

# REPLY TO COMMENTS ON "HEAVY SNOWFALL DURING AN ARCTIC OUTBREAK ALONG THE COLORADO FRONT RANGE"

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We thank Dr. Auer for his interesting comments (Auer, 1991) on our manuscript (Wesley *et al.*, 1990, hereafter referenced as WWP). The components of his note are particularly useful due to his extensive experience in observing snowstorms for many years in this region.

Certainly, the extreme arctic outbreaks of the type which occurred 1–5 February 1989 may occur only about once or twice per decade in this region, and our experience supports this qualitative estimate. However, less extreme but dynamically similar events, such as 9–10 February 1988 (Wesley and Pielke, 1990), 19–23 December 1990, 19–25 December 1983, etc., are much more common, and still are characterized by overrunning-induced snowfall, though usually for a shorter period of time. Thus the scenario described in WWP may not

be as unusual a weather situation as Dr. Auer implies in his first paragraph. It is a common occurrence along the Front Range for surface pressure to increase rapidly as snowfall increases in intensity.

Much of the discussion in the second paragraph of Dr. Auer's note seems to agree with the major points of WWP. One important point: most of the average terrain height along the Continental Divide in northern Colorado and southern Wyoming ranges from 7000 to 10000 ft MSL. In the case of the February 1989 storm, the deepening of the cold air to and above 10,000 ft was followed by propagation of the cold air westward, over the Divide and down the western slope of Colorado. In fact, this 'spillover' induced extremely heavy snowfall in those regions. We feel that westward propagation in this type of storm is inevitable if the cold air deepens to a height greater than the average barrier height, given the

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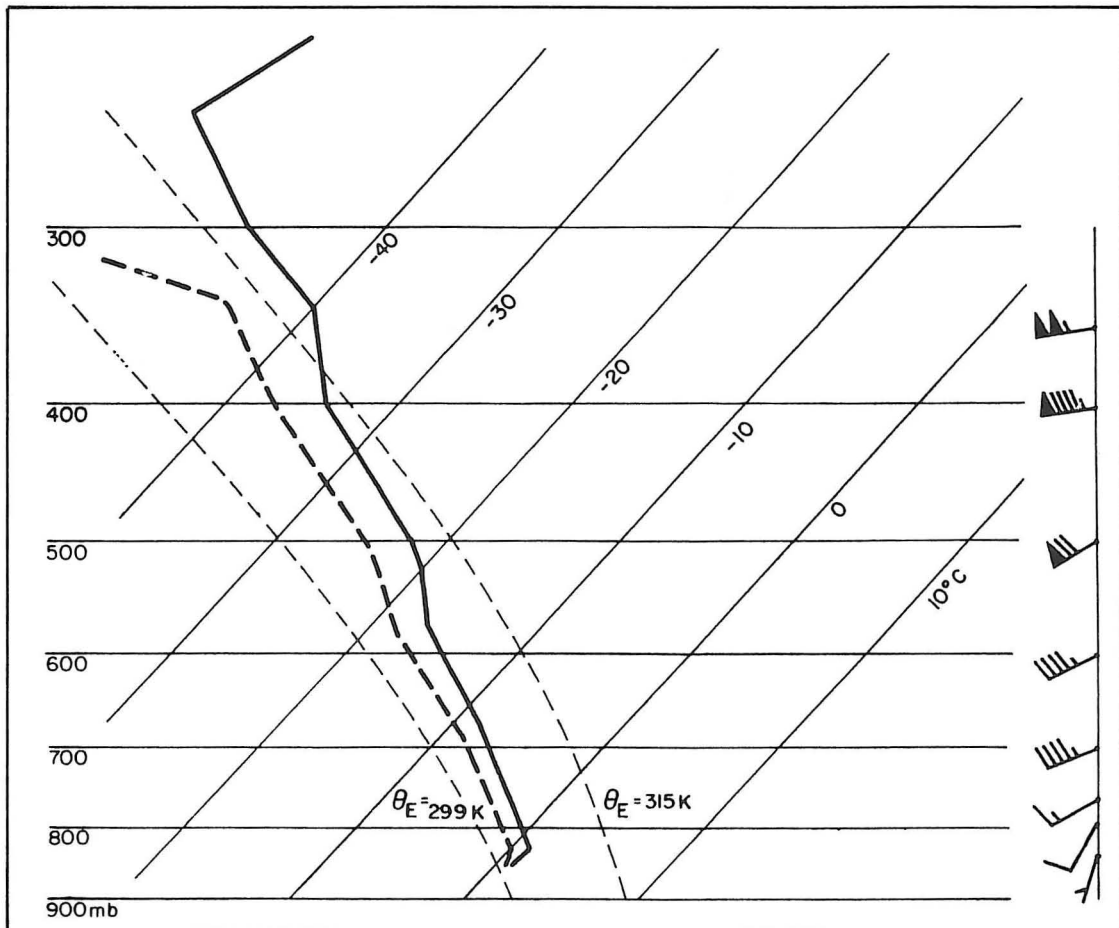


Fig. 1. Skew-T diagram for GJT radiosonde data at 0000 UTC 4 February 1989. Isotherms (in Celsius) are the diagonal solid lines. Dashed lines are selected moist adiabats.

dense, coherent and persistent nature of this air mass.

During our initial analyses, we examined the radiosonde data from Grand Junction, Colorado (GJT) along with many other relevant surface and sounding data during this storm. In obtaining a representative sample of the low-level overrunning air mass, the profiles measured at GJT were probably more appropriate than local surface observations at Craig, Eagle and Rifle, for example. Also, the persistent wind direction of  $240^\circ$  in the mid-levels at GJT conveniently places FCL directly downstream of GJT. We repeat the important aspects of those profiles here.

Relatively warm, moist conditions developed at GJT during the 4-day period as westerly flow strengthened. At 0000 UTC 3 February, surface temperature and dew point at GJT were  $+10^\circ\text{C}$  and  $-5^\circ\text{C}$ , respectively. A nearly dry adiabatic lapse rate characterized the layer from the surface to about 600 mb, with increasing relative humidities to nearly 70% at 600 mb, and southwesterly winds increasing from 20 to 50 knots through the layer. By 0000 4 February (see Fig. 1), the atmosphere above GJT was nearly saturated up to 400 mb, with surface temperature just above freezing. Winds in the 800–600 mb layer had veered slightly to approximately  $250^\circ$  and strengthened. Twelve hours later, after a strong short-wave had passed to the east, surface temperature remained at freezing, with a strongly stable lapse rate to 800 mb, and a nearly dry adiabatic profile to 700 mb. The lapse rate above this level was slightly more stable. The dew point profile revealed nearly saturated conditions at the surface and in the 700–550 mb layer. At 800 mb, the relative humidity was 67% within a shallow, drier region. Winds remained west-southwesterly and strong through the 800–400 mb layer.

This time period (0000 UTC 3 February to 1200 4 February) covers most of the periods of heavy snow observed at FCL (see WWP). Upon comparison with the Denver soundings in

Fig. 5 of WWP, the GJT profiles agree well with those measured at DEN above 700 mb. A representative wet-bulb  $\theta$  value is approximately  $+10^\circ\text{C}$  for the 800–600 mb layer (we estimate that downstream overrunning of the arctic air mass would induce significant upward motion in this layer). A buoyant parcel would thus yield strongest dendritic growth in the 650–600 mb layer; this layer of about 2000 ft depth is centered at about 3000 ft above the top of the cold air at DEN. We do not attempt to speculate whether overrunning- or dynamically-induced upward motion was strongest in this layer over the Front Range, although a deepening cold pool would enhance both processes. As stated in WWP, a large portion of the observed snowfall was of the dendritic habit.

It is clear from these data that the moisture for the snowfall along the Colorado Front Range originated to the west, as stated in WWP. However, we were unable, given the coarse nature of radiosonde data over the western U.S., to quantitatively distinguish the relative importance of simple overrunning versus dynamically-induced lifting. That question in itself would constitute a separate lengthy study. Thus we simply stated the known facts and did not attempt to speculate beyond the role of the deepening cold pool in enhancing upward motion.

#### References

- Auer, A. H., Jr., 1991: Comments on "Heavy snowfall during an arctic outbreak along the Colorado Front Range." *Nat. Wea. Dig.*, current issue.
- Wesley, D. A. and R. A. Pielke, 1990: Observations of blocking-induced convergence zones and effects on precipitation in complex terrain. *Atmos. Res.*, **25**, 235-276.
- Wesley, D. A., J. W. Weaver and R. A. Pielke, 1990: "Heavy snowfall during an arctic outbreak along the Colorado Front Range." *Nat. Wea. Dig.*, **15**(3), 2-19.