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MESOSCALE SIMULATION OF A WINTER STORM OVER UTAH

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[Editor's Note: This Technical Attachment is a brief summary of a thesis completed by Chris Gibson as partial fulfillment of the requirements for a M.S. degree in meteorology from the University of Utah. This paper also represents results of an ongoing COMET Cooperative project between the university and WSFO Salt Lake City regarding the operational use of the Utah mesoscale model.]

A mesoscale model developed by Paegle and McLawhorn (1983) and most recently described by Nicolini et al. (1993) has been run at the University of Utah in a quasi-operational mode since late 1991. This model, hereafter referred to as the Utah model, incorporates a detailed specification of the terrain over the intermountain region, enhanced vertical resolution in the boundary layer, treatment of short-wave and long-wave radiation, and resolvable-scale precipitation. Gridded data from the Utah model has been available to the National Weather Service Forecast Office in Salt Lake City since November 1992. Data from the NGM is used to initialize the Utah model and nudge the lateral boundaries during 12 hour integrations. Utah model runs presented here were completed on a 33 x 33 horizontal latitude-longitude grid with .266° latitude by .266° longitude spacing (approximately 30 km resolution). Figure 1 shows the grid of the Utah model superimposed over the model terrain as well as available surface and upper air observation stations. Our purpose here is to demonstrate the application of mesoscale model output for evaluation of the three-dimensional circulation over complex terrain.

The storm analyzed here developed in early January 1992 as a disturbance in the baroclinic zone over the central Pacific Ocean and then moved towards the western United States. As the storm entered a region of strong split flow, the northern part of the trough was weakened considerably while the trough deepened in the southern branch. The southern portion of the system was characterized by a distinct pool of cold air moving onshore across southern California and progressing eastward along the Arizona-Utah border. Gibson (1993) provides a detailed description of the synoptic-scale three-dimensional circulation of the storm. Figure 2 represents a satellite image from 1800 UTC 6 January 1992, as the major frontal band was pivoting north and east across Utah. The coldest air over the region was moving eastward into southern Utah behind the cloud band. Figure 3 shows a manual surface analysis, using all available data, valid at 0000 UTC 7 January.

Standard analysis techniques applied to the forecast data from the NGM (not shown), indicated that positive quasi-geostrophic (QG) forcing would accompany the frontal band and heavy precipitation would be likely for the mountains and valleys of southern Utah. While this analysis led to accurate overall forecasting of the event, use of the Utah model output is helpful in diagnosing the complicated structure of the front. The Utah model run discussed here was initialized with data from the NGM analysis of 1200 UTC 6 January and nudged with the 6 and 12 hour forecasts.

Analysis Over Northern Utah

Over northwestern Utah, only trace amounts of precipitation fell as the front moved over the area despite the accompanying cloud bank (Fig. 2). Mountaintop winds (not shown), as measured by remote instrument platforms, indicated southwest to west winds during passage of the cloud band. This largely eliminated the downslope drying from the Wasatch Range, which was responsible for the lack of precipitation. The conditions forecast by the Utah model over the grid point nearest to Salt Lake City are presented as a time-height diagram in Fig. 4. Equivalent potential temperature (Θ_e) is superimposed on the relative humidity field in Fig. 4a, and the vertical velocity field in Fig. 4b. At 500 mb, Θ_e began to decrease after 1400 UTC, while at 700 mb, Θ_e did not begin to decrease until after 1600 UTC. Relative humidity (Fig. 4a) at 400 mb decreased from >70% to near 30% between 1400 and 1700 UTC. A short-lived area of ascent, centered near 600 mb, occurred at 1400 UTC (Fig. 4b). After this period, descent developed over Salt Lake City in the middle troposphere, reaching values as large as -20 cm s^{-1} at 400 mb.

This transition, forecast by the Utah model, to cooler, drier air aloft over Salt Lake City suggests the passage of an upper front according to the conceptual model of a katafront described by Browning and Monk (1982). Since the air aloft is sinking along isentropes, the features of the upper front are often easier to determine from the Θ_e field than the temperature or potential temperature fields (Browning, 1986). Synoptic-scale descent develops as strong southerly flow in the upper troposphere blows through the northwest-to-southeast oriented frontal zone. Figure 5 shows the streamlines and pressure values on the 305 K isentropic surface at 1800 UTC 6 January from the Utah model output. Descent is implied over northwest Utah where the northward movement of the front stalled, while strong southerly flow is directed through the frontal zone, descending along isentropic surfaces. Generally, stable conditions were observed over northwest Utah with lenticular cloudiness accompanying the frontal passage.

Analysis Over Southern Utah

The front had much different characteristics as it progressed across southern Utah. A time-height diagram is presented in Fig. 6 for the Utah model forecast over a grid point located in the Colorado River Basin near Lake Powell. The katafront identified over western Utah passed above this grid point during the first 3 hours of the model simulation. Notice the sharp drop in relative humidity after the upper front passed aloft (Fig. 6a) and strong descent developed in its wake (Fig. 6b). After 1700 UTC 6 January, strong cooling and drying (i.e., lowering of Θ_e values) began in the middle troposphere, especially near 700 mb. This cooling represented the passage of a lower tropospheric cold front. Even though the amount of water vapor is diminishing, high relative humidity developed at lower model layers. Rising motion occurred ahead of the front with values as large as 10 cm s^{-1} at 700 mb (Fig. 6b) which continued after its passage. The time-height sections in Fig. 6 also indicate that Θ_e decreased above 800 mb while remaining nearly constant near the surface, which led to a convectively unstable atmospheric column by 1900 UTC. This phenomena may be due to blocking of the lower atmospheric flow by the complex terrain of southern Utah. As the cold front moved rapidly through the middle troposphere, its motion was retarded at low levels by the terrain.

The forecast discussion issued on the afternoon on 6 January by the Salt Lake City Weather Service Forecast Office commented on extensive lightning in the Four Corners area during this period. The destabilization of the vertical column in the model and the vertical velocities help to explain the instability over southeast Utah which accompanied the front. This simulation also supports the hypothesis of Smith (1982) who presented a model for the generation of an unstable layer over mountainous regions due to blocking of the low level flow by terrain. He found that a pattern of vertical differential temperature advection developed due to low-level frictional drag induced by an idealized mountain.

Conclusion

We have presented a brief examination of one front simulated with the Utah model during January 1992. A more detailed description of the system is given by Gibson (1993). Because the Utah model is nudged on its lateral boundaries by the NGM forecast, the mesoscale forecast is heavily dependent on the skill of the regional scale model. The Utah model introduces mesoscale structure to the flow and thermodynamic fields through the effects of the underlying terrain and other physical processes. National Weather Service Forecast Offices will soon have the equipment to perform mesoscale simulations in near real time on workstations that are commonly available in universities. This technology should improve the ability to forecast mesoscale phenomena, especially in regions of complex terrain.

References

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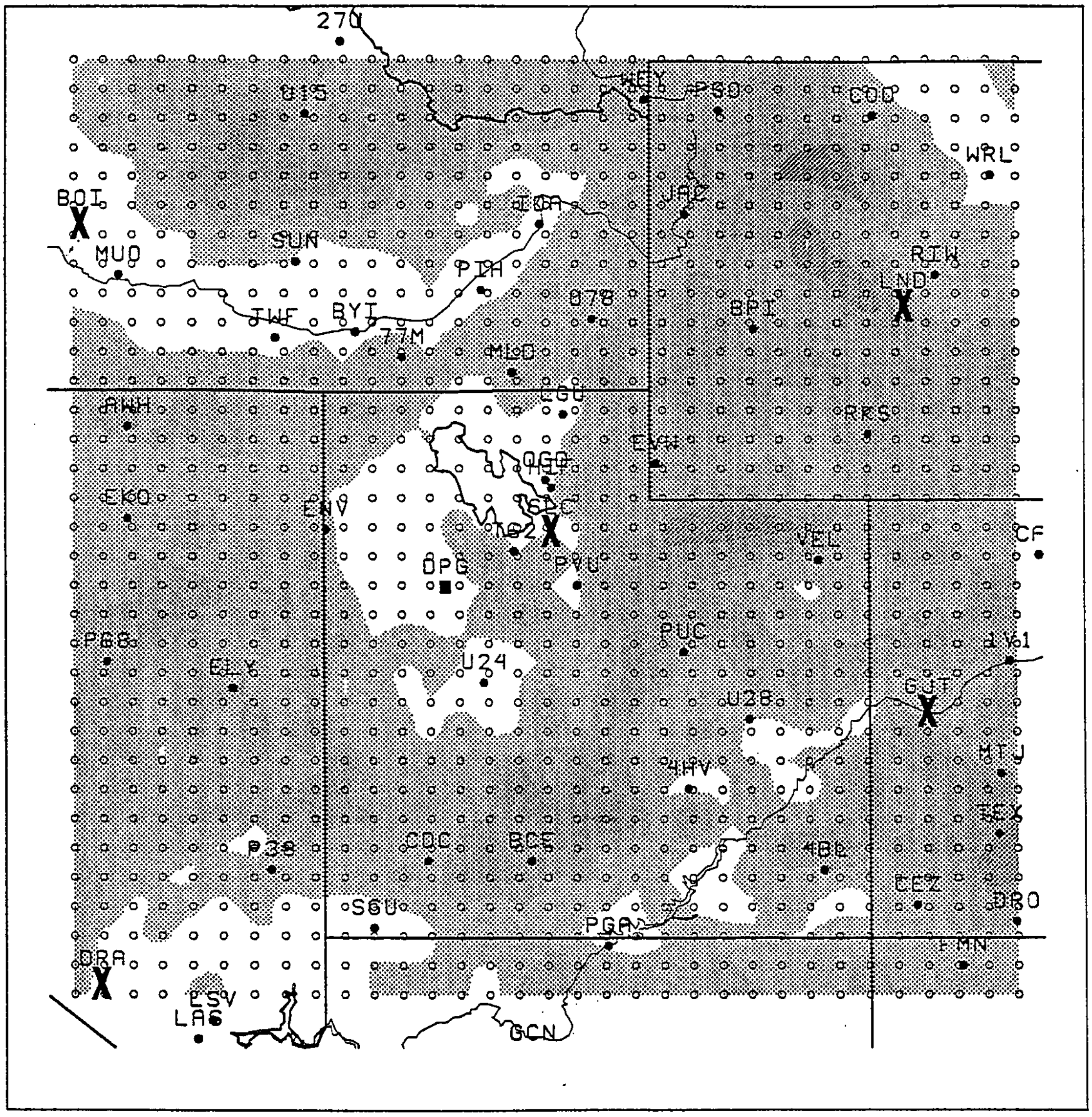

Figure 1. Utah model grid point locations (open circles) with surface airways stations (small filled dots), upper air stations (X), Dugway profiler (square), and model surface elevation (elevations denoted by progressively darker shading at 500 m intervals beginning with the 1500 m level.).

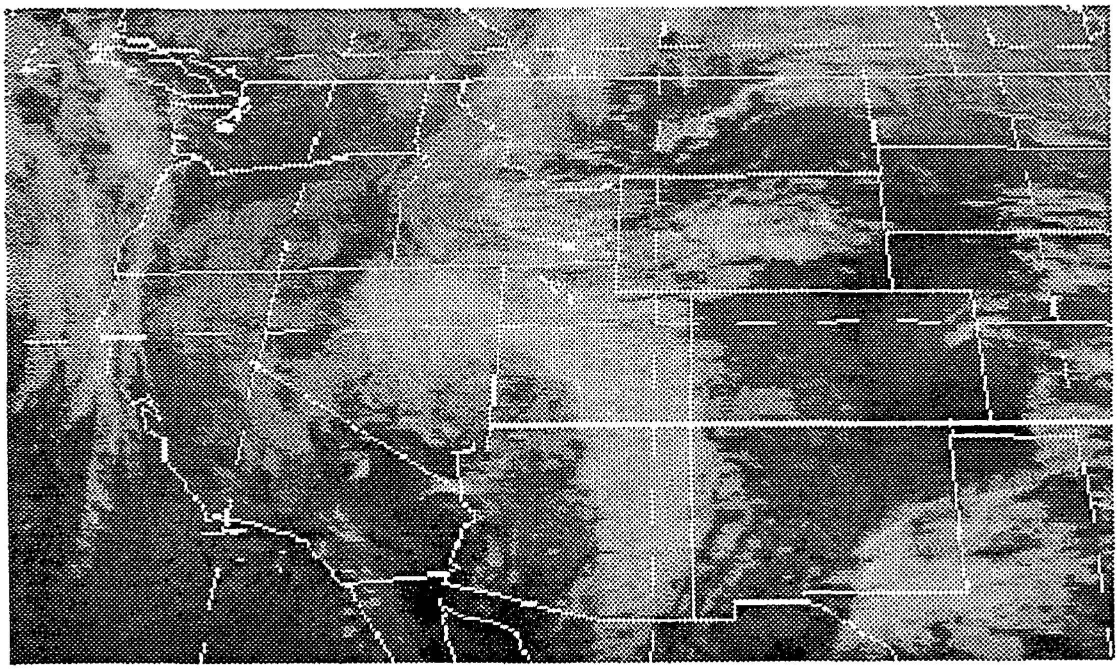

Figure 2. Infrared satellite image at 1800 UTC 6 January 1992.

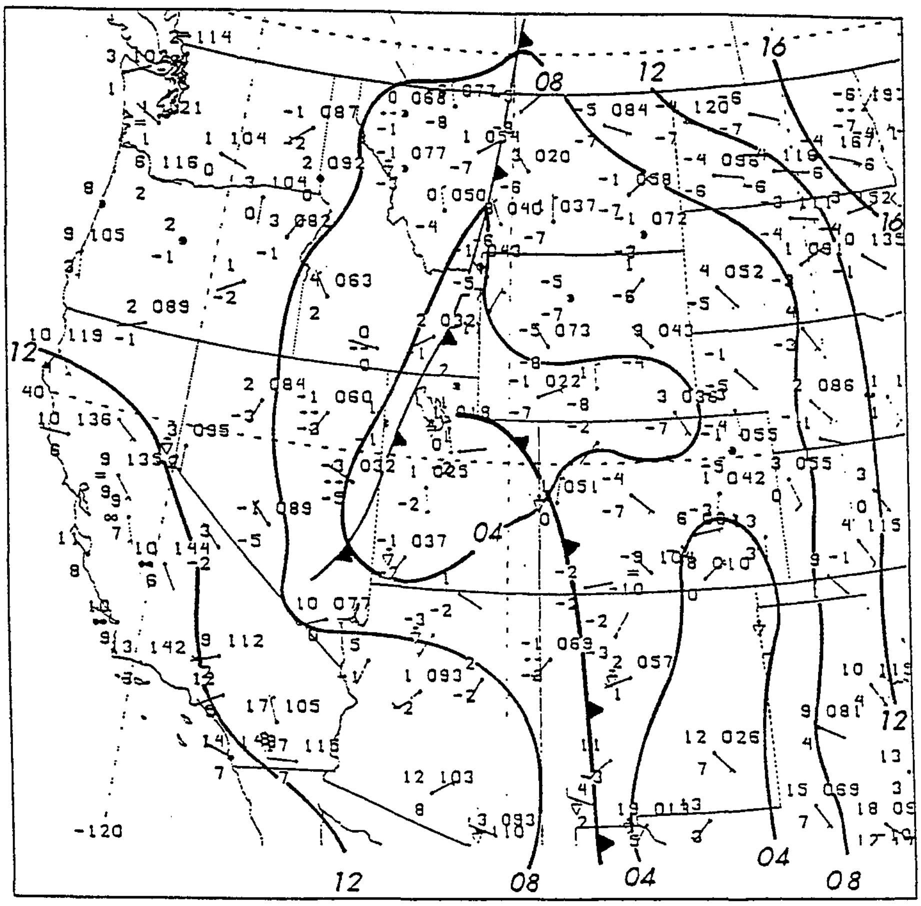

Figure 3. Manual surface analysis valid 0000 UTC 7 January 1992.

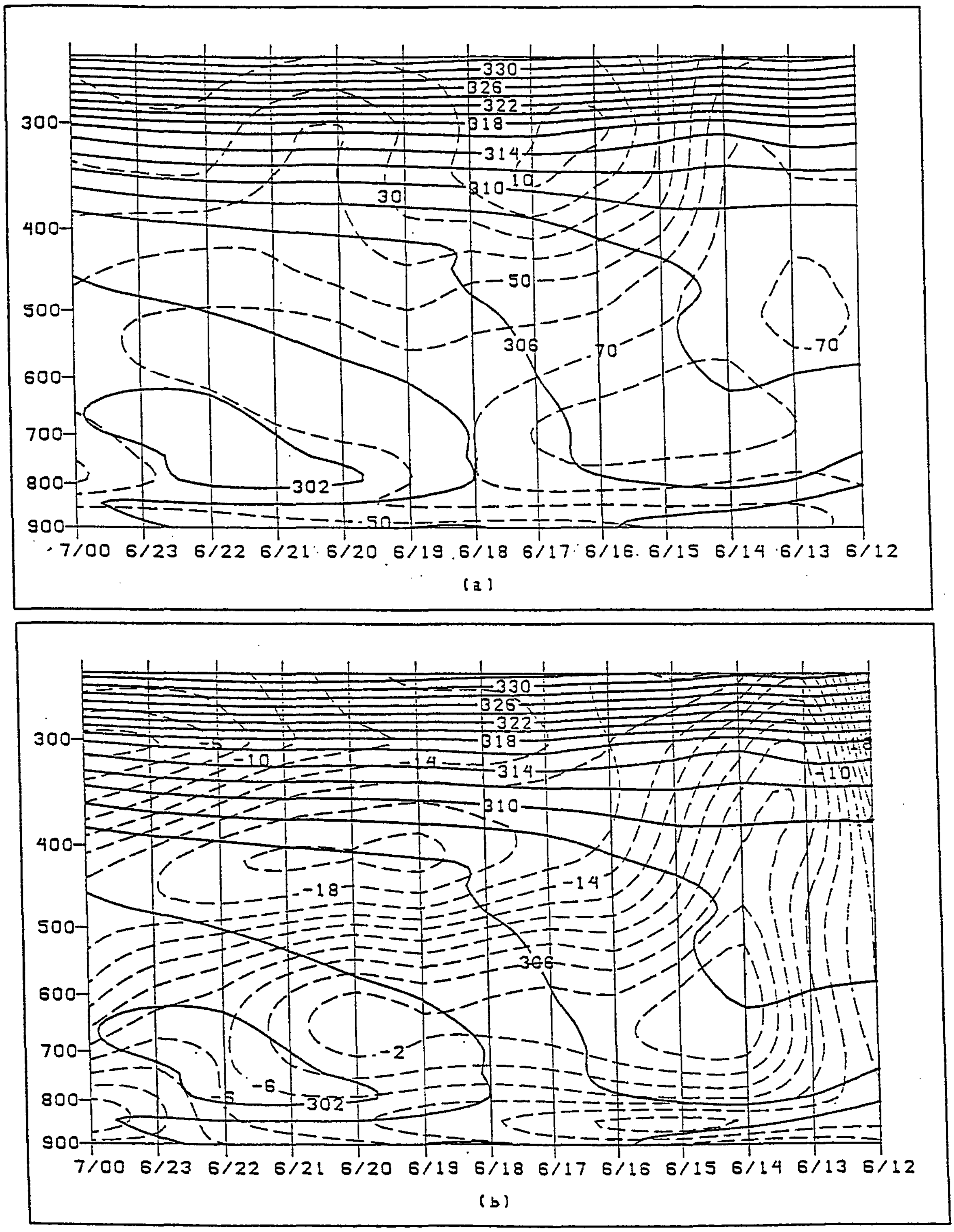

Figure 4. Time-height diagram at the grid point nearest to SLC (17;17) from the Utah model run initialized at 1200 UTC 6 January 1992: (a) θ_e in K (solid lines; contour interval 2 K) and relative humidity in percent (dashed lines; contour interval 10%) and (b) θ_e in K (solid lines; contour interval 2 K) and vertical velocity in cm s^{-1} (dashed lines; contour interval 2 cm s^{-1}). Time increases from right to left.

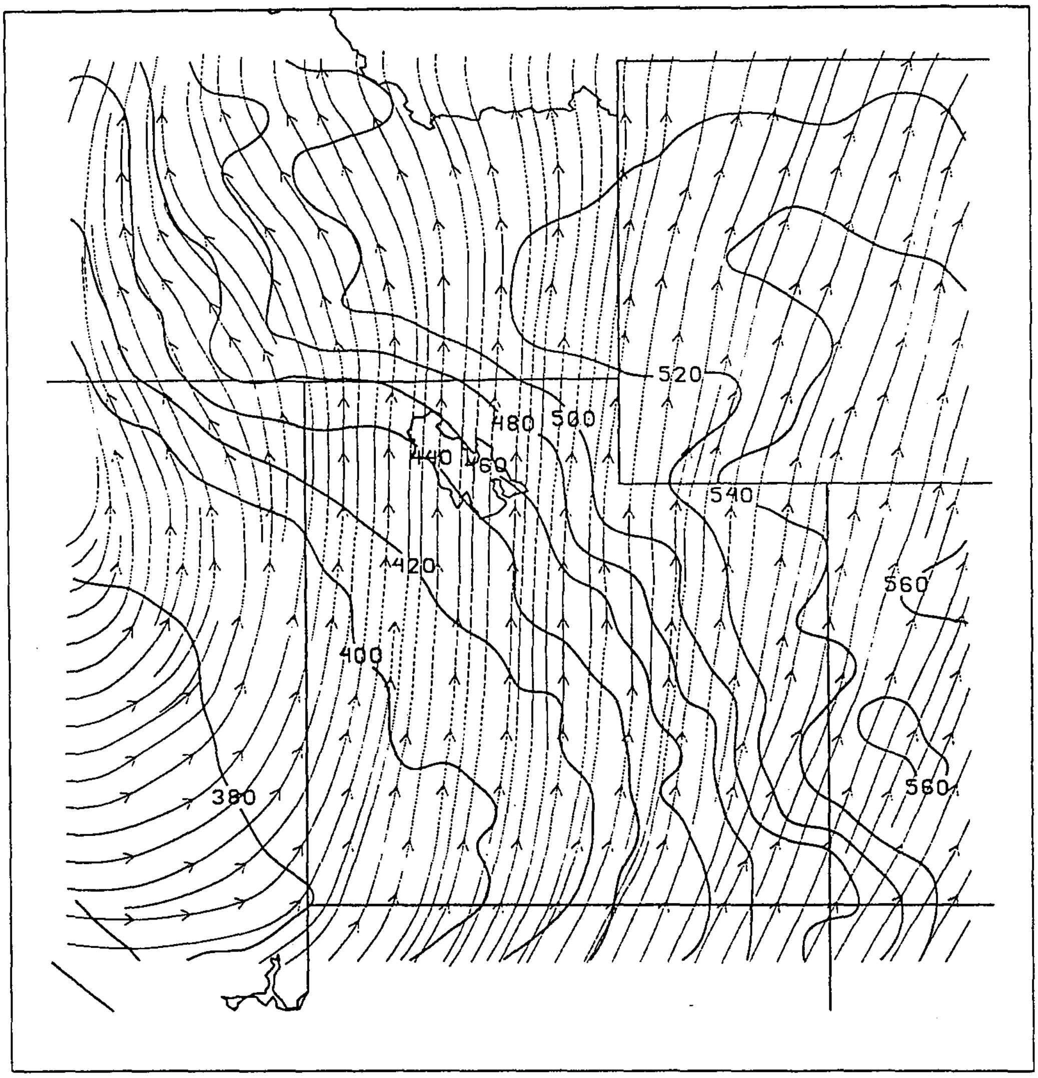

Figure 5. Streamlines and pressure (contours every 20 mb) on the 305 K isentropic surface at 1800 UTC 6 January from the Utah model run initialized at 1200 UTC 6 January 1992.

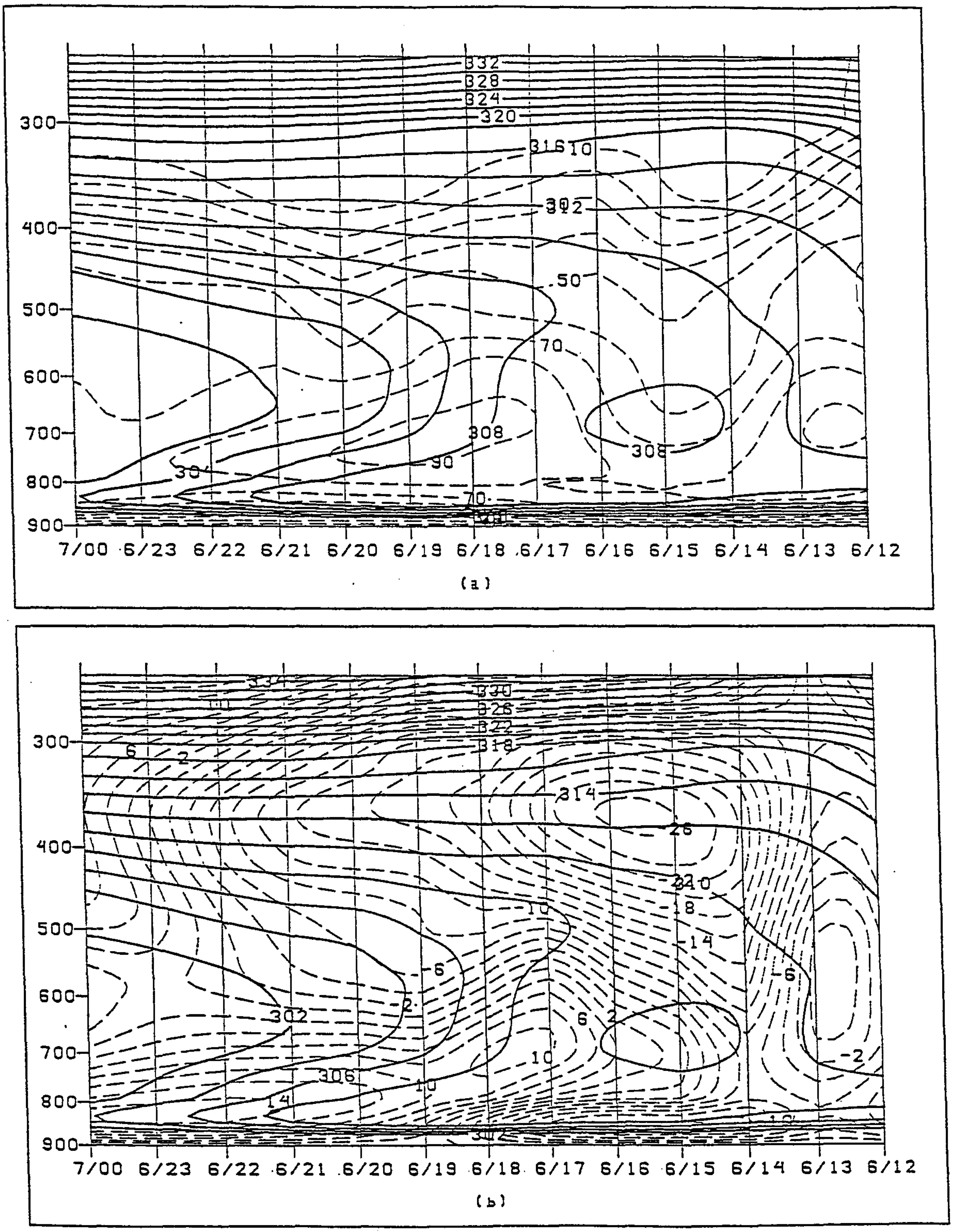

Figure 6. Time-height diagram at the grid point 24;6 from the Utah model run initialized at 1200 UTC 6 January 1992: (a) θ_e in K (solid lines; contour interval 2 K) and relative humidity in percent (dashed lines; contour interval 10%) and (b) θ_e in K (solid lines; contour interval 2 K) and vertical velocity in cm s^{-1} (dashed lines; contour interval 2 cm s^{-1}). Time increases from right to left.