NOAA Technical Memorandum ERL WPL-70

DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA

FINAL REPORT — DOPPLER RADAR DATA ANALYSIS DURING FISCAL YEAR 1980

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CONTENTS

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ABSTRACT

Two triple Doppler radar case studies are discussed. The first is of a post frontal band observed as it moved up the foothills of the Sierra Nevada mountains. The band structure was primarily helical, with inflow from the right front of the band at low levels, an updraft slightly behind the reflectivity core of the band, and outflow toward the left front. The band structure was similar to but smaller in scale than bands observed in the Sacramento Valley.

The second case is of a weak frontal passage followed by a strong squall line passage. The squall was intense enough to have an associated tornado, but was quite shallow. Reflectivity in the squall line was a maximum of 52 dBZ at 0.6 km msl, dropping to below 20 dBZ above 5.1 km msl.

1. INTRODUCTION

This report covers analysis of Doppler radar data performed at the Wave Propagation Laboratory during fiscal year 1980. The data were taken as part of our participation in the 1978 field season of the Sierra Cooperative Pilot Project (SCPP), sponsored by the Water and Power Resources Service (WPRS). Two case studies are discussed. The first is of a post-frontal band that passed through the experimental area during the afternoon of February 6, 1978. The second is of a frontal passage followed by a band that occurred on February 7, 1978.

Considerable work during the early part of FY80 was devoted to two tasks that are not discussed in this report. The first task was the completion of a computer-generated movie showing the velocity and reflectivity structure of the SCPP storm of March 2, 1978 (Moninger 1980a). Copies of this movie are now in the hands of sponsoring officials in WPRS.

The second task was the investigation of a discrepancy between multi-Doppler-measured horizontal winds and the horizontal winds measured by the data system on the University of Wyoming King Air aircraft. The results of this investigation are contained in correspondence between John Marwitz of the University of Wyoming, Larry Vardiman of the WPRS, and the senior author of this report. The discrepancy was found to result from a bias in the airborne navigational Doppler radar, occurring when the aircraft was flying just above regions of high reflectivity. No evidence of bias in the multi-Doppler horizontal winds was found.

2. CASE 1 -- POST-FRONTAL BAND PASSAGE 2/6/78

Synoptic Overview

On 2/6/78, a cold front associated with a low pressure area off the coast of Oregon passed over the experimental area. Figure 1.1 shows the surface weather map for 1300 PST. The location of the front shown, microbarograph data (not shown), and reflectivity data from the Skywater radar (see Moninger, 1980b) indicate that the time of frontal passage was approximately 1030.

Considerable stabilizing of the atmosphere immediately after the frontal passage is evident from the absence of echo behind the front (Fig. 1.2). However, by 1331 a post-frontal convective band began to form over the Sacramento valley (Fig. 1.3). This band intensified and passed over the experimental area at approximately 1446 (Figs. 1.4-1.6). The velocity of this band deduced from these Skywater radar data is 17 m/s toward 66°. The orientation of the band is normal to this, i.e., 156°-336°.

Soundings before and after the band passage are shown in Fig. 1.7. The air ahead of the band was conditionally unstable from the surface to 7.2 km with maximum instability occurring at 2.4 km (θ_E = 297.2°). The post-band sounding at 1600 is quite similar, although general warming has occurred at most levels below 4 km. Near-surface winds (0 to 2.7 km — not shown) decrease and veer 10° to 20° as the band passes.

Triple Radar Volume Scans

The volume scans that show this band passage are indicated in Table 1.1. Vertical velocities (maximum errors < ±5 m/s, see Moninger 1980b) were obtained for all of these volume scans. Most of the data from these scans will be shown in vertical slices normal to the axis of the band. The locations of these vertical slices are shown in Fig. 1.8.

TABLE 1.1--Volume Scans Observing Band Passage

Volume number	Time	Location
27	1429	Auburn - Sheridan line
28	1438	Auburn - Sheridan line
29	1446	Over Auburn
30	1451	Over Auburn

Figures 1.9 and 1.10 each show three vertical slices of the band-relative winds. Note the strong shear in the wind component normal to the band. The wind changes from inflow below ∿2.5 km to outflow above ∿2.5 km. (The melting layer is below this at about 1.8 km). Note the apparent eddy caused by this shear in Fig. 1.9b, at $Z \approx 2.8$ km. The location of these slices is indicated in Fig. 1.8b.

Figure 1.11 shows three cross sections through the band itself, as nearly as we can determine. A roll-like structure is seen in all three slices, centered at $Z \approx 3$-4 km, $X' \approx 34$ km. (The X' axis has its origin at CP-3 and extends along the 66° radial.) Band-relative inflow near the surface reaches 16 m/s and averages ∿12 m/s. Outflow above 4 km is 10-12 m/s. The roll-like structure appears to be about 10 km wide.

Maximum vertical shear of the horizontal wind is 1.0-1.5×10^{-2}. The updraft in Fig. 1.11b near $X' = 28$ km has a maximum value of 6 m/s, and seems to be rather uniform in the vertical. The absence of 30 dBZ reflectivity near $X' = 33.5$ km in Fig. 1.11c is an artifact due to beam blockage at CP-3.

Figure 1.12 shows the same regions as Fig. 1.11, 5 minutes later. Both the reflectivity core of the band and the center of the roll have moved 5 km to the NE (in the X' direction) from their locations in Fig. 1.11b. Behind the core of the band, the vertical velocity is slight. This may be seen most clearly in Fig. 1.12b, for X' < 33 km.

Figure 1.13 is a copy of Jim Moore's schematic of a convective band in the Sacramento Valley (Personal communication). Except for the horizontal scale, it represents data similar to those shown in the previous figures, suggesting that this structure can exist farther up the slope than we had previously thought.

Figures 1.14 and 1.15 give the horizontal winds with the band motion not removed for the volume scans at 1446 and 1451. The location of the vertical slices shown in Figs. 1.11 and 1.12 is indicated in Fig. 1.14a. We have sketched in the line of maximum wind shift where it was evident. At some levels, such as Z = 2.1 km seen in Fig. 1.14c, there are two wind shift lines about 10-15 km apart, roughly parallel, and running along 135°-315°. Examination of Figs. 1.8b and 1.8c, the Skywater reflectivity plots, reveals that 135°-315° is not inconsistent with the small-scale orientation of the part of the band that is passing over Auburn, even though the larger scale band orientation is 155°-335°.

The two wind shift lines evidently indicate the existence of a pre-band jet similar to the pre-frontal jet. This may be seen most clearly in Fig. 1.14c, where we have drawn in a line indicating the ambient wind flow direction. Between the wind shift lines, the total wind vectors deviate from the ambient wind direction. This deviation indicates a jet moving toward 315° at 10-14 m/s. The jet is 10-15 km wide and is, of course, superimposed on the roll-like motion seen in Figs. 1.11 and 1.12.

Summary

In the afternoon of 2/6/78, a post-frontal convective band passed over the experimental area. The band formed in conditionally unstable air over the Sacramento Valley, and moved nearly directly up the foothills of the Sierra Nevada (toward 66°) at 17 m/s.

The overall air motion near the band was helical. Air approached the band from the SSE at low levels, was lifted on the SW (trailing) side of the band, and exited from the band toward the NE or ENE at upper levels. Thus, although the band appears in Figs. 1.12 and 1.13 to be a "front-feeder," the feeding is really not from directly up the foothills, but from presumably moister air farther south. Figure 1.16 is an artist's conception of the helical wind flow around this band.

3. CASE 2 -- FRONTAL PASSAGE 2/7/78

Synoptic Overview

On 2/7/78 a moderate-to-weak occlusion passed over the experimental area, causing intermittent rainfall throughout the day. The occlusion was centered off the coast of Washington State (see Fig. 2.1).

During the day, winds in the lowest 5 km gradually and rather uniformly veered and decreased in magnitude, as may be seen in Figs. 2.2-2.4. These figures show the 1.2-km winds, the 3.7-km winds, and the shear between those two levels. The winds were strong in the morning hours and decreased after 1000.

The reflectivity profiles shown in Fig. 2.5 suggest the temperature structure throughout the day. At 0753 a strong bright band may be seen at 2.4 km, with moderately strong reflectivities up to 6 km. This indicates a 2.4-km freezing level and considerable moisture throughout the lower atmosphere. The reflectivity at 1106 shows drying or stabilizing in the 4-6 km levels, indicated by the decreased reflectivity, and a dropping of the freezing level to 1.2 km. By 1330 the freezing level has dropped to 0.6 km, the lowest we have observed it in the radar data, and the reflectivity below 1.5 km has increased dramatically. (It should be noted that the radar scans from which these data were taken were of local "hot spots" of reflectivity. Nonetheless, the inferred freezing level should be representative of the ambient atmosphere, and the rate of decrease of reflectivity with height gives a suggestion as to the ambient stability.)

Sounding information, not shown, indicates that the period of greatest instability occurred between 1300 and 1600. The Showalter indices at these times were -1 and -3, respectively. The total totals indices were 54.8 and 60.2, respectively. The 500-mb charts (not shown), as well as the soundings, indicate a temperature drop from -18°C to approximately -25°C between 0400 and 1600. Surface warming also occurred. Between 0700 and 1600 the surface temperature rose from 11.5°C to 15°C. Precipitable water content was approximately 1.73 cm during the afternoon.

The surface warming, combined with the lowering of the freezing level shown in the reflectivity profiles, implies a considerable destabilizing of the lowest 1 km of the atmosphere, particularly around 1330. This situation gave rise to a tornado at Rio Linda at 1326. (Rio Linda is about 13 km to the SW of the region we were scanning at 1330.)

Frontal Location

A considerable body of evidence suggests that the front passed over the experimental area at 1000 PST. First, the NWS surface maps for 1000 show the front in the appropriate location. Second, cross sections deduced from soundings (Personal communication, J. Moore, 1979) show the coldest deviations from standard temperature occurring at or near 1000. Third, the wind at radar CP-3 reached a maximum (22 m/s) at 1100, and was in excess of 15 m/s between 1000 and 1100. There was no shift in wind direction during this time, indicating that the front did not reach the surface, but the relatively high wind speeds themselves suggest the frontal passage. Finally, the microbarograph at CP-3 indicated a dip in pressure at 0930, indicating a weak frontal passage. Further evidence that the front passed at or near 1000 is in Figs. 2.2 and 2.3. They show the change in wind direction between the morning and afternoon scans: the wind shifted from the SE to the SW and W. Also, the low-level jet died out after 1000.

In the afternoon, at about 1330, a post-frontal band passed over. This was indicated by a shift in the surface wind at CP-3 from 155° to 225°, a small dip in the pressure measured on the microbarograph, and rainfall of 0.41 inches between 1300 and 1400.

Triple Radar Volume Scans

Of the nine volume scans that were processed on 2/7/78, three are of particular interest. They are those taken over the Doppler radar triangle at 0753, 1106, and 1330. Figures 2.6-2.9 show perspective plots of the reflectivity structure seen by CP-3 in these three scans. The 0753 scan (Figs. 2.6, 2.7) shows a large, relatively uniform reflectivity region. This is a pre-frontal rainband. Figure 2.8 shows the reflectivity for 1106. At this time, we see evidence of broken post-frontal convection. Unfortunately, the radar signal did not extend high enough for us to deduce vertical velocities.

Figure 2.9 shows the reflectivity at 1330. Here we see two regions of strong reflectivity. The northern region is the one we scanned in detail; the southern one may be the remnant of the storm that caused the Rio Linda tornado. In this case also, we were unable to deduce reliable vertical velocities. At high elevation angles, the CP-3 radar measurements were biased by an estimated 5 m/s by signals from side lobes. This is an appreciable problem only in a region of weak signal directly over a region of very strong signal, as was the case here.

In the morning, before the front, winds were very strong, as is indicated by the hodographs, (Figs. 2.2-2.3), and there was substantial shear (Fig. 2.4). This may have acted to supress vertical velocities. At any rate, vertical velocities were slight in this early morning case, as is indicated by Fig. 2.10. This shows a vertical E-W slice, located 16.5 km N of CP-3, roughly in the middle of the radar triangle. Almost no vertical velocity is evident; what is evident is the strong veering of the wind with height.

In the weak post-frontal case, at 1106, winds also veered with height (see Figs. 2.2-2.4), and almost no horizontal variation of the wind was evident.

The horizontal winds for the strong post-frontal squall are shown in Fig. 2.11. We have sketched in the apparent wind shift line, which passes through the reflectivity core located 15 km N of CP-3. This reflectivity core is also a core of negative vorticity, which has a maximum value in this region of $6 \times 10^{-3}\ s^{-1}$.

This strong vorticity, and the similarity of the horizontal structure of this storm to the storm of 2 March 1978 (reported in Moninger, 1980b), suggest that this storm may have contained strong updrafts. However, the absence of high reflectivity above 5 km in this storm indicates that any updrafts were insufficient to lift large hydrometers through the dry ambient atmosphere above 3.5 km.

Summary

On 2/7/78, the Doppler radars observed a weak frontal passage followed a few hours later by a strong band which had associated with it a tornado. Strong horizontal wind and strong shear were associated with the front, however immediately after the frontal passage, a cooling, drying and general stabilizing of the atmosphere were evident.

By four hours after the frontal passage, instability had increased enough to allow the development of a strong band. The band was associated with high reflectivities at low levels, but was very shallow, being confined to the lowest 5 km of the atmosphere.

4. CONCLUSION

The first case study, of a band moving up the Sierra Nevada foothills while maintaining a well defined helical structure, indicates that this structure may be a more common one in the SCPP area than had previously been thought. The 10-15 km wide horizontal jet associated with this band is unusually narrow, and should be an area of productive future investigation.

The second case study, while frustrating because of its limited vertical velocity data, indicates that intense storms in the SCPP area can be very shallow, primarily because of very limited moisture above the lowest few km. Whether the seeding of such an intense and shallow storm can be effective and safe is clearly an open question — one that should be studied in detail before actual seeding is attempted.

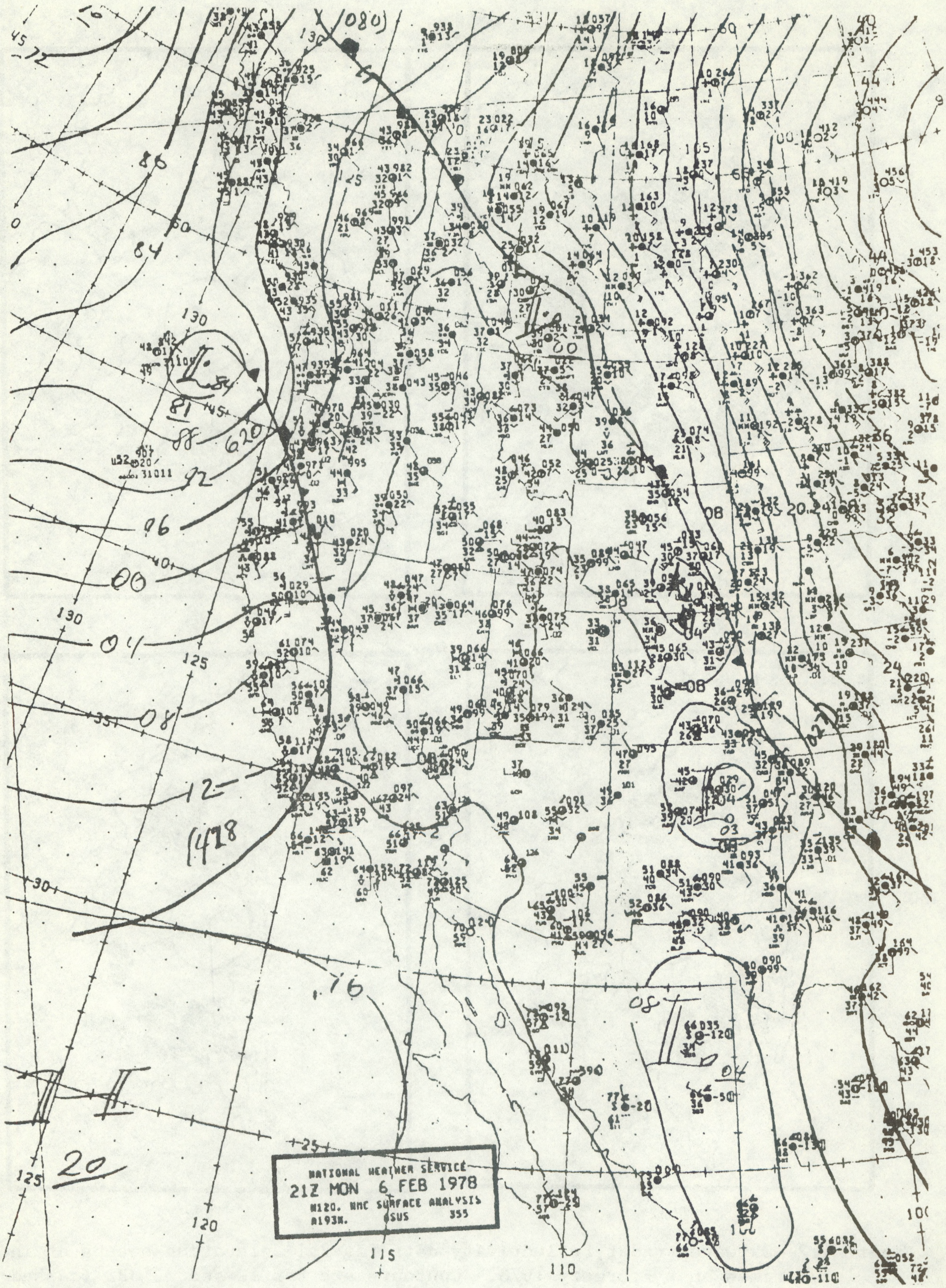


Figure 1.1--Surface weather map, 1300 PST, 6 February 1978.

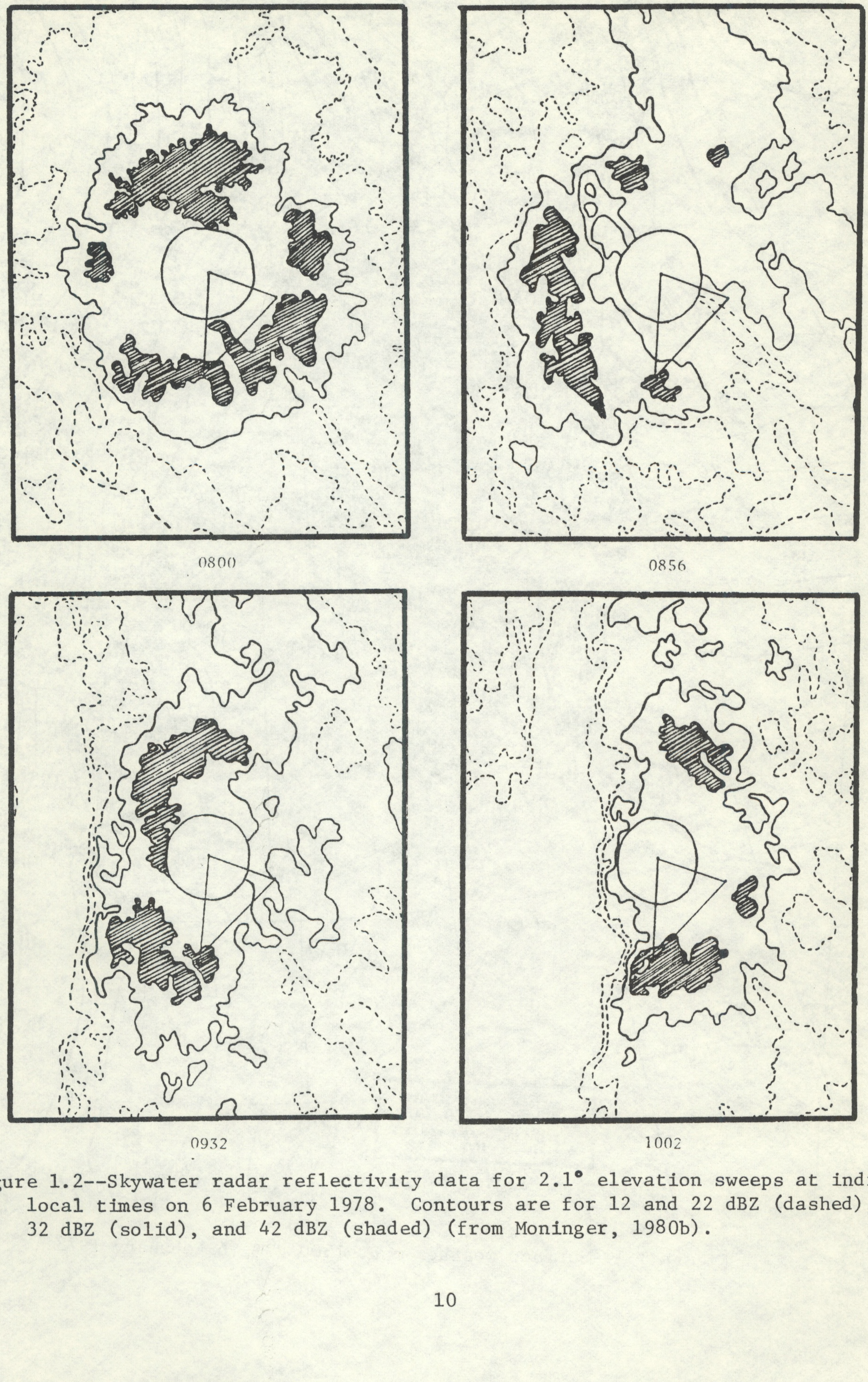


Figure 1.2--Skywater radar reflectivity data for 2.1° elevation sweeps at indicated local times on 6 February 1978. Contours are for 12 and 22 dBZ (dashed), 32 dBZ (solid), and 42 dBZ (shaded) (from Moninger, 1980b).

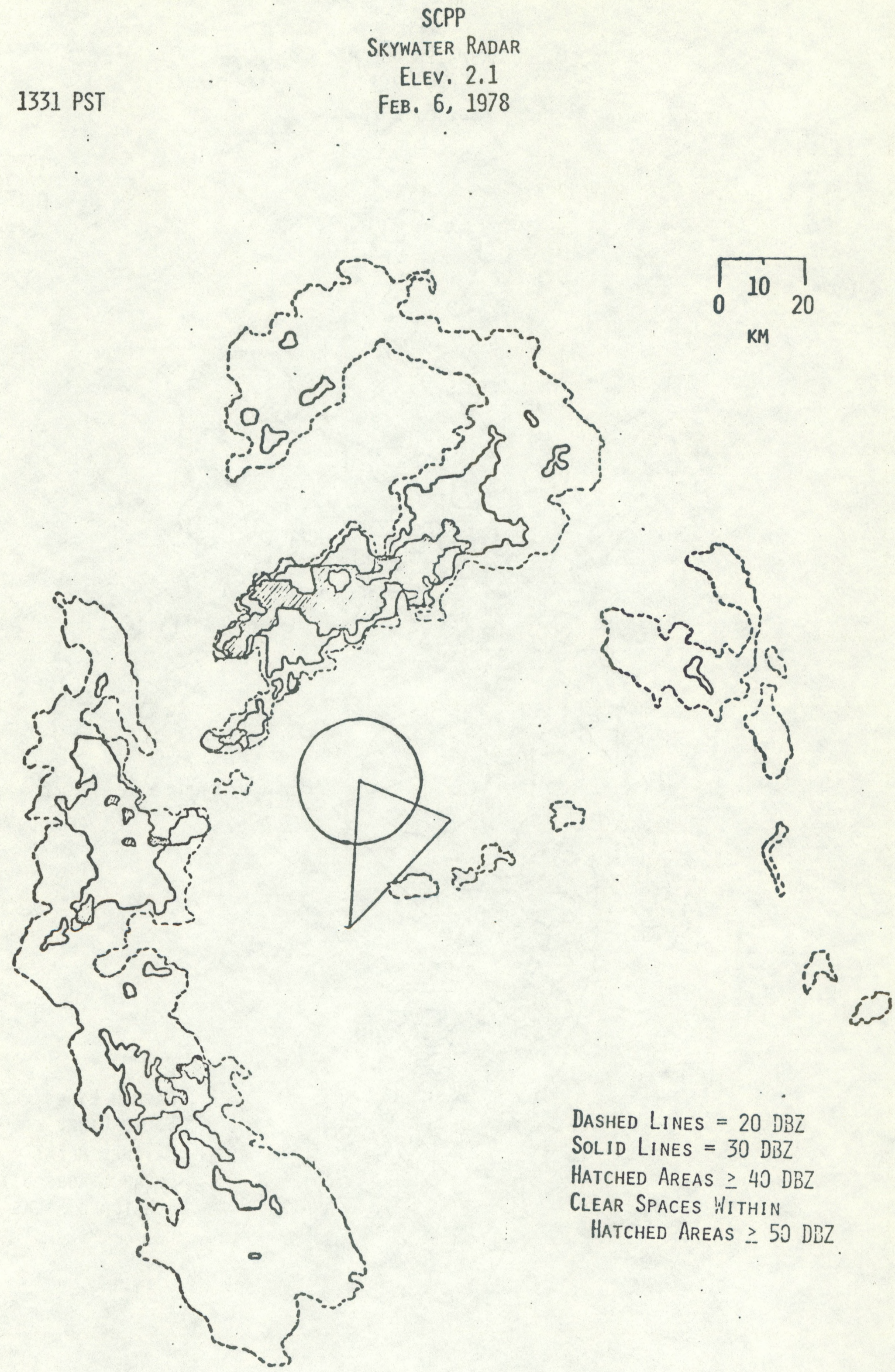


Figure 1.3--Skywater radar reflectivity data for 2.1° elevation sweep for 1331 PST, 6 February 1978. Contours are for 12 and 22 dBZ (dashed), 32 dBZ (solid) and 42-50 dBZ (shaded).

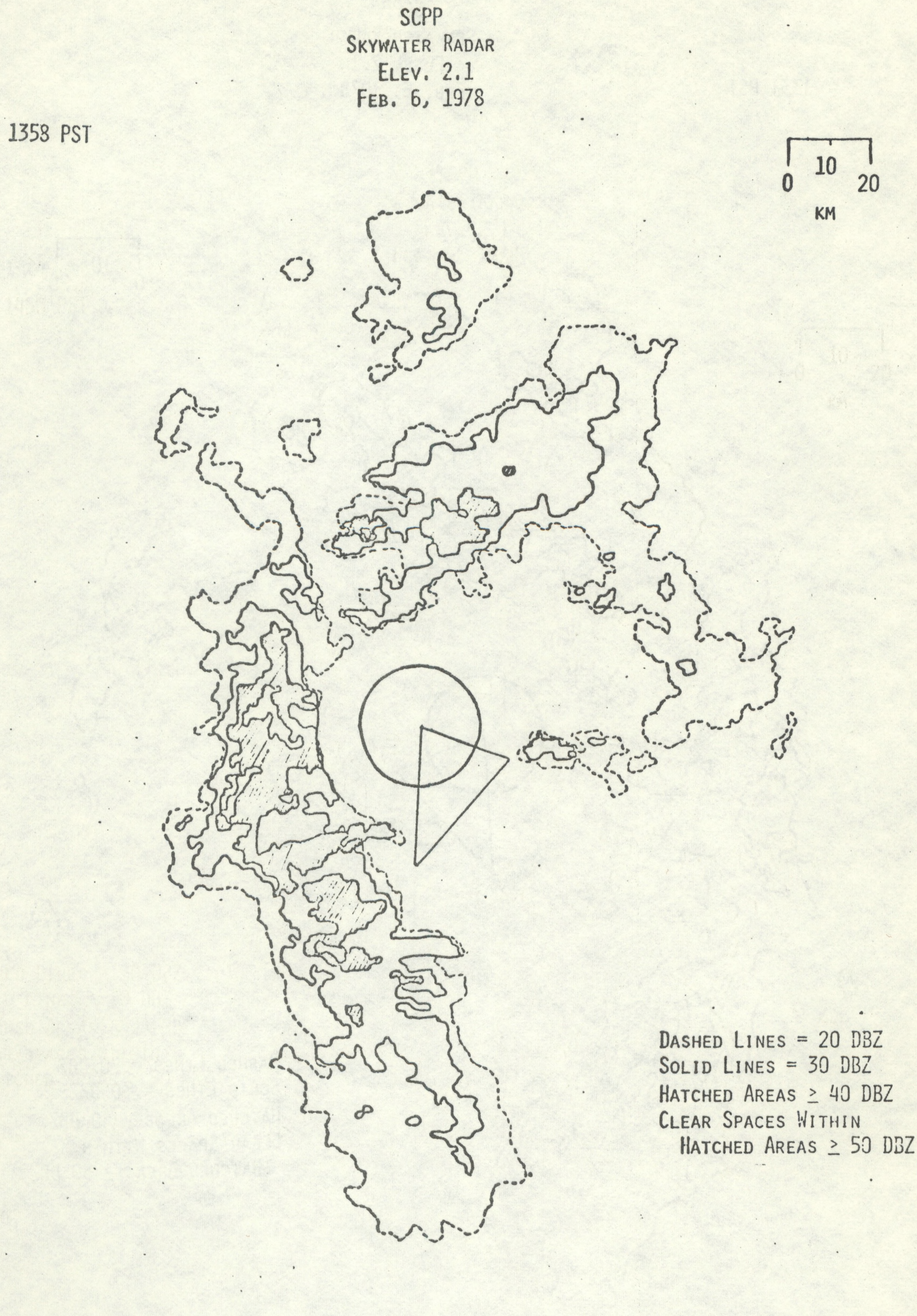


Figure 1.4--Skywater reflectivity data (as in figure 1.3), for 1358 PST.

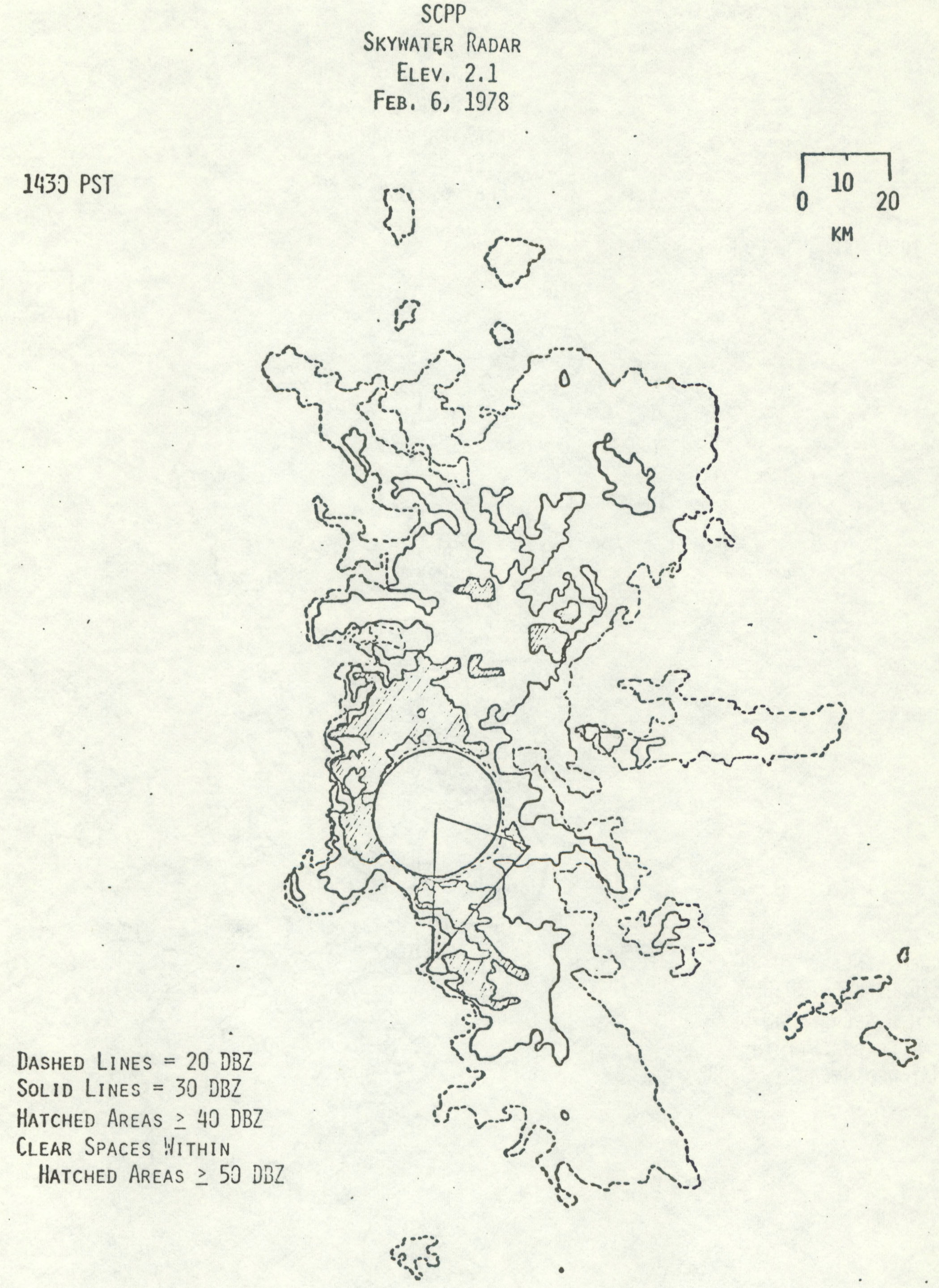


Figure 1.5--Skywater reflectivity data (as in figure 1.3) for 1430 PST.

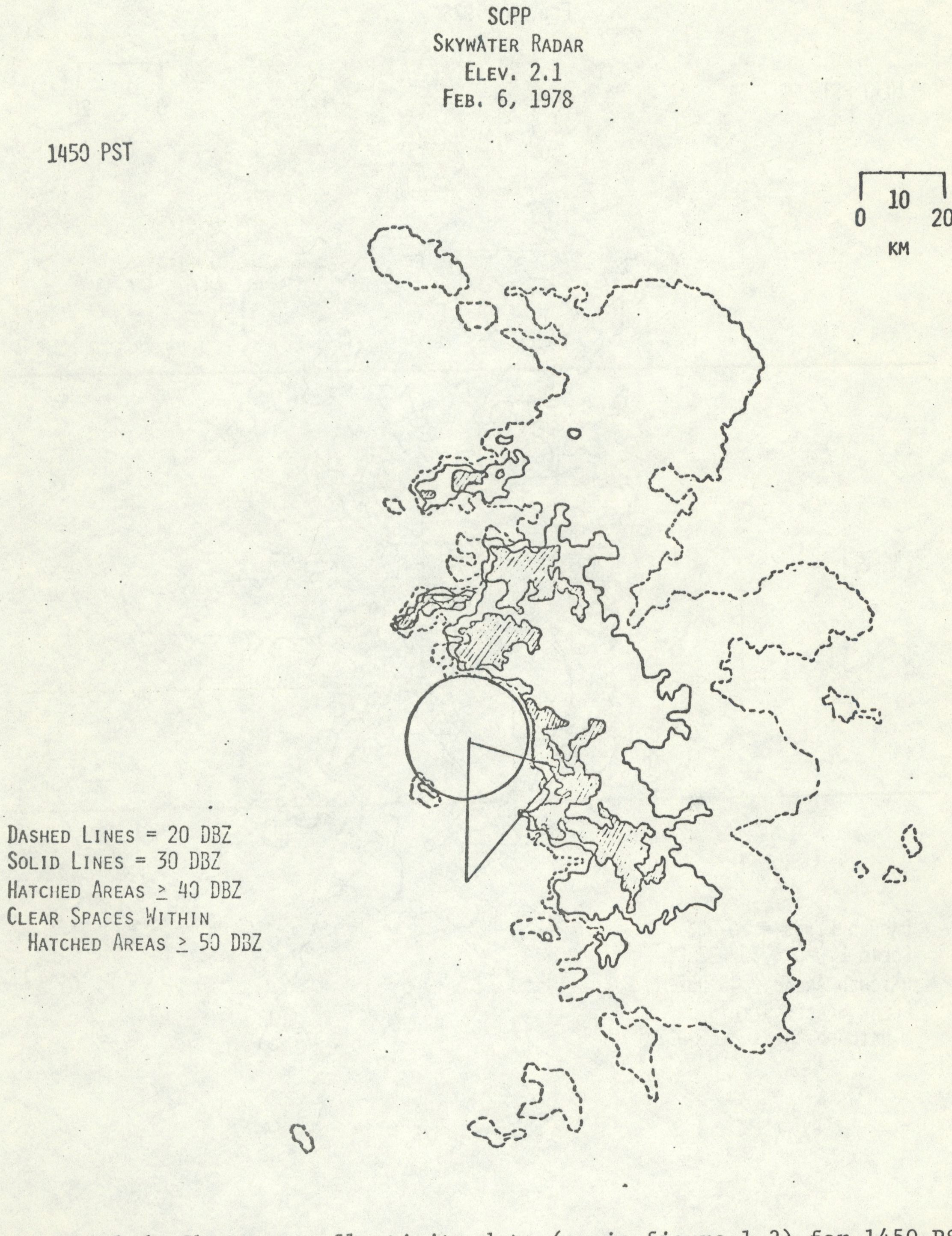


Figure 1.6--Skywater reflectivity data (as in figure 1.3) for 1450 PST.

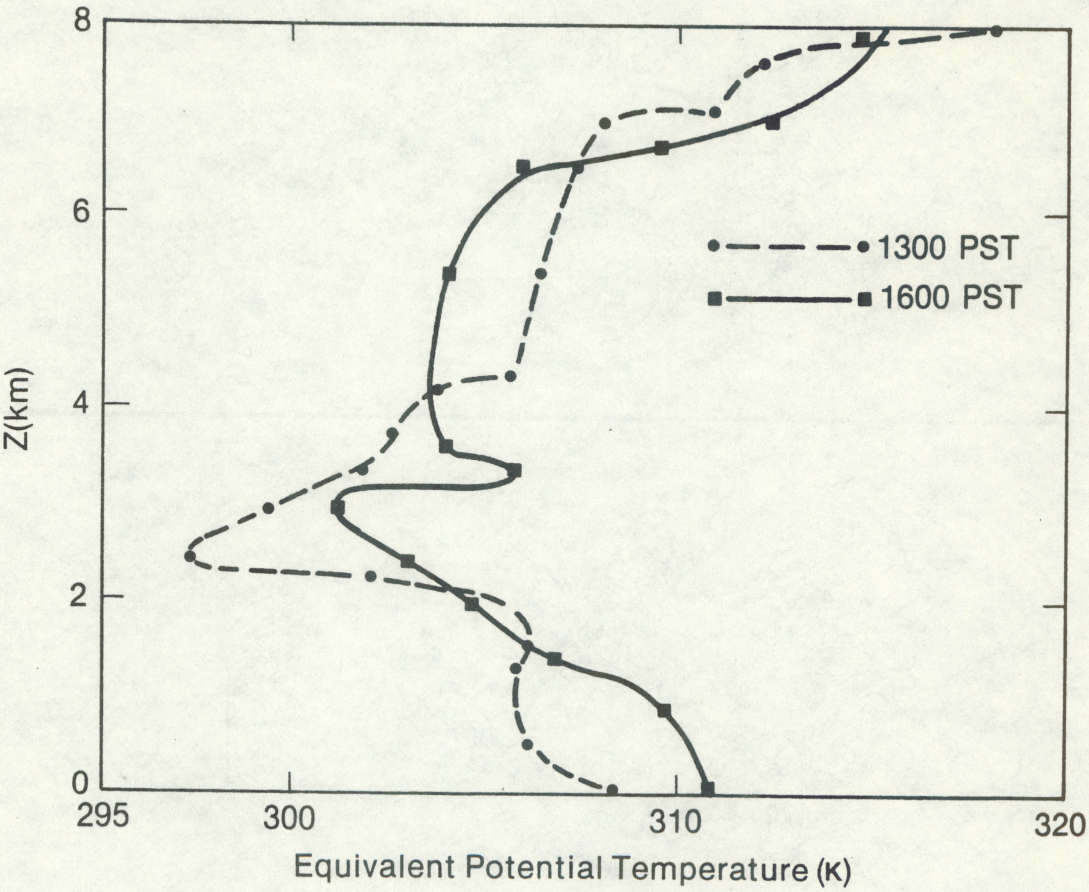


Figure 1.7--Sounding data 1300 PST and 1600 PST.

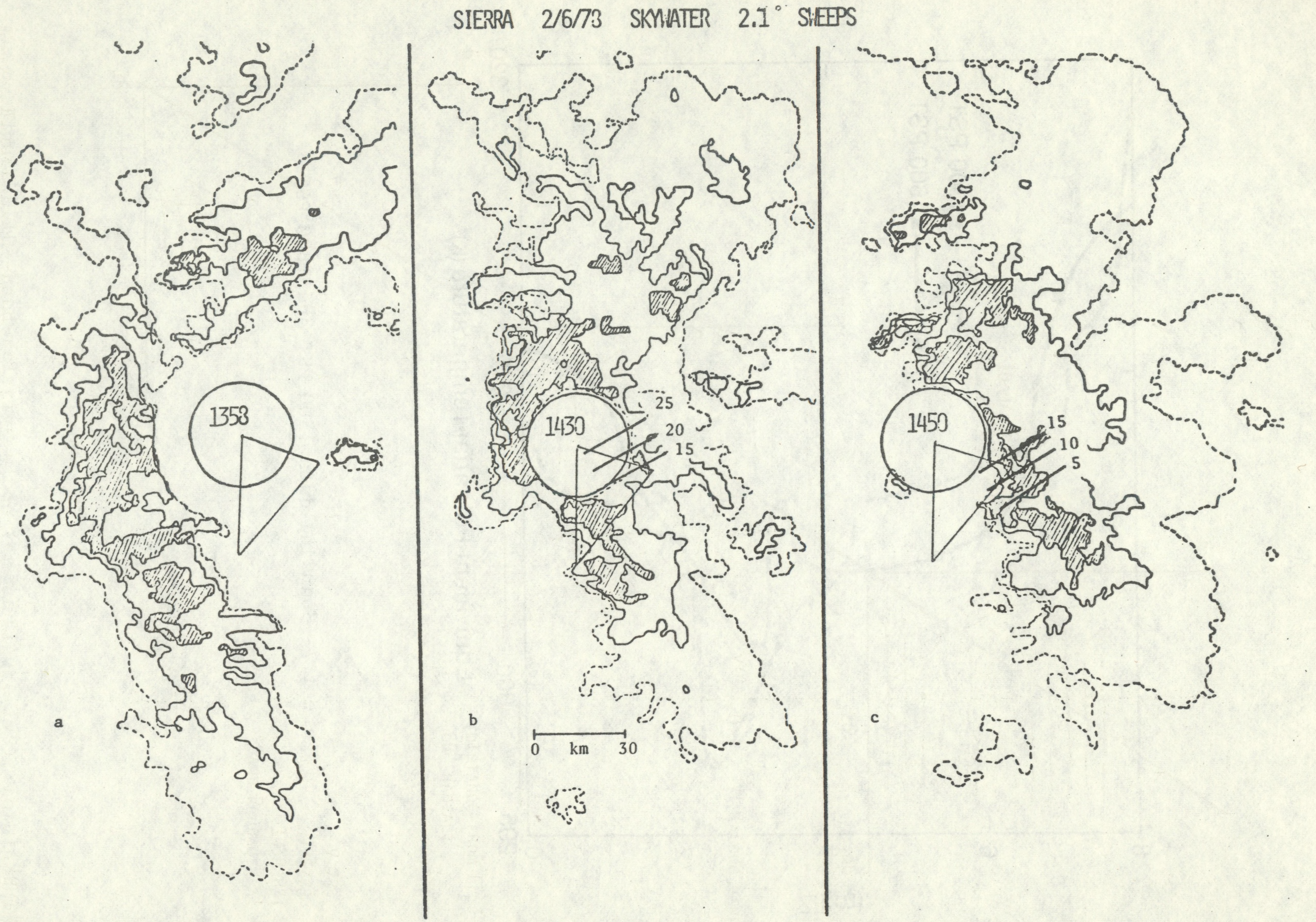


Figure 1.8--Skywater reflectivity data, 6 February 1978, for 1358 PST (a), 1430 PST (b), and 1450 PST (c). The locations of vertical radar data slices shown in subsequent figures are indicated. Contour levels are as in figure 1.3.

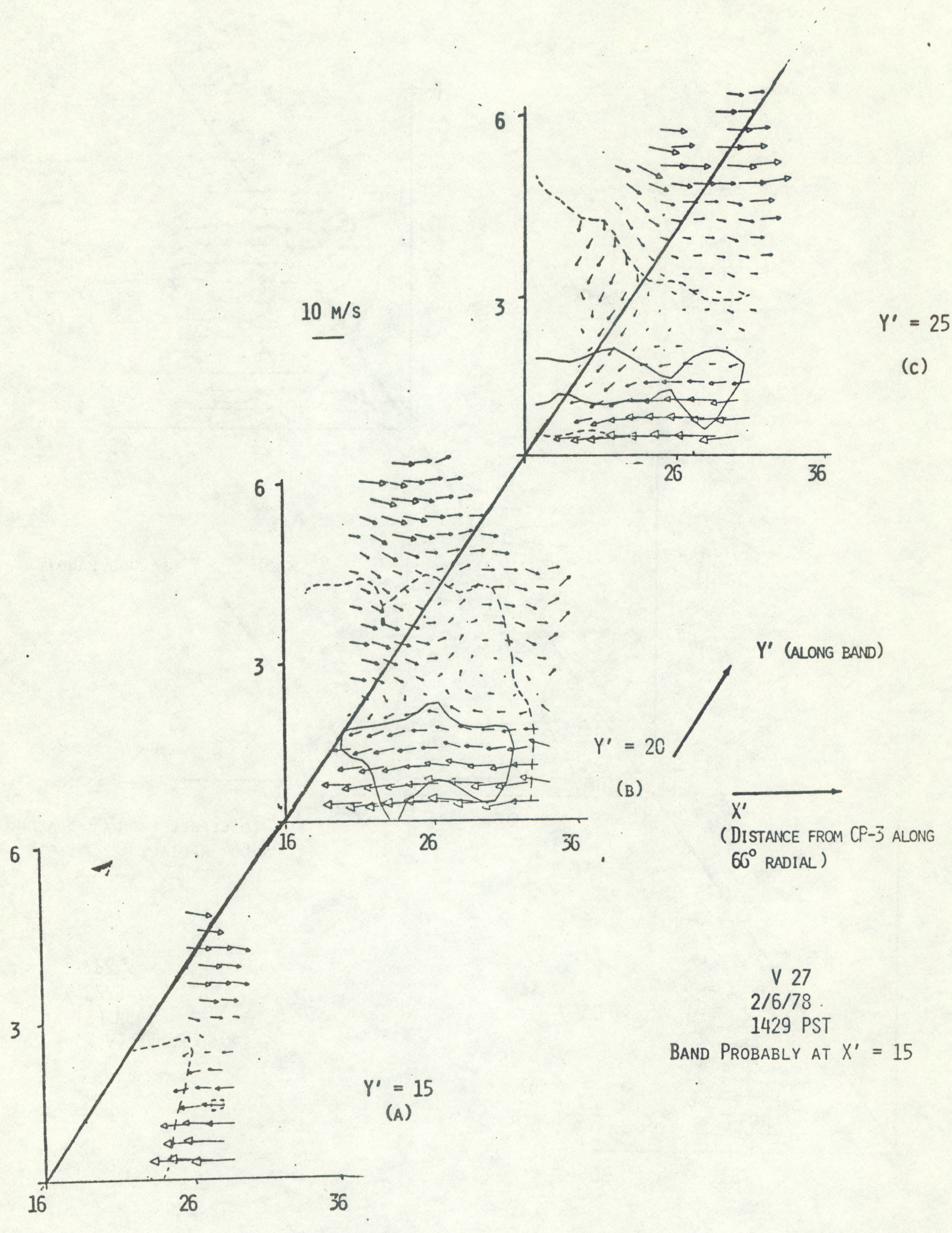


Figure 1.9--Band-relative winds in three vertical planes normal to the band axis, 1429 PST, 6 February 1978. The X' axis is the 66^o radial from radar CP-3. The Y' axis is the 336^o radial from CP-3.

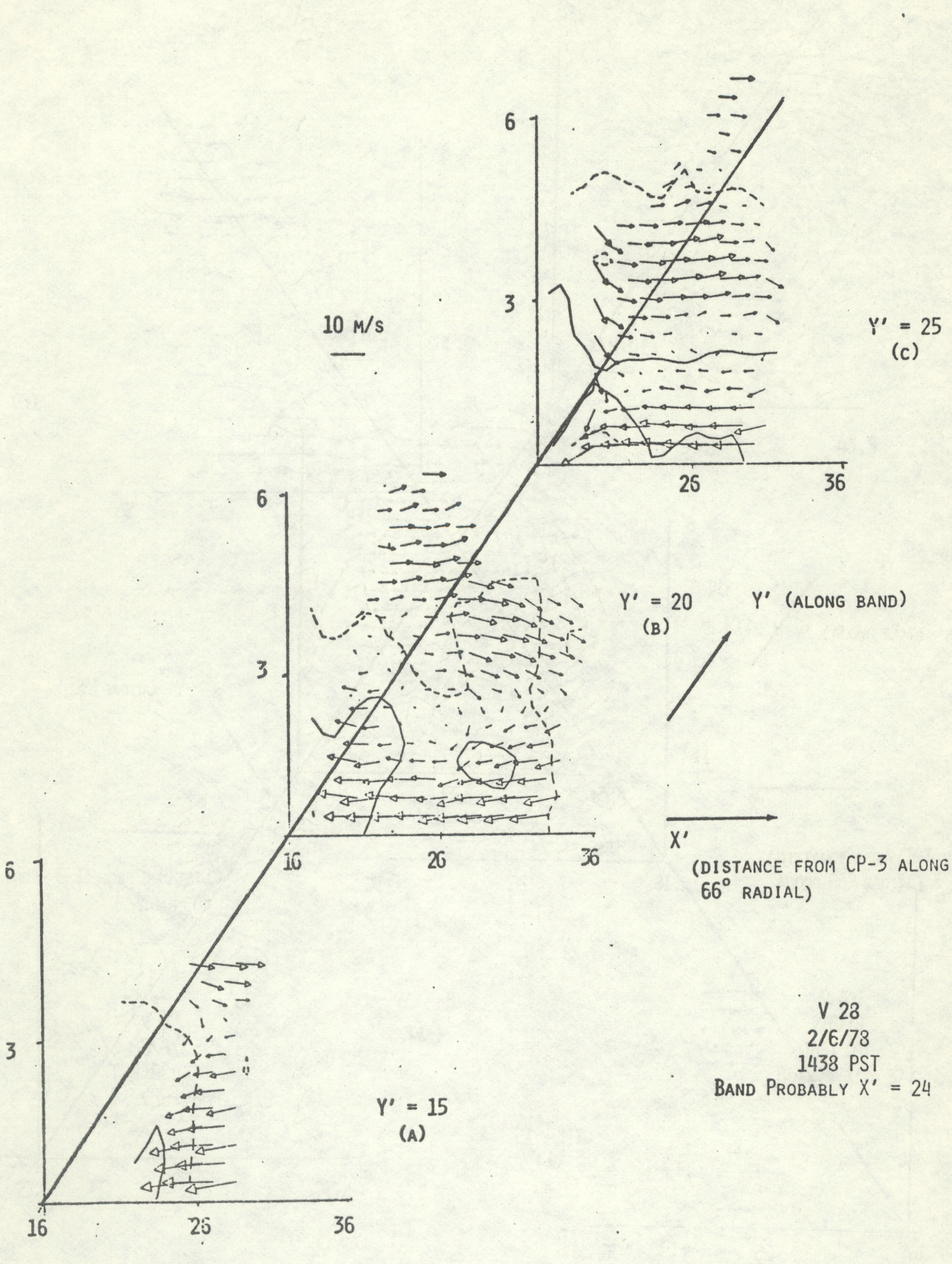


Figure 1.10--Band-relative winds (as in figure 1.9), for 1438 PST.

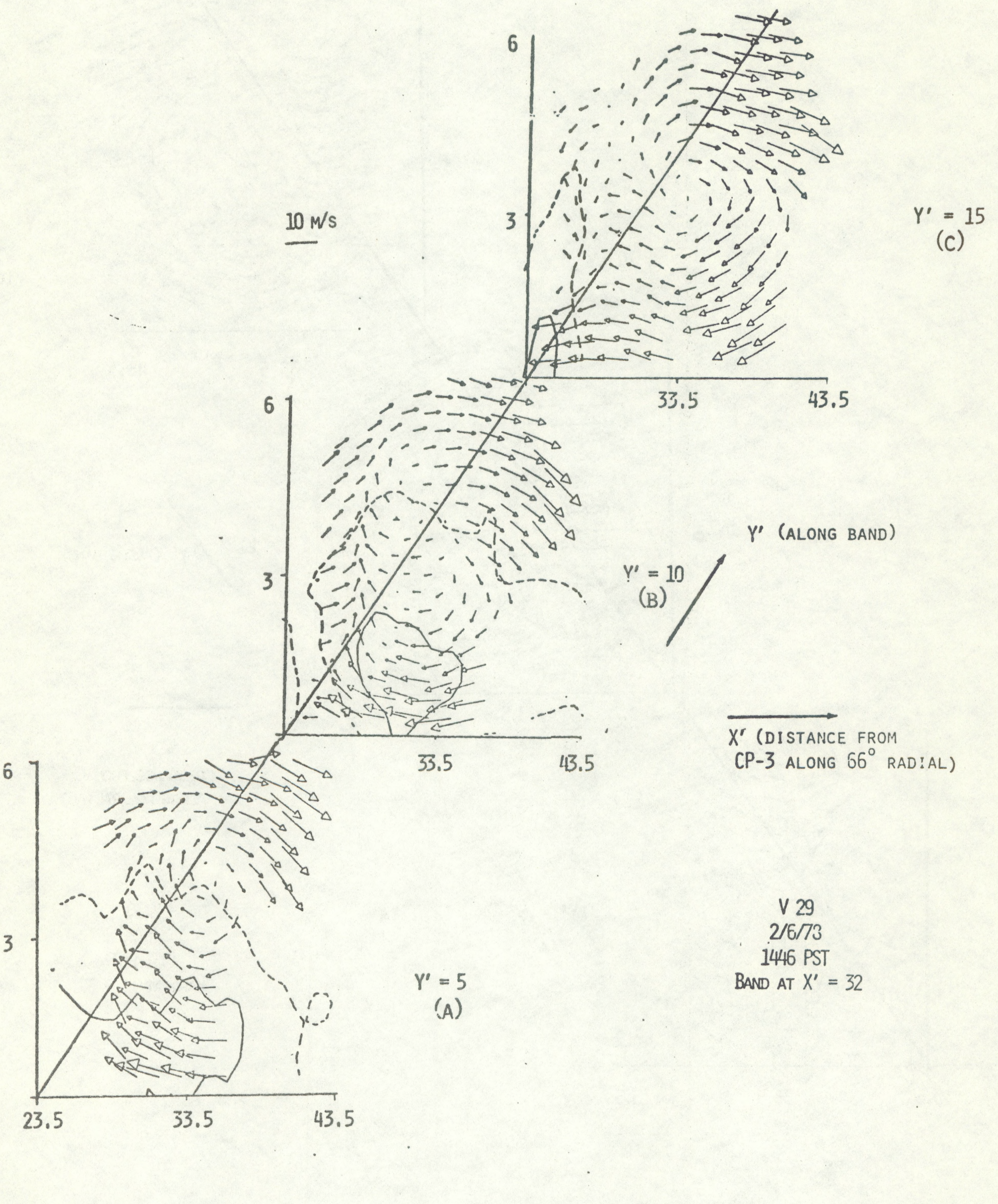


Figure 1.11--Band-relative winds (as in figure 1.9), for 1446 PST.

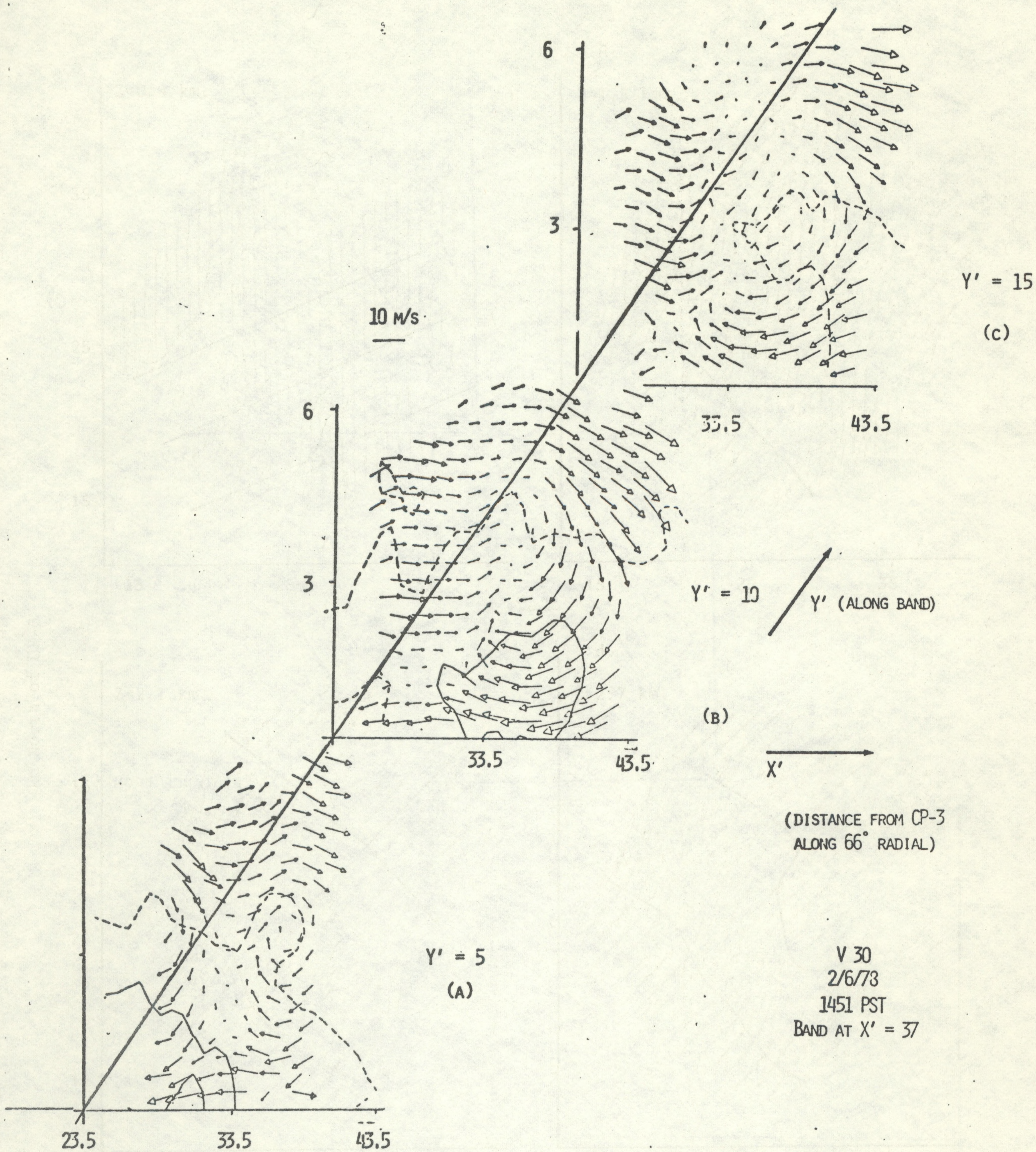


Figure 1.12--Band-relative winds (as in figure 1.9), for 1451 PST.

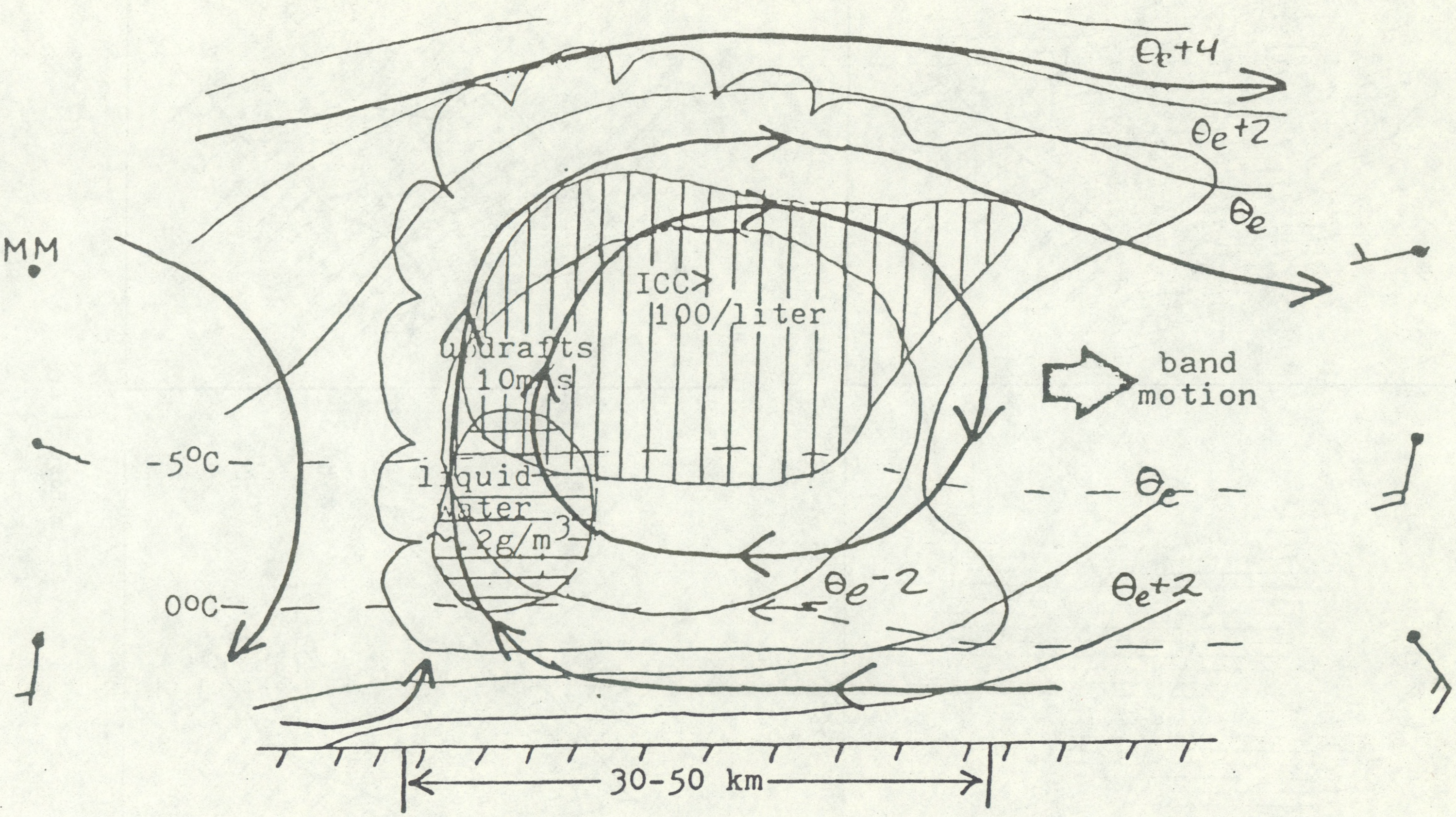


Figure 1.13--Convective band schematic. Wind barbs shown at 2, 4 and 6 km are band relative speed in knots. Schematic is representative of a band in the valley. (Courtesy J. Moore, WPRS.)

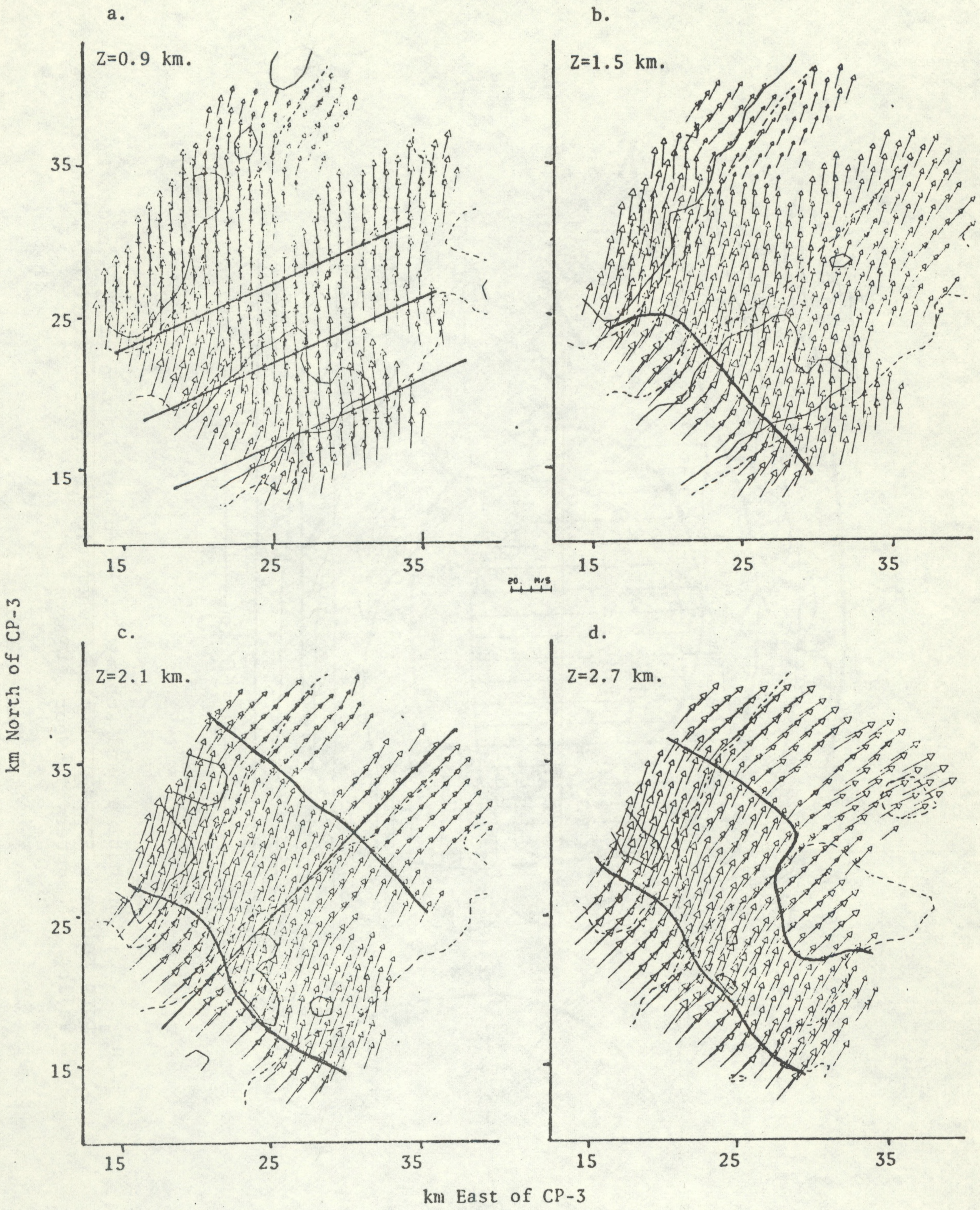


Figure 1.14--Total horizontal winds for the heights indicated, 1446 PST, 6 February 1978. The bold straight lines show the locations of the vertical slices shown in figure 1.10. Wavey bold lines indicate regions of maximum wind shift. Reflectivity contours: 20 dBZ, 40 dBZ (dashed), 30 dBZ (solid).

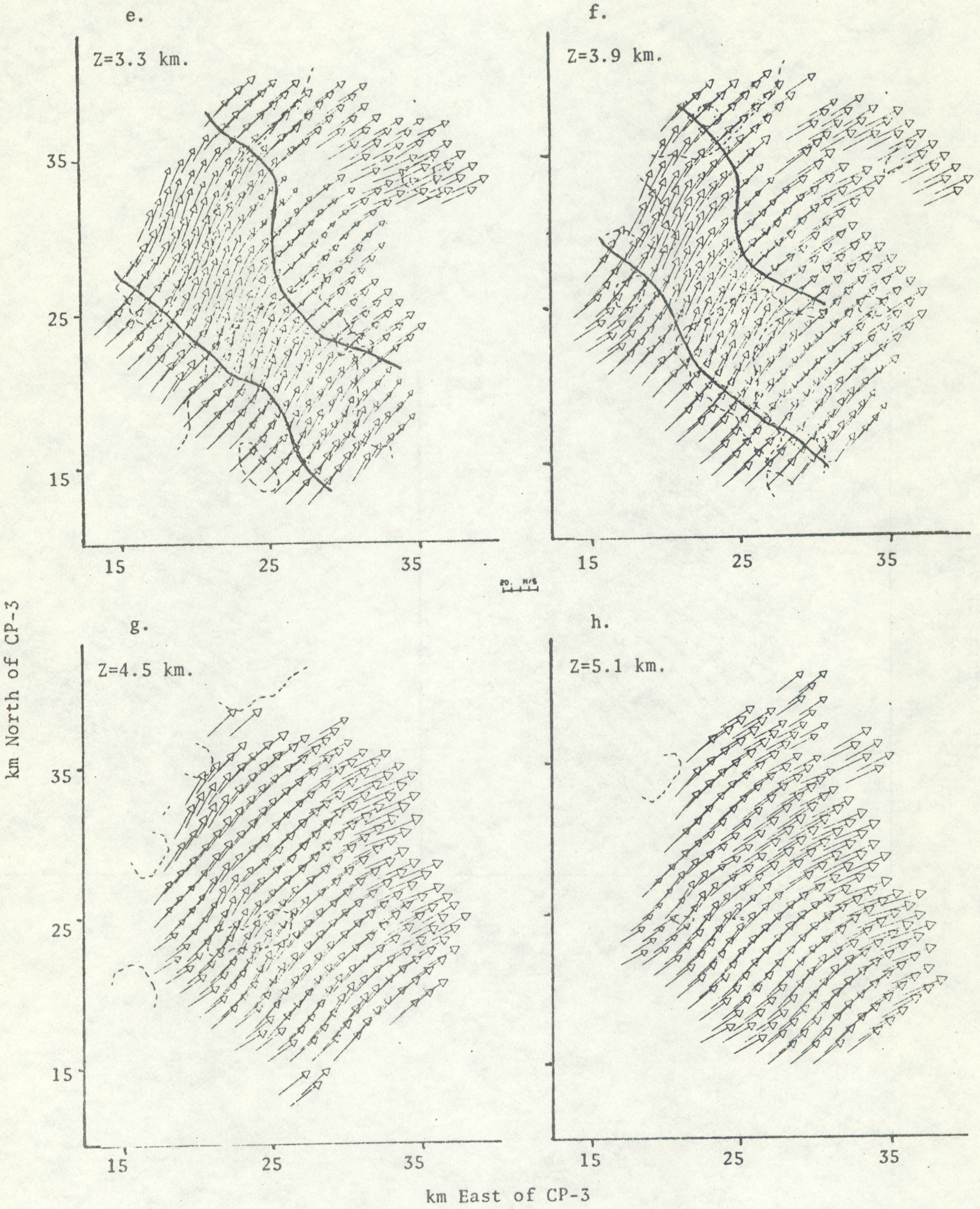
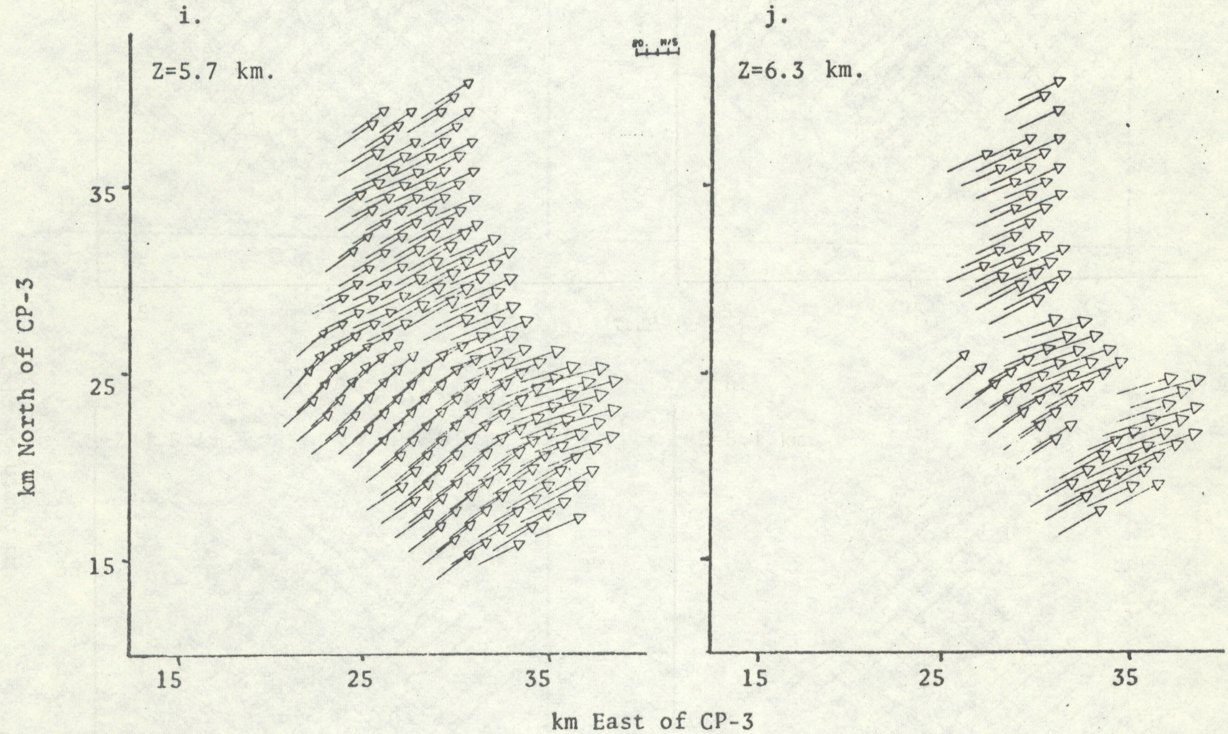


Figure 1.14--continued.



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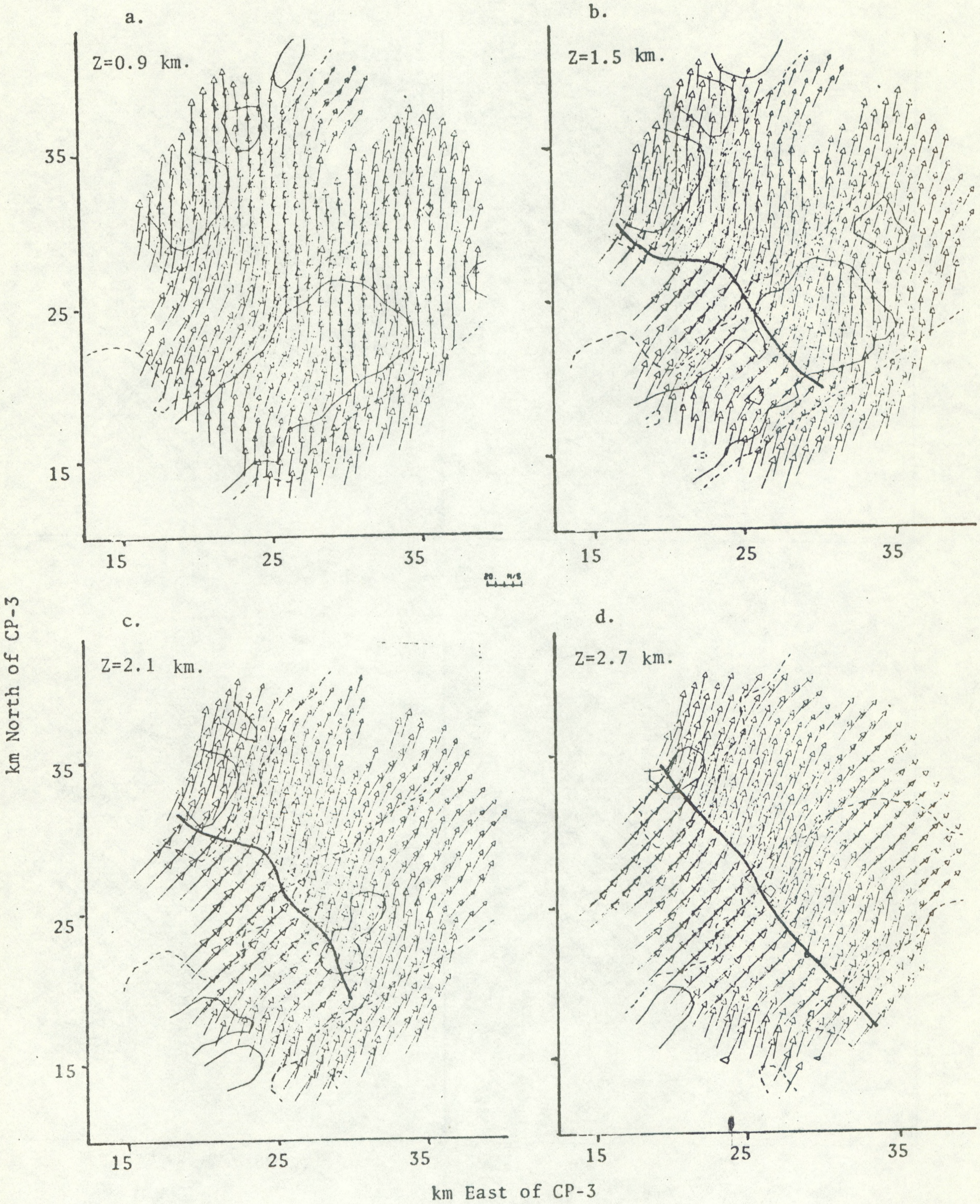
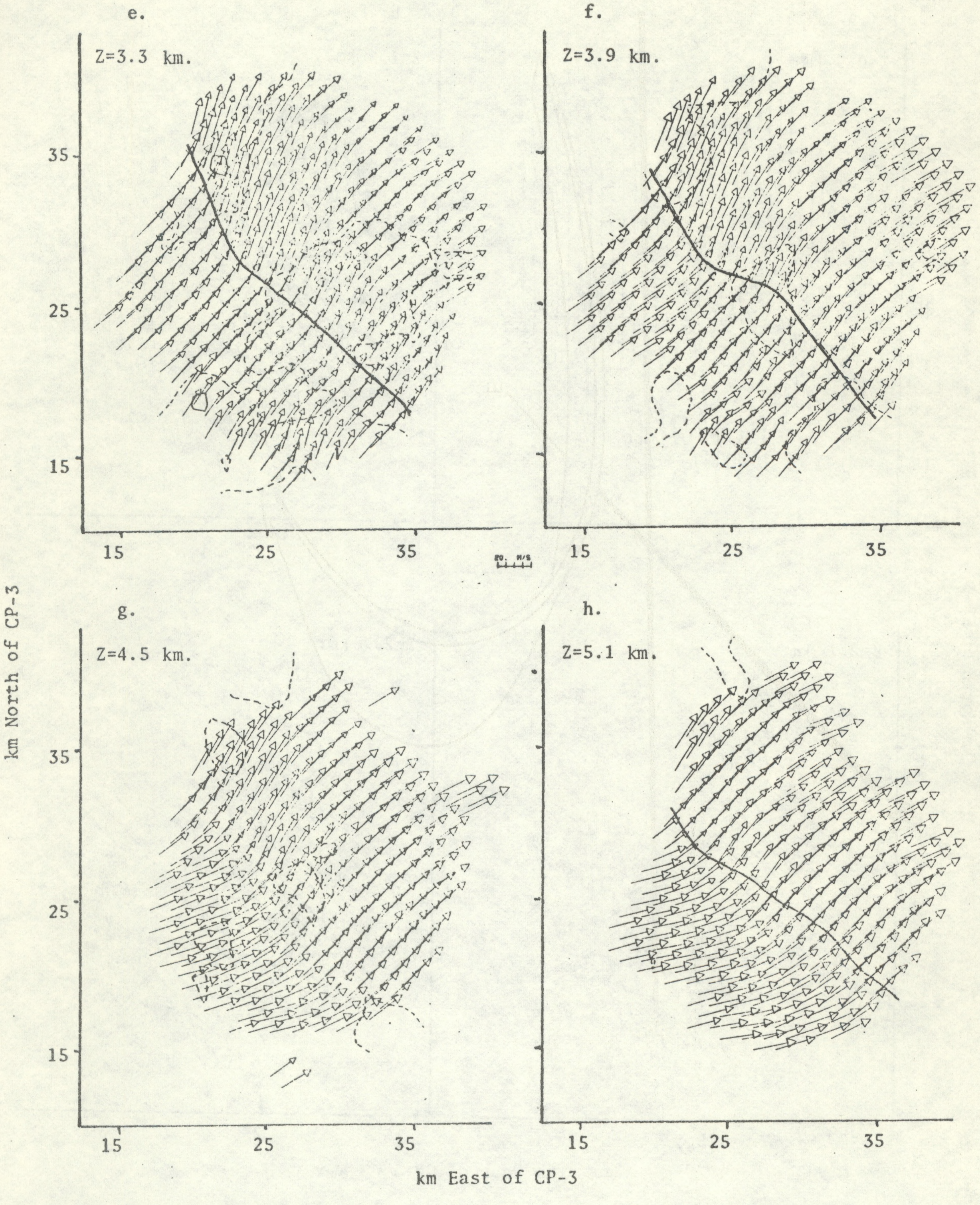


Figure 1.15--Total horizontal winds (as in figure 1.14), for 1451 PST, with vertical slices from figure 1.12 indicated.



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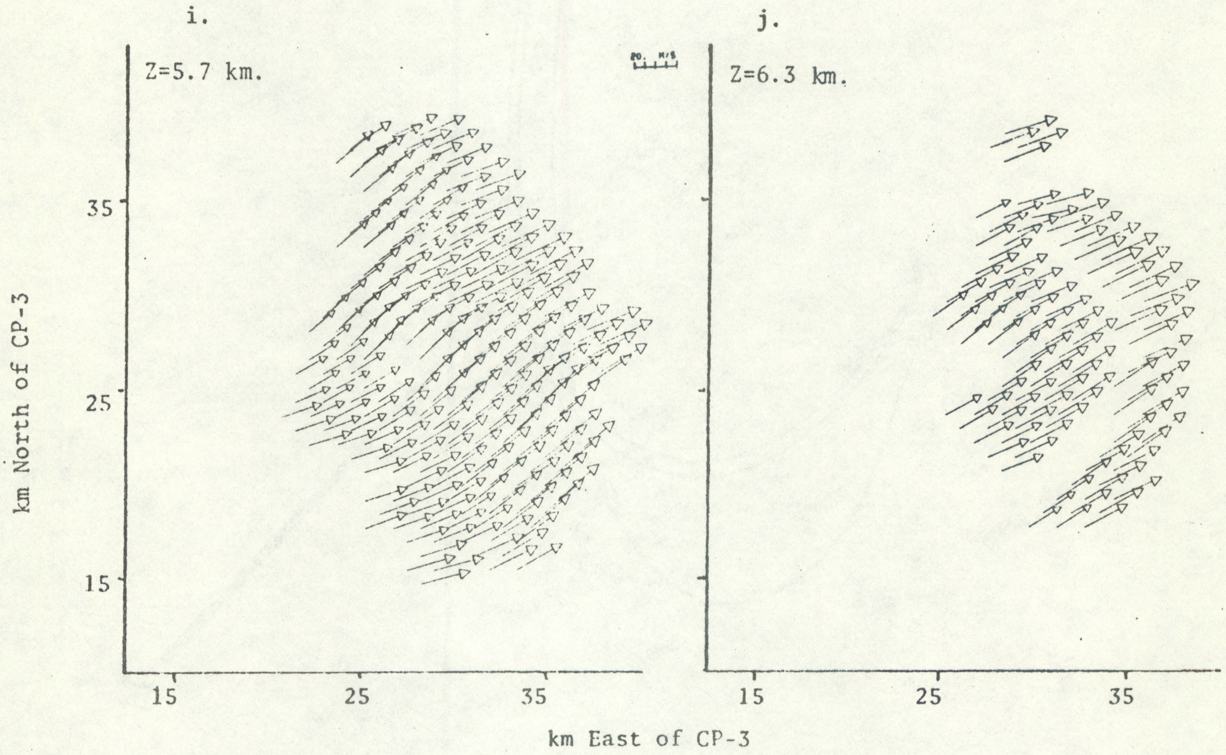

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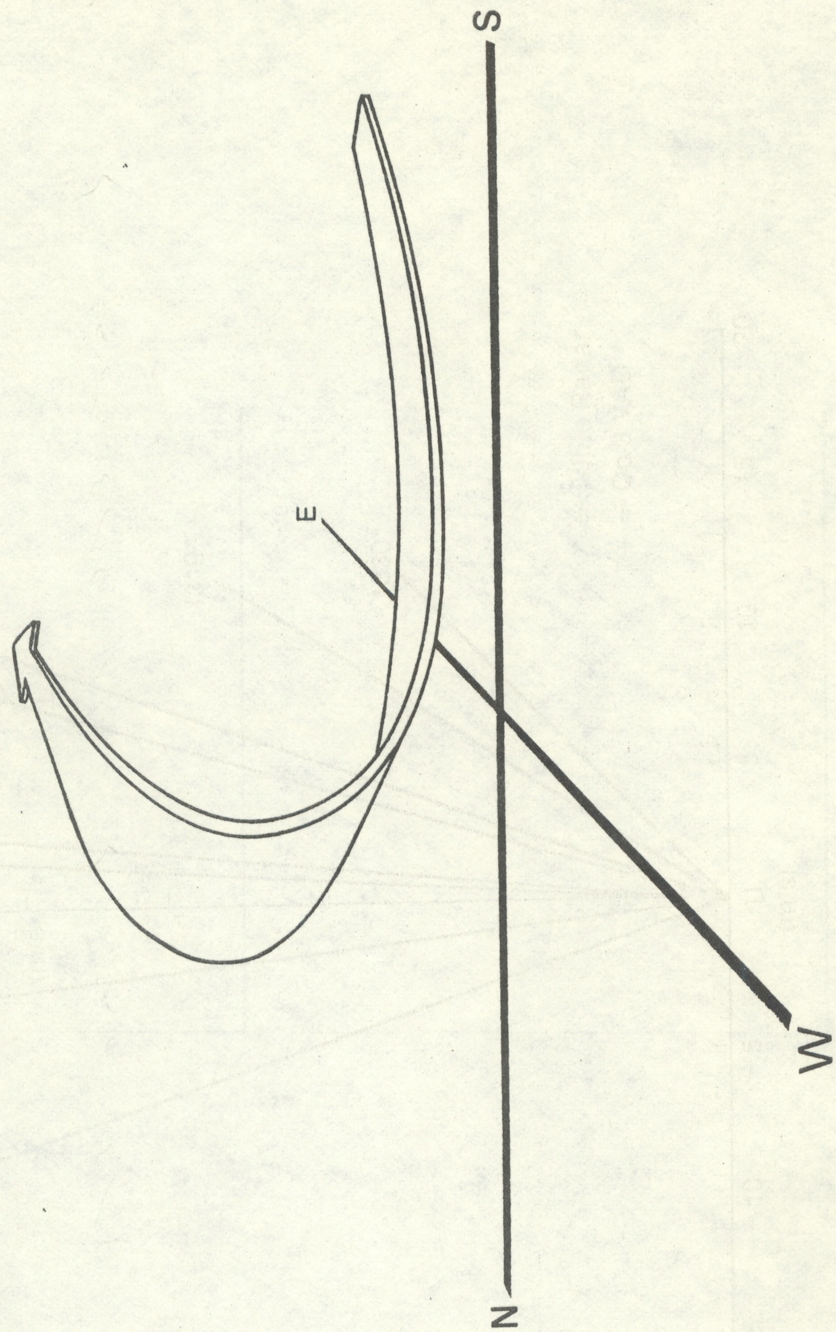

Figure 1.16--Artist's conception of inflow, updraft and outflow associated with the band.

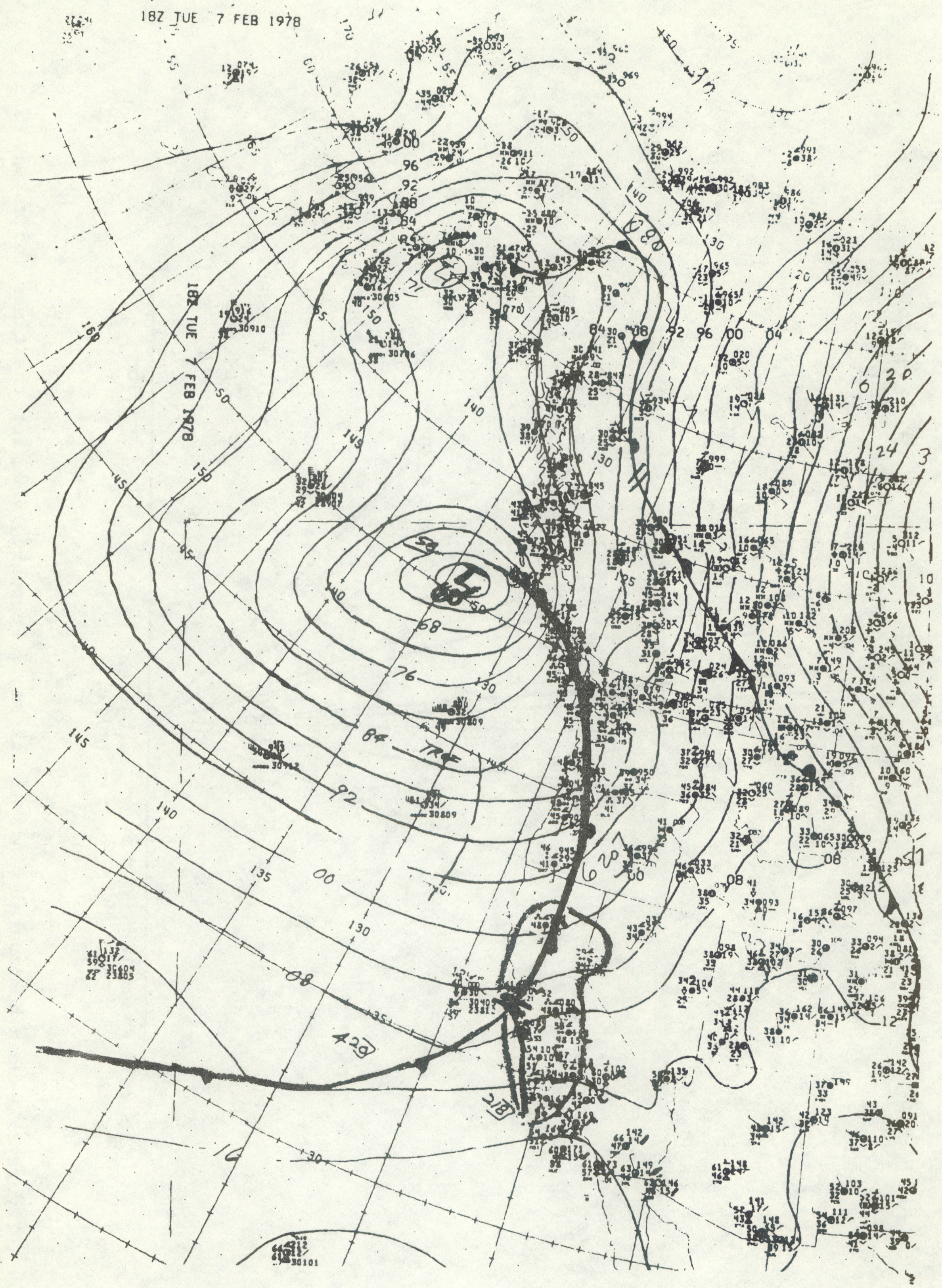

Figure 2.1--Surface weather map, 1000 PST, 7 February 1978.

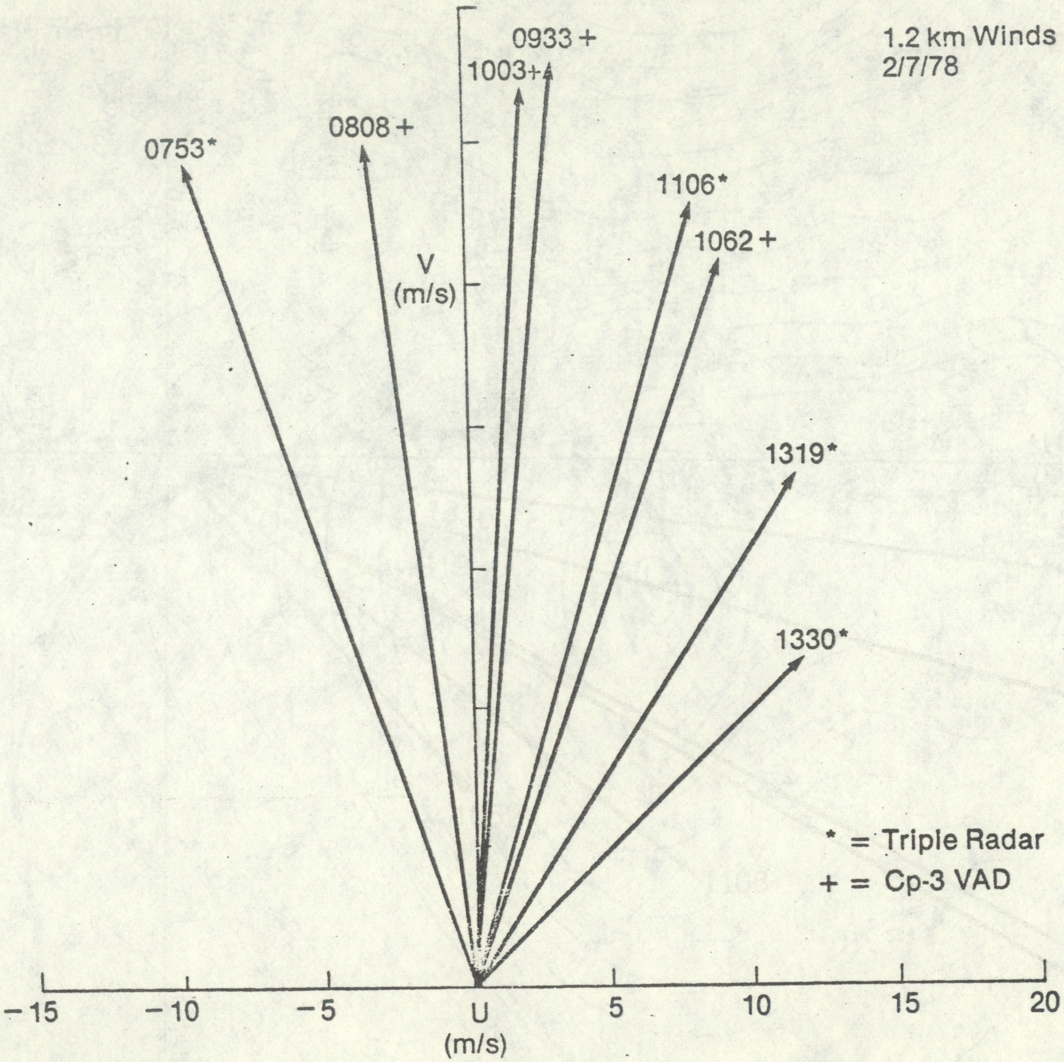

Figure 2.2--Mean horizontal winds at 1.2 km, 7 February 1978, for the times indicated.

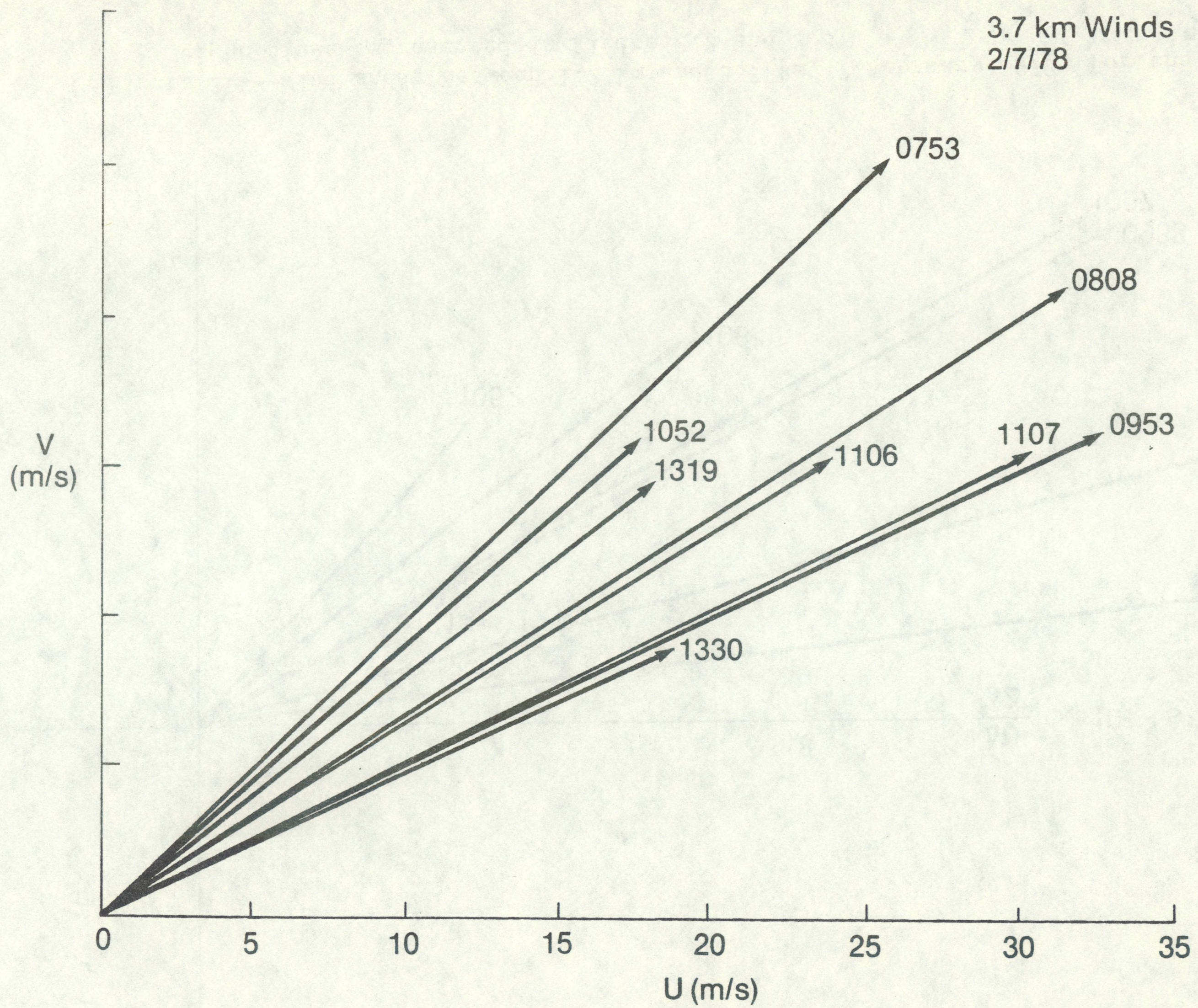

Figure 2.3--Mean horizontal winds at 3.7 km, 7 February 1978, for the times indicated.

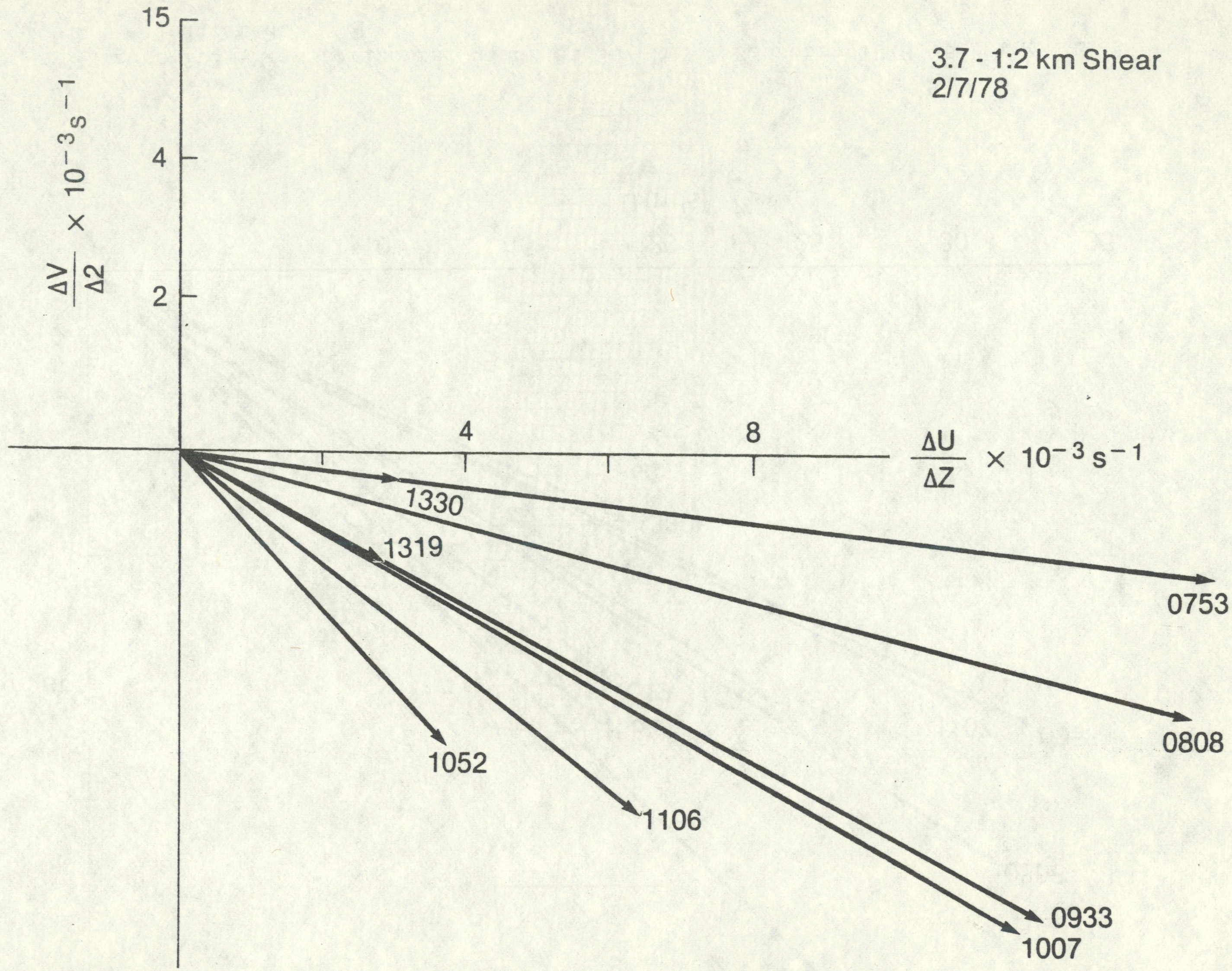

Figure 2.4--Wind shear between 1.2 km and 3.7 km, 7 February 1978, for the eight times represented in Figure 2.2 and 2.3.

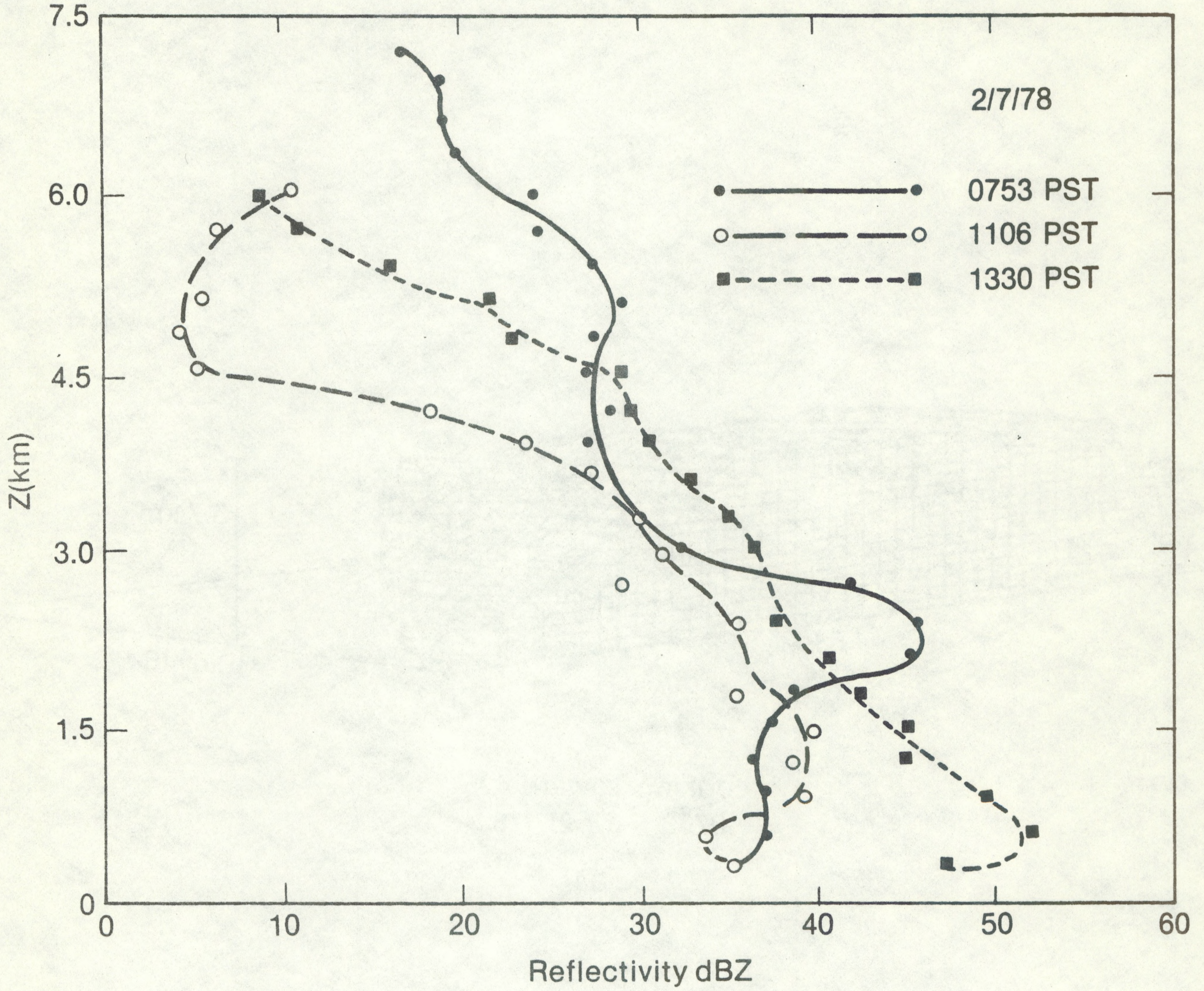

Figure 2.5--Reflectivity vs. height, 7 February 1978, for the times indicated.

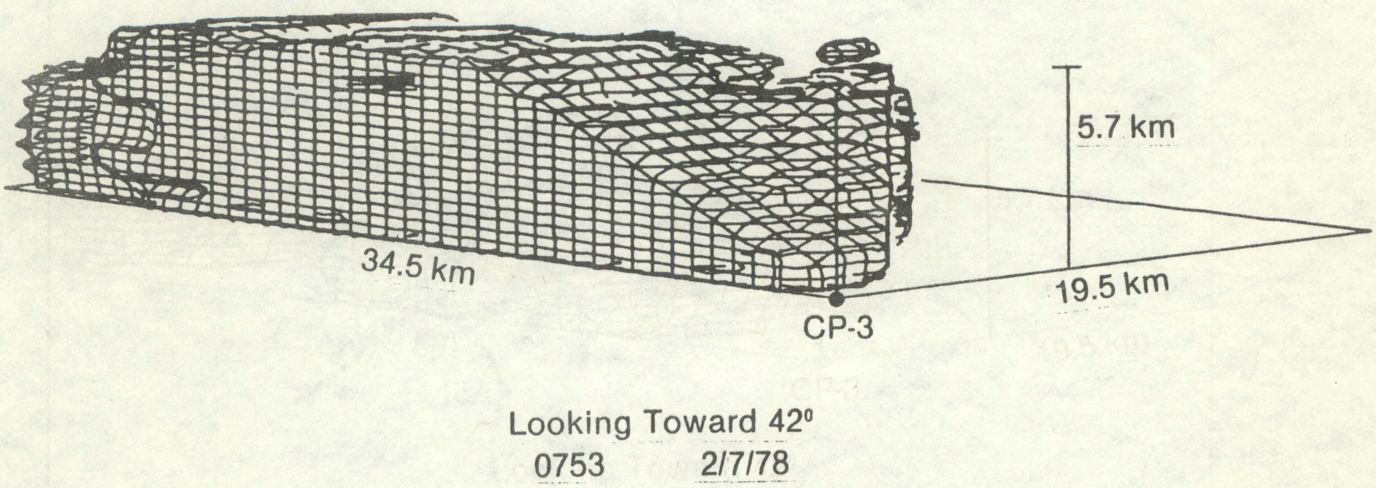

Figure 2.6--30-dBZ reflectivity contour, 0753 PST, 7 February 1978. View is across radar triangle toward 42°.

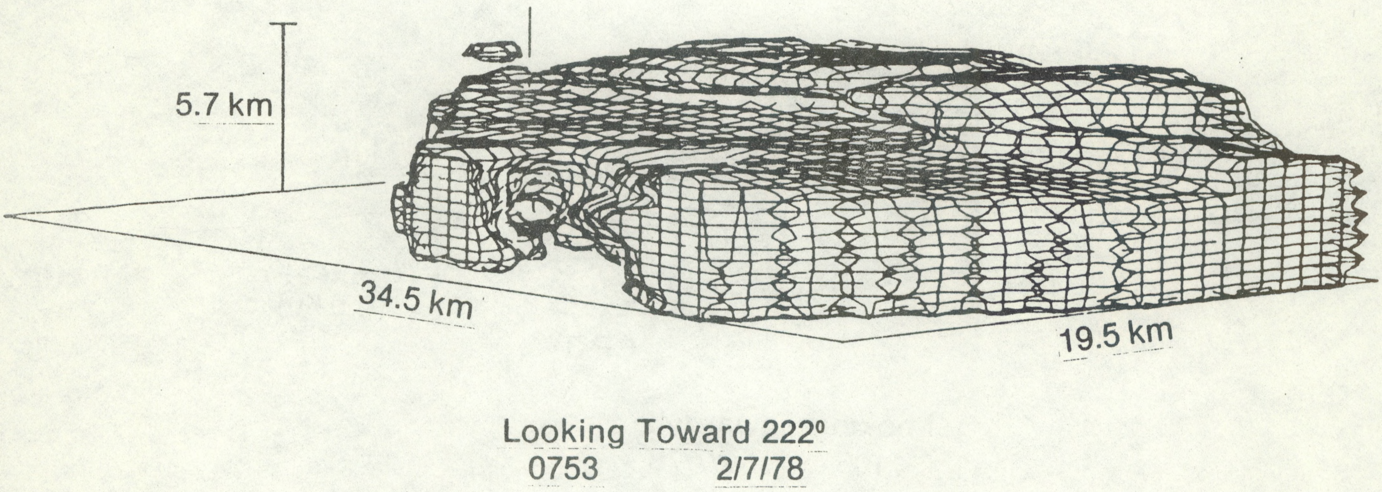

Figure 2.7--30-dBZ reflectivity contour (as in figure 2.6) with view toward 222°.

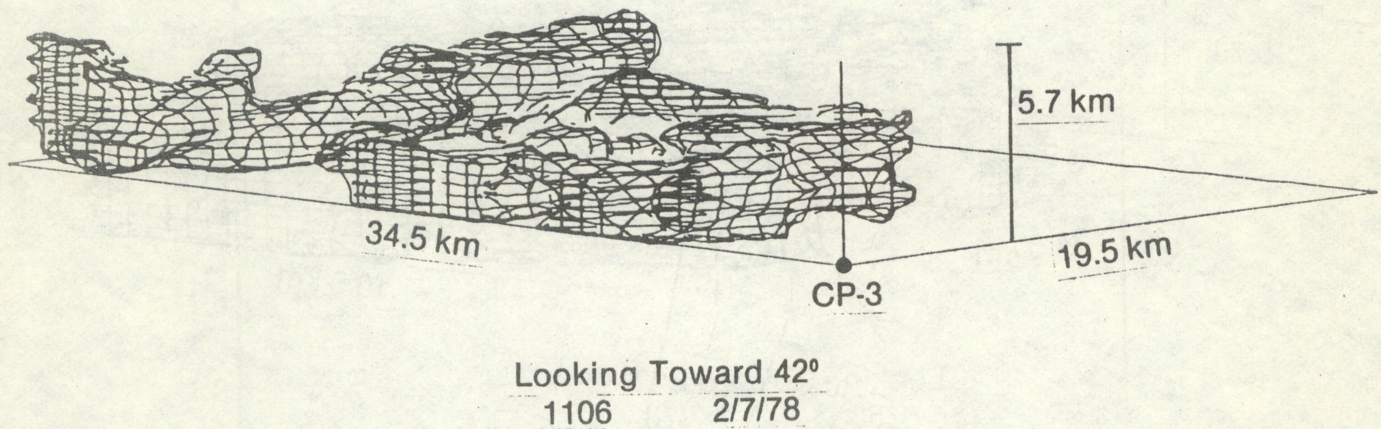

Figure 2.8--30-dBZ reflectivity contour (as in figure 2.6) for 1106 PST.

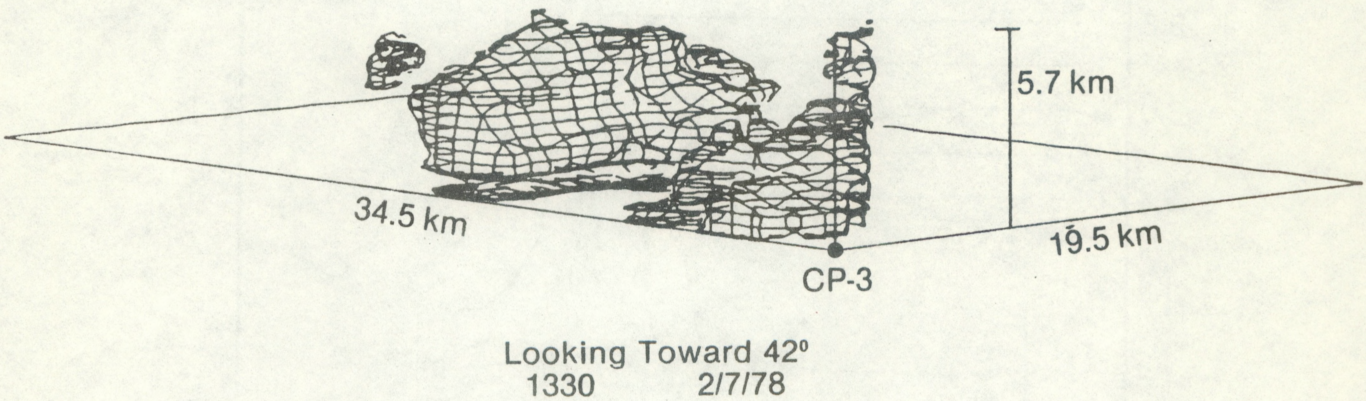

Figure 2.9--30-dBZ reflectivity contour (as in figure 2.6) for 1331 PST.

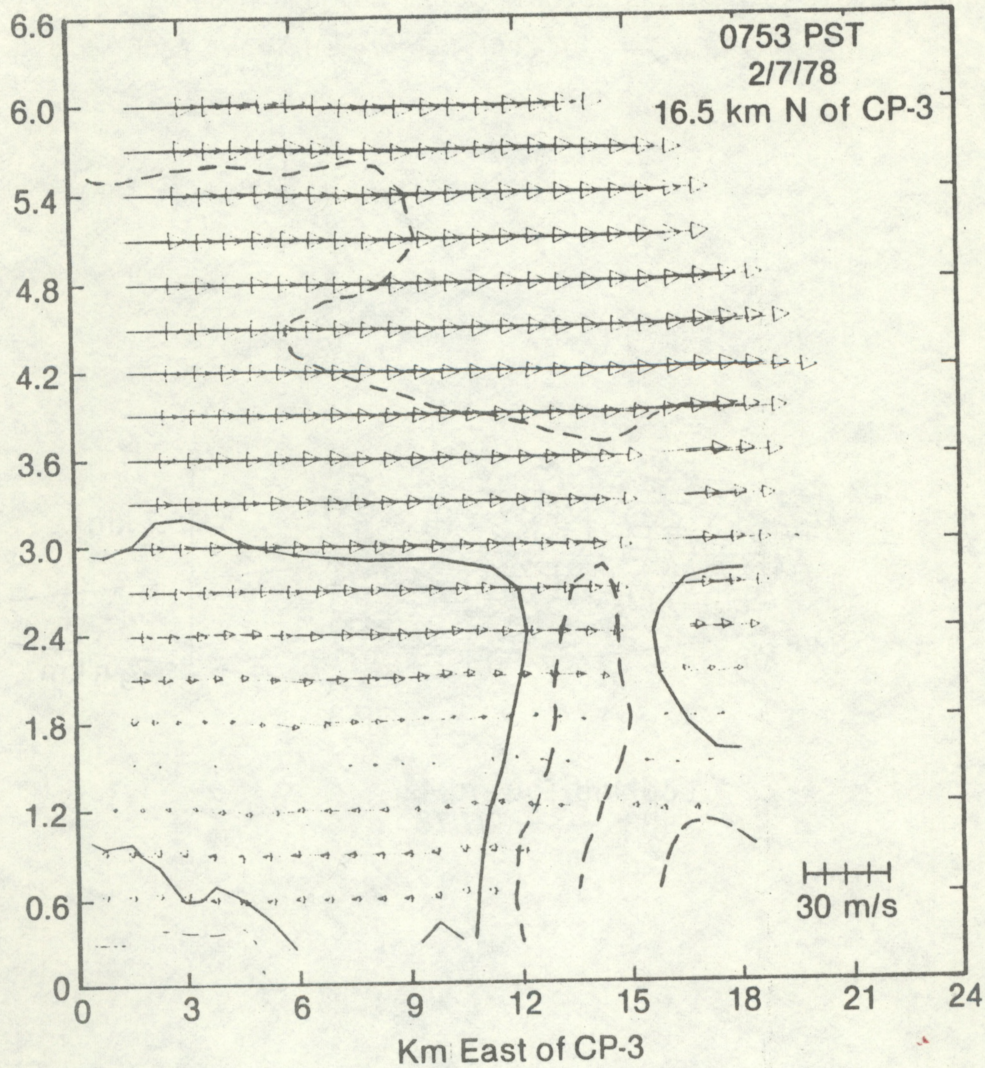

Figure 2.10--Total winds in a vertical east-west oriented plane 16.5 km north of radar CP-3, 0753 PST, 7 February 1978. Reflectivity contours: 20 dBZ (dashed), 30 dBZ (solid).

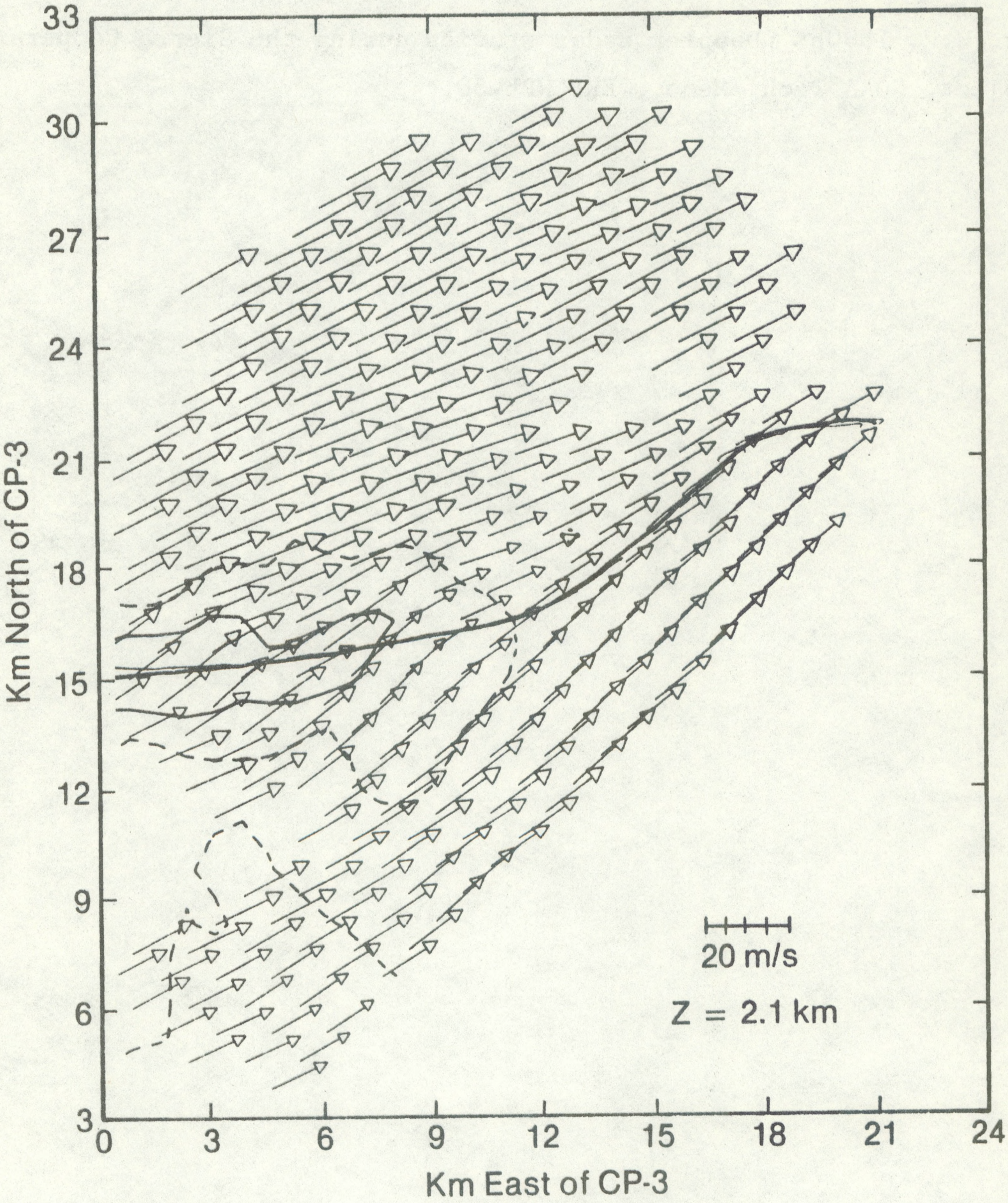

Figure 2.11--Horizontal winds at 2.1 km altitude, 1330 PST, 7 February 1978. Reflectivity contours: 20 dBZ (dashed), 30 dBZ (solid).

5. REFERENCES

Moninger, W.R., 1980a: Triple Doppler radar study of winter storms in the Sierra Nevada foothills, Preprints, 19th Conference on Radar Meteorology, April 14-18, 1980, American Meteorological Society, Boston, Mass.

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