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THE PENNSYLVANIA ICE STORM OF 7 JANUARY, 1995

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1. INTRODUCTION

Cold air damming in the valleys and along the eastern slopes of the Appalachian mountains has posed a forecast problem for meteorologists for decades (Williams 1960; Richwien 1980). During the cold season, cold air damming events play a key role in major east coast snowstorms (Kocin and Uccellini 1990) and in ice storms (Forbes et al. 1987). In the warmer season, low-level cold air damming can play a significant role in temperature and cloud forecasts along the east coast.

Forecasting cold air damming is a difficult task. Classic cases of cold air damming (Kocin and Uccellini 1990) with winter storms include the presence of a strong surface anticyclone or ridge over the northeastern United States, relatively dry air, which will support evaporative cooling, and downstream confluence in the upper troposphere (300 to 200 mb). The confluence aloft is associated with an upper-level jet entrance region. The resulting ageostrophic circulations associated with this jet entrance region play a significant role in maintaining the low-level cold air along the eastern slopes of the Appalachian mountains. Other factors that play a significant role in cold air damming events include evaporative cooling, ascent in a statically stable atmosphere, the orographic contribution to ascent due to the mountains, and the shape of the orographic barrier. For a detailed account on how these mechanisms contribute to cold air damming see Forbes et al. (1987).

This study examines the meteorological conditions associated with an ice storm that occurred over central and eastern Pennsylvania on 6-7 January of 1995. This was not a significant event, yet it illustrates the difficulties associated with forecasting precipitation type with conflicting model guidance. Cold air damming played a significant role in this event despite the fact that a strong surface anticyclone was not present over New England. In the classical sense, this did not appear to be an ideal system for an ice storm. It will be shown how in a stable atmosphere, which was initially dry at low-levels, the *ageostrophic winds* diagnosed from AVN, ETA, and

NGM forecast data, provided an essential tool to diagnose the potential for an ice storm over the region.

2. METHODOLOGY

The data used in this study included grid point data from three of the National Meteorological Center's (NMC) operational models, including the ETA, NGM, and AVN. PC-GRIDDS was used to compute the ageostrophic winds, divergence, and the wet-bulb temperature. Wet-bulb temperatures were computed for 1000 and 850 mb over the eastern United States. These variables are similar to the fields operationally used by the forecasters at the Central Pennsylvania National Weather Service Office (NWSO CTP). Other data used included observed surface and upper-air data obtained from the Pennsylvania State University meteorological system (Cahir et al. 1981).

3. RESULTS

a. Overview

The forecasts prior to the precipitation event indicated that a surface anticyclone would rapidly weaken and move over the western Atlantic. The 2100 UTC 6 January surface analysis (Fig. 1a) revealed a surface anticyclone over the western Atlantic with a strong pressure gradient from the mid-Atlantic states to the mid-western United States. By 0000 UTC 7 January, 1995, the surface anticyclone continued to move eastward and weaken while a weak surface cyclone was present over the Ohio river valley (Fig 1b). Over central Pennsylvania, the surface winds became more easterly despite the larger-scale gradient supporting southerly flow. The surface streamline analysis valid at 0000 UTC, showed a strong southerly component over Pennsylvania (Fig. 2a) while streamlines of ageostrophic flow indicated a northeasterly component (Fig. 2b). At this time, a mixture of snow, sleet, and freezing rain was occurring over most of central Pennsylvania. By 0300 UTC 7 January (Fig. 1c), the surface low over the Ohio river valley had moved into eastern Ohio, while a secondary low had developed in the baroclinic zone extending across eastern Virginia and the Delmarva region. At Williamsport, PA, the surface winds were northeasterly.

By 1200 UTC 7 January, 1995, the western surface low had tracked from central Pennsylvania into southeastern New York, while the coastal low moved across New Jersey into southern New England (Fig. 1d). Despite the relatively weak circulations, the 12-h pressure falls over Pennsylvania and the east coast were impressive, with many locations experiencing from 16- to 20-mb pressure falls in 12-h. Several areas across central Pennsylvania received 0.4 to 0.8 inches of precipitation, which fell primarily as freezing rain and sleet.

Preliminary NWS forecasts for this event included snowfall in the 2 to 4 inch range throughout most of central Pennsylvania. Forecasts for central Pennsylvania also emphasized that the precipitation would likely mix with, or change to, rain or freezing rain. Over southeastern Pennsylvania, forecasts called for rain. The largest accumulations of ice due to freezing rain occurred in the Harrisburg region. The event began primarily as an ice storm over central Pennsylvania and portions of southeastern Pennsylvania.

b. Model Forecasts

The 12-, 24-, and 36-h forecasts from the NGM, ETA, and AVN models indicated the potential for a mixed precipitation event over central Pennsylvania during the evening hours on 6 January (around 0000 UTC 7 January). For brevity, NGM forecast products are not shown.

The 36-h AVN and ETA forecasts of mean sea level pressure and 1000-500 mb thickness valid 0000 UTC 7 January, 1995, are shown in Figures 3 and 4, respectively. Based on the position of the 540 dm contour (Wagner 1957), the AVN forecast suggested a 50% or greater chance for snow across northern Pennsylvania, while the ETA appeared to indicate mixed precipitation or rain. The location of the mesoscale surface high and trough along the New Jersey coast in the AVN model output, is in close proximity to the mesoscale surface circulations observed at 0300 UTC (Fig. 1c). The AVN appears to have better forecast the low-level cold air and evaporative cooling potential than the ETA. However, the ETA had a better forecast position of the surface cyclone moving across the Ohio river valley.

The 36-h ETA and AVN forecasts of 1000 mb wet-bulb temperatures are shown in Figures 5 and 6, respectively. The corresponding 1000 mb ageostrophic winds are shown in Figures 7 and 8. Both models indicated northerly ageostrophic flow over the region, suggesting the potential for a prolonged period of cold air damming. Both models indicated that the potential for freezing precipitation extended into northern Virginia and Maryland. The NGM showed a similar trend at this time, but the ageostrophic winds (not shown) had a stronger easterly component. However, the wind speeds over central Pennsylvania were in excess of 45 kt. The direction of the low-level ageostrophic winds in the AVN and ETA models were in close agreement to the observed ageostrophic winds (Fig 2b).

The 48-h AVN and ETA model forecasts of mean sea-level pressure valid at 1200 UTC 7 January, 1995 are shown in Figures 9 and 10, respectively. The AVN depicted a weak surface low over southwestern New York State, with the primary surface low located over Long Island, New York. The ETA tracked the Ohio Valley cyclone into northern New York. *Operational forecasters were faced with two conflicting forecasts.* Clearly, the ETA forecast would have allowed warm air to penetrate the region, turning all the precipitation to rain. However, the AVN suggested that the re-development of a surface cyclone along the coast would cut-off the warm air advection, with a longer period of snow and mixed precipitation. By comparing these two forecasts to Figure 1d, it appears that by 36-h, the AVN had a better handle on the situation than the ETA. However, the AVN developed the surface cyclone faster and further southwest of the observed position. The stronger western cyclone and the slower development along the coast, probably allowed more warm air to move over the region, leading to an ice storm situation rather than a snow situation.

Despite significant differences in the forecast track of the surface cyclone, the 36-h forecast from the three models indicated strong northerly ageostrophic winds at 1000 mb, strong divergence at 250 mb (not shown); with the 850 mb 0°C isotherm extending across central Pennsylvania (not shown). The 12- and 24-h AVN and ETA model forecasts prior to the event predicted a scenario similar to the 36-h forecasts and are not shown. The trend in successive runs of both the AVN and NGM was for slightly higher thickness values over central Pennsylvania, similar to the 36-h thickness forecast produced by the 1200 UTC 5 January ETA (Fig. 4). However, the 850 mb 0°C isotherm (and wet-bulb zero line) forecasts remained consistent with the zero isotherm extending across central Pennsylvania.

The AVN initial analyses of mean sea-level pressure and 1000-500 mb thickness valid 0000 UTC 7 January are shown in Figure 11. These data depict a surface cyclone over Kentucky and a surface anticyclone over the western Atlantic. Of course, the mesoscale feature along the New Jersey coast (Fig. 3) was not present in this analysis. At this time, the 540 dm 1000-500 mb thickness (hereafter, thickness) line was located north of Pennsylvania, and the 546 dm thickness line was located across southern Pennsylvania, suggesting that the mean virtual temperature of the 1000-500 mb layer over the region was between 0° and +3°C. Usually, over the eastern United States, the 540 dm thickness line is approximately the 50% probability of snow delineator (Wagner 1957).

The AVN initial analyses of 1000 mb wet-bulb temperatures and ageostrophic winds valid at 0000 UTC 7 January, 1995 are shown in Figure 12. These data indicate strong northerly ageostrophic winds and cold air damming over central and eastern Pennsylvania. Comparisons to Figure 2b reveal that the AVN initial analysis had the proper circulation for the analyzed fields. The fact that low-level temperatures were at or below 0°C, and the thickness values were generally between 540-546 dm over the region, suggests that a layer of warm air was present in the 1000 to 500 mb column that was able to maintain a mean virtual temperature between 0° and +3°C.

The AVN initial analyses of 850 mb wet-bulb temperatures and winds valid at 0000 UTC 7 January, 1995 are shown in Figure 13. These data indicate that temperatures were forecast to be near or above freezing over most of central and southeastern Pennsylvania. The position of the zero degree line was in close proximity to the ETA forecast from 12-h earlier, and the AVN forecast from 24-h earlier (not shown, 1200 UTC AVN 6 January, 1995 data were not available).

4. DISCUSSION

The ice storm of 7 January, 1995 was not a major weather event. The precipitation amounts associated with this event were generally less than 0.8 inches in regions where freezing rain and sleet occurred. This case was documented to show how gridded model data can be used to determine the precipitation type.

One of the most significant problems with this case was how to deal with conflicting model guidance. NGM and AVN forecasts 24- to 36-h prior to the event, pointed to a snow event changing to sleet and freezing rain. Forecasts from the ETA, which did not re-develop the surface cyclone along the coast, suggested snow or a wintry mix that would rapidly change to rain. Although no single model was perfect, the AVN appeared to provide the best guidance. One significant error with the AVN was that it was too quick to re-develop the surface cyclone along the east coast, and it was too slow to move the cyclone north and east.

The ETA failed to predict the re-development along the coast. However, by maintaining a stronger low-level cyclonic circulation along the western slopes of the Appalachian mountains, the ETA provided a better forecast of the low-level thermal character of the atmosphere than the AVN and NGM, especially 36-h prior to the event. After 0000 UTC on 7 January, 1995, the ETA's failure to re-develop the surface cyclone along the southern New England coast reduced the utility of its forecasts much beyond the 36-h time period.

The key forecast decision point was during the period between 0000 and 0600 UTC 7 January. Initially, all three models suggested the potential for a wintry mix over central Pennsylvania, despite the relatively high thickness values and the warm 850 mb temperatures. The key feature was the low-level cold air damming and the northerly ageostrophic winds in the model forecasts (Figs. 7 and 8). Both the 1000-500 mb thickness values and 850 mb temperatures suggested an intrusion of warm air above the low-level cold air. The combined effects of evaporative cooling and low-level cold air damming would act to keep the cold air in place at the surface.

The 1000 mb and 850 mb wet-bulb temperatures revealed the effects of evaporative cooling in the model atmosphere (Figs. 5, 6, 12, and 13). Over central Pennsylvania at 0000 UTC, the 850 mb isotherms (not shown) were nearly coincident with wet-bulb contours. Hence, by 0000 UTC, the potential for evaporative cooling in the model atmospheres had been realized.

An examination of the Pittsburgh, PA sounding valid 0000 UTC 7 January (Fig. 14) shows that the nose of the warmest air and a nearly saturated environment were present near 850 mb. These data also indicate that the lowest levels of the atmosphere were cold and stable on the west side of the Appalachian mountains. Unfortunately, the Sterling, VA sounding was not available. However, if the Pittsburgh sounding was representative of the conditions over central Pennsylvania, any ascent in the lower levels of the atmosphere would induce cooling which would mitigate the warming due to warm air advection.

5. CONCLUSION

This case clearly illustrates how gridded model data can be extremely useful in an operational forecast environment. On the negative side, conflicting model forecasts force the operational forecaster to choose the appropriate model. On the plus side, with gridded data, operational forecasters can quickly and easily examine fields that are not available on pre-generated graphical products.

Using PC-GRIDDS, forecasters can quickly examine fields such as wet-bulb temperatures and ageostrophic winds. The low-level ageostrophic winds have been shown to be useful in forecasting cold air damming (Kocin and Uccellini 1990; Forbes et al. 1987). The results associated with this study suggest that model forecasts of low-level ageostrophic winds are a useful forecast tool in identifying cold air damming. The low-level wet-bulb temperature field provides an indication of the temperature once precipitation begins.

This study suggests that operational forecasters need updated information on the inherent biases in the operational dynamical model guidance. Additionally, to improve the quality of precipitation type forecasts, operational meteorologists can benefit from real-time access to gridded model data.

ACKNOWLEDGMENTS

The authors would like to thank the staff at the National Weather Service Office in State College for collecting the model data for this case during the event. A special thanks to John LaCorte and David Nicosia for their development of winter weather forecasting scripts for PC-GRIDDS. Additionally, the authors would like to thank Dr. Greg Forbes of The Pennsylvania State University, for allowing us access to the Pennsylvania State University meteorological system, as well as his insights related to the analysis of ageostrophic winds over the region.

REFERENCES

Cahir, J. J, J. M. Norman, and D. A. Lowry, 1981: Use of a real-time computer graphics system in analysis and forecasting. *Mon. Wea. Rev.*, **109**, 485-500.

Forbes, G. S, R. A. Anthes, and D. W. Thomson, 1987: Synoptic and mesoscale aspects of an Appalachian ice storm associated with cold-air damming. *Mon. Wea. Rev.*, **115**, 564-591.

Kocin, P. J., and L. W. Uccellini, 1990: *Snowstorms Along the Northeastern Coast of the United States*. Amer. Meteor. Soc., 280 pp.

Richwien, B. A., 1980: The damming effect of the southern Appalachians. *Nat. Wea. Dig.*, **5**(1), 2-12.

Wagner, A. J, 1957: Mean temperature from 1000 to 500 mb as a predictor of precipitation type. *Bull. Amer. Meteor. Soc.*, **38**, 584-590.

Williams, B. B, 1960: The 1960 ice storm in northern Alabama. *Weatherwise*, **13**, 196-203.

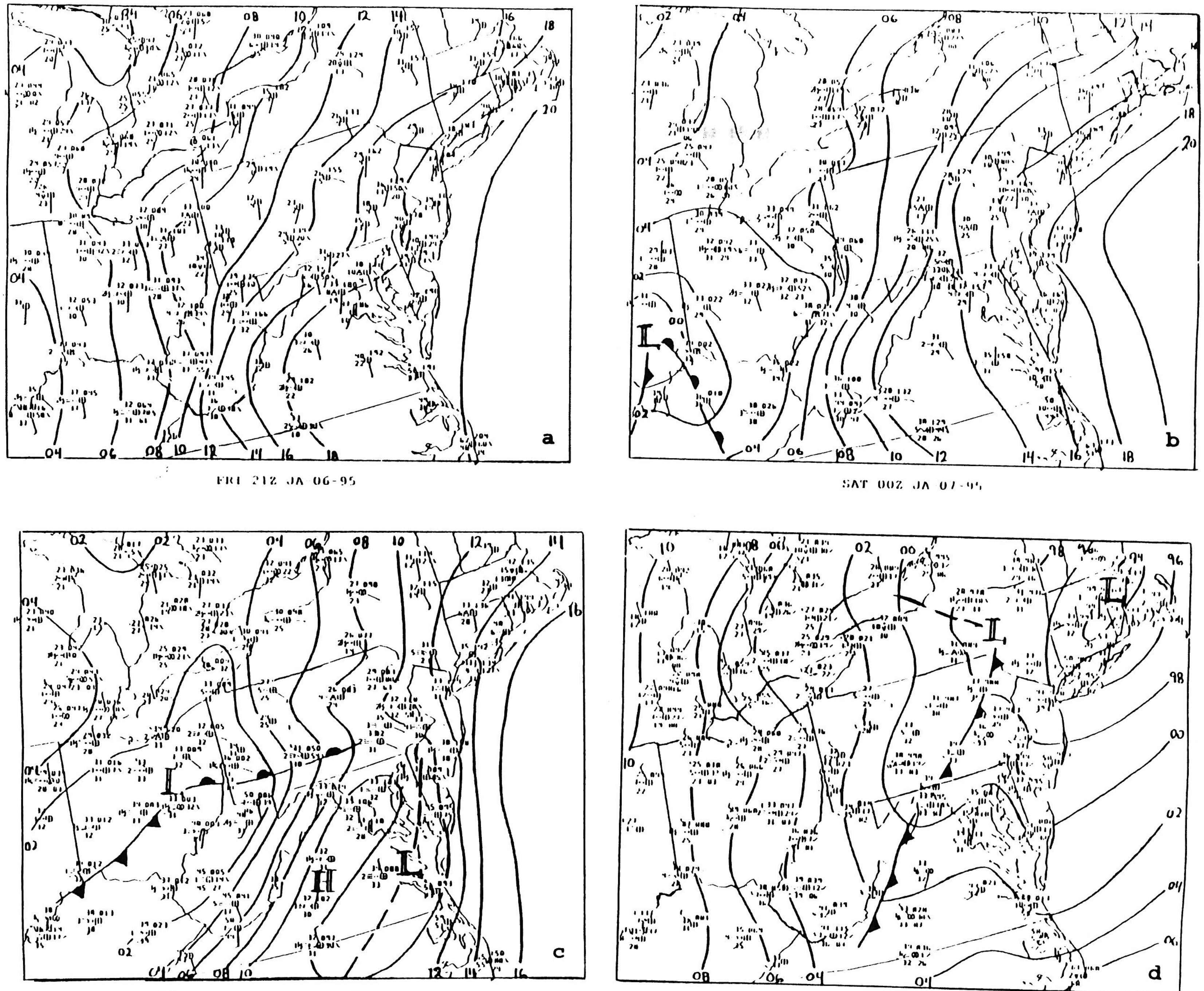


Figure 1. Surface observations, fronts, and isobars valid at: a) 2100 UTC 6 January, b) 0000 UTC 7 January, c) 0300 UTC 7 January, and d) 1200 UTC 7 January. Isobar contour is 2 mb.

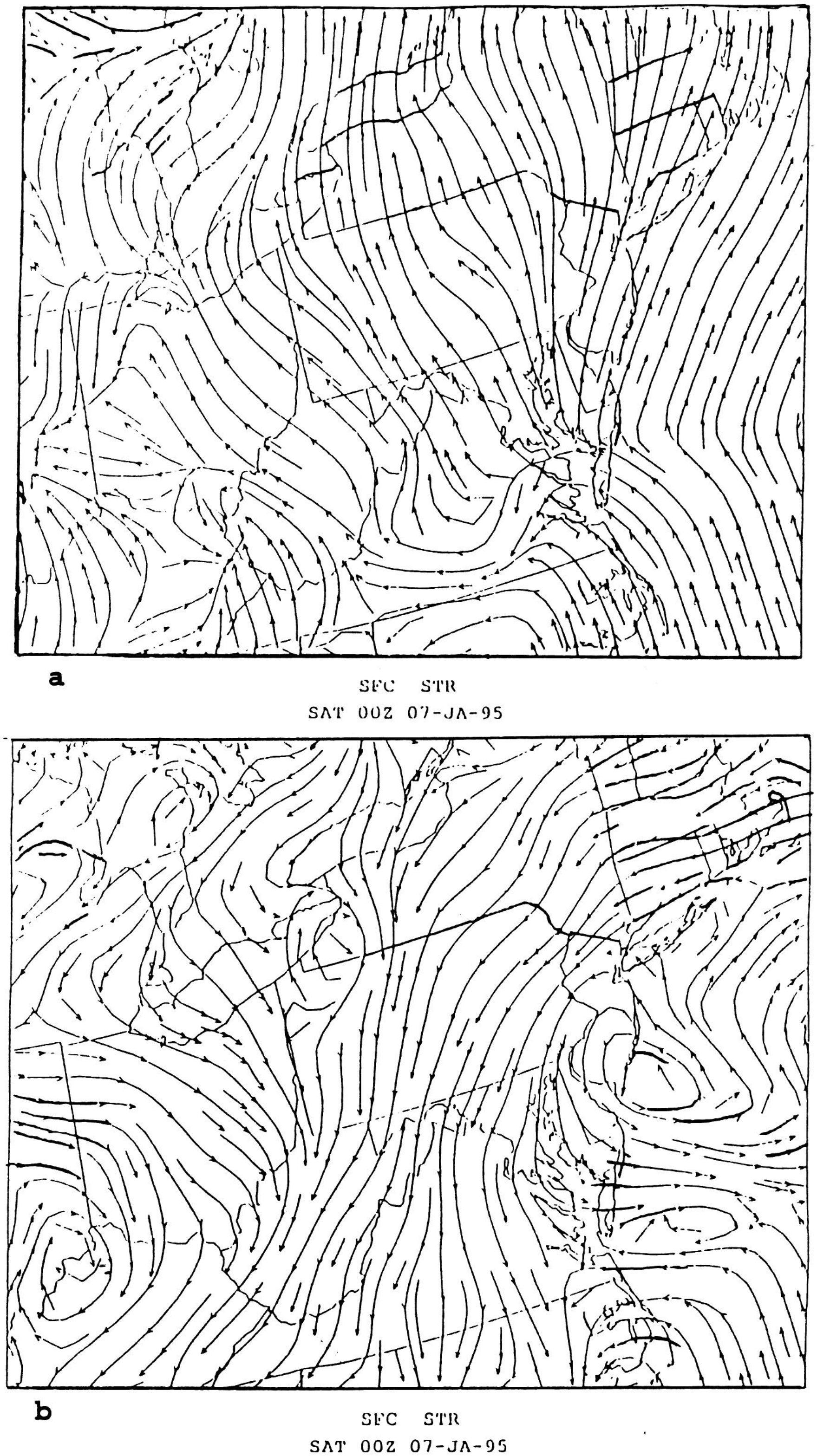


Figure 2. Surface streamline analysis valid 0000 UTC 7 January, 1995 for a) the observed wind, and b) the ageostrohic wind.

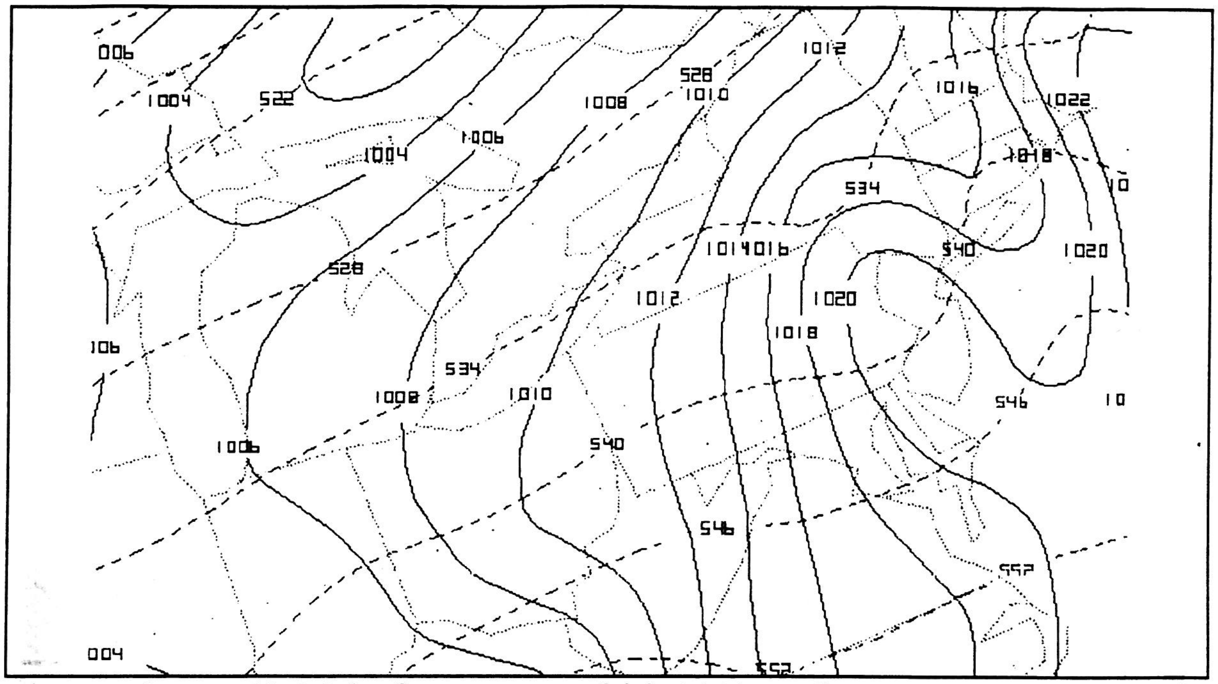


Figure 3. AVN 36-h forecast valid 0000 UTC 7 January, 1995 of the mean sea level pressure (mb) and 1000-500 mb thickness (dm). Pressure contours are every 2 mb and thickness contours are every 60 m.

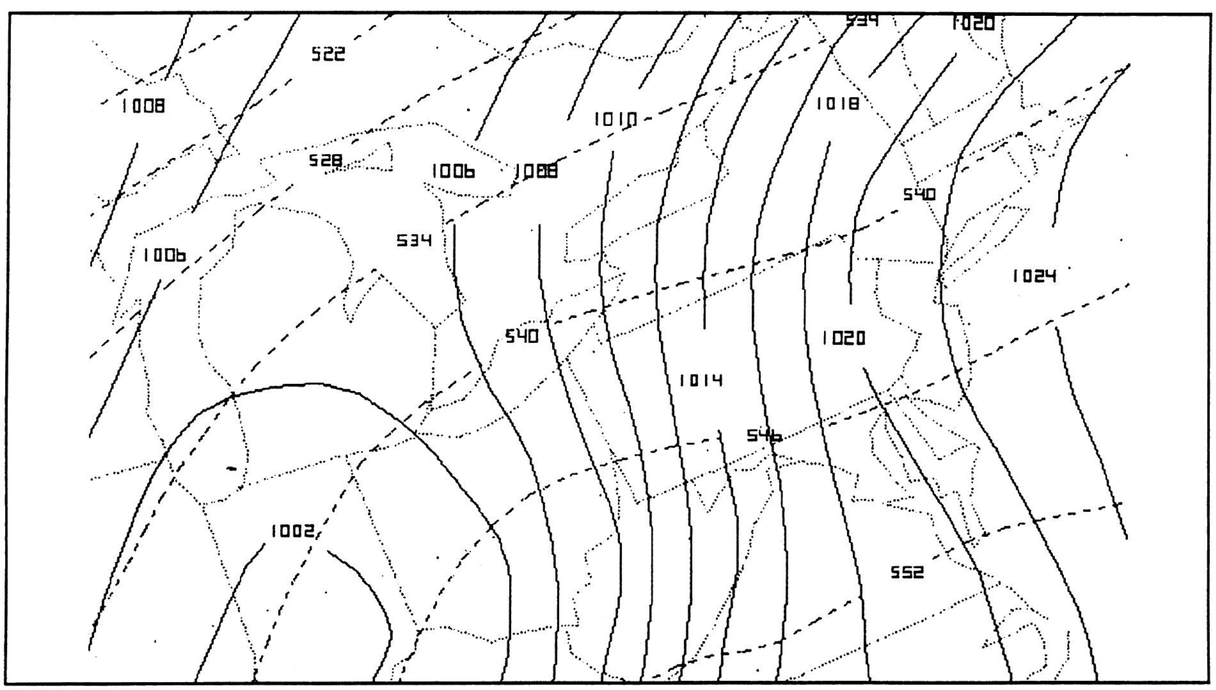


Figure 4. As in Figure 3, except for the ETA model forecast.

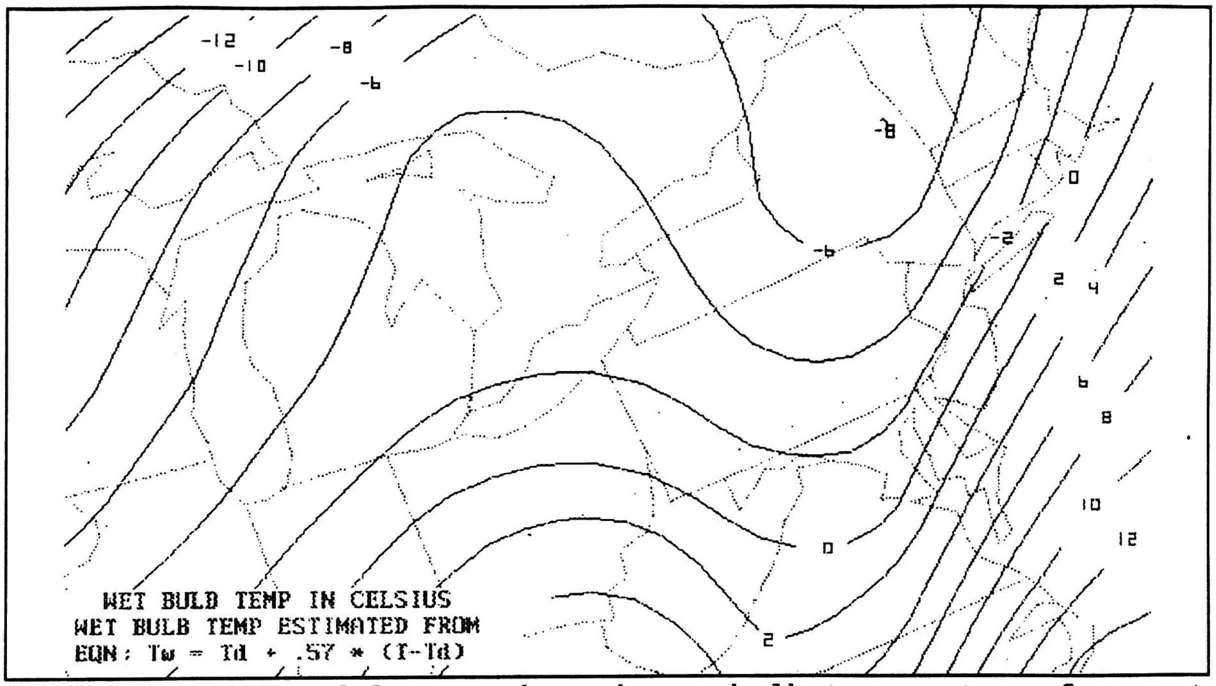


Figure 5. ETA model 1000 mb 36-h wet-bulb temperature forecast (°C) valid at 0000 UTC 7 January, 1995. Contour increment is every 2°C.

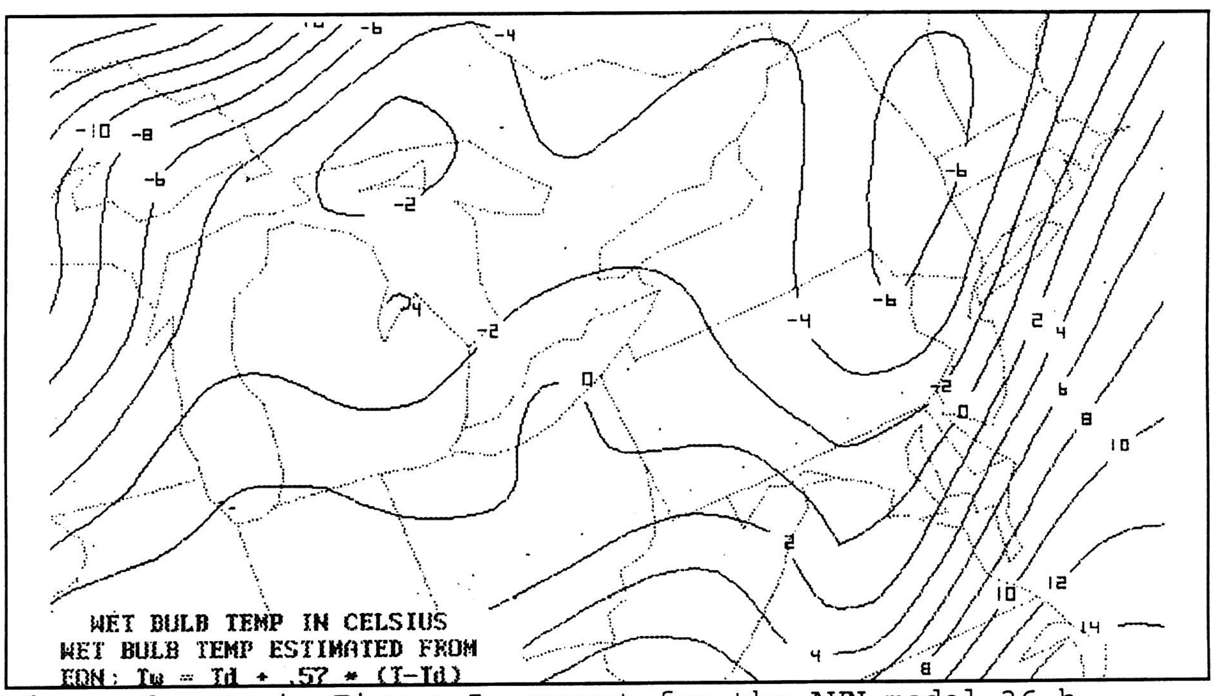


Figure 6. As in Figure 5, except for the AVN model 36-h forecast.

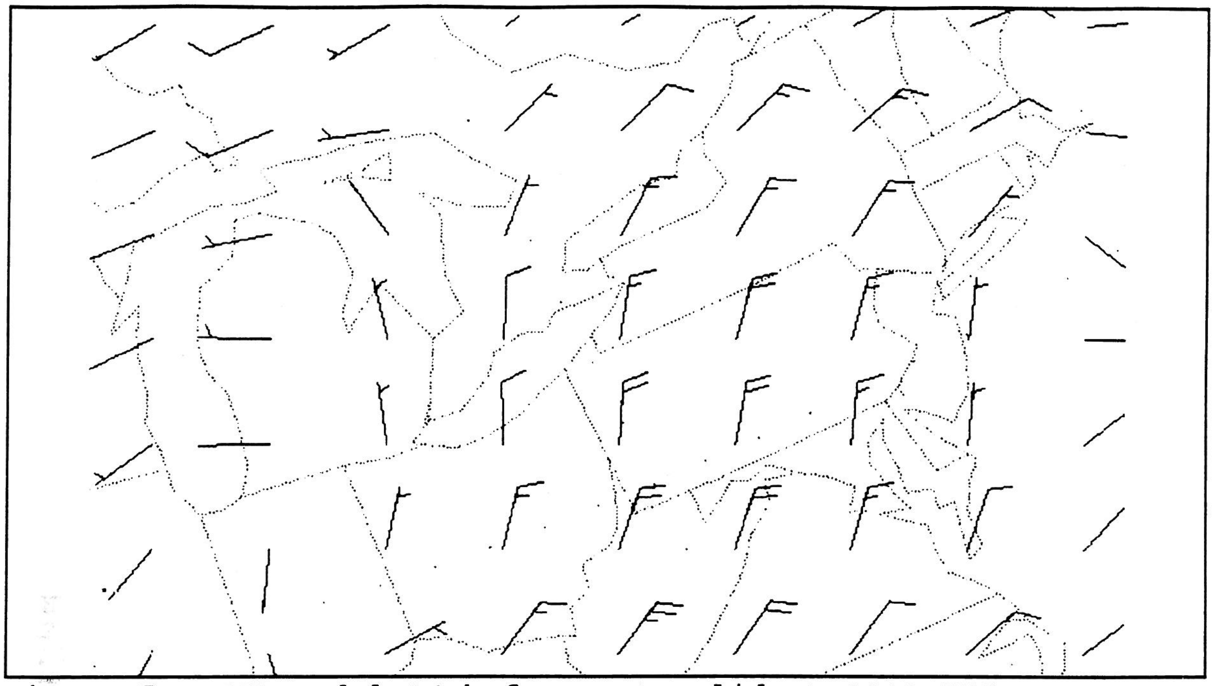


Figure 7. ETA model 36-h forecast valid at 0000 UTC 7 January, 1995 of the 1000 mb ageostrophic wind (m s^{-1}).

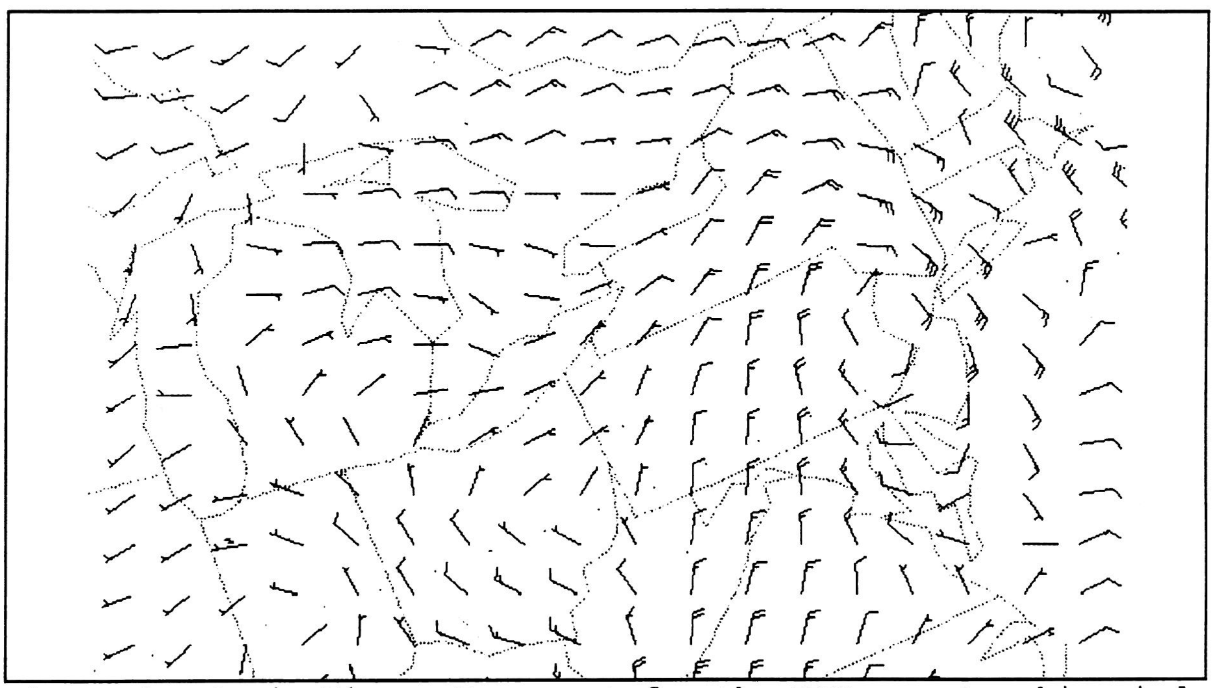


Figure 8. As in Figure 7, except for the AVN ageostrophic wind.

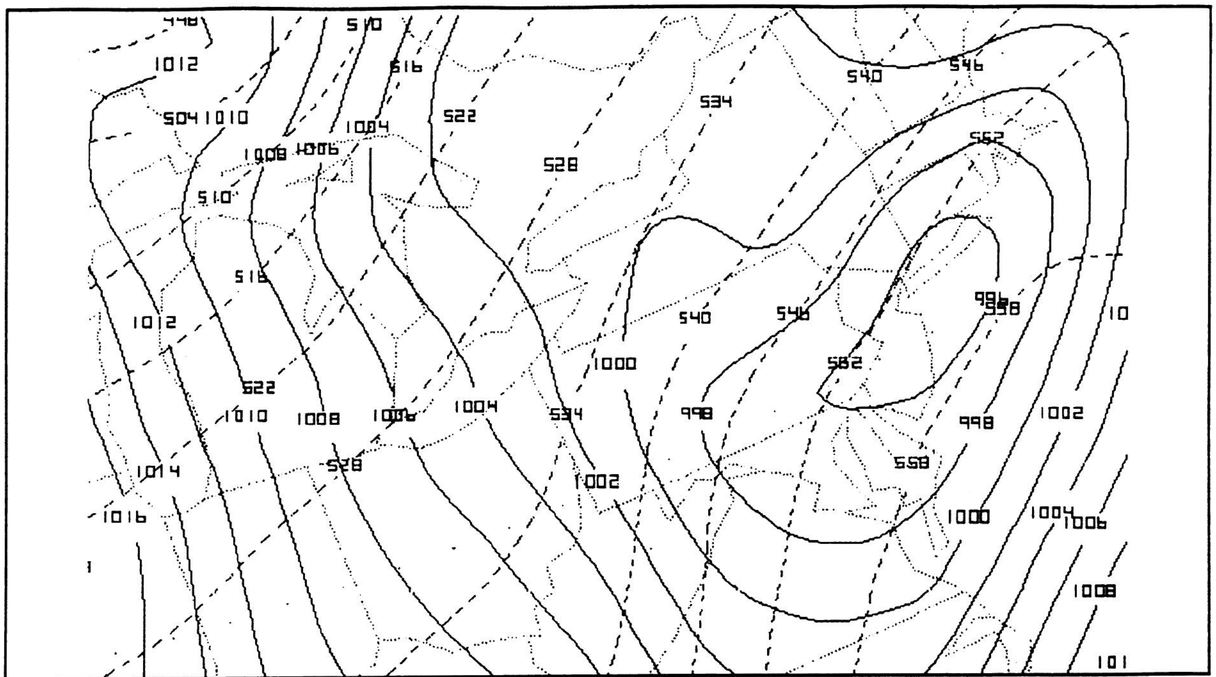


Figure 9. As in Figure 3, except for the AVN 48-h forecast valid 1200 UTC 7 January, 1995.

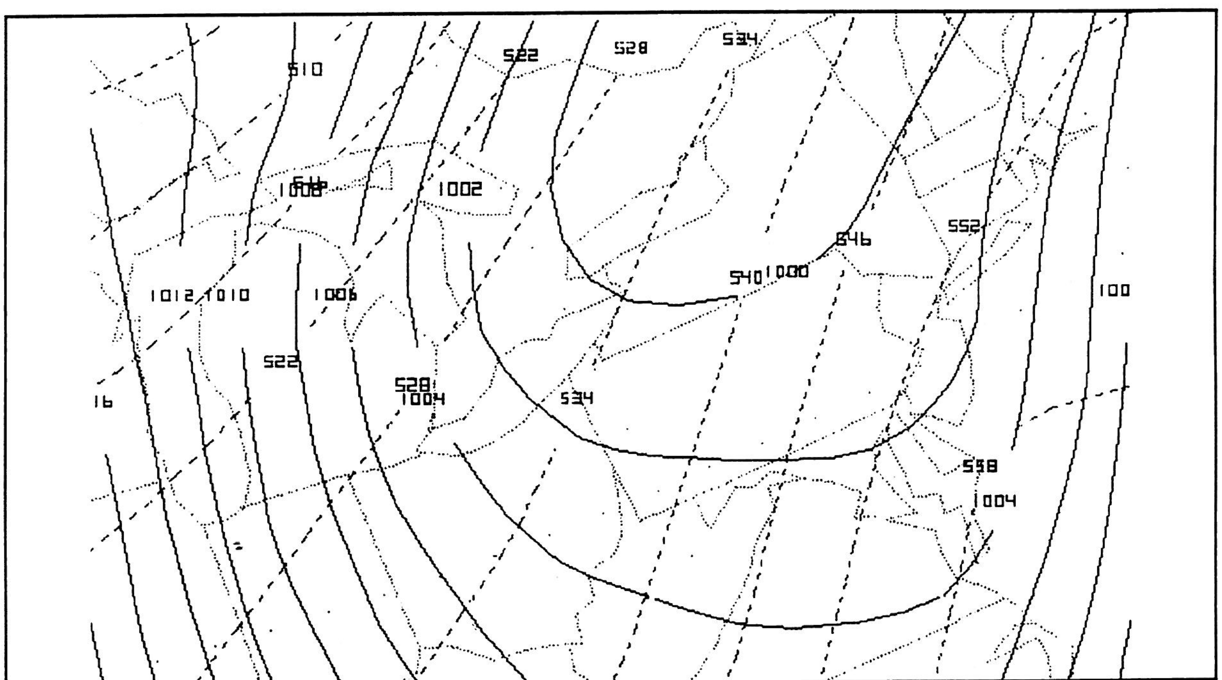


Figure 10. As in Figure 9, except from the ETA model.

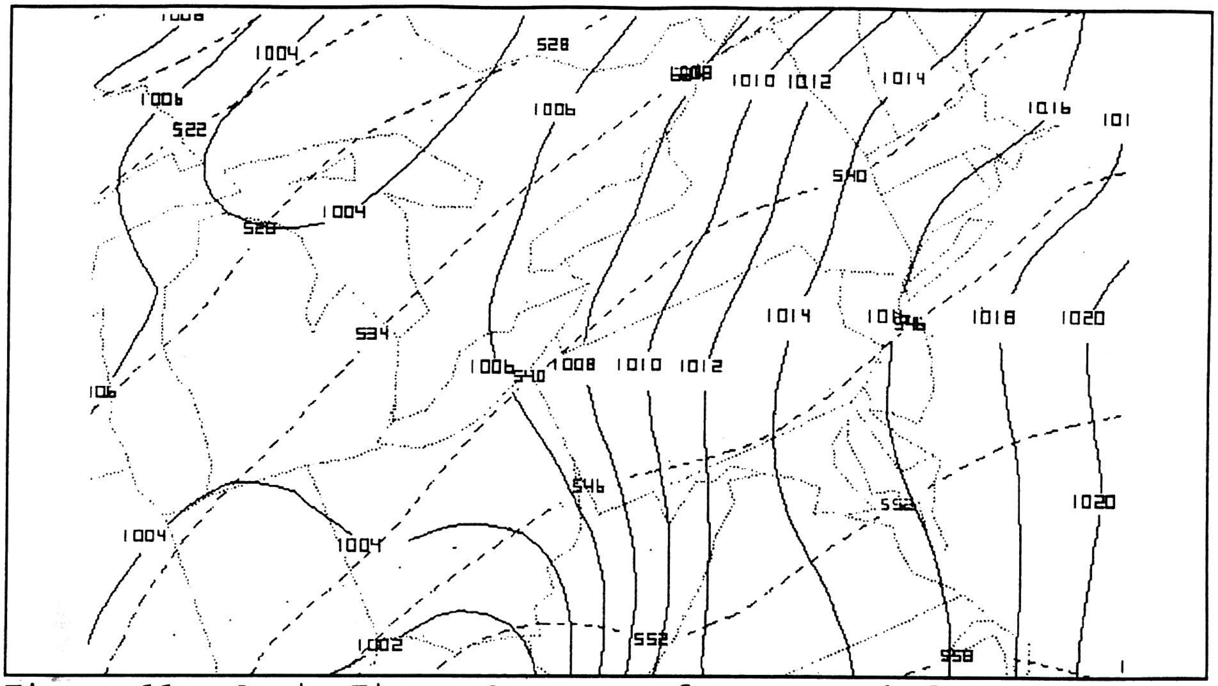


Figure 11. As in Figure 3, except for AVN 00-h forecast valid 0000 UTC 7 January, 1995.

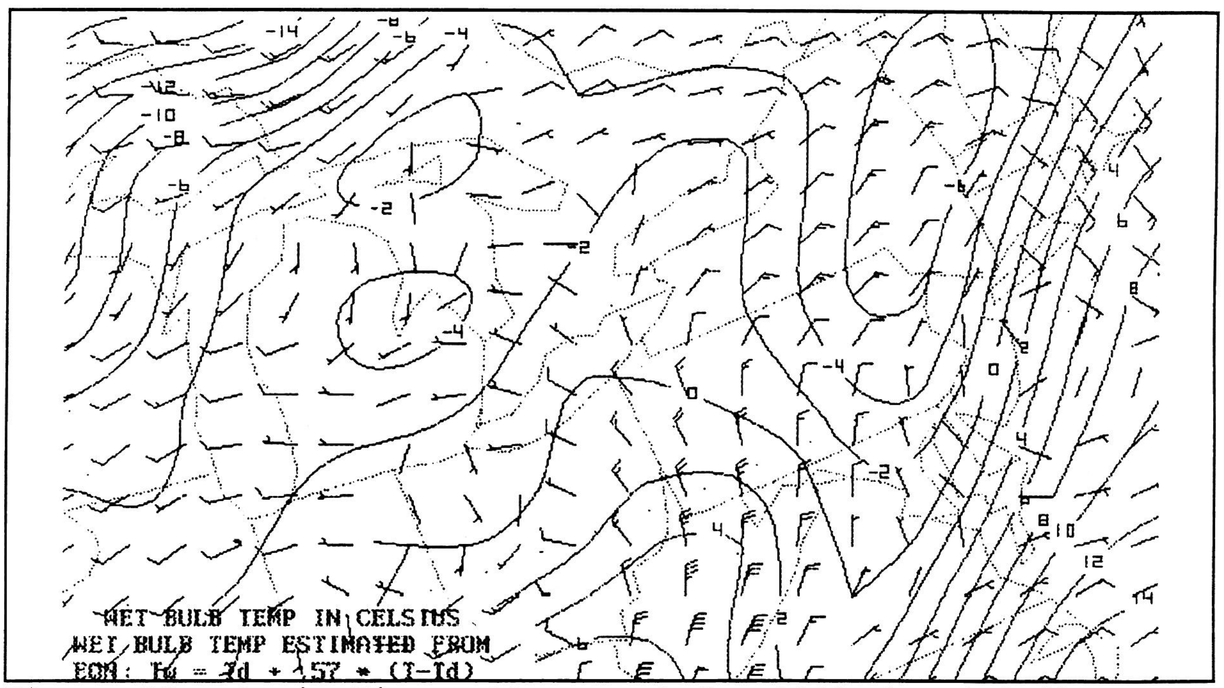


Figure 12. As in Figure 11, except for 1000 mb wet-bulb temperatures (°C) and ageostrophic wind (m s^{-1}).

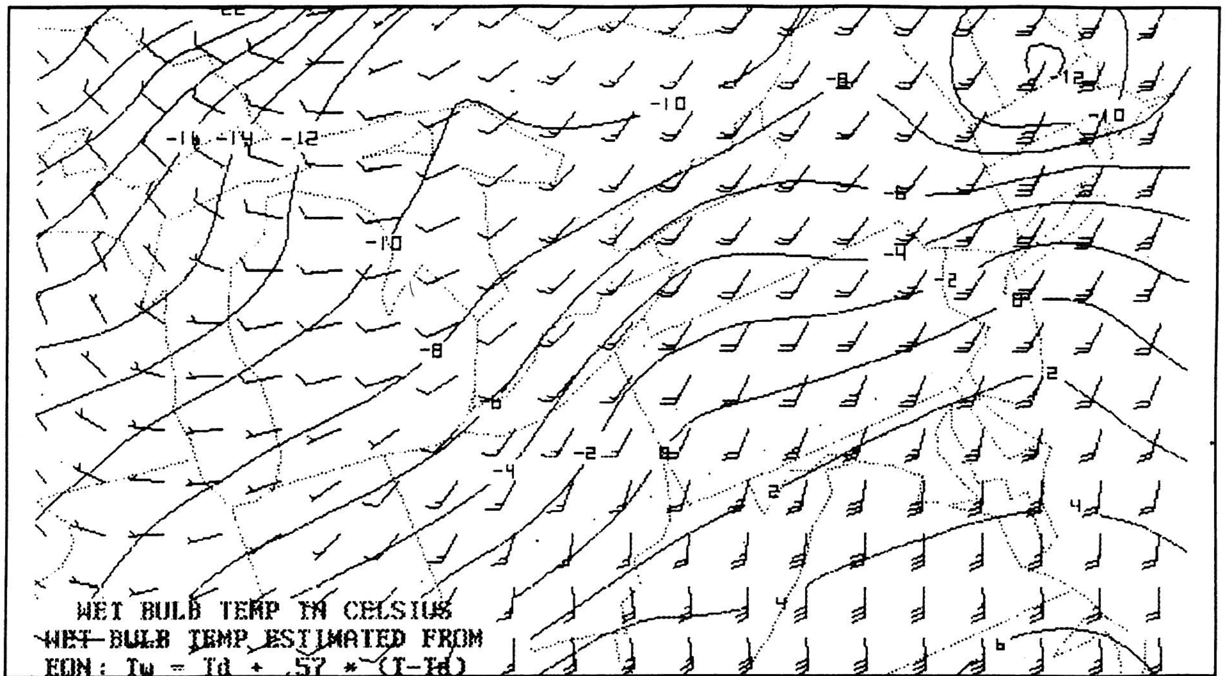
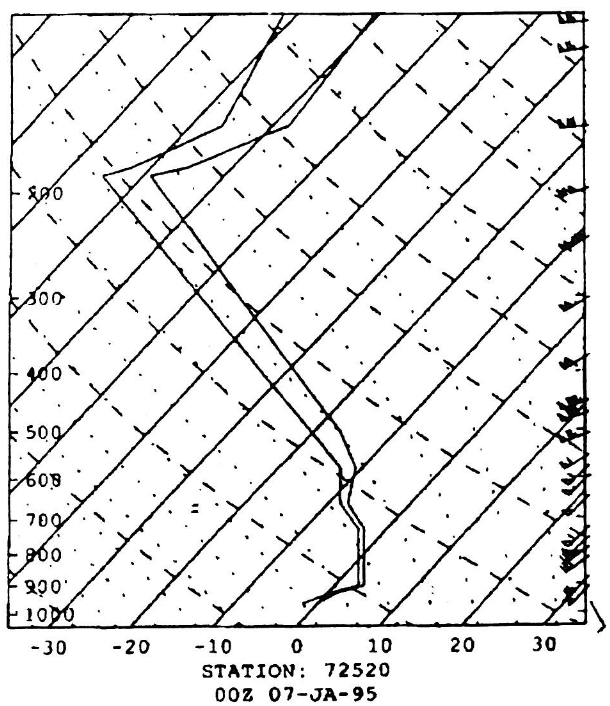


Figure 13. As in Figure 12, except for the 850 mb wet-bulb temperature (°C) and wind ($m\ s^{-1}$).



P	T	TD	RH	HT	WS	WD
100	-61	-72	21	520	74	265
154	-58	-66	34	500	73	260
181	-65	-72	36	440	78	265
187	-69	-75	41	390	149	250
500	-17	-20	75	350	141	240
575	-11	-13	86	300	106	240
660	-8	-9	93	250	98	240
729	-3	-3	95	210	95	250
901	3	3	96	200	88	250
925	1	1	96	180	74	250
964	0	-2	87	160	59	240
				150	58	225
				140	57	225
				120	52	225
				90	58	225
				80	52	230
				70	43	235
				60	40	235
				40	34	225
				30	32	225
				0	10	150

Figure 14. 0000 UTC 7 January, 1995 NWSFO Pittsburgh upper-air sounding.