WESTERN REGION TECHNICAL ATTACHMENT
NO. 03-05
May 28, 2003

A LOW LEVEL BLOCKING RIDGE ALONG WITH DOWNWARD MOTION ALOFT IN THE RIGHT FRONT QUADRANT OF THE UPPER LEVEL JET - A RECIPE FOR MINOR FLOODING AND HIGH WINDS

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INTRODUCTION

During the period 7-9 November 2002, urban and small stream flooding along with damaging mountain/desert wind developed over southern California (Fig. 1). Over 10 inches of rain fell in the San Bernardino mountains, tapering off to about 4 inches in the southernmost mountains. Urban and small stream flooding was reported in Mill Creek Canyon below Yucaipa Ridge, 40 miles east of Ontario CA (a location open to westerly flow with shear, rocky faces lining the canyon). No flash flooding was reported. In the mountain and desert areas mountain wave wind gusted to over 90 mph. Interestingly, although southern California was in the front-right quadrant of the jet with downward motion aloft (Moore and VanKnowe, 1992) nearly a foot of rain fell in the northern mountains. The very high 850 mb dew point (near 8 degrees C), usually more commonly associated with strong summer thunderstorms than winter rainfall, points toward extremely high moisture content and a warm rain process. The 850 mb temperature was well over the 5 degree C value generally needed to bring the snow level down to the ski resorts near the 6500 - 7000 foot level. (The freezing level was above 10,000 feet for the entire event). Coupled with a nearly saturated 850-700 mb layer, a strong, slow-moving low level jet at 850 mb of at least 20 knots, and a precipitation band slowed by very strong 850 mb blocking, it is suspected that a very efficient, warm rain process, amplified by upslope flow in the mountains, helped generate the copious rainfall. Mountain rainfall totals were about 4-7 times higher than coastal totals in the north, with even higher ratios in the south. Cross-sections, along with other data were taken to evaluate this scenario (figure 2). In this Technical Attachment (TA) we will analyze the event using the MesoETA model.

CASE COMPARISON

Many high accumulation events in southern California involve a very slow moving mean trough, its associated very strong jet, and a series of strong waves moving through the mean trough position as the trough moves slowly through California. In this case, figures 3a-d show a large, slow moving "anchor" low with an "anchor jet" that exceeded 200 knots at one time. Figures 3a-d show conditions at 1800 UTC 8 November 2002, 0000 UTC 9 November 2002, 1200 UTC 9 November 2002 and 0000 UTC 10 November 2002, respectively. The anchor jet, with two 160 + knot jet streaks (waves) moving through it (figure 3b), remains north of southern California during the entire event. Such strong 250 mb anchor jets and strong imbedded waves have been important features in the past for identifying strong pacific storms with copious rains in southern California. Small (1993) noted a "130 knot jet streak approaching the coast" as a key feature in the flash flood events in February 1992. For comparison, figure 4 shows the 2 large troughs and their associated strong 130+ knot (150 mph) jet streaks rotating through the mean anchor trough/anchor jet position during the 10-12 February 1992 cases. The anchor jet was oscillating from about 130 knots to over 170 knots as the waves moved through the mean trough/mean jet position. The jet streaks associated with the waves can be seen at 33N/130W and 33N/145W. In this case, the 130 knot jet streaks south of Southern California were strong enough to generate strong "negative tilt diffluent" troughs with very high rainfall rates in the convection and dynamics at and north of the jet axis. The first trough can be seen along the coast. During the 10-12 February 1992 event 1.55 inches of rain fell in one hour with 0.65 inches in 15 minutes on the 10th, and 1.64 inches fell in one hour on the 12th. Since the amounts were above 1.25 inches in one hour, they were at least good candidates for flash flooding in southern California. Flash flooding occurred on both the 10th and 12th of February 1992.

In contrast, the 7-9 November 2002 case had mainly light-moderate stratiform precipitation and no flash flooding. There was a strong upper level jet to the north, but no strong vorticity centers (no strong synoptic scale ascent) over southern California (Fig. 3a-d). Notice the relatively warm flow shown by the very high (mid 570's in decameters) 500 mb heights. There is also a very high (around 560 decameter) 1000-500 mb thickness over southern California. Infrared satellite imagery in figures 5 and 6 show the very powerful jet pulling moisture from a decaying tropical system at 1200 UTC 6 November 2002, adding copious moisture to the moisture stream seen flowing into southern California at 1200 UTC 9 November 2002. Figure 7a-d shows the 850 mb heights, wind, and 850-700 mb mean relative humidity at 1200 UTC 8 November 2002, 0000 UTC 9 November 2002, 1200 UTC 9 November 2002, and 0000 UTC 10 November 2002 respectively. From about KSNA northward there were a whopping 4 consecutive sounding times (a 36 hour period from 1200 UTC 8 November 2002 to 0000 UTC 10 November 2002) with 850-700 mb mean relative humidity greater than 80-85 %, along with relatively warm 850 mb winds between 20 and 40 mph for high rain accumulations at both coastal and mountain sites.

The pattern and timing of moisture increases in the vertical prior to rainfall depends on the event type ("bottom up", "top down", or both) and is critical for beginning and ending the rainfall event. During many of the lighter rainfall events in southern California, the moisture is generally surface based with little moisture aloft. These "marine layer events" are topped out around 3000 to 6000 feet with mainly night and morning precipitation. Similar to the effects of a "low strong inversion" (about 1300 feet/10 degree C) at the beaches, these 3000 foot and deeper marine layers usually result in low clouds lingering into the afternoon, and sometimes all day. They are characterized by a "bottom up" type deepening trend, during which the moisture deepens from the surface upward in moist zonal or cyclonic westerly flow (with an onshore flow and/or trend). Measurable rain can begin at about 4-6 thousand feet deep. Clouds around 2000 feet thick accompany "trace" events and about 3500-5000 foot thick clouds accompany the more isolated - scattered, measurable light rain events. Saturated layers 5000-6000 feet thick have delivered scattered - widespread 0.10-0.25 inch amounts with marine layers of only 6000 feet deep at KNKX. This is especially true when an eddy or fairly strong low level onshore flow (about 10-15 knots near 850 mb) results in upslope flow, a locally deeper marine layer, and highest rainfall in/near the mountains. With enough cold advection near 850 mb the inversion can weaken and "bust up" the solid cloud deck. In these cases the boundary layer will "convect", resulting in a transition from steady light rain to convective showers (especially when the air aloft is cold enough and the surface moist layer is a few thousand feet deep or deeper). As the event winds down, broken cloud decks can still be generated via solar heating with surface based moist layers that have thinned to only about 1500 feet deep. If the clearing progresses from the coast inland as the cool, stabilizing sea breeze air sweeps over the area ("reverse clearing"), then the moisture left over from rainfall can result in fog overnight in the inland areas that have cleared. [Some discussion and satellite imagery of a "showery/reverse clearing" pattern is shown in Small (1999)]. With the saturated, stationary/warm frontal type airmass such as the 7-9 November 2002 case, the fog actually develops with the rain rather than during the night after the rain event ends and the clouds clear.

As is common for cases with huge rainfall accumulations, the 7-9 November 2002 event started out as a "top down" event, with the moisture moving in aloft first. This "top down" moistening can occur any time of year via overrunning precipitation as a storm approaches, or when the flow turns south around the summer subtropical high. The precipitation from high based showers or isolated thunderstorms helps to moisten the lower layers. (Cold pool or heating-related convection is frequently reduced or delayed til the higher clouds move out, leaving a moist low/mid level airmass to convect. Consequently, until then, the tendency is toward a more "stratiform" precipitation). Figure 8a at 0000 UTC 8 November 2002 shows this upper level moisture moving in aloft to begin moistening the lower levels, partially by raining into it (usually rain finally reaches the ground when the 50 % relative humidity level lowers to about the 650 to 700 mb level). Next, the "bottom up" processes develop in the boundary layer as low level onshore flow increases, as seen in figure 8b. Figure 8b at 1200 UTC 8 November 2002 shows the classic warm advection sounding. There is a nearly saturated layer of increased stability (an inversion in this case) between about 900 mb and 700 mb with a very impressive 8 degree C 850 mb dew point and strong winds. Figure 8c shows summer-like precipitable water values [locally in excess of 1.5 inches (well over 2 times normal for the cool season)] which persisted between 1.25 and 1.50 inches for the entire event. Even 1 inch of precipitable water is quite high for the cool season. The very moist airmass in the lower-mid levels is apparent in this case. There was strong low level flow at 850 mb (20 knots or greater). The high freezing level/snow level confirms that the airmass was very warm. The high heights (mainly around 570 decameters), high thicknesses (mainly in the low 560s in decameters), along with high precipitable water values (above 1.25 inches, which is above 2 times normal) resulted in a very efficient warm rain process. As a matter of fact, the 850-700 mb airmass was nearly saturated (above 90 percent) much of the time with 850 mb wind speeds in the 25-40 knot range.

As for blocking, the strong gradient in the 850 mb heights, or a "low level blocking 850 mb ridge" (for example, figure 9a) is a good indicator that the baroclinic band and possibly heavy rain, snow, etc, may linger over an area, making the area vulnerable to additional waves in the baroclinic zone. The 850 mb height difference of over 110 meters between the Tucson (KTUS) and Desert Rock (KDRA) indicated a strong south to north height gradient, strong westerly flow, and very slow southward movement of the front for continued large rainfall accumulations northern coastal areas. The coastal rain amounts were then dramatically magnified in the mountain areas. This height gradient reflects the surface pressure gradient shown in figure 9b.

On the other hand, potentially higher rainfall rates can occur when this 850 mb gradient is more east-west [blocking ridge in the form of a large 850 mb height gradient between Miramar (KNKX) and Tucson (KTUS)]. Figure 10a-b shows examples of very strong south-north and east-west blocking for comparison using the 850 mb heights and winds. Figure 10a shows the "zonal" case, with very strong (about 140 meters over 400 miles) south to north blocking and a 45 knot westerly low level jet. In this type of situation the stronger portion of the wave and associated dynamics pass by to the north. Figure 10b is the more "volatile" case, with a very strong (about 80 meters over 400 miles) east to west blocking and a 30 knot jet (southerly flow). In these cases the negative tilt trough and strong dynamics approach from the west. Usually, for the volatile east-west (or "front-side') blocked cases, about 30-60 meters of blocking (strong) is a significant concern. [As a matter of fact, of the 7 storms with blocking that reached at least 60 meters (very strong front-side blocking) between 1998 and 2002, 6 resulted in at least 1.25 inches of rain at KSAN, which is about one-eighth of the annual rainfall]. During these "east-west blocked" events (commonly seen with negative tilt diffluent troughs) there is a strong southerly (or even southeast) flow as the surface low wraps up and moves north. Consequently, the strong low level jet and the frontal band with very high rainfall rates stalls, or moves very slowly east across southern California. Also, this pattern can result in a strong subtropical or even tropical connection and rapidly bring up huge amounts of moisture from the ITCZ and surrounding area well to the south (between the equator and about 10 degrees north).

As for wind, figure 9a shows the 850 mb heights, 700 mb wind and the 850 mb wind at 0000 UTC 9 November 2002, near the period of strongest surface wind [maximum sustained wind of 66 mph with a gust to 93 mph at Burns Canyon (BNY) on the eastern slopes of the San Bernardino Mountains]. The 850 mb winds of 30-40 knots, the 50-60 knots at 700 mb, and the synoptic scale downward motion associated with the right front quadrant of the upper level jet easily supplied the upper level support to generate these surface winds. Sustained surface winds that equaled the 850 mb winds, and isolated gusts around twice the 850 mb wind speed (well above the maximum 700 mb wind speed) developed. The strong south to north 850 mb height gradient accurately reflects the south to north surface pressure gradients of over 14 mb from the KLAX/KSAN area on the southern California coast to a 999 mb low over southern Nevada in the KLAS/KTPH area (figure 9b). Unlike the strong east-west blocking usually found with the negative tilt diffluent trough events, the east-west blocking was only a paltry 20 meters. It was the huge south-north blocking of over 110 meters (indicative of a strong westerly low level jet) that stalled the baroclinic band and slowed the movement of the region of heaviest precipitation in this case.

Figure 2 shows the location of the cross section used in figure 11a-b. Figure 11a at 0000 UTC 9 November 2002 shows deep moisture in westerly flow up to the mountain crest, with downslope flow and drying below mountain crest east of the mountains [Although there was over 10 inches of rain in the mountains, the southern deserts (KPSP and KTRM) did not receive measurable rain, which is an interesting characteristic of many westerly zonal flow events]. Deeper moisture and/or a more easterly flow is usually needed for significant precipitation in the southern deserts.

SUMMARY AND CONCLUSION

Long-duration high accumulation events are a significant forecast problem. They can develop when the region of moderate or heavy precipitation along a baroclinic band slows or stalls (possibly due to blocking of the 850 mb jet by a strong height gradient/blocking ridge at 850 mb). In these cases the potential exists for waves in the flow to periodically enhance the precipitation on these slow moving, blocked bands. The wind driven moisture flux/moisture convergence results in a very moist airmass (mean relative humidity of 80-85 percent or more) in the 850-700 mb layer. (During many southern California rain events, the deep moisture will extend no higher than the 850-700 mb region, so the characteristics of a storm can often be determined by looking at the wind, relative humidity, and instability in this layer). During the more extreme cases, a nearly saturated airmass extends from the surface to well above 500 mb. With 4 raobs meeting this 850-700 mb 80-85 % value, the isolated urban and small stream flooding during the 7-9 November 2002 storm was more of a "duration" (prolonged rainfall) and "frequency" (back to back waves in moist westerly flow) problem rather than an "intensity" (rainfall rate) problem. Basic ingredients in the case include a very powerful jet aloft driving a strong low level flow of 20-30 knots or more at 850 mb. This is coupled with a warm airmass extending upward into the 850-700 mb layer, moistened to at least 80-85 % mean relative humidity. Just as important are 850 mb dew points in excess of about 5 degrees C (usually associated with strong summer thunderstorms), which indicate a very warm (and usually saturated) airmass during the cool season. Dew points of that magnitude generally correspond to precipitable water values over an inch (approximately 2 times normal). The 5+ degree C 850 mb temperature also indicates a high freezing level (above about 6500-7000 feet) and a warm rain process in place. Very powerful jet streams that exceed about 200 mph (or about 175 knots) in southern California can easily produce these parameters, especially with a subtropical moisture fetch. One of these monsters can easily produce storm total precipitation of a foot or more from multiple imbedded waves or a series of storms. This is especially true north of the jet axis in the dynamics and convection, where very high rainfall rates can more frequently occur resulting in periods of high rainfall frequency (waves rotating through the mean trough position) and duration. Although the synoptic scale downward motion associated with the right front quadrant of the upper level jet helps transport some momentum downward to the low level jet, the drying effect of the subsidence aloft is easily counteracted by the strong moisture convergence and upslope flow near the surface over and west of the mountains. In this case the low level mechanics prevail over upper level jet dynamics and high rainfall totals still occur.

As for wind, flow direction is important for offshore flow patterns as well as for southwest through northwest wind patterns. Due to mountain/canyon orientation, northeast (southwest) winds are optimal for waves and gap flow in the northern portions of the San Diego CWFA, whereas a more easterly (westerly) flow favors waves and gap flow in the southern portions of the CWFA. When the flow direction is optimal (and usually associated with surface pressure gradients of about 3.5 mb or more between the coast and local deserts), gusts seem to reach about 2 times the 850 mb wind speed in the favored areas where the wave surfaces. This is especially true for winds upward of about 25-30 knots at 850 mb (or about 50 knots at 700 mb). In this 7-9 November 2002 west wind case, synoptic scale downward motion in the right front quadrant of the jet, although not able to reduce the rainfall west of the mountain ridge line, actually couples with mountain wave activity to help surface the winds in the mountains and deserts. The 850 mb and 700 mb winds near 40 knots and 60 knots respectively resulted in local mountain wave winds in excess of 60 mph with gusts over 90 mph at BNY, (a "favored area" during west wind patterns). To further complicated matters, a "Palm Springs Rotor" brought east wind gusts to18 knots to KPSP, while at the same time west wind gusts reached 44 knots 20 miles away at KTRM. With little rain, wind gusts to 40 mph can result in at least local visibilities of 1/4 mile or less in blowing sand and dust, making the forecast problem surrounding wind events even more challenging. This 7-9 November 2002 case was no exception.

REFERENCES

Moore, J. T., and G. E. VanKnowe, 1992: The Effect of Jet Streak Curvature on Kinematic Fields. *Mon. Wea. Rev.*, **120**, 2429-2441

Small, I. J., 1999: An Observational Study of a California Bight Coastal Convergence Zone Produced by Flow Interaction With Mainland Topography: Precipitation Producer in Southern California. Western Region Technical Attachment No. 99-19, http://www.wrh.noaa.gov/wrhq/99TAs/9919/index.html

Small, I. J., 1993: The February 1992 Record Flash Flood Events In Southern California. Post-Print Volume, Third National Heavy Precipitation Workshop, Pittsburgh, Pennsylvania, November 16-20, 1992. NOAA Technical Memorandum No. ER-87, 139-148, 8 pp. http://www.ntis.gov/

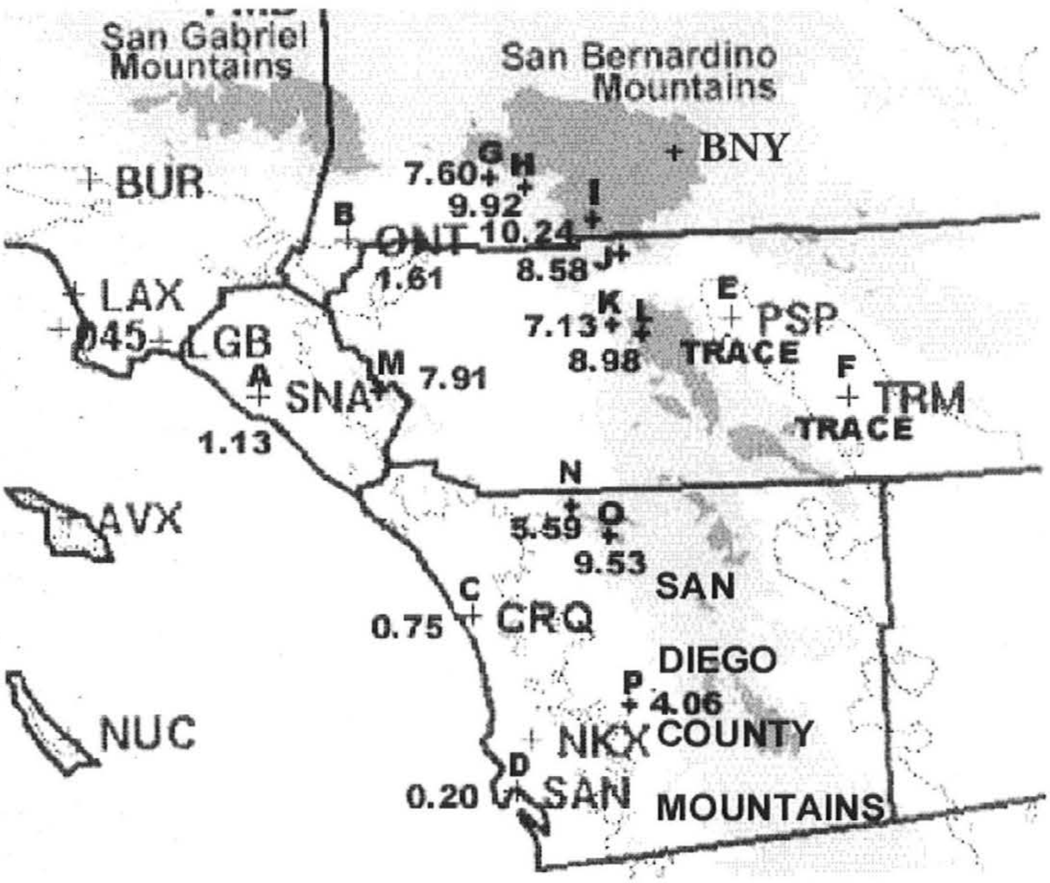

Fig. 1. A map of selected rainfall totals (in inches) for the period November 7-9, 2002. The locations and elevations are as follows:

A) SNA - Santa Ana Airport (135 feet MSL)
B) ONT - Ontario Airport (943 feet MSL)
C)CRQ - Carlsbad Airport (328 feet MSL)
D) SAN - San Diego Lindbergh Field (15 feet MSL)
E) PSP - Palm Springs Airport (425 feet MSL)
F) TRM - Thermal Airport (-117 feet MSL)
G) Panorama Point (3881 feet MSL)
H) Plunge Creek Canyon (3582 feet MSL)
I) Yucaipa Ridge (9020 feet MSL)
J) Tick Ridge (4560 feet MSL)
K) Vista Grande (4920 feet MSL)
L) Pine Cove (6300 feet MSL)
M) Santiago Peak (5649 feet MSL)
N) Oat Flats (3068 feet MSL)
O) Birch Hill (5645 feet MSL)
P) Mt. Woodson (1720 feet MSL)

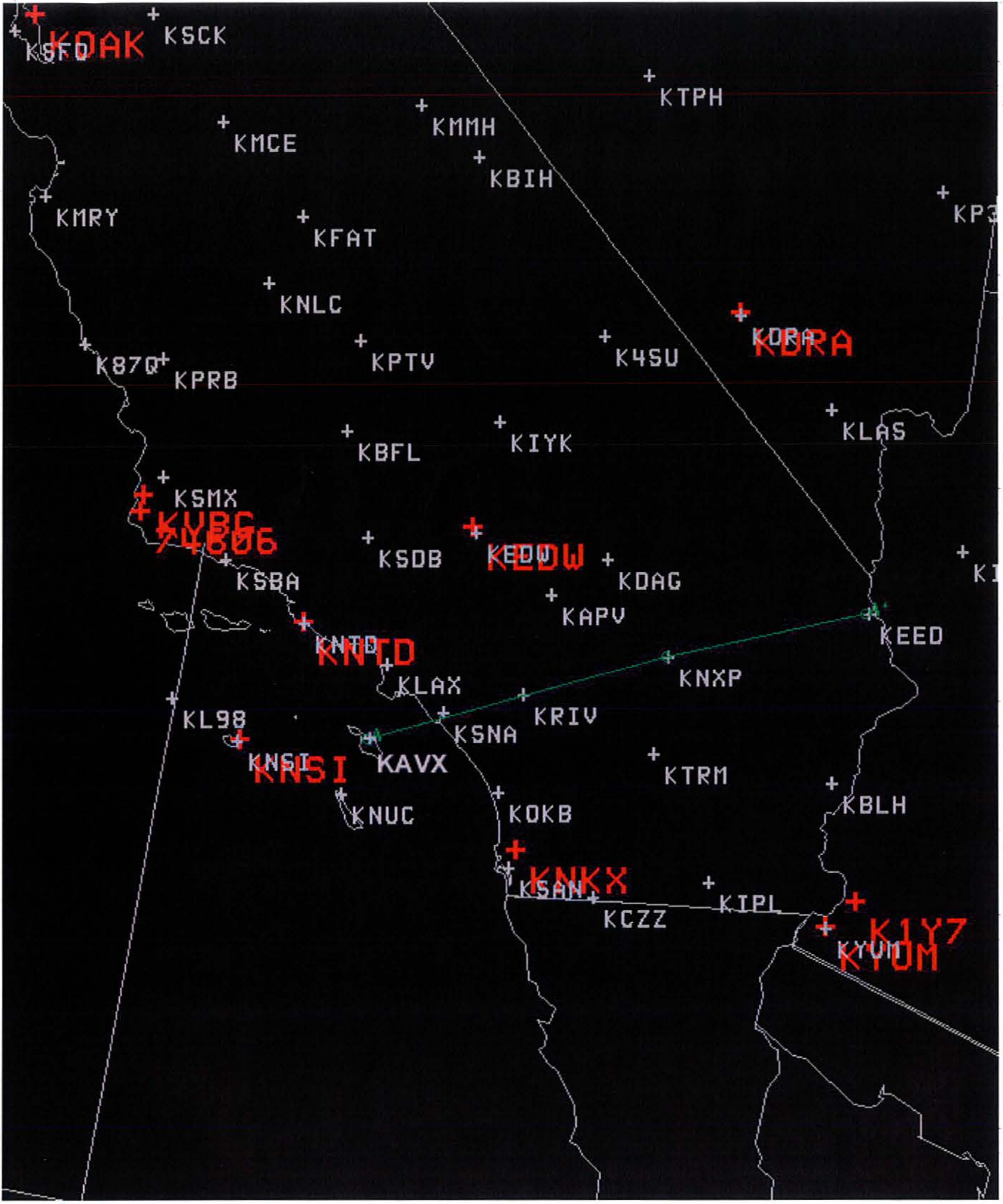

Fig. 2. Green line is the location of the cross-secti
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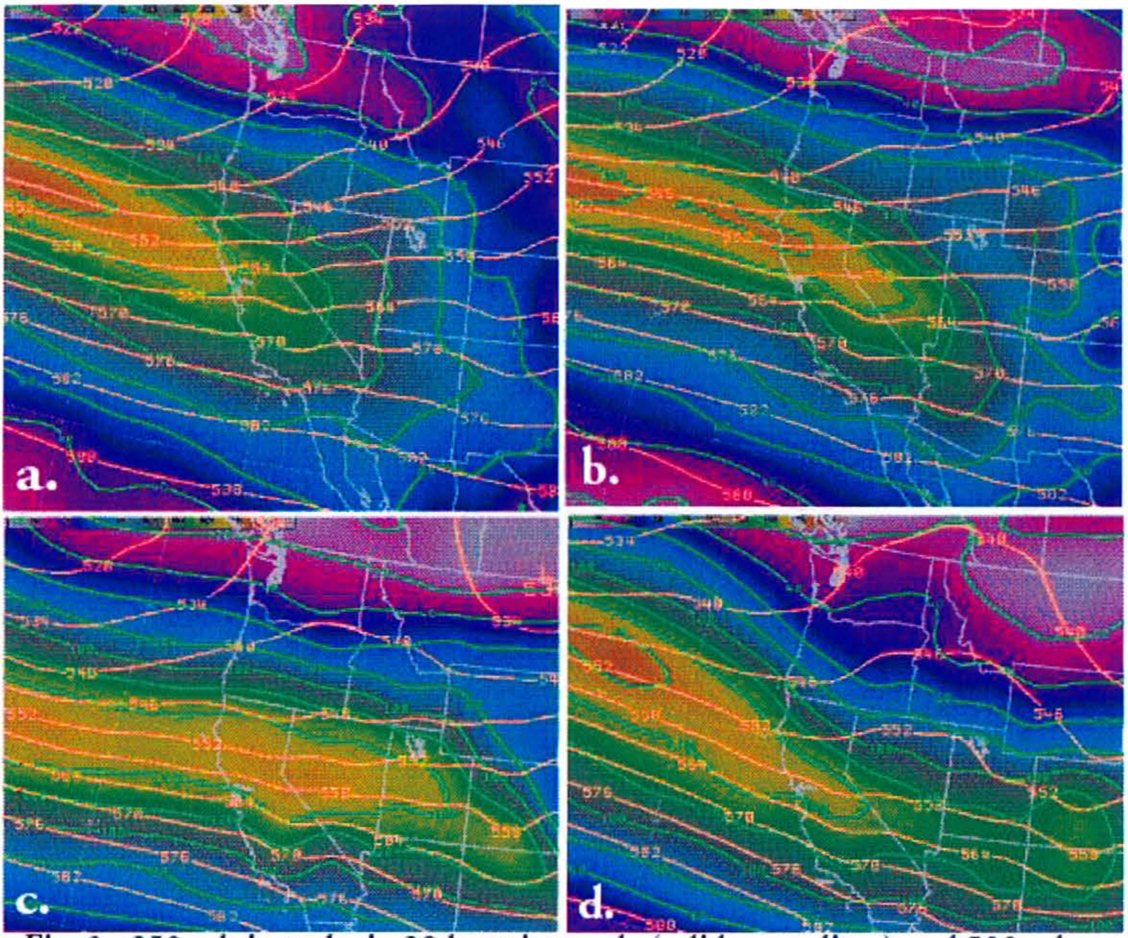
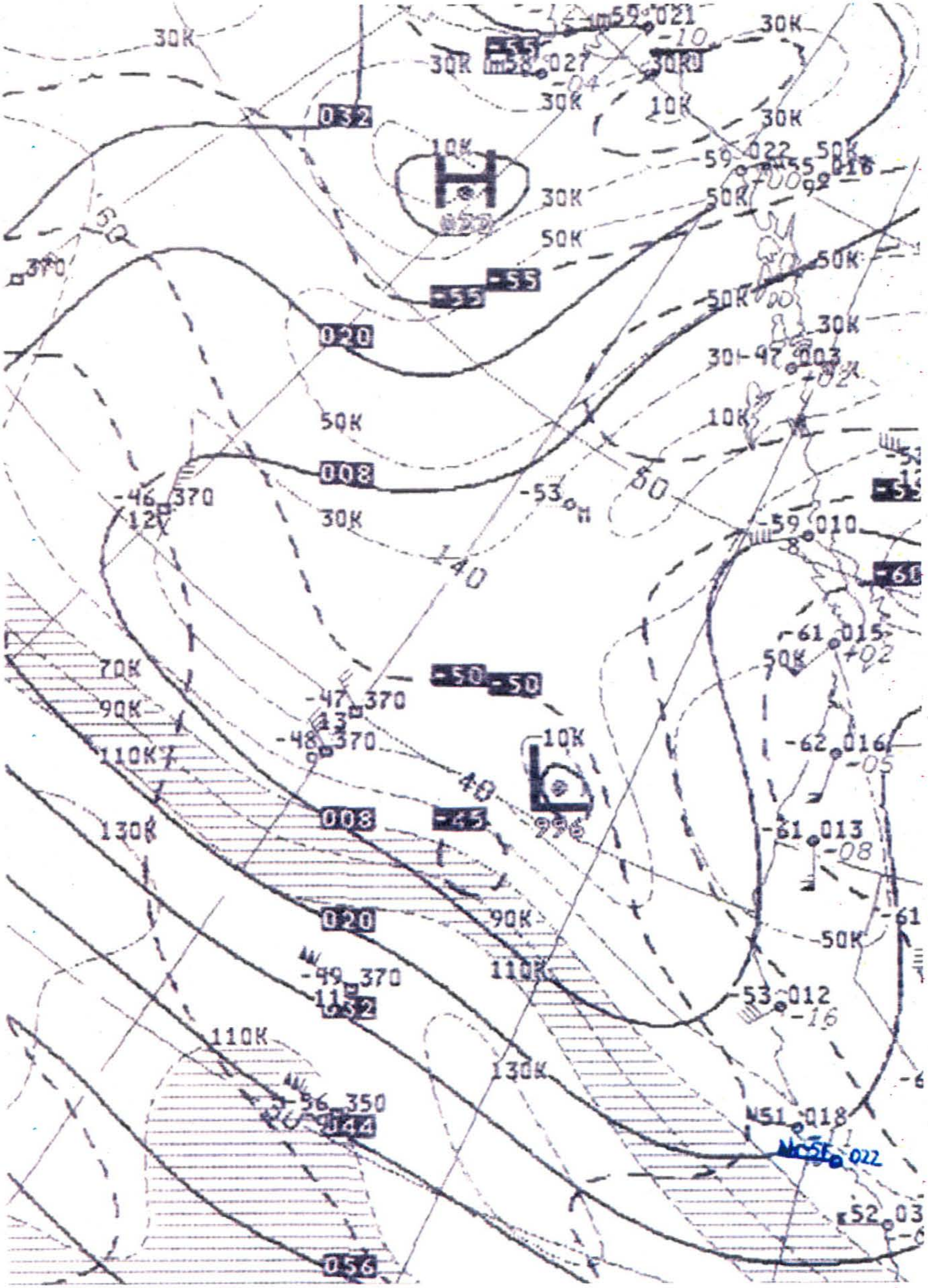


Fig. 3. 250 mb isotachs in 20 knot intervals (solid green lines) and 500 mb heights in 60 decameter intervals (solid orange lines) at (a) 1800 UTC 8 November 2002 , (b) 0000 UTC 9 November 2002 , (c) 1200 UTC 9 November 2002 and (d) 0000 UTC 10 November 2002.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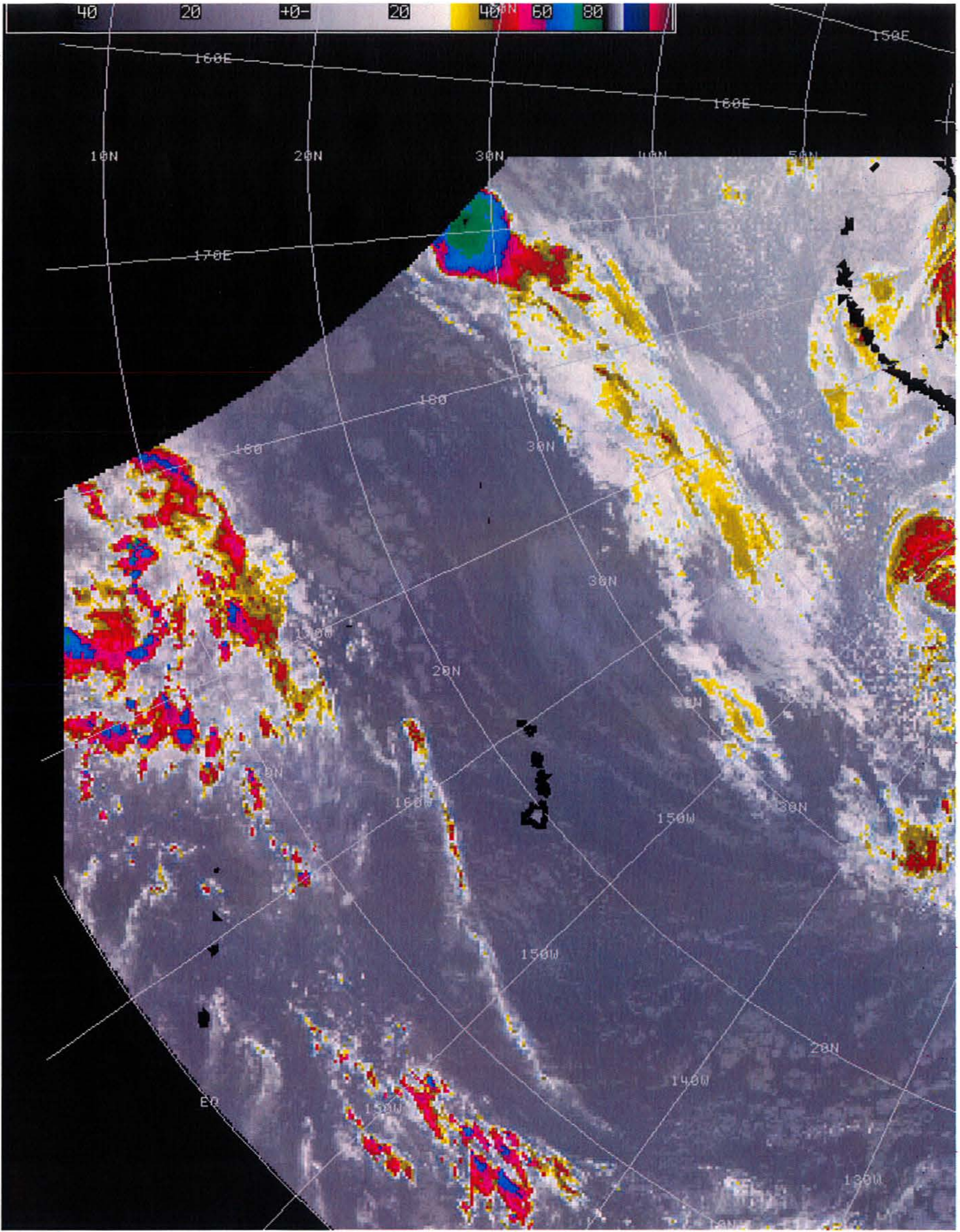


Fig. 5. 1200 UTC 6 November 2002 infrared

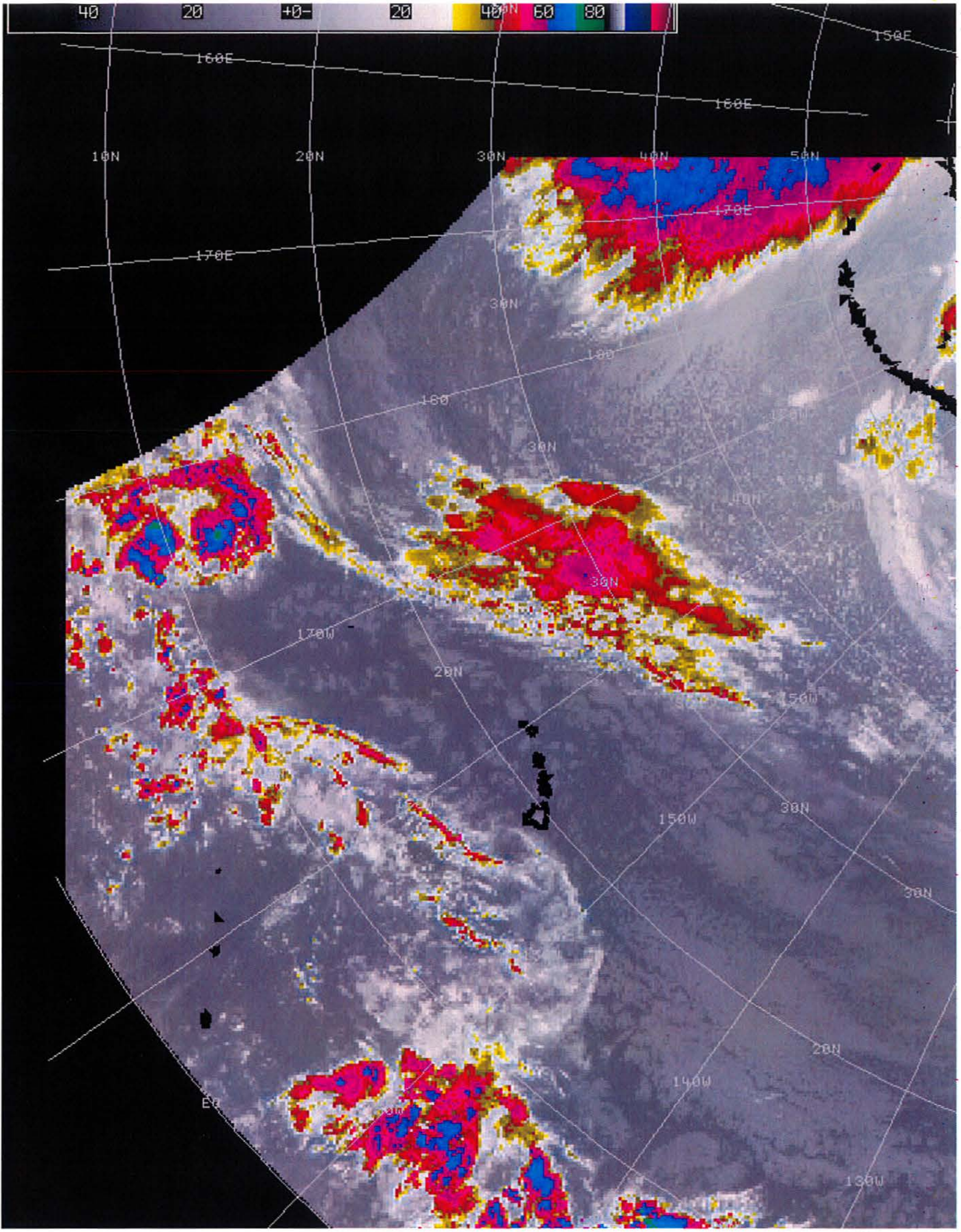


Fig. 6. 1200 UTC 9 November 2002 infrared

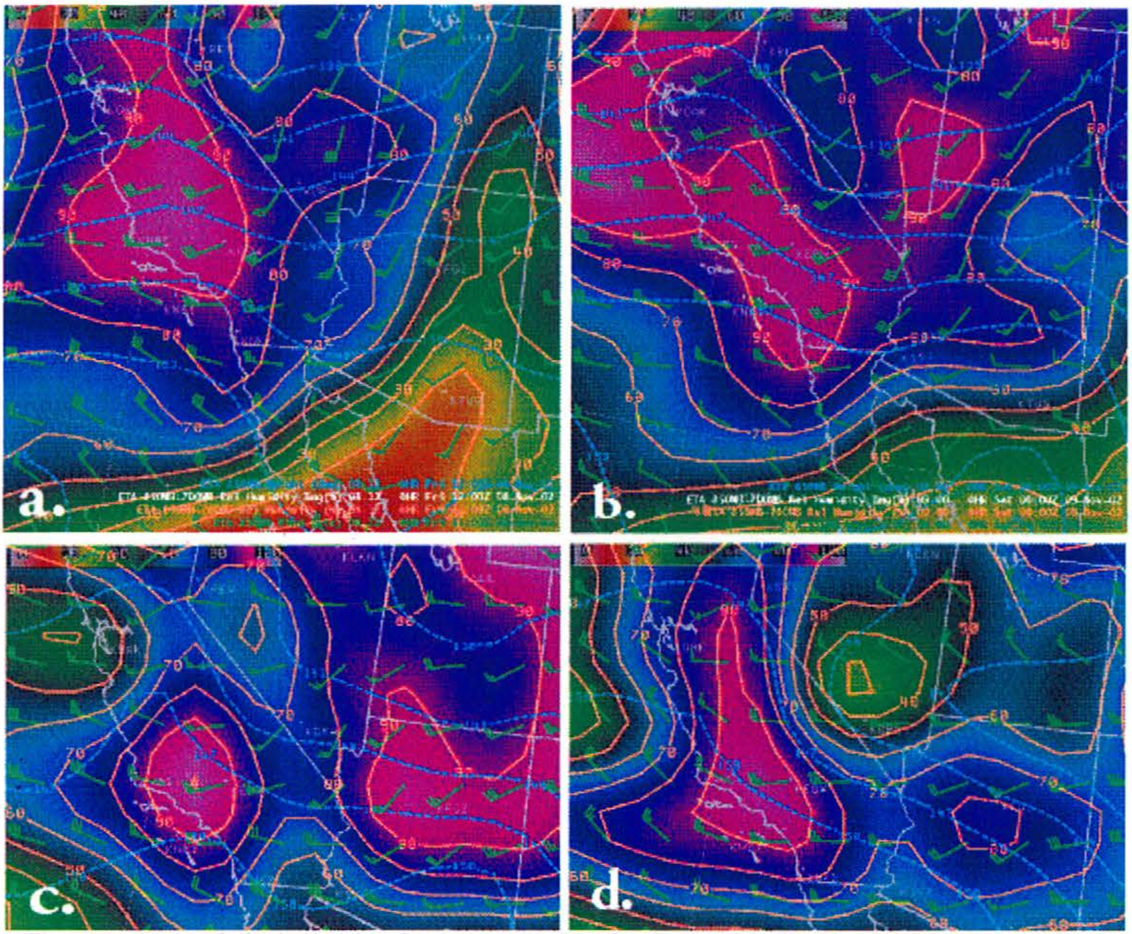
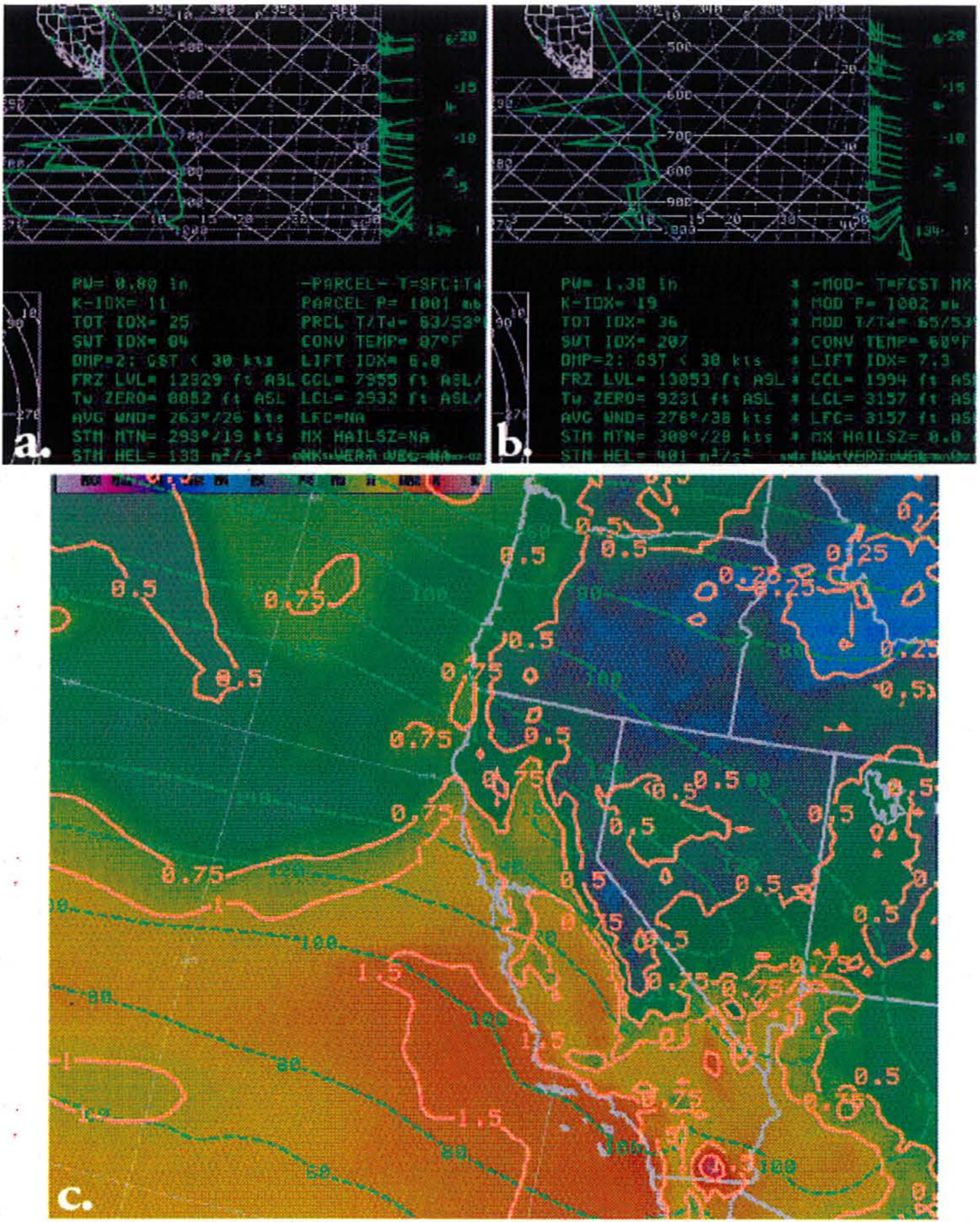


Fig. 7. 850 mb heights in decameters (dashed), 850 mb winds (knots) and 850-700 mb mean relative humidity, in intervals of 10 percent (solid) valid at (a) 1200 UTC 8 November 2002, (b) 0000 UTC 9 November 2002, (c) 1200 UTC 9 November 2002, and (d) 0000 UTC 10 November 2002.



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TOT IDX= 25           PRCL T/Td= 63/53°
SWT IDX= 84           CONV TEMP= 87°F
DMP=2: GST < 30 kts   LIFT IDX= 6.8
FRZ LVL= 12929 ft ASL CCL= 7955 ft ASL/
Tw ZERO= 8852 ft ASL  LCL= 2932 ft ASL/
AVG WND= 263°/26 kts  LFC=NA
STM MTN= 293°/19 kts  MX HAILSZ=NA
STM HEL= 133 m²/s²
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K-IDX= 19             # MOD P= 1002 mb
TOT IDX= 36           # MOD T/Td= 65/53
SWT IDX= 207          # CONV TEMP= 60°F
DMP=2: GST < 30 kts   # LIFT IDX= 7.3
FRZ LVL= 13053 ft ASL # CCL= 1994 ft AS
Tw ZERO= 9231 ft ASL  # LCL= 3157 ft AS
AVG WND= 276°/38 kts  # LFC= 3157 ft AS
STM MTN= 308°/28 kts  # MX HAILSZ= 0.0
STM HEL= 401 m²/s²
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Fig. 8. KNKX sounding at (a) 0000 UTC 8 November 2002 and (b) 1200 UTC 8 November 2002. (c) 0000 UTC 9 November 2002 250 mb isotachs in knots (dashed lines) and precipitable water (inches).

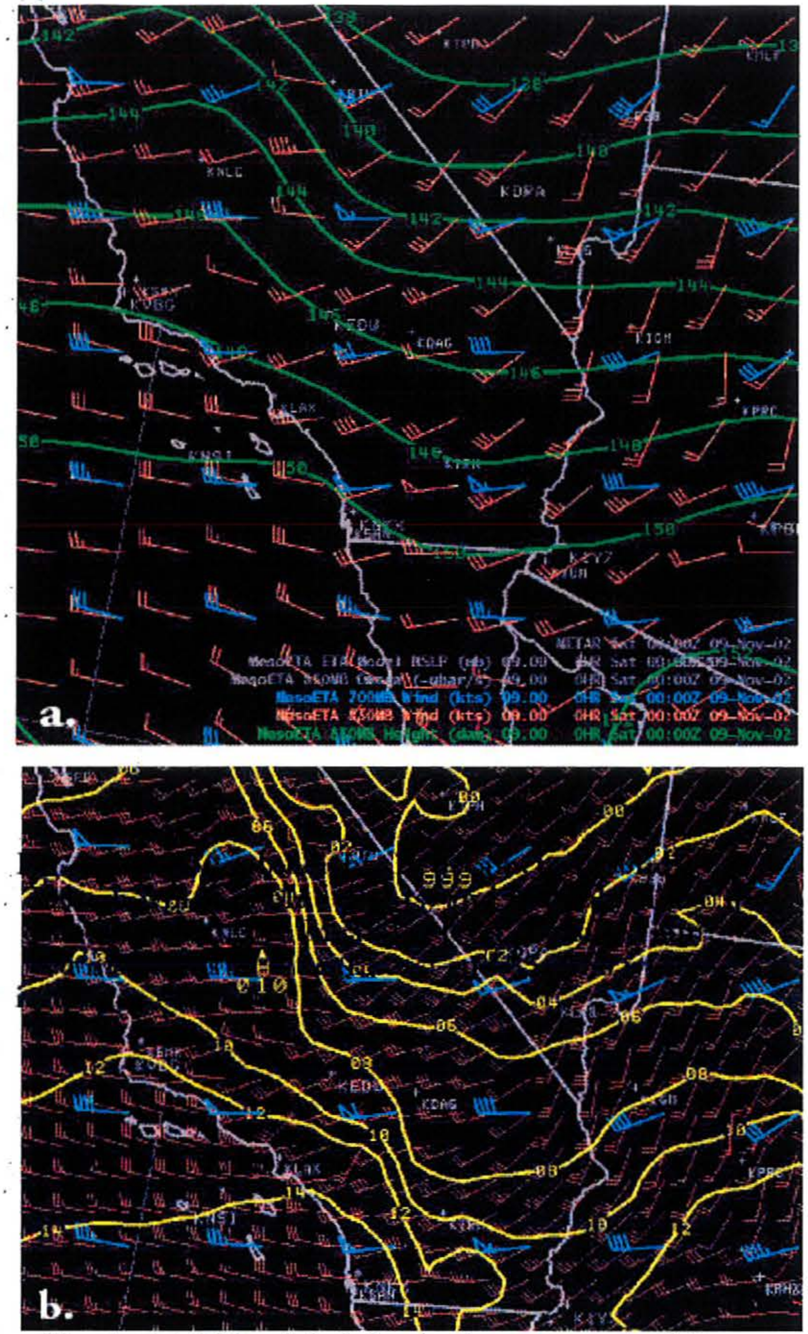
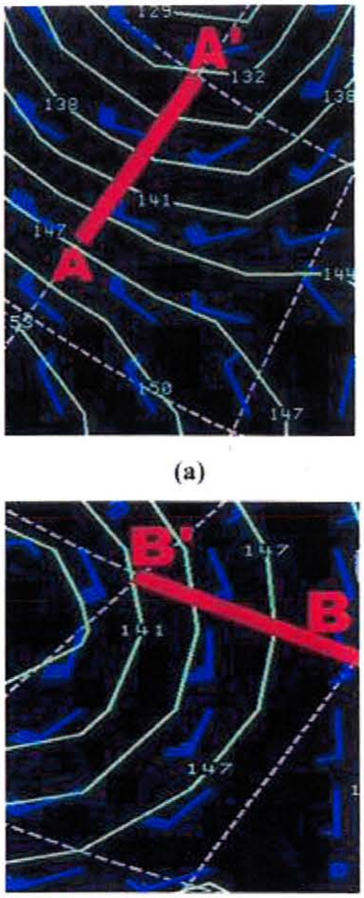


Fig. 9. (a) 850 mb heights in decameters (solid), 700 mb winds in blue (knots) and 850 mb winds in orange (knots). (b) Mean sea level pressure (mb), 700 mb winds in blue (knots) and 850 mb winds in orange (knots).



(a)

(b)

Fig. 10. Examples of south-north blocking verses east-west blocking using 850 mb heights (intervals of 3 decameters) and wind speed (knots). Red lines are approximately 400 miles in length. (a) Very strong (about 140 meters over 400 miles) south to north blocking and a 45 knot low level westerly jet (zonal flow), with the wave and most of the dynamics passing by to the north. (b) Very strong (about 80 meters over 400 miles) east to west blocking and a 30 knot jet (southerly flow), with a negative tilt trough and strong dynamics approaching from the west.

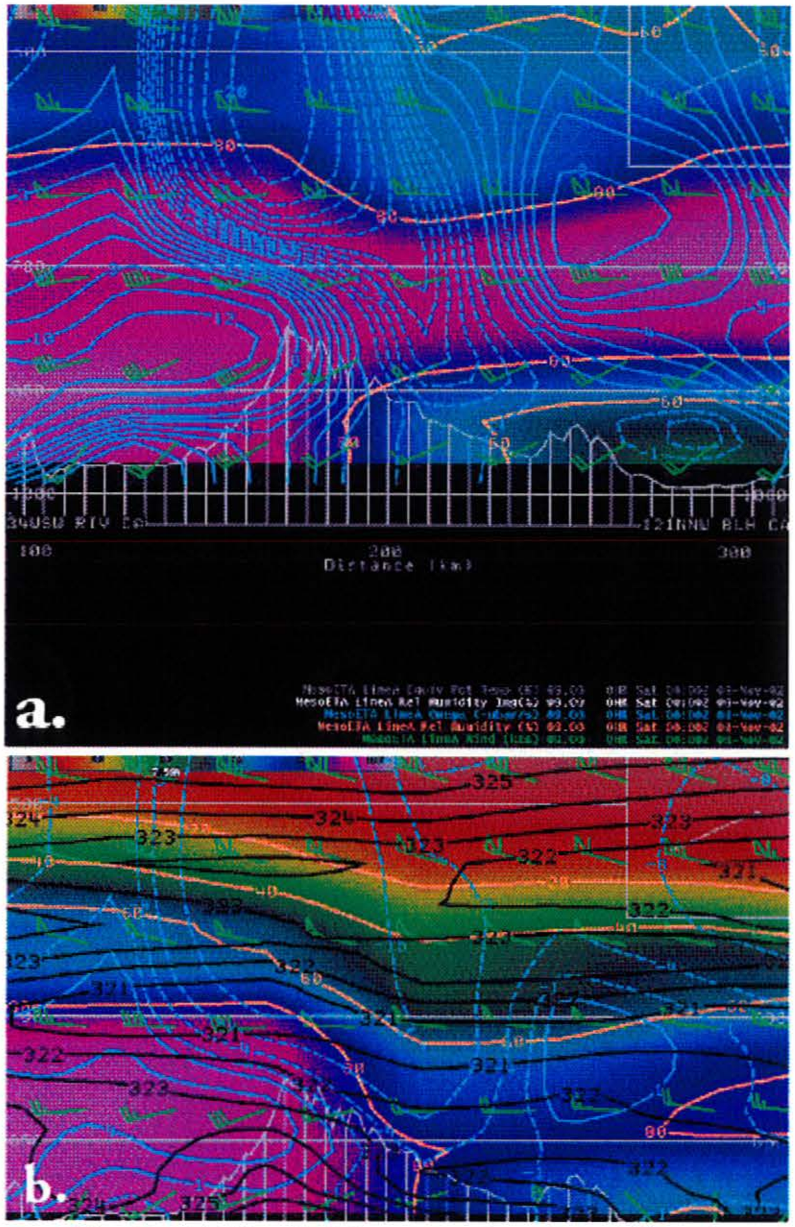


Fig. 11. (a) Time/height crossection of wind (knots), vertical velocity in microbars per second (dashed blue lines) and relative humidity in percent (solid orange lines) at 0000 UTC 9 November 2002. (b) Time/height crossection of wind (knots), vertical velocity in microbars per second (dashed blue lines), relative humidity in percent (solid orange lines), and potential temperature (solid black contours) at 0900 UTC 9 November 2002.