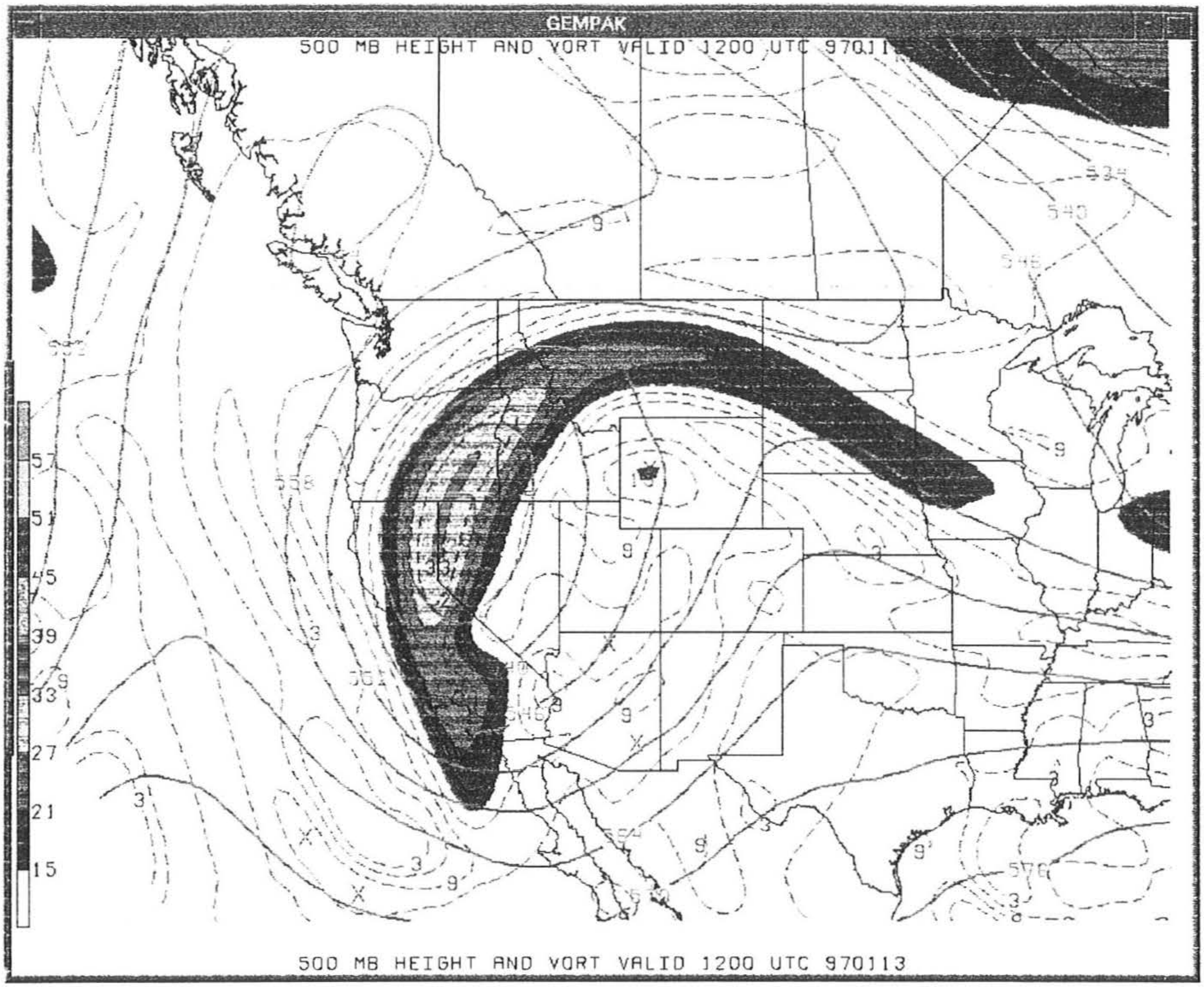


Figure 3: 500 mb height contours and wind fields valid at 1200 UTC 12 January 1997.



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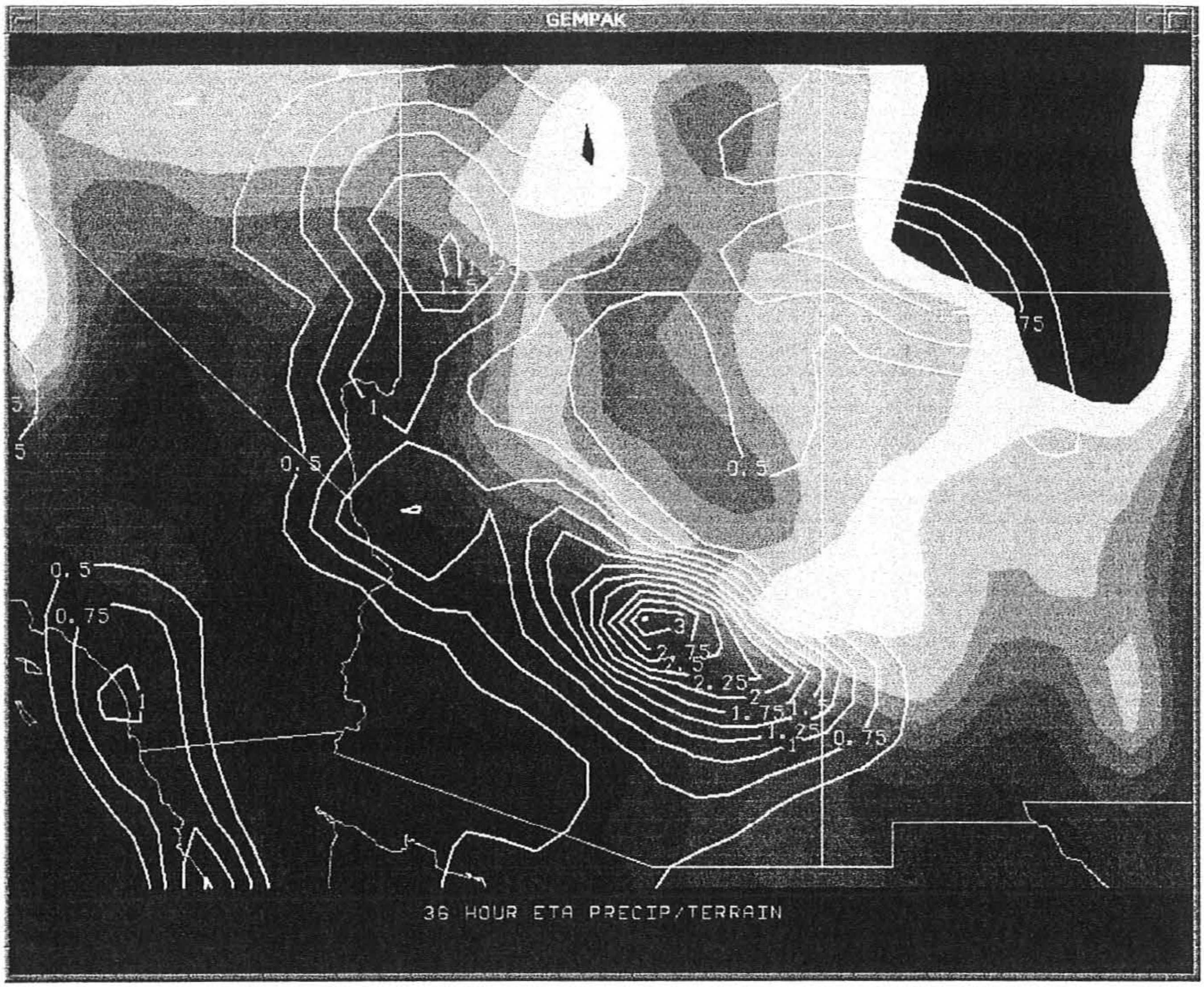


Figure 5: 36 hour total precipitation from the 0000 UTC 13 January 1997 Eta-48 model run.

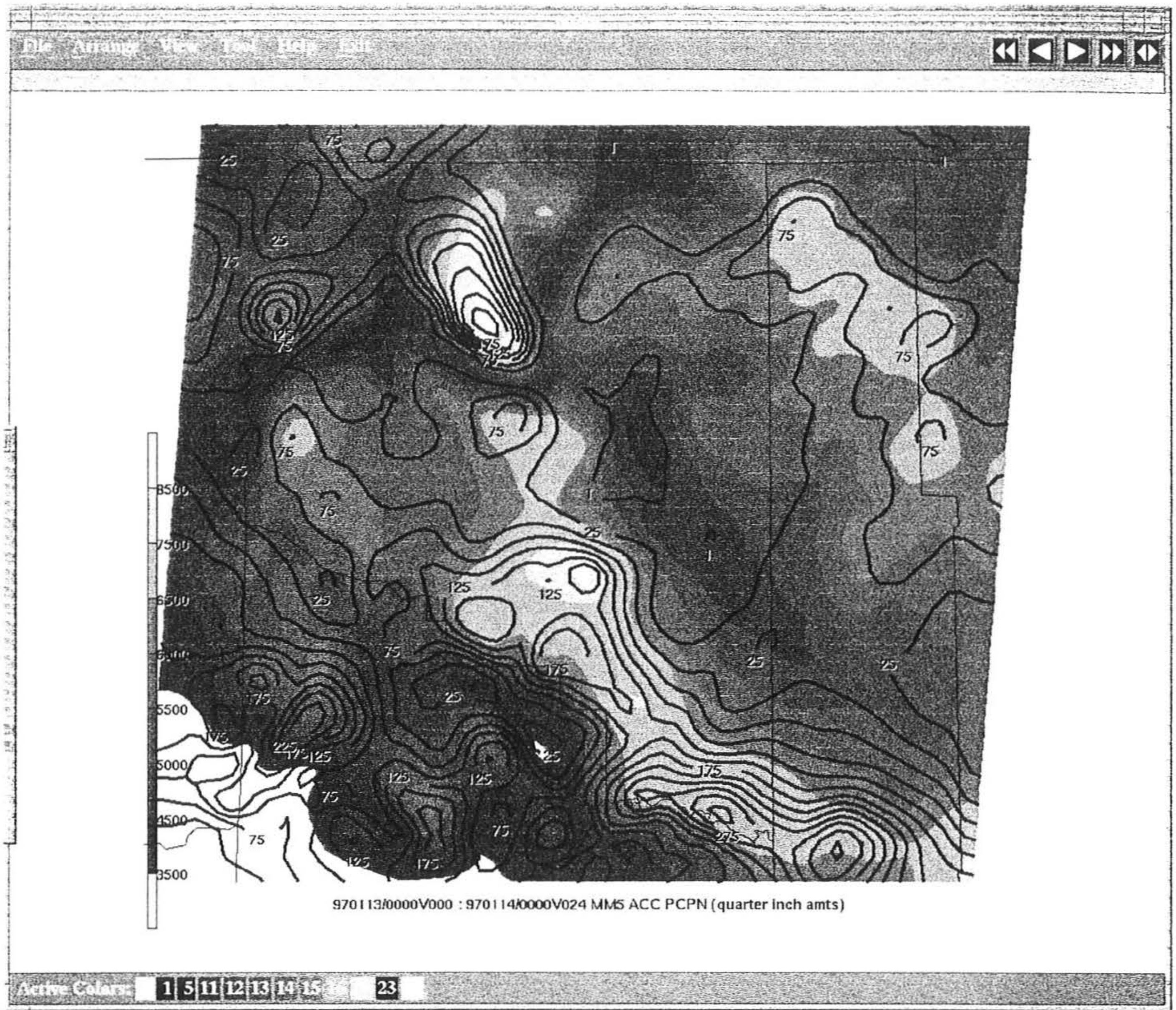


Figure 6: 36 hour accumulated precipitation from the MM5 run initialized from the 0000 UTC 13 January 1997 Eta-48 model output.

Figure 7: Near surface winds in the inner domain nest of the MM5 run, valid at 0800 UTC 13 January 1997. Terrain is shaded.

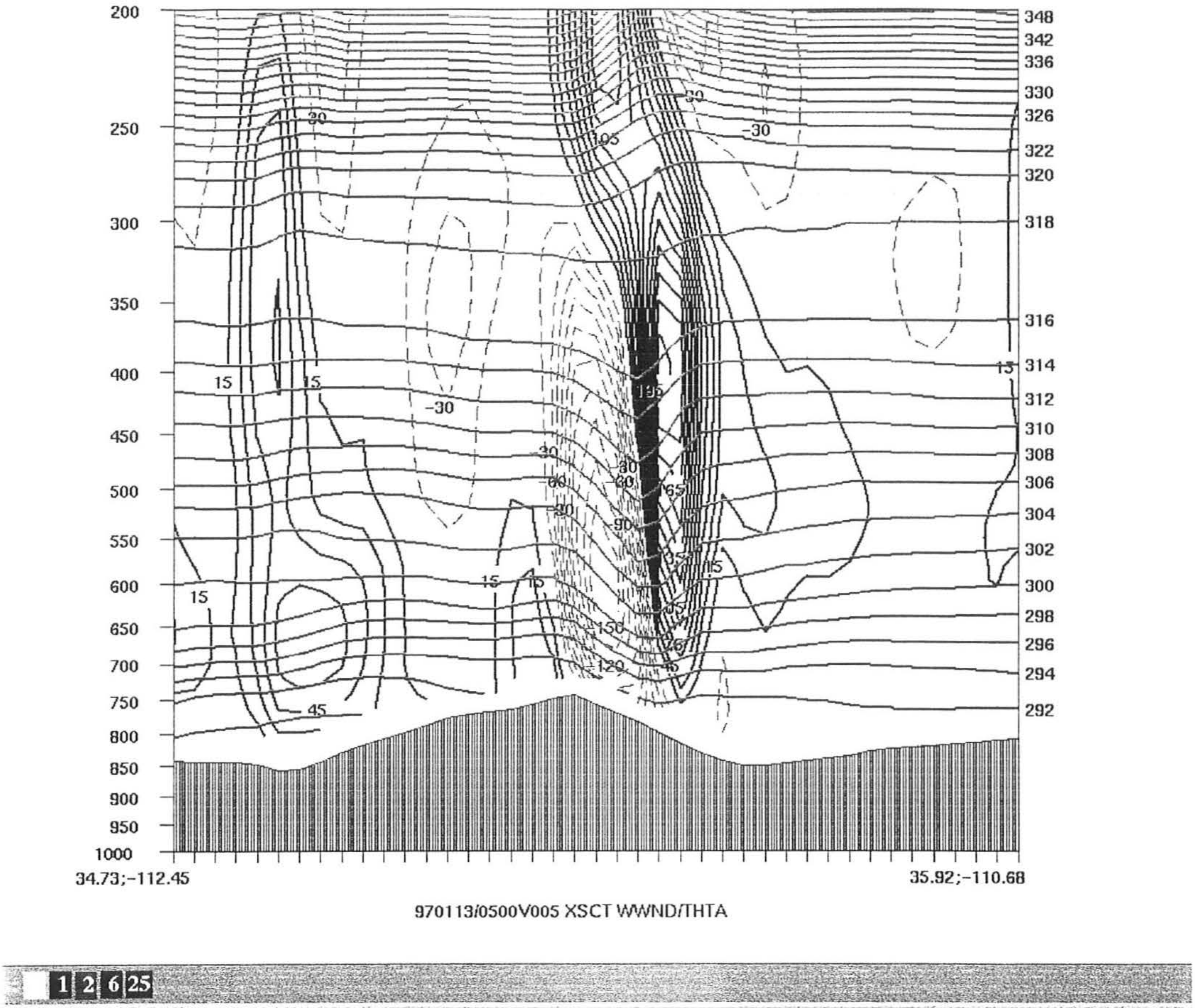
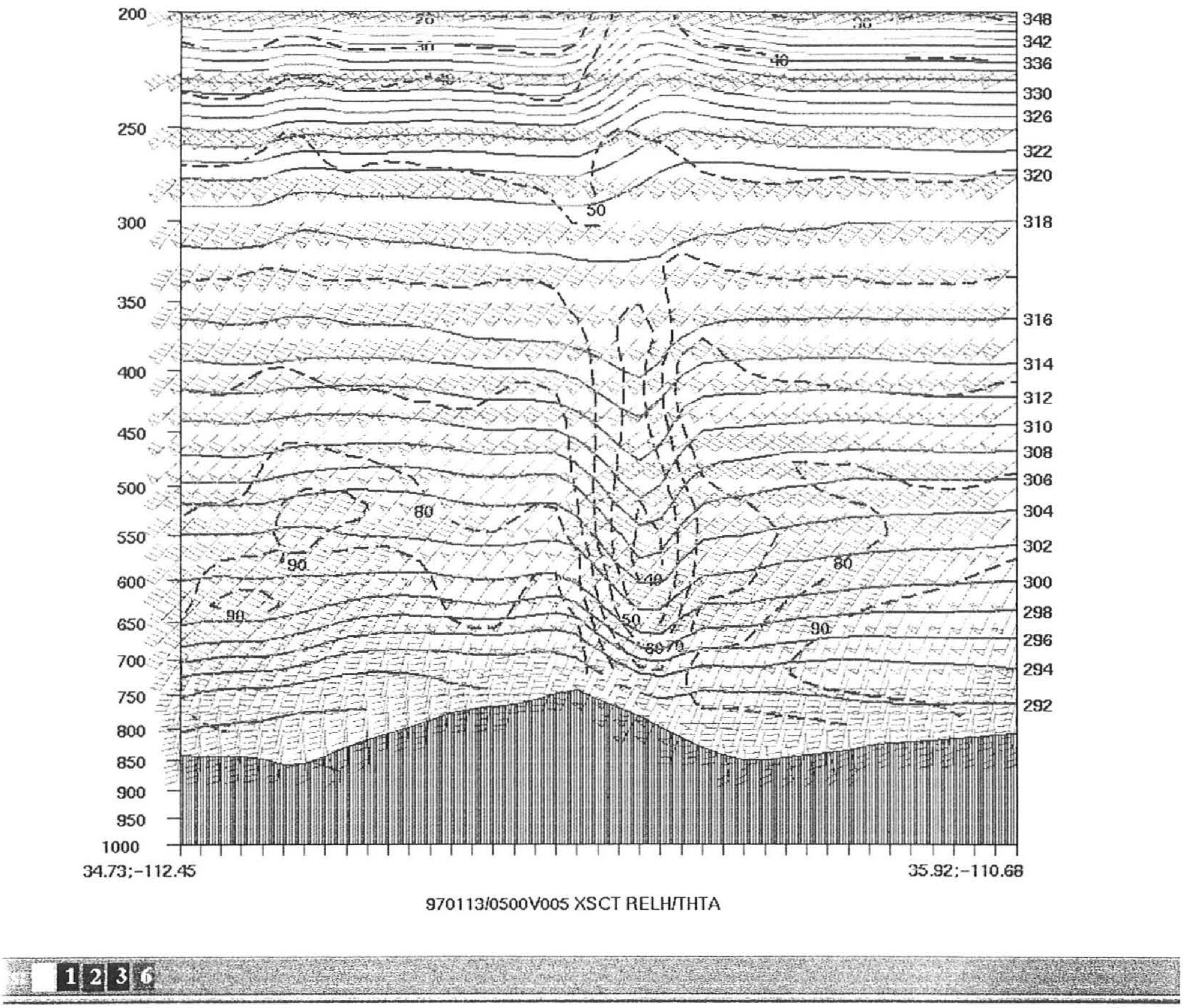


Figure 8: Cross section from Chino Valley (34.73;-112.45) to Hotevilla (35.92;-110.68) of potential temperature (solid red) and vertical motion (solid-rising/dashed-sinking) valid at 0500 UTC 13 January 1997.



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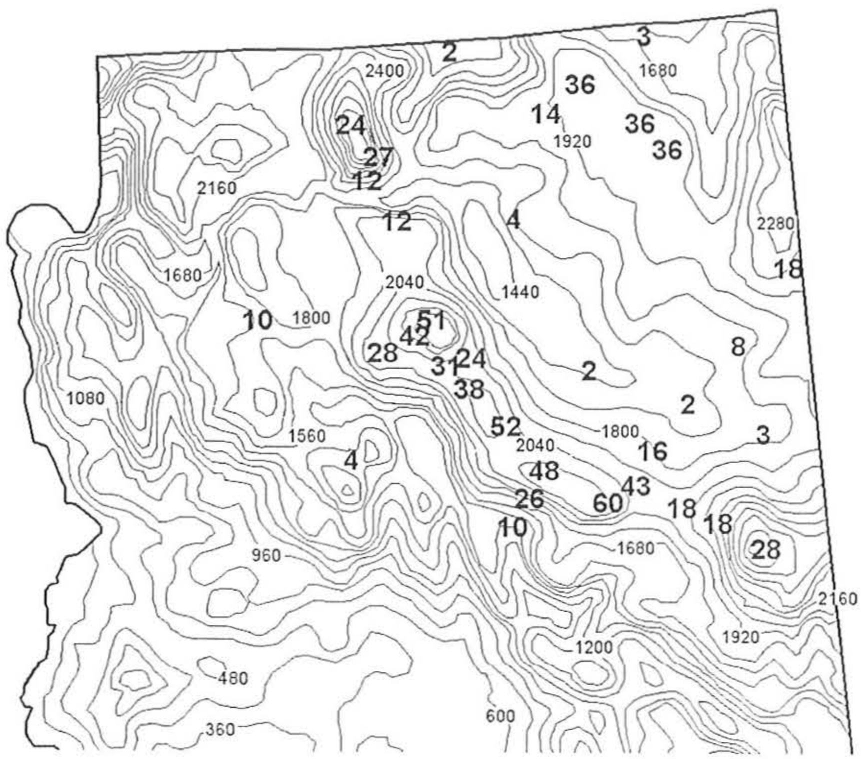

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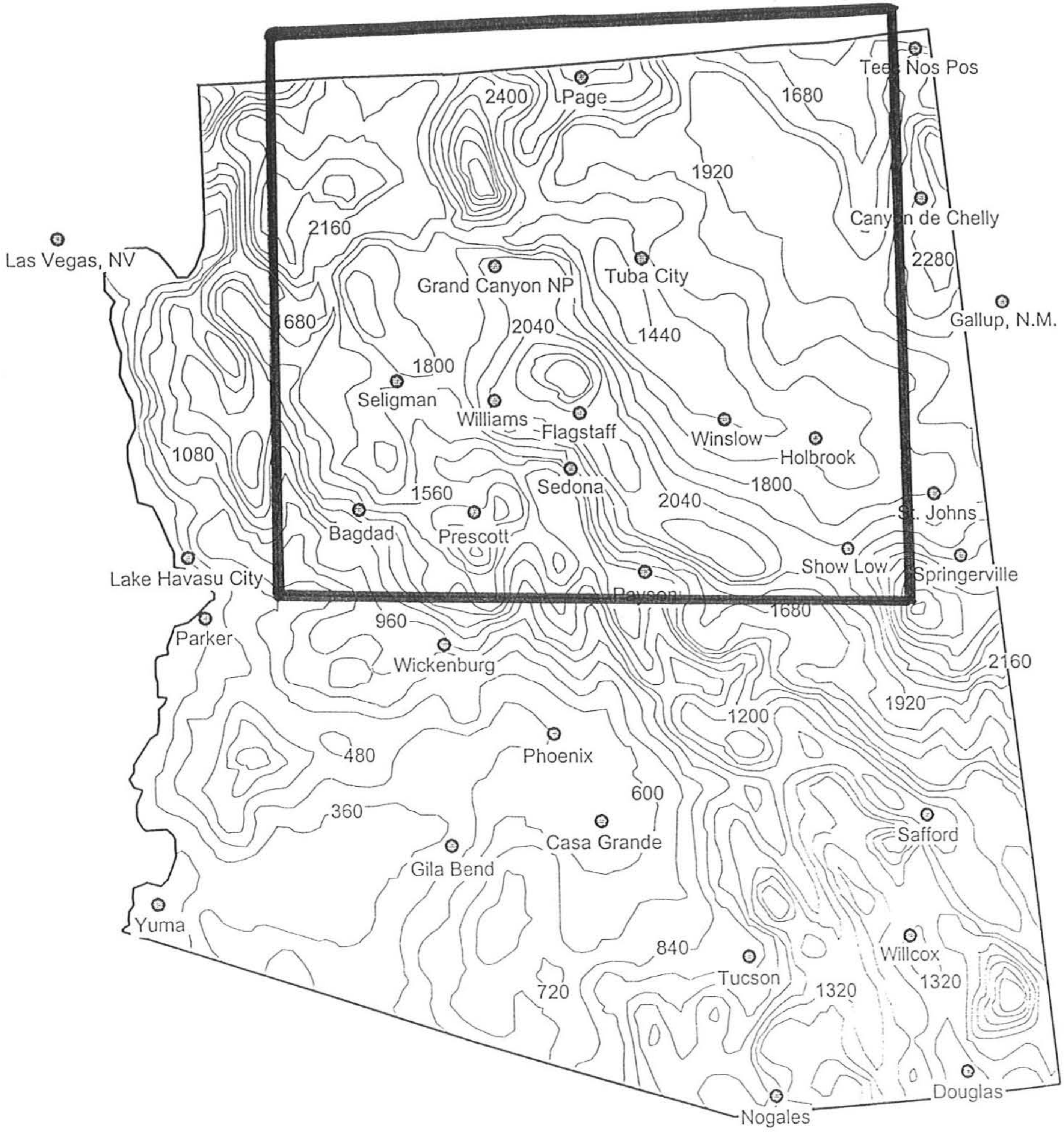

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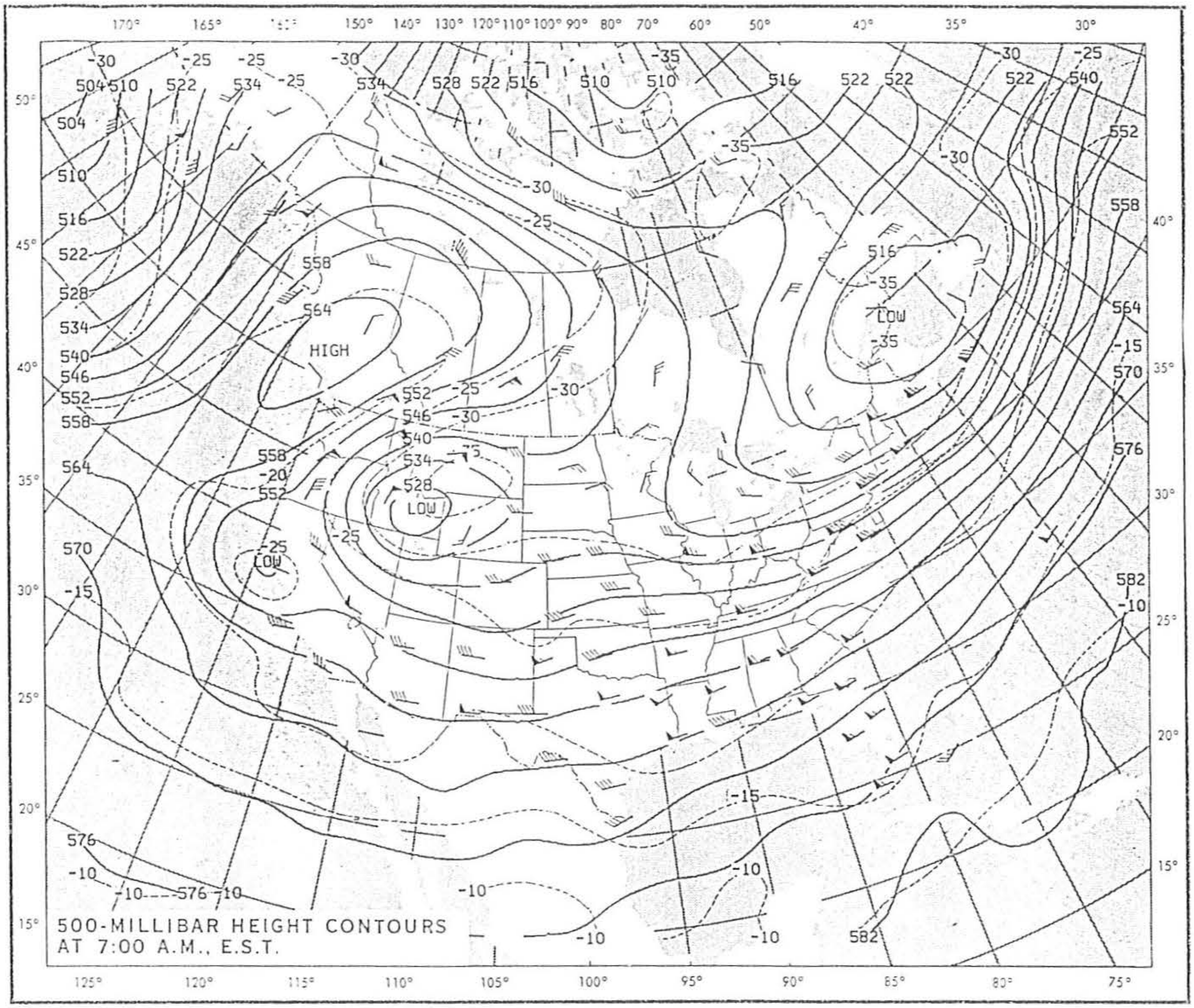

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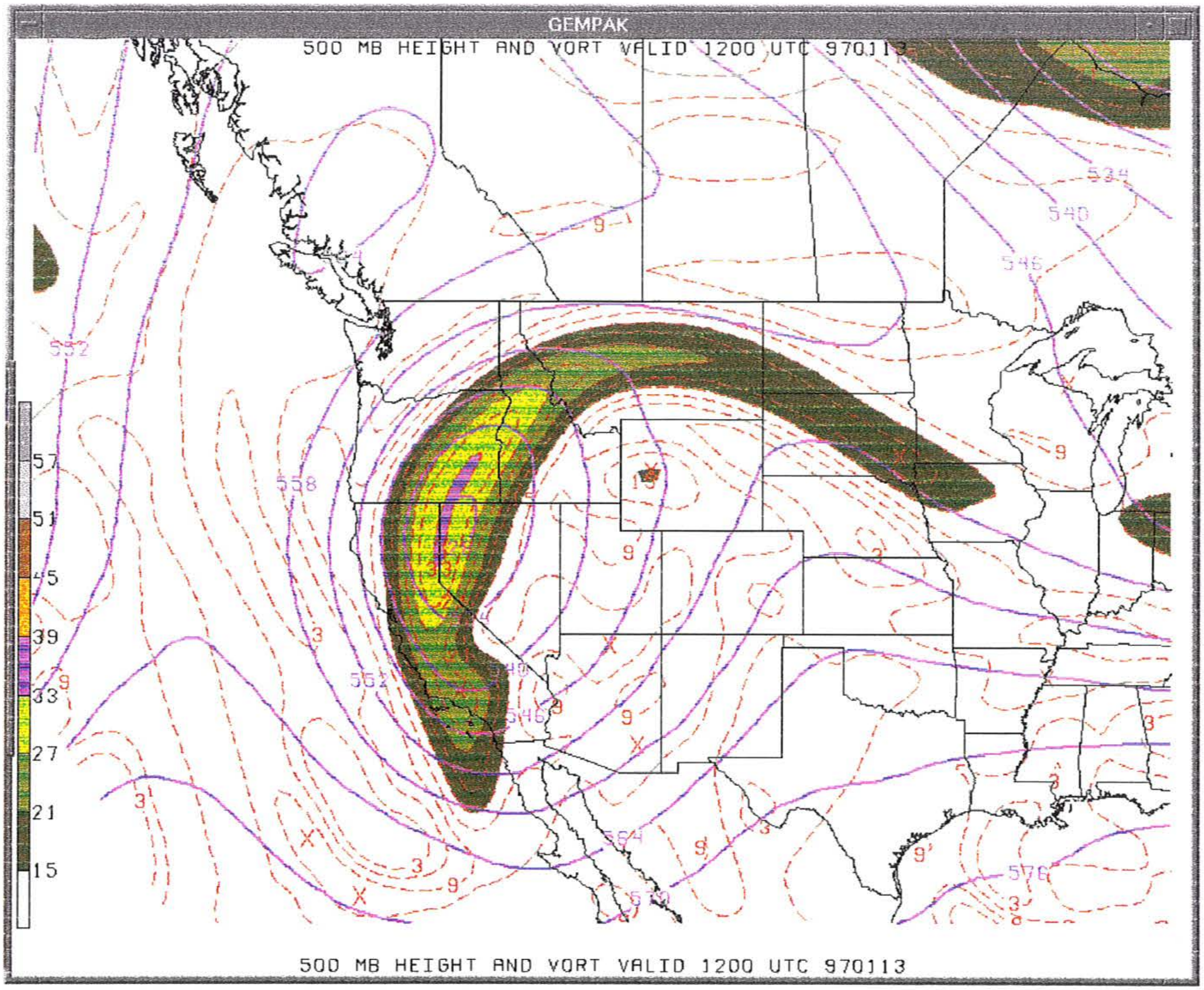

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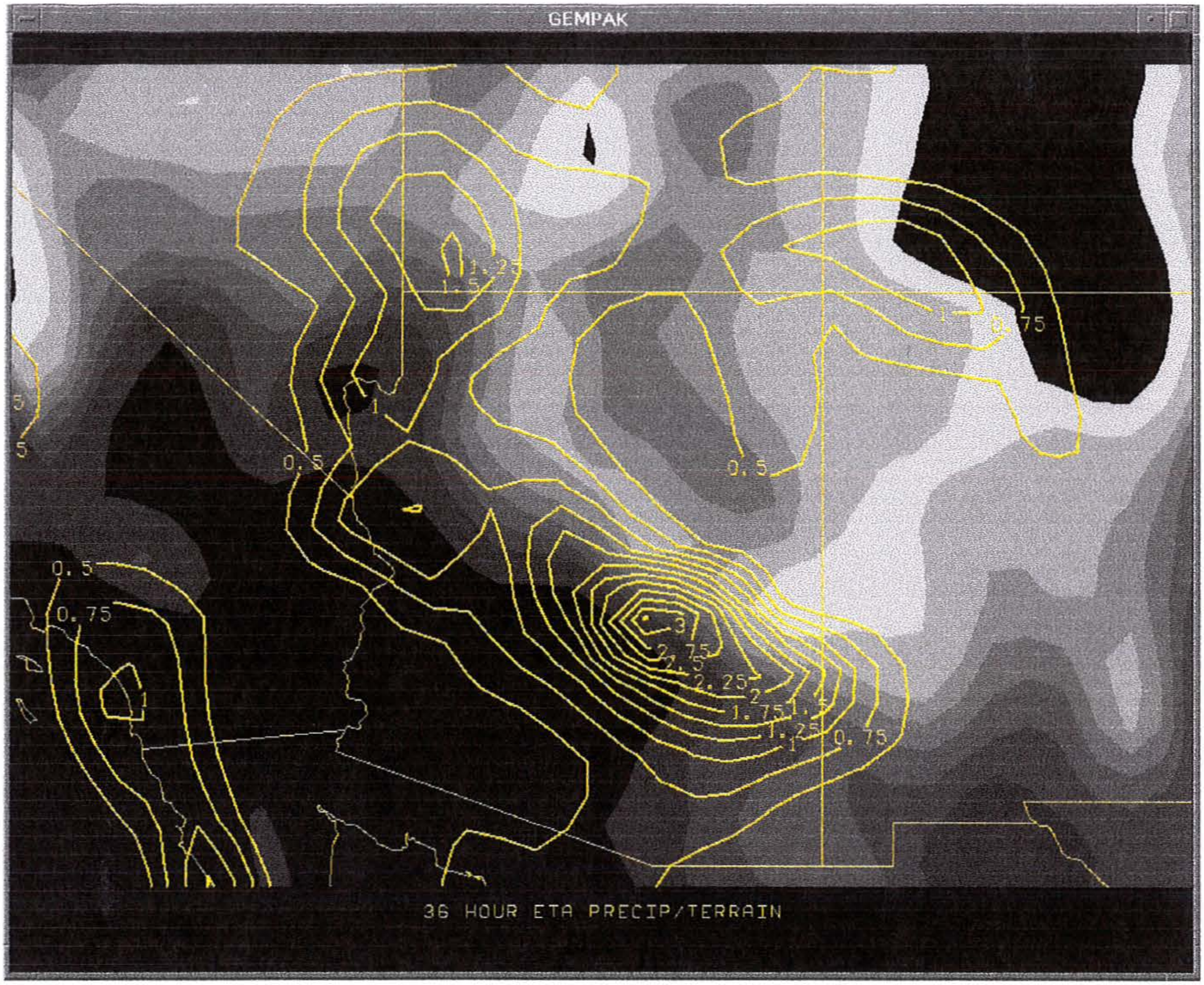

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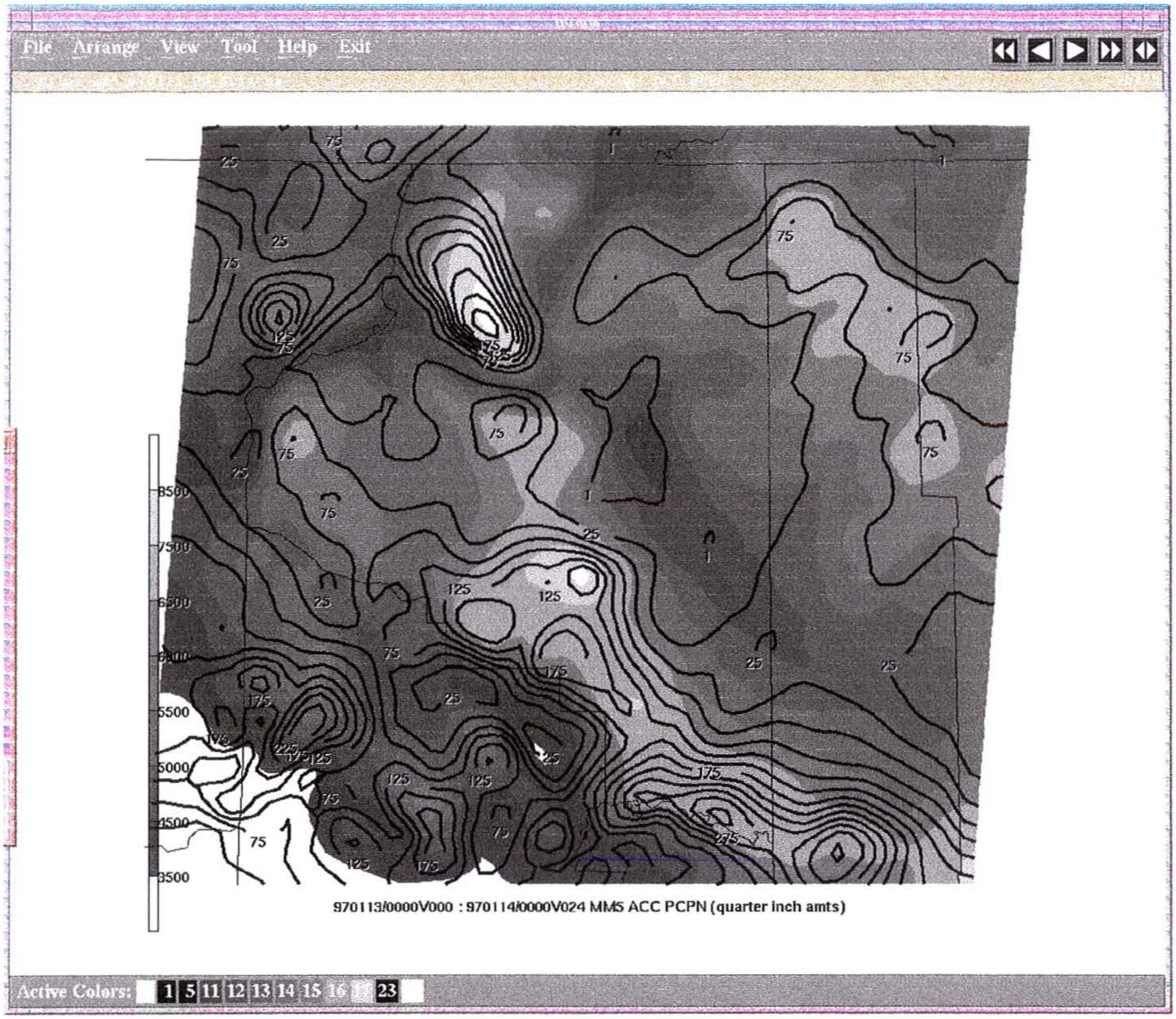

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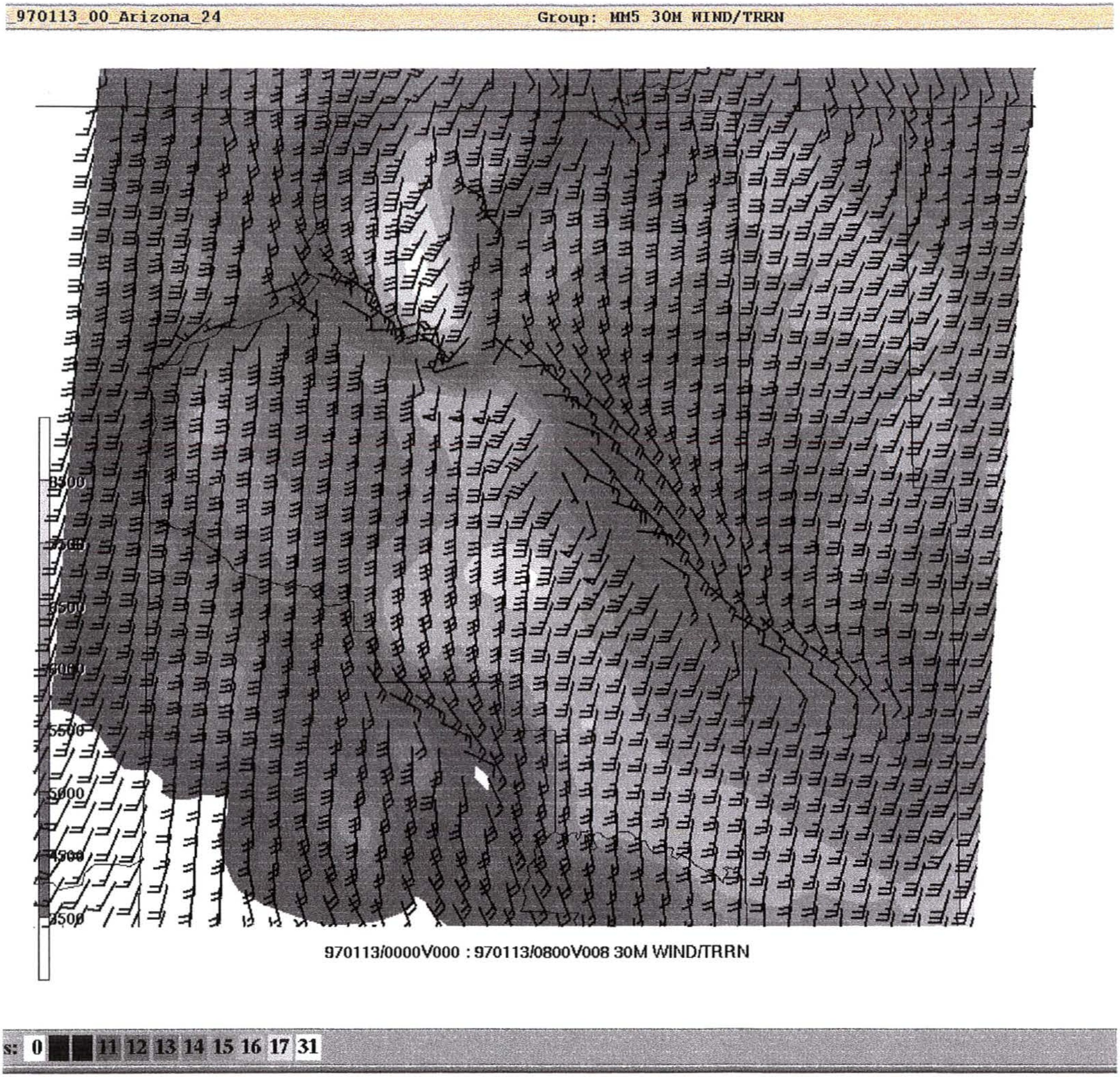

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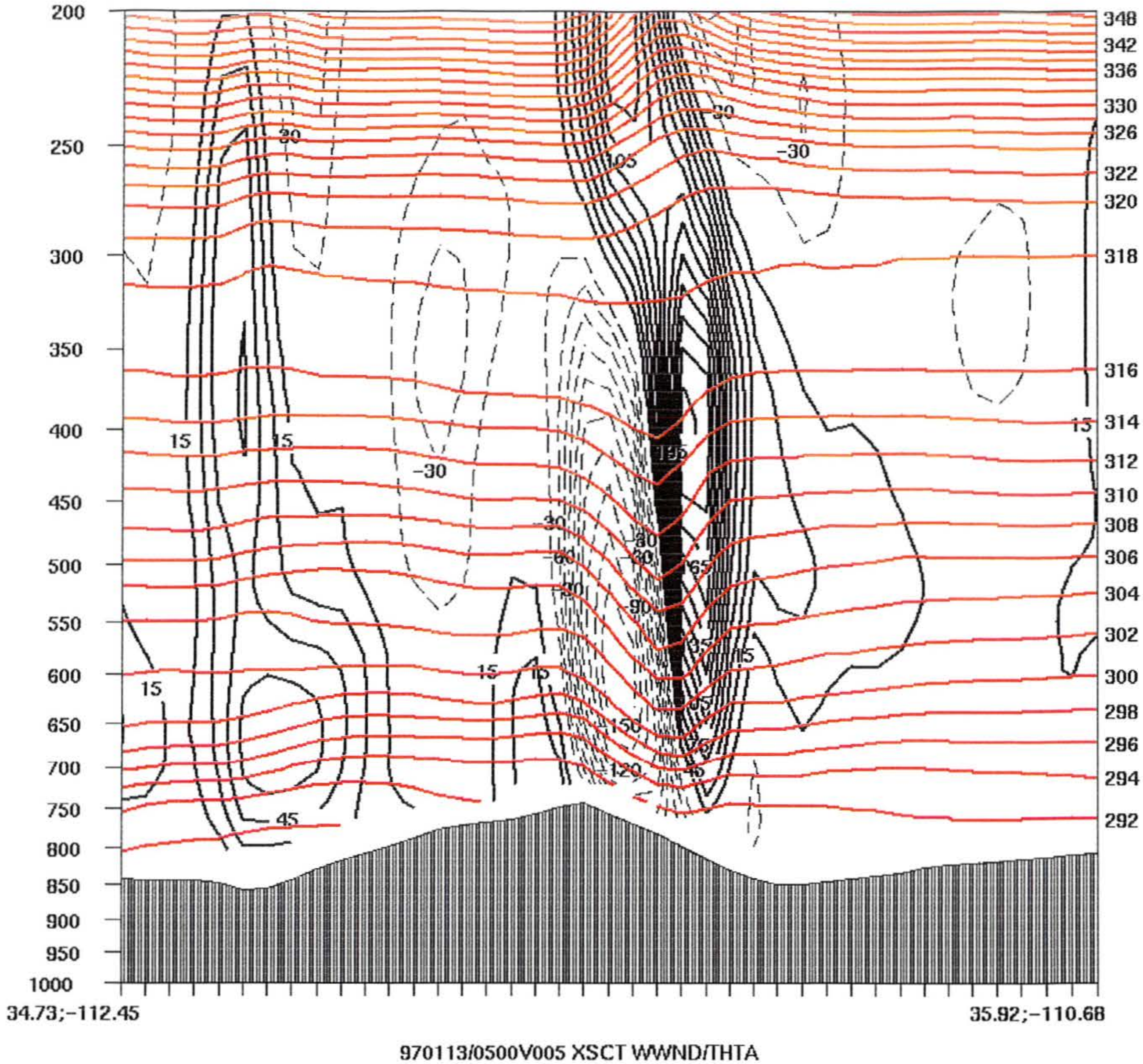

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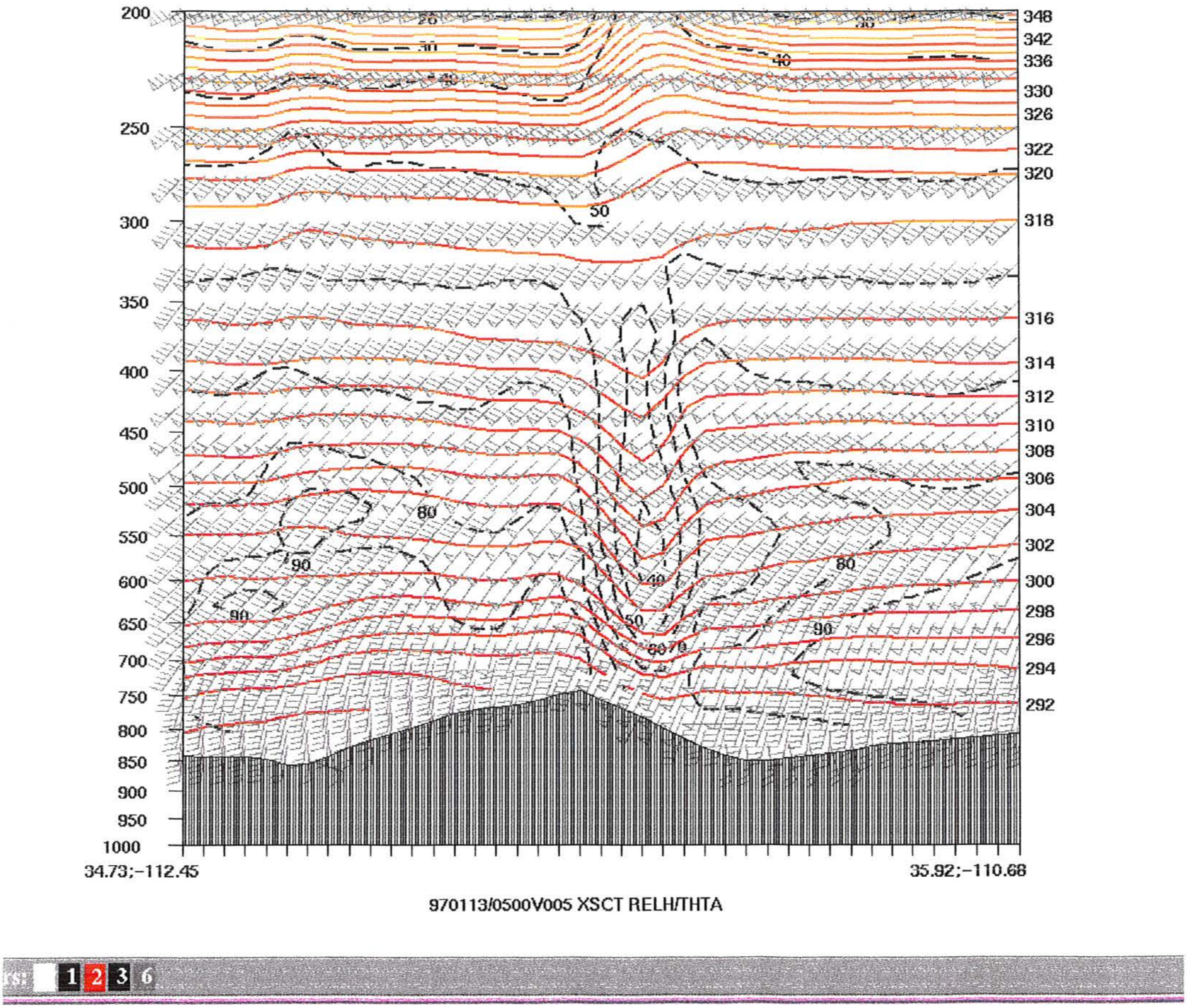

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