NOAA Technical Memorandum ERL WPL-124

THE INFERENCE OF FRONTAL TEMPERATURE CHANGE FROM THE OBSERVED WIND FIELD

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1. INTRODUCTION

Assuming steady state and neglecting viscosity, the equations balancing the inertial, and buoyancy terms in the equations of motion can be used to provide a relationship between the wind and temperature discontinuities in the atmosphere. If it is specified that the dynamic boundary condition be satisfied across a frontal discontinuity, a relationship between the slope and the magnitudes of the discontinuities is obtained known as the Margules Equation.

It is the purpose of this memorandum to conduct a preliminary examination of the adequacy of this relationship for quantitatively inferring the magnitude of front-related temperature inversions from the wind field discontinuity and its temporal slope provided by the radar wind profilers. If the speed of the front is known, the wind field can provide an estimate of the spatial frontal slope. On the other hand, if a profiler network is available the slope can be found directly. Although evidence of frontal surfaces is fairly common in profiler wind fields, these events are often poorly defined at the ground in northeastern Colorado (Shapiro, private communication) as shown in our examples. Furthermore, in the early stages of the experimental network, frontal events commonly occurred when one or more profiler stations of the network were inoperative. We therefore concentrate on two well defined events in 1984. In the first case discussed (that of 14 October 1984) the front was fairly well defined at the ground on the surface charts and in the satellite-observed cloud fields. It therefore provided an opportunity to test the combined use of profiler data and surface weather maps for deducing the temperature discontinuity. In the second case (that of 25 November 1984) the front was poorly defined at the ground, and in fact, was apparently badly misplaced on the map analysis of 1200 Z. However the wind field discontinuity was clearly revealed at three stations in the profiler network, so this case was used to test the use of the network for providing the frontal slope needed to deduce the temperature discontinuity.

From Figs. 1-3 it is clear that there is considerable subjectivity in the choice of slope in the time-height field of profiler winds. Clearly, the slope near the nose of the front is dominated by surface friction, and far behind the front the frontogenetical dynamics are so weak that the Margules relationship is unreliable. Therefore, some intermediate choice should be most appropriate. To minimize the problem of subjectivity in this study, we have reversed the problem and have chosen to use the temperature discontinuity from the most appropriate radiosonde observation, together with the wind discontinuity from the profiler wind field, to calculate the slope predicted by the Margules Equation. This slope in the time-height domain is then superimposed on the profiler wind fields in Figs. 1 and 2. The readers may then judge for themselves whether they would a priori have chosen that slope from the raw record; if their choice would have been similar, they would obviously have arrived at a good estimate of the true temperature change across the front.

When clean records from a network of profilers are available, they can directly provide the spatial slope, speed and orientation of the front. Using this slope and speed, a slope on the time-height plot can be found and plotted on the wind field. Since this slope is independent of the Margules Equation, it is only a test for internal consistency and coherence between the profilers in the network. However, having the frontal orientation from the profiler network, the wind components above and below the front can be calculated, and, using the temperature discontinuity observed by the most appropriate radiosonde, an independent slope can be calculated and superimposed on the profiler wind field. This procedure was followed for the case of 25 November 1984; and, again, the readers may judge whether the agreement with the observed spa-

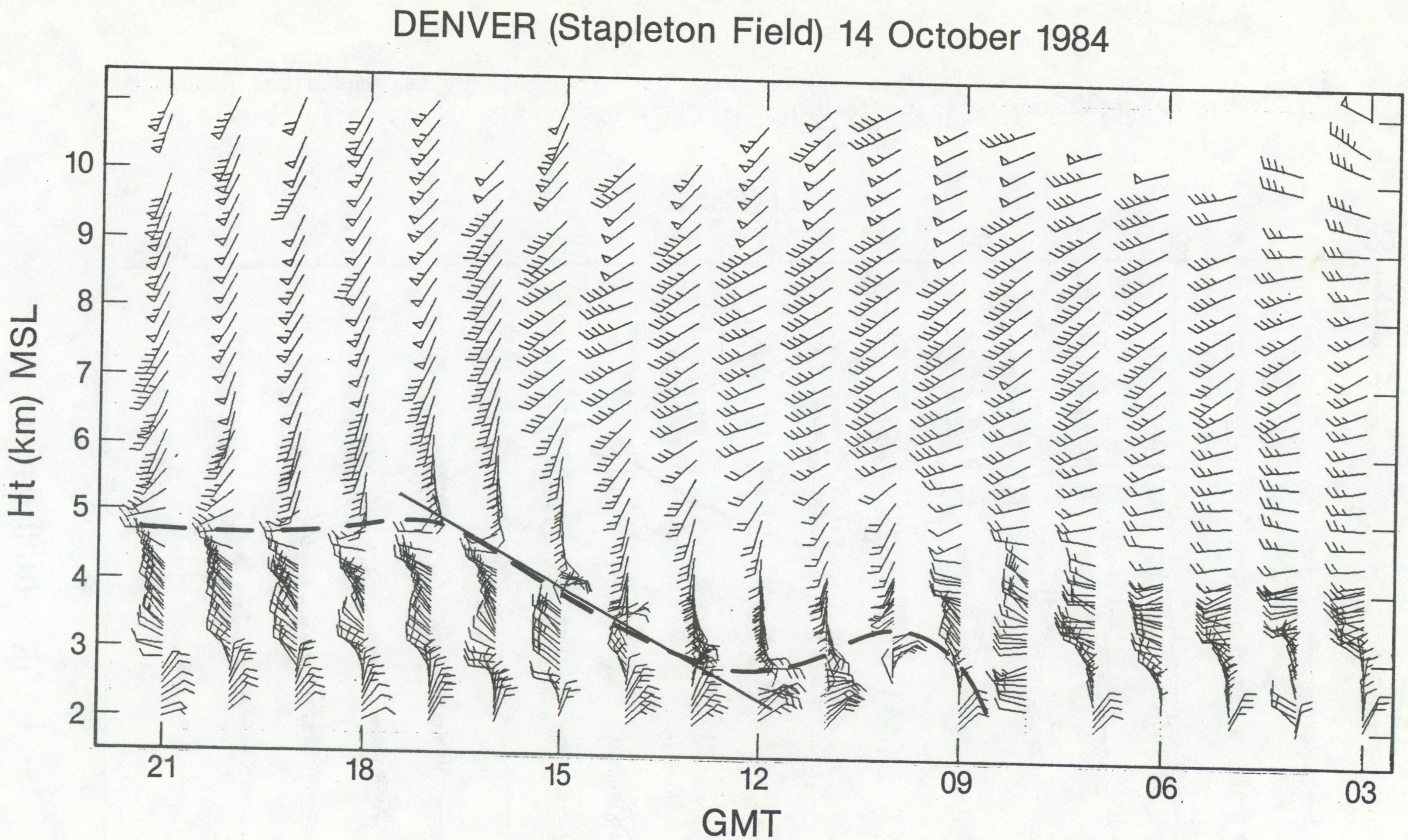

Figure 1. Time-height wind field display at Denver on 14 October 1984. Wind speed scale same as in Fig. 3.

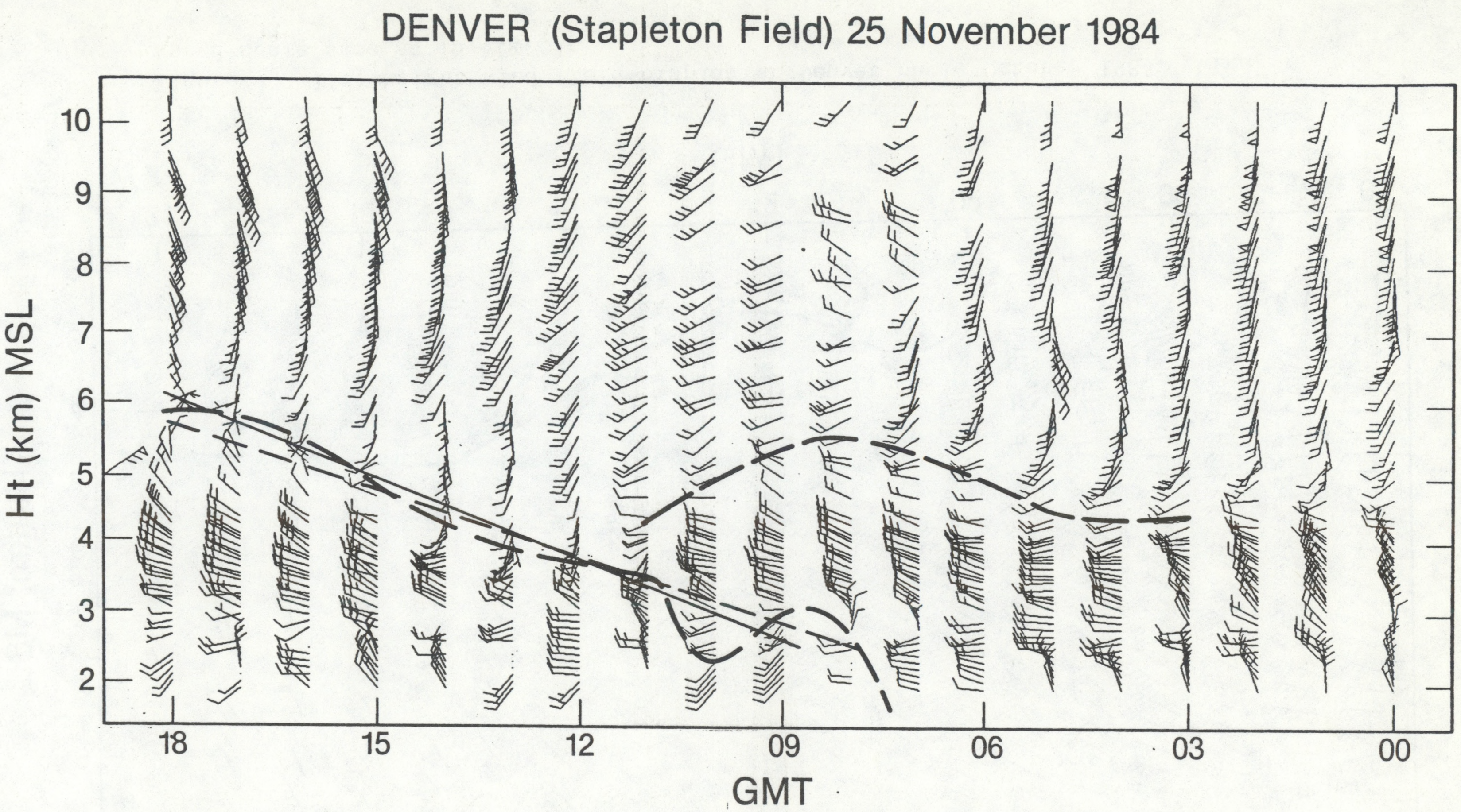

Figure 2. Time-height wind field display at Denver on 25 November 1984. Wind speed scale same as in Fig. 3.

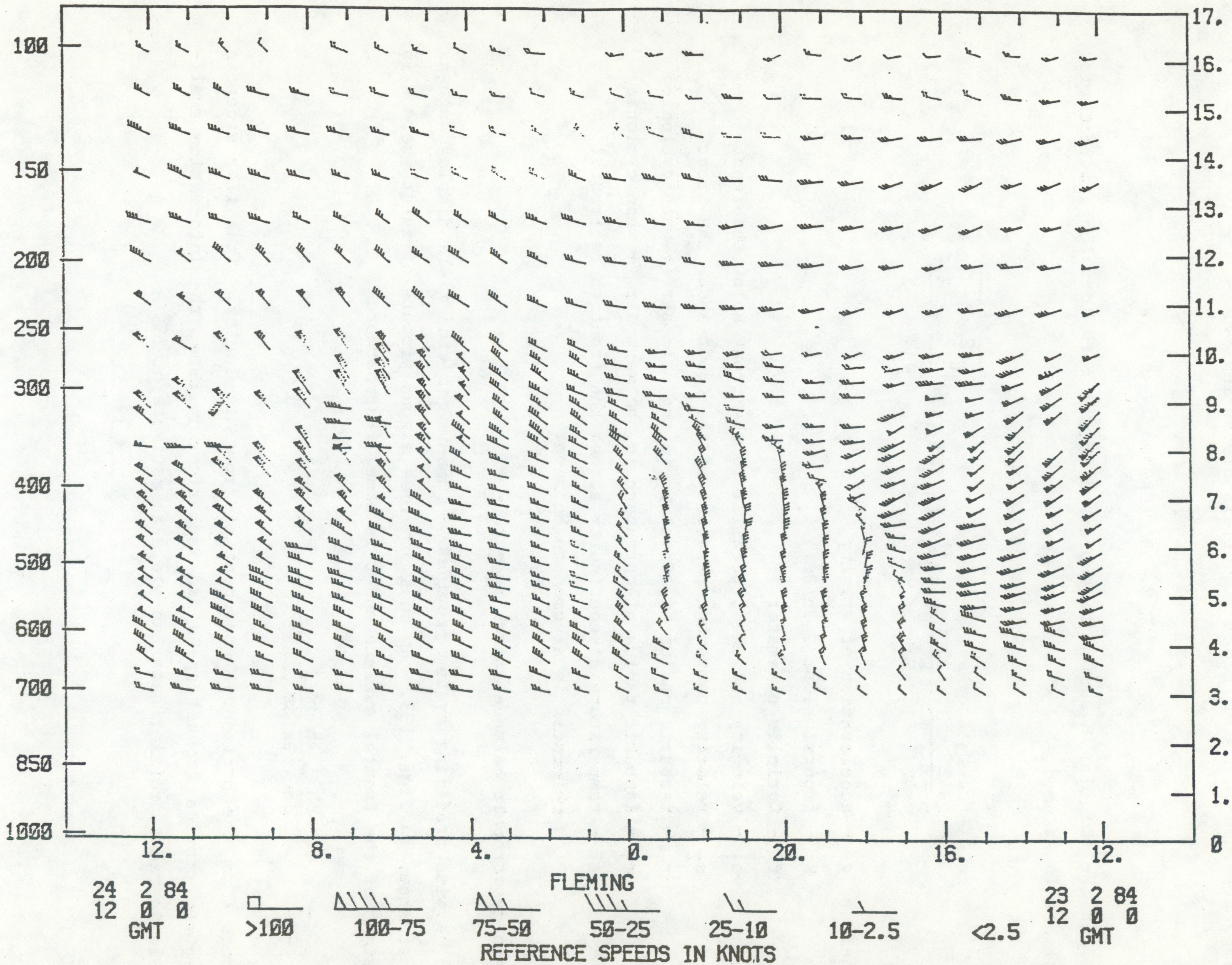

Figure 3. Time-height wind field display at Fleming on 24 February 1984. Left ordinate is pressure in millibars (standard atmosphere); right scale is height in kilometers.

tial slope is adequate, and whether they would a priori have chosen a similar temporal slope in the original wind field discontinuity.

2. BACKGROUND

If the Margules Equation is expressed in the form in which gradient wind balance is assumed,

$$2\,\frac{T_2 - T_1}{T_2 + T_1} \equiv \frac{\Delta T}{\bar{T}} = (gS)^{-1}\left[f(u_1 - u_2) + \frac{\overline{u_1^{\,2}}}{r_1} - \frac{\overline{u_2^{\,2}}}{r_2}\right] \qquad (1)$$

where
- g - acceleration of gravity
- S - frontal slope $\equiv \partial h/\partial x$
- f - Coriolis parameter
- u_1 - velocity component parallel to the front below the front
- u_2 - velocity component parallel to the front above the front
- r_1 - isobaric radius of curvature in the cold air (+ when cyclonic)
- r_2 - isobaric radius of curvature in the warm air (+ when cyclonic)
- ΔT - temperature discontinuity across the front where frontal thickness is assumed to be zero.

When geostrophic balance exists $r_1 = r_2 = \infty$.

A wind profiling system provides a time-height wind field display such as that shown in Figs. 1-3. It thus provides a good picture of dh/dt where h is height of the frontal surface and t is time. Furthermore

$$\frac{dh}{dt} = \frac{\partial h}{\partial x}\frac{dx}{dt} = SC$$

where C is the horizontal component of frontal velocity. Thus if a synoptic map can provide frontal speed and isobaric curvature, the information available in radar profiler data can yield an estimate of ΔT.

3. CASE OF 14 OCTOBER 1984

The time-height wind field recorded by the WPL profiler at Denver (Stapleton Airport) is shown in Fig. 1 and the Denver raob is shown in Fig. 4. At 1500 GMT and at a height of 4 km, we see from Fig. 1 that the winds are approximately

9 ms^{-1}	from 303 deg	below the front
15 ms^{-1}	from 180 deg	above the front.

From the surface weather map shown in Fig. 5, we see that the frontal speed and orientation is approximately

6 ms^{-1} at 47 deg.

The temperature difference, from Fig. 4 is $\Delta\theta \simeq 1$ C. (Actually we use the potential temperature (θ) difference, because the model assumes the total change in temperature to occur discontinuously, while the actual change occurs over a finite height interval.) The vector diagram used to obtain the wind components parallel to the front is shown in Fig. 6. The wind difference, so obtained, is 8.7 ms^{-1}. Using $g = 9.8$ ms^{-2}, $f = 10^{-4}$ s^{-1} at Denver's latitude, $C = 6$ ms^{-1}, $\overline{T} \simeq 260$ K and $\Delta T = 1$ K, and ignoring isobaric curvature, which makes a negligible modification in this case, we find a slope of $S = 0.023$, so:

$$\frac{dh}{dt} = (0.023)(6) = 0.14 \ ms^{-1} = 1.5 \ km/3 \ hr \ .$$

This slope is shown superimposed on the wind field in Fig. 1 and it is seen to be in satisfactory agreement with the slope of the frontal wind discontinuity over the height range from 3-5 km.

Clearly, if an analyst had chosen a frontal slope similar to the solid line, the estimate of ΔT would be accurate. If he had chosen a slope near the nose or far behind the front, the estimate would have been seriously in error.

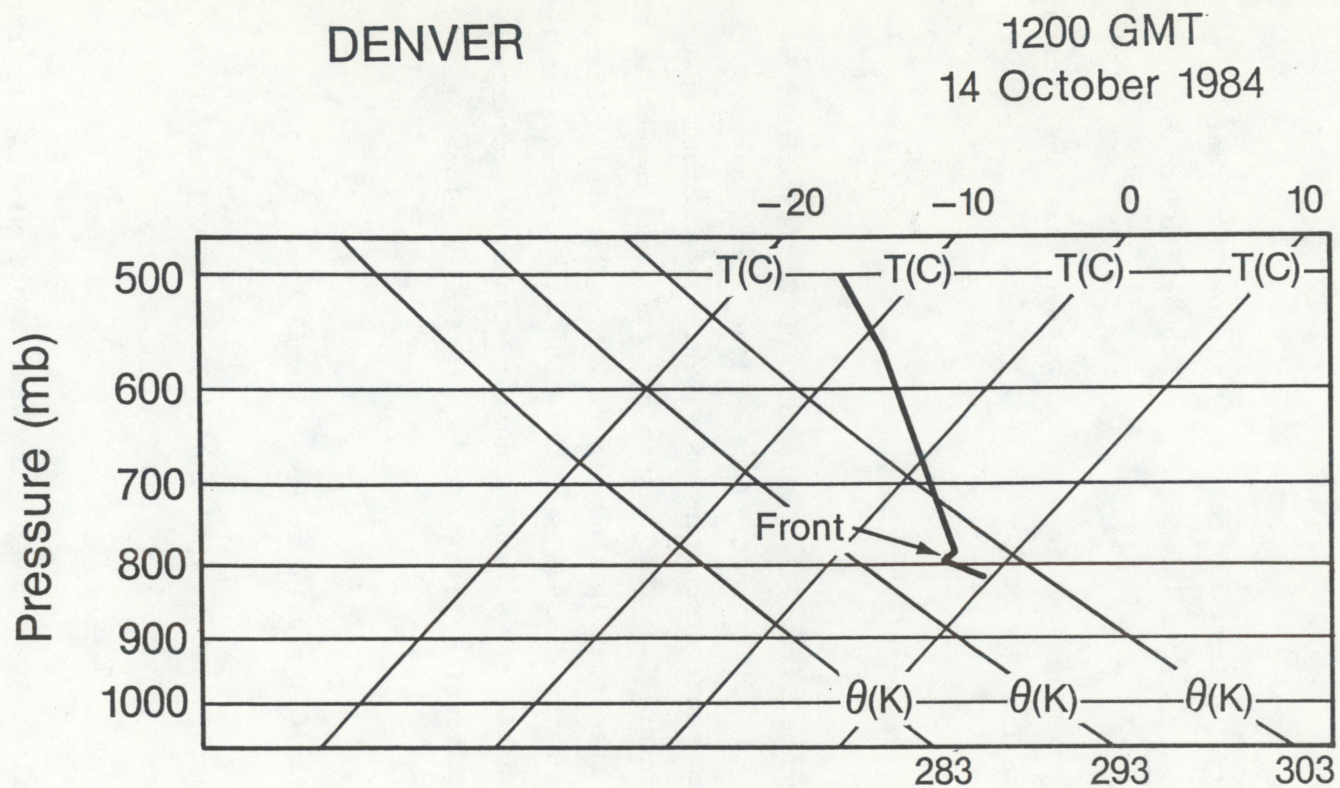

Figure 4. Denver raob for 1200 GMT on 14 October 1984.

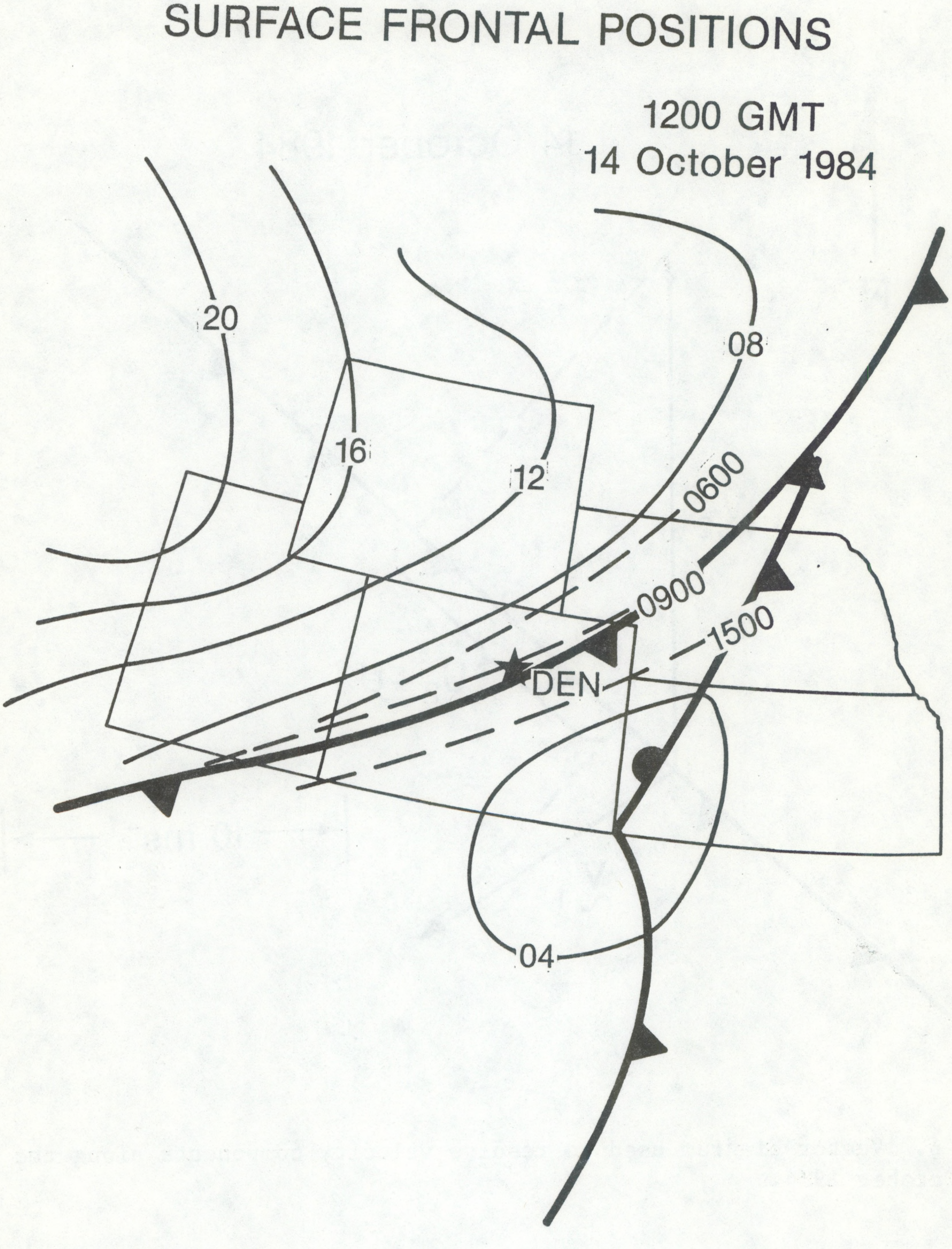

Figure 5. Surface weather map for 14 October 1984.

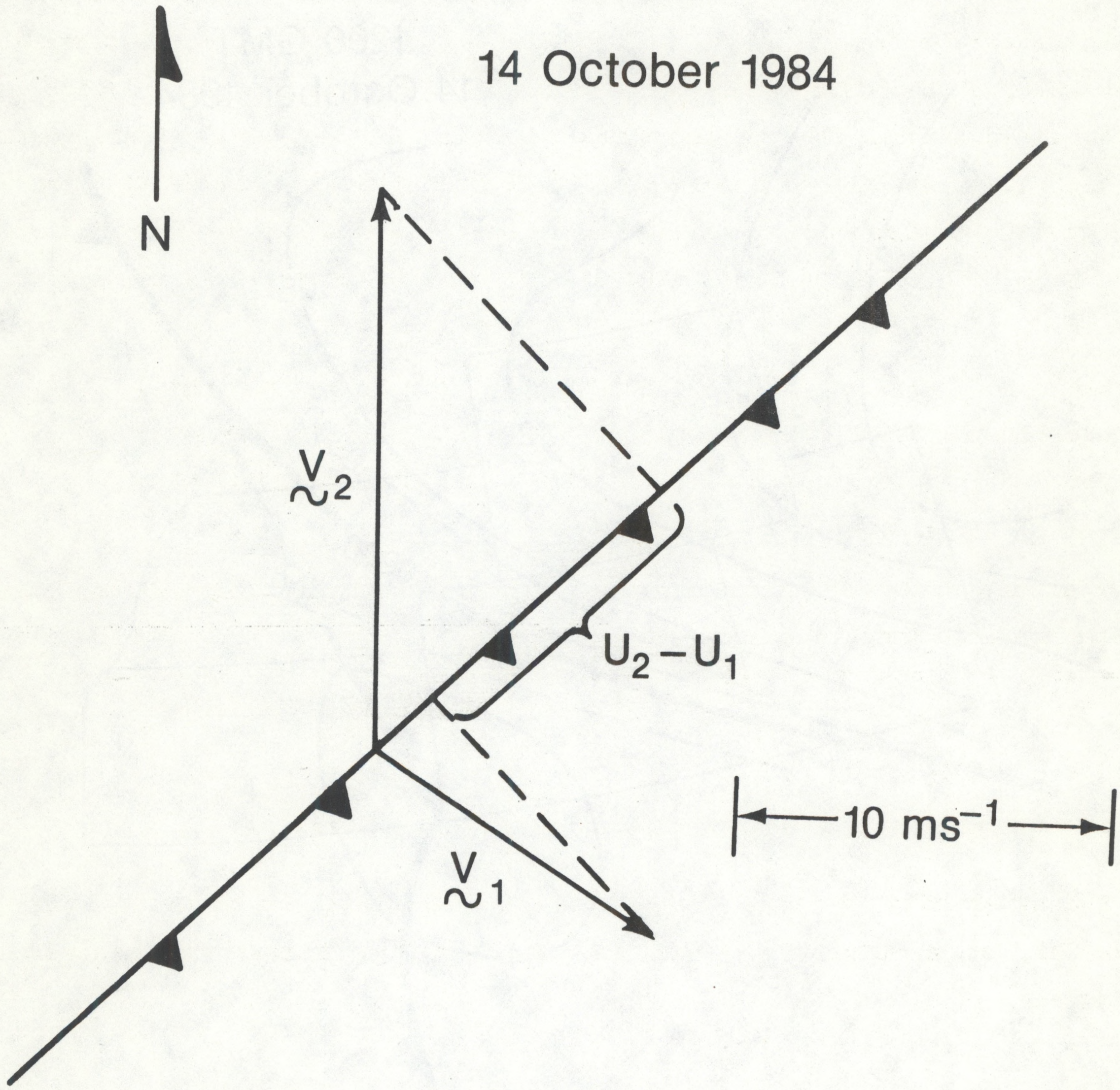

Figure 6. Vector diagram used to resolve velocity components along the front. on 14 October 1984.

4. CASE OF 25 NOVEMBER 1984

The time-height wind field recorded by the WPL Profiler at Denver is shown in Fig. 2 and the Denver raob is shown in Fig. 7. The surface weather map shown in Fig. 8 gives such an erratic location of the surface front that it is unuseable to obtain frontal speed and orientation. Therefore, in this event, we have obtained the frontal slope directly from a triangle of sounders at Stapleton Field (DEN), Fleming and Platteville, CO. The map indicating the location of these stations is shown in Fig. 9, and the wind fields at Fleming and Platteville corresponding to Fig. 2 at Denver are shown in Figs. 10 and 11. The height of the wind field discontinuity at the three sites are about

Fleming	3.3 km (MSL) at 1500 GMT,	4.0 km at 1800 GMT
Platteville	4.0 km (MSL) at 1500 GMT,	5.0 km at 1800 GMT
Denver	4.8 km (MSL) at 1500 GMT,	6.0 km at 1800 GMT.

The frontal slope, speed and orientation are found to be 0.02, 4.3 ms^{-1} and 86° respectively. Therefore,

$$\frac{dh}{dt} = SC = (.02)(4.3) = 0.086\ ms^{-1} \equiv 0.93\ km/3hr .$$

This slope is shown as the dashed line superimposed on Fig. 2.

On the other hand, we could use eq. (1) to calculate the slope, S. Then, at 1400 GMT, at a height of 4 km, we see from Fig. 2 that the winds are approximately

7 ms^{-1} from 280° below the front

15 ms^{-1} from 170° above the front.

The vector diagram used to obtain the wind components parallel to the front is shown in Fig. 12, giving $u_2 - u_1 = 4\ ms^{-1}$. From the raob in Fig. 7, $\Delta\theta \simeq 1.5$ C, so eq. (1) gives (again ignoring isobaric curvature)

$$S = (dh/dt)/C = 0.023$$

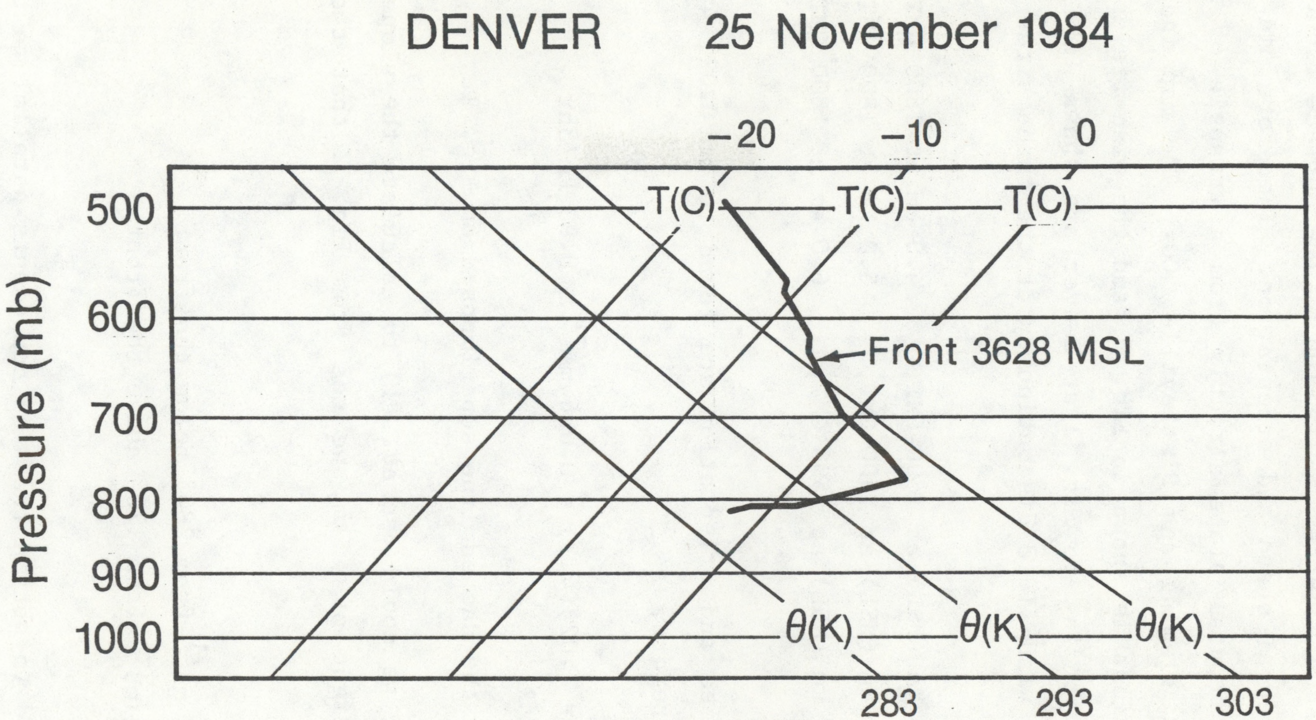

Figure 7. Denver raob for 1200 GMT on 25 November 1984.

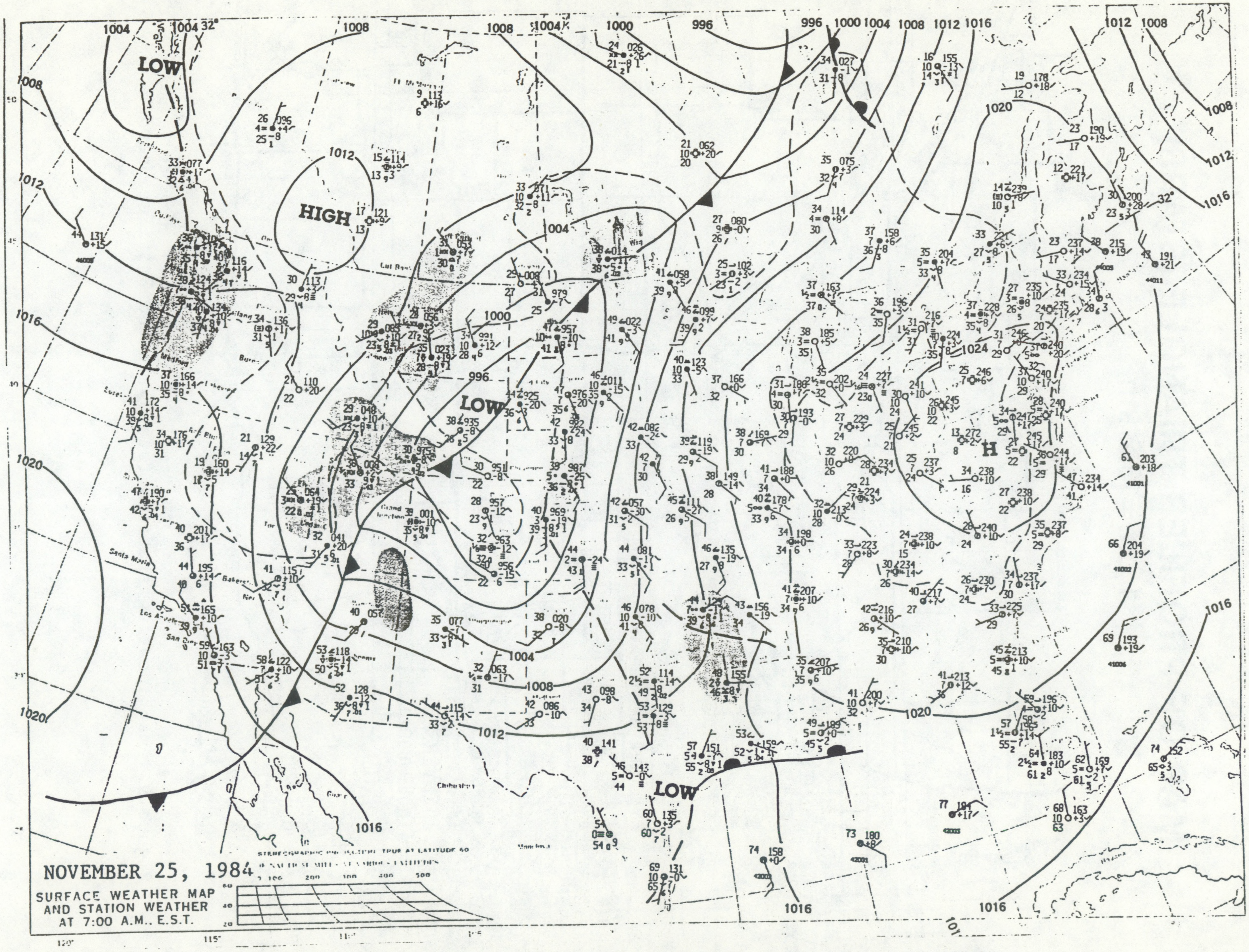

Figure 8. Surface weather map for 1200 GMT on 25 November 1984.

MAP OF PROFILER TRIANGLE (STARS)
1 cm=13.2 km

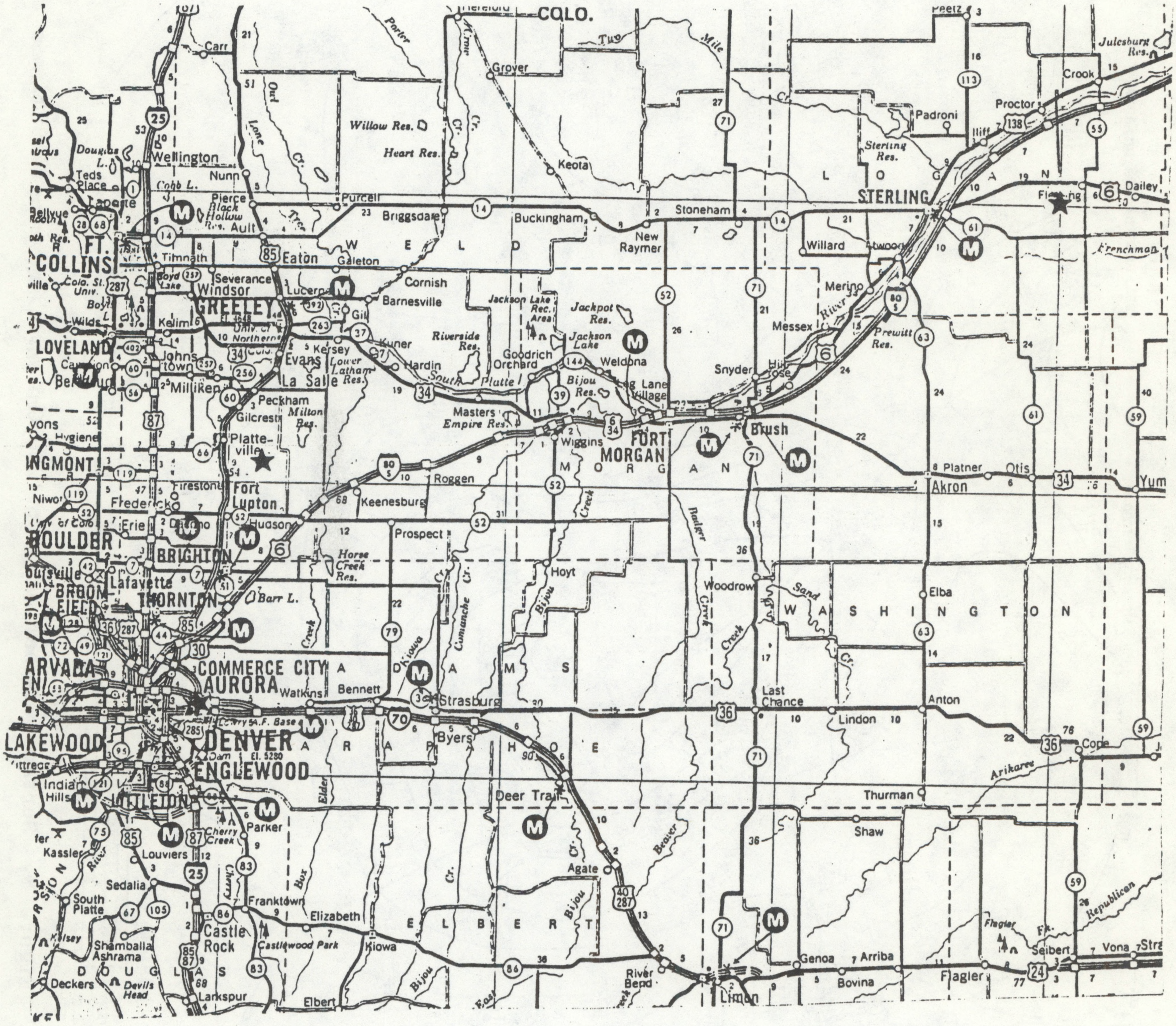

Figure 9. Map locating stations (stars) in the Profiler network.

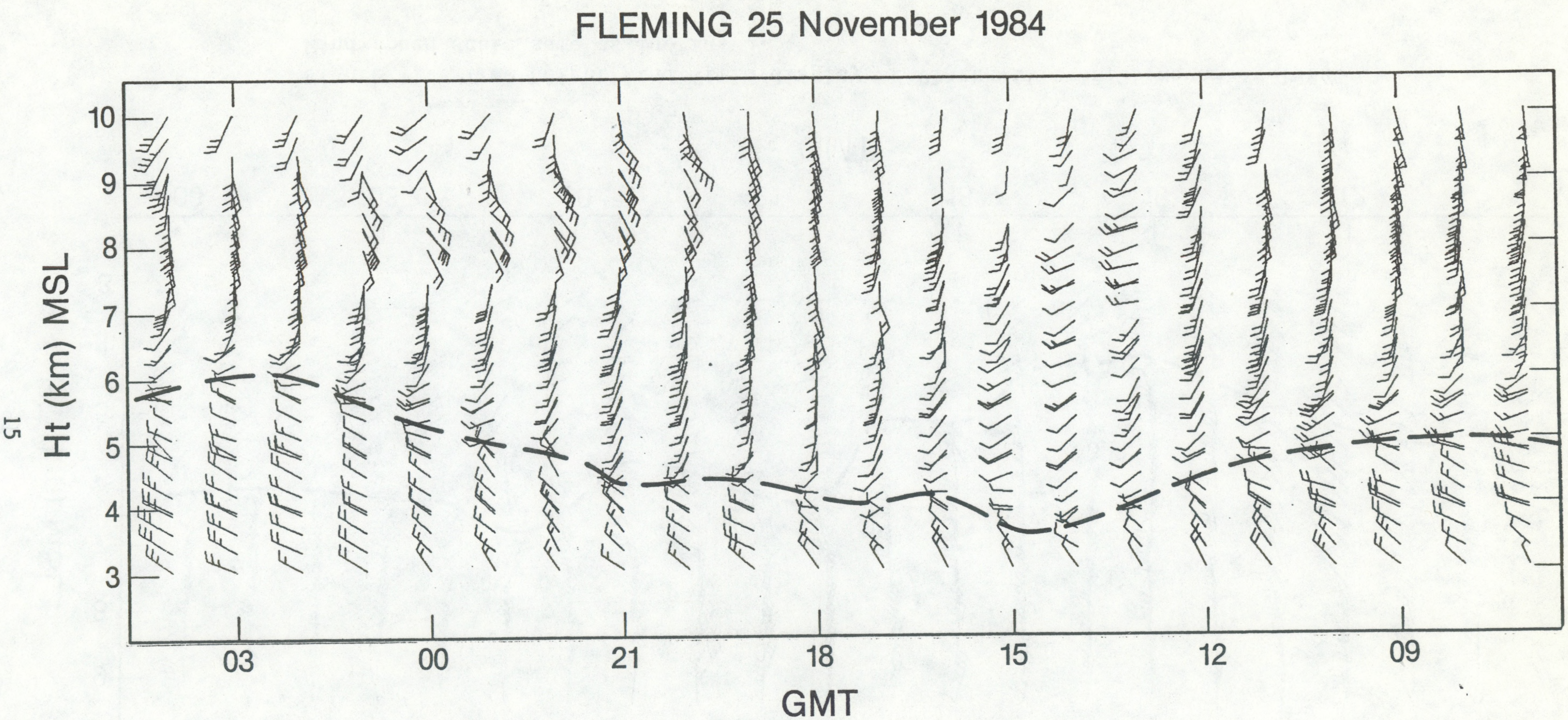

Figure 10. Time-height wind field display at Fleming on 25 November 1984.

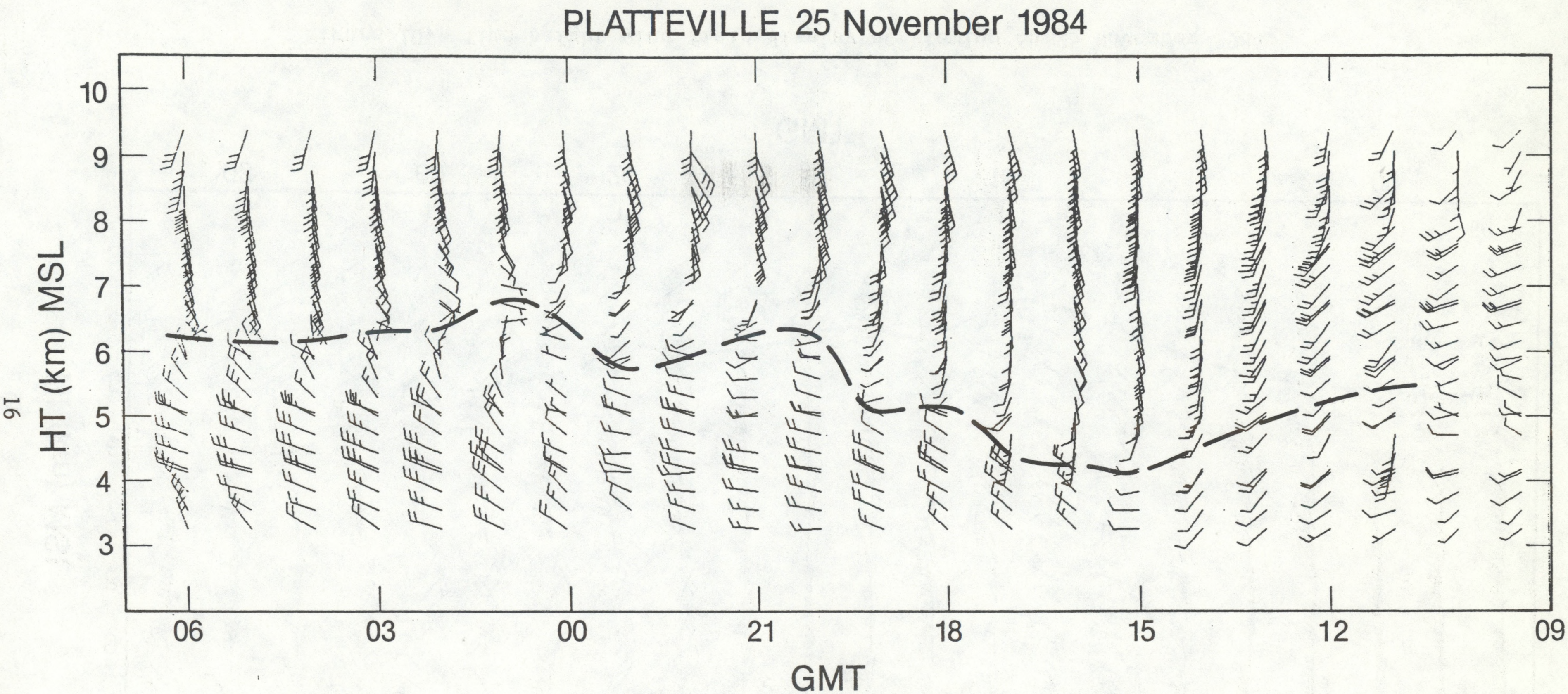

Figure 11. Time-height wind field display at Platteville on 25 November 1984. Wind speed scale same as in Fig. 3.

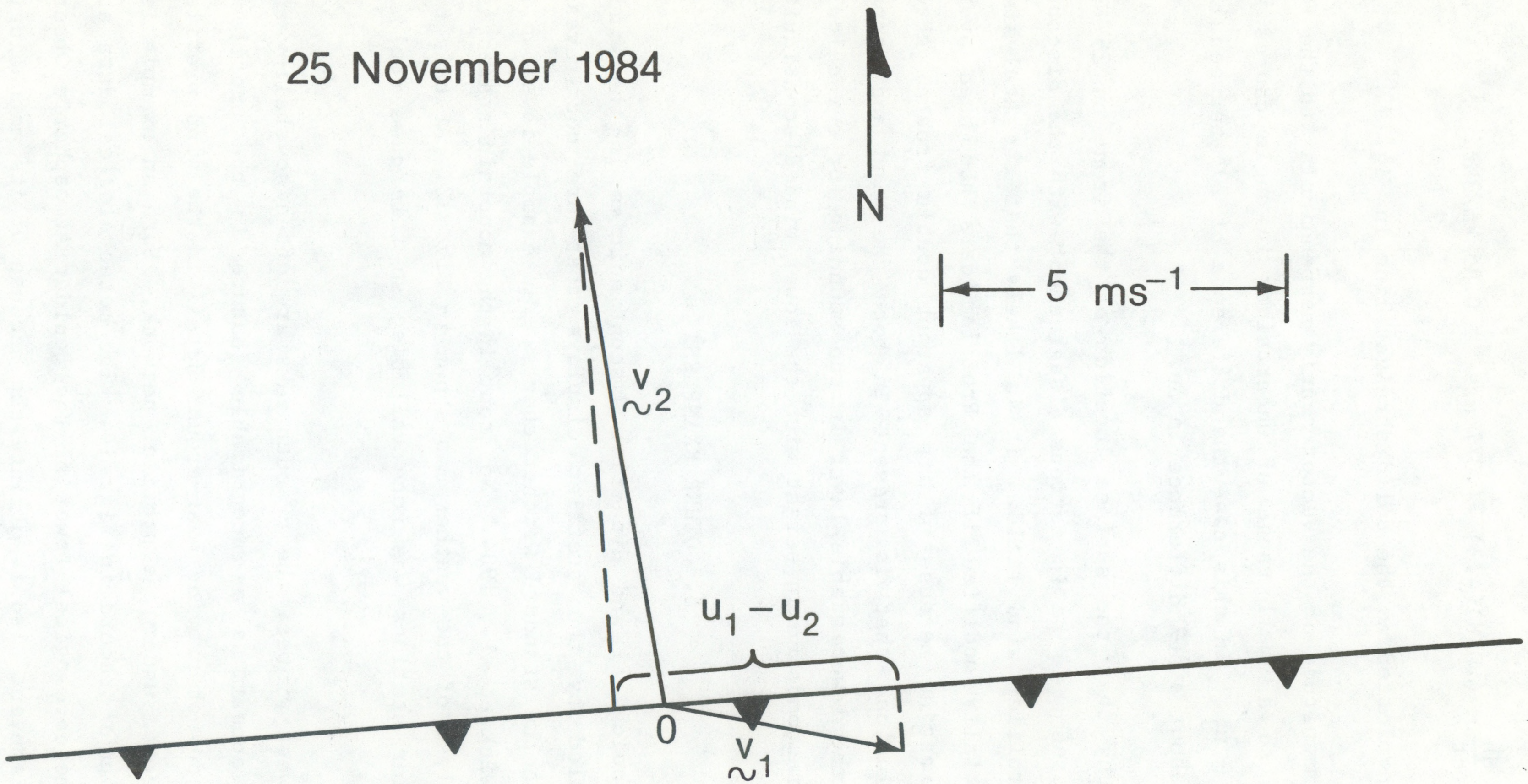

Figure 12. Vector diagram used to resolve velocity components along the front on 25 November 1984.

whence

$$\frac{dh}{dt} = (.018)(4.3) = .077\ ms^{-1} \equiv 0.85\ km/3hr.$$

This slope is shown plotted as the solid straight line in Fig. 2.

Note that the magnitude of the vector nearly perpendicular to the front in Fig. 12 is large, so a small range of uncertainty in angle causes a large uncertainty in $u_2 - u_1$. In this case the difference of 20° between 1200 and 1400 GMT produces about a 40% difference in Δu.

It is noteworthy that the surface location of the front on 25 November (shown in Fig. 8) seems to be in serious disagreement with the discontinuity revealed by the Profiler wind field. It is likely that the analysis would have been substantially modified if the Profiler data had been available. This case is interesting because of its apparent double frontal structure, suggesting an occlusion, that is present in both the wind and temperature fields. We chose the lower stable layer in the sounding for our calculations because of its correspondence in height with the lower wind discontinuity.

5. OTHER EXAMPLES

Sometimes morphological and dynamical discontinuities in the wind field are clearly revealed by the profiler displays that are not revealed or displayed on any of the standard weather charts. An example is shown in Fig. 3 provided by Chadwick et al., 1984. No front in the mountain states is being carried by the analyst of the weather map shown in Fig. 13. At this time the triangle of profiler stations was not available, so this case could not be analyzed further.

During the midwest winter, the cP outbreaks are often so shallow and cold that they do not appear as a recognizable feature in the profiler winds because the radars do not provide near-ground detail in the wind profiles--the events slide undetected under the profiler network. Such an example is shown by the acoustic sounder record in Fig. 14. The meteorological data are provided by a 300 m meteorological tower of the Boulder Atmospheric Observatory near Erie, CO. This event also is of interest because of its morphological

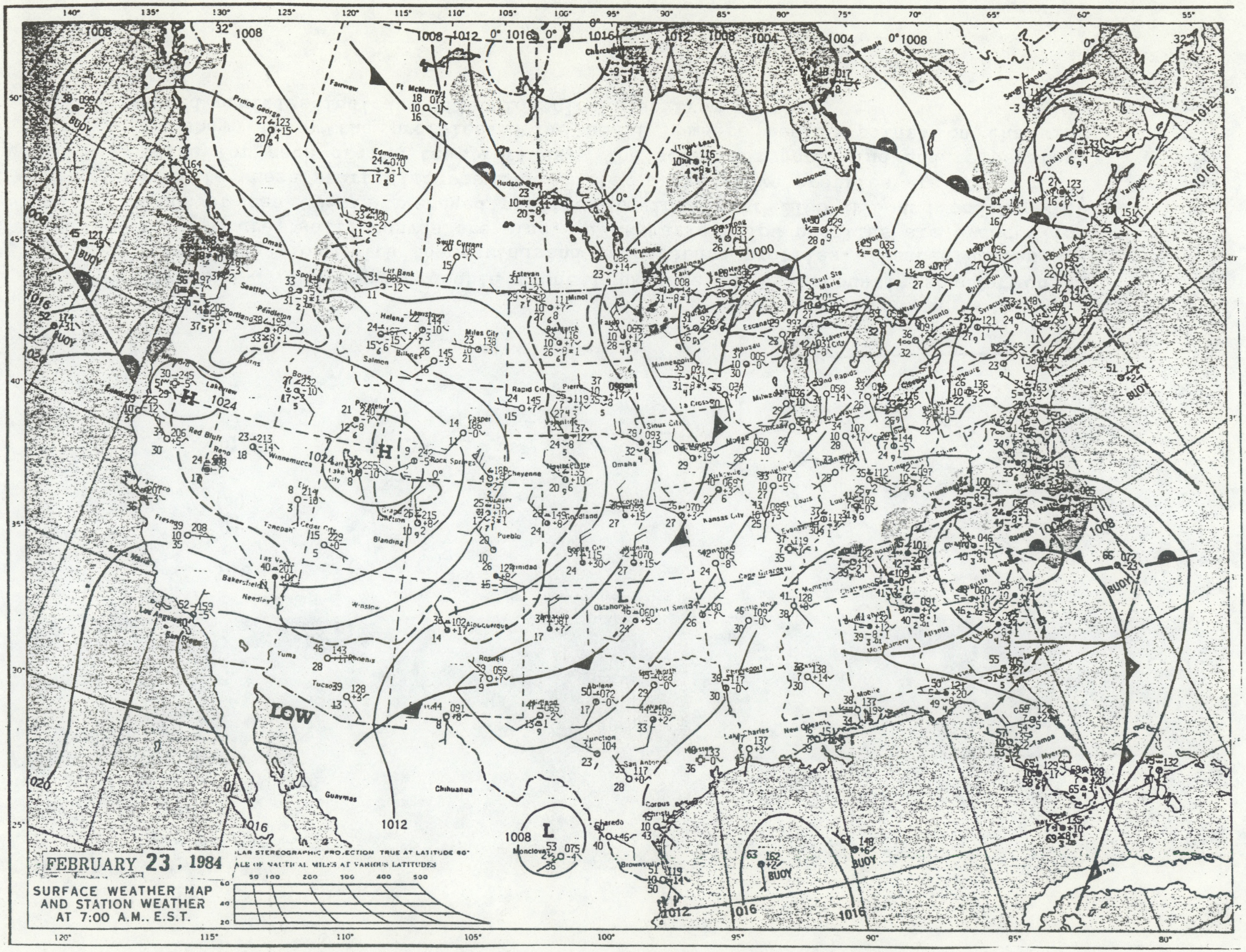

Figure 13. Surface weather map for 1200 GMT on 23 February 1984.

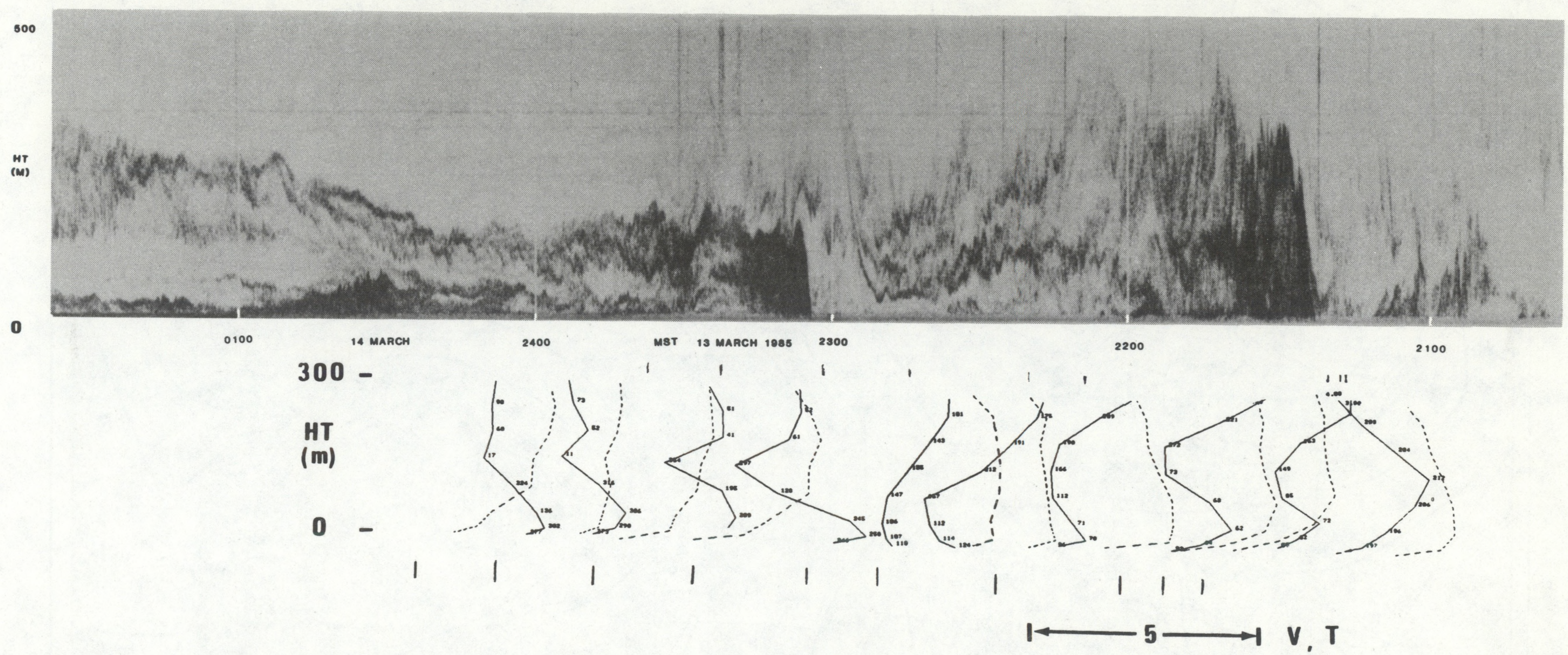

Figure 14. Display of double frontal passage by BAO acoustic sounder on 13 March 1985 along with tower wind and temperature profiles. Dashed curves are temperature; solid curves are wind. Tick marks below profiles are 0 deg C for each of ten 20-min averaged profiles beginning at 2100 MST and ending with profile whose start time was 2400. Tick marks above profiles are the 5 m s^{-1} value for each of the ten profiles. The scale for both wind and temperature is shown below the profiles. The small numbers beside points on the wind speed profiles indicate direction clockwise from north.

resemblance to the event 25 November shown in Fig. 2 except that the 14 March event has been scaled down in depth by an order of magnitude.

6. DISCUSSION AND CONCLUSIONS

There is good general agreement between the Margules relationship and observations of wind and temperature height profiles through fronts for the examples analyzed here. However several points should be emphasized:

A) Synoptic weather maps often provide a poor estimate of frontal speed and orientation, especially in those parts of the mountain and central states where upper level discontinuities often do not reach the ground (Shapiro, private communication).

B) The network of profilers provided values of frontal slope and speed very consistent with eq. (1). Spaced profilers are very desirable for this method of temperature profile recovery.

C) Cold winter frontal events often slide beneath the profiler network essentially undetected.

D) The profiler wind fields often provide a much more accurate picture of frontal position and upper air morphology than is revealed by the other data fields available to the analyst and forecaster.

E) Although the agreement of predictions provided by the Margules relationship with observed quantities is good for certain height ranges of the frontal zone, it would clearly fail seriously if the observed slopes were chosen near the nose of the front, where surface friction dominates, or far behind the front, where the frontogenetical dynamics is very weak and static conditions largely prevail. Therefore there is a serious degree of subjectivity in the choice of dh/dt that would have to be studied carefully. Clearly a network of profilers would avoid this as well as the problem pointed out in (A). There is also considerable subjectivity in the choice of $\underset{\sim}{V}_1 - \underset{\sim}{V}_2$, especially in the choice of appropriate direction. This range of uncertainty amounts to perhaps 20-50 degrees and may make the technique impractical.

F) There are large undulations in the profiler time-height plots of frontal position. An accurate estimate of the frontal slope therefore requires a relatively long time average. Therefore, a continuous pattern of wind field history (such as those in Figs. 1-3) would have to be supplied the analyst in real time.

G) When one (or both) of the wind components is nearly normal to the front, its projection on the front depends critically on direction; then a small uncertainty in direction can cause a large uncertainty in $u_2 - u_1$ and, therefore, in ΔT. The technique then becomes impractical.

REFERENCES

Chadwick, R. B., A. S. Frisch and R. G. Strauch, 1984: A feasibility study on the use of wind profilers to support space shuttle launces, NASA Contractor Report 3861.