EFFECTS OF THE LONGMONT ANTICYCLONE ON SNOWBANDS DURING WISP

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1. INTRODUCTION

An anticyclonic eddy forms to the lee of the Cheyenne Ridge (a ridge extending eastward from the Rocky Mountains) when the flow upstream of the ridge is northerly. Fig. 1 presents a schematic of the low-level flow. The feature was first documented by Johnson *et.al.* (1984). They stated: "(A) surface anticyclonic circulation had been noticed by the authors to develop frequently downstream of the Cheyenne Ridge when a northwesterly gradient wind in the lower troposphere exists over the area...The extension of the cool anomaly southeastward from Cheyenne is undoubtedly aided by cold advection in the northwesterly flow there." Their Fig. 8c demonstrates the anticyclonic turning to the lee of the Cheyenne Ridge and the colder temperatures characterising the region of northwesterly winds.

Forecasters in this region have since called the phenomenon the Longmont Anticyclone (J. Brown, pers. comm.), with the geographical reference specifying the preferred approximate location of the center of the region of strongest anticyclonic turning (see the location of Longmont (LGM) in Fig. 1). Snook (1993) investigated the effects of the Cheyenne Ridge on low-level northerly flow using a mesoscale model, and confirmed anticyclonic turning in this flow for low-Froude number upstream conditions. During the winters of 1990 and 1991 the Winter Icing and Storms Project (WISP) was conducted in northeastern Colorado (see Rasmussen *et.al.* 1992). Investigators from a number of universities, as well as from NCAR and NOAA, documented the evolution of supercooled liquid water during winter storms in this region of complex terrain using data collection at the surface and aloft. A major objective of this effort was to evaluate the effects of topography on snowfall distributions. Preliminary analyses of all WISP intensive observing periods (IOPs) in 1990 and 1991 have brought to light a noteworthy synopsis. Out of 25 total IOPs during the 2-year project, the Longmont Anticyclone (LA) appeared to exert a significant influence on the development and intensity of snowbands or convective snow-producing regions during 16 events. Of these events, the LA appeared to be dominant in several light snowfall IOPs.

The generalised schematic shown in Fig. 1 presents one example of the low-level wind pattern associated with the LA, based primarily on the case study discussed in this manuscript. Typically, following the passage of a cold front of either Canadian or Pacific origin, a period of gusty northerly surface winds occurs over the eastern plains of northern Colorado and southeastern Wyoming, accompanied by northwesterly mid-level flow. The observed surface winds are partially isallobaric in nature, with surface pressures rising rapidly over eastern Wyoming. For time periods of a few or more hours, the northerly or northwesterly low-level flow in the lee of the Cheyenne Ridge turns anticyclonically and decelerates.

The hatched region of Fig. 1 specifies a region of decelerated northerly flow. The associated convergence in the low-level flow in the northern portion of this region may generate convection and showery precipitation, depending on the atmospheric stability and moisture profiles, while partly cloudy, non-precipitating conditions are observed over the Cheyenne Ridge and to the east of the hatched region. In other situations, preexisting precipitation bands advecting into this region may intensify as they move southward and encounter low-level convergence. Significant precipitation can occur over the Boulder-Longmont-Platteville-Denver (BOU-LGM-PTL-DEN in Fig. 1) areas during these situations, despite the shallow, anticyclonic nature of the postfrontal air mass and the lack of significant upslope during north to northwesterly winds at the surface.

The 16 January 1991 episode was chosen in this study for detailed analysis due to the persistent intensification of snowbands via low-level

* NCAR, P.O. Box 3000, Boulder CO 80307, is sponsored by the National Science Foundation.

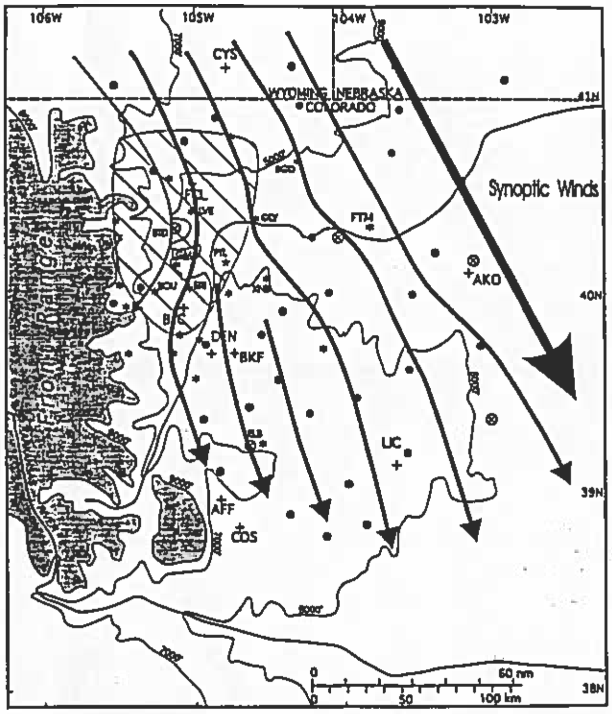

Figure 1. Schematic of the general low-level wind flow present during the Longmont Anticyclone event of 16 January 1991. Solid contours indicate elevation.

convergence associated with the LA. The purpose of this paper is to demonstrate its effect on the snowfall distribution.

2. EVENT SUMMARY

This section describes the characteristics of three major snowbands which developed during the period 0300-1300 on 16 January 1991. Generally, snowbands developed to the lee of the Cheyenne Ridge and propagated southward through the WISP domain. In some cases weak echoes did originate in Wyoming and intensified in the convergent LA region.

a. Initial snowband (B1)

During the initial stages of the LA (0300-0600) a snowband developed and intensified within the WISP domain. The 2.0 km MSL CAPPI (constant altitude plan-position indicator) of Mile High Radar (MHR) reflectivity at 0330 (Fig. 2) indicated the initiation of an active precipitation pattern, with a newly-developed snowband (denoted hereafter as B1) extending from FCL southeastward toward PTL, containing reflectivity values of 15 to 25 dBZ. Other significant features were relatively small pockets of reflectivity up to 30 dBZ, to the west and south of Denver. One hour later, the reflectivity pattern was similar with the exception

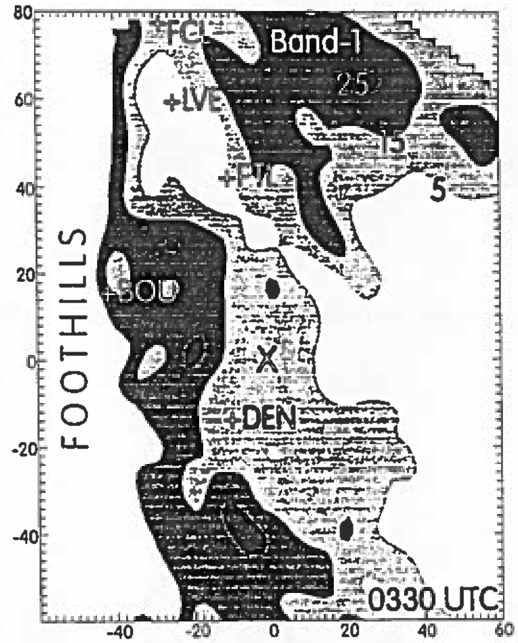

Figure 2. 2.0 km MHR CAPPI at 0330

of weakening intensity over the BOU region and advection of B1 toward the south. Cellular features up to 30 dBZ were present just north and northeast of Denver within B1. DEN and CYS both reported light snow showers at 0300 and 0400, while FCL reported only mostly cloudy conditions at 0400. By 0600 a pronounced LA was present. Low-level wind flow was characterised by significant convergence over the foothills and immediately adjacent plains northwest of Denver. Major low-level reflectivity features at 0600 (not shown) included cellular echoes with values up to 30 dBZ associated with B1. These were located just east, north and northeast of DEN. At 0700, DEN reported steady light snow, which continued over the next 2 hours.

b. Snowband B2

A new band (hereafter called B2) began to develop near LVE between 0600 and 0700 in the low-level convergent region. The MHR CAPPI at 2.0 km MSL at 0700 (Fig. 3), when the strongest signature of the LA was present, showed an organised band (B2) of enhanced reflectivity oriented ESE-WNW extending from just south of LVE to northeast of DEN. The band exhibited several cellular features with reflectivity values up to 30 dBZ, which is relatively high for light snow events in this region. The eastward extent of B2 was clearly defined about 30 km ENE of MHR. The western end of this band contained an extension toward the north, with 25 dBZ echoes extending northward along the foothills well into the BTD vicinity. Operators at the UND radar site northeast of Denver reported that 20 dBZ echoes within B2 reached heights of about 5.5 km MSL, or near 500 mb, at this time. The secondary snowband (B1), now weaker and oriented E-W, was located well south of DEN at 0700 and consisted of primarily 10 to 20 dBZ values. Generally, B2 appeared to propagate southward at approximately 11 ms^{-1}.

Data from the CHILL radar and MHR at 0705 provided more detailed information on the three-dimensional structure of the band. Fig. 4 shows a north-south cross section of reflectivity and dual-Doppler derived band-relative velocities through B2, at a distance of 28 km west of MHR. B2 was composed of several strong vertical extensions of reflectivity, with a maximum height of about 6 km MSL. These appeared to be shallow convective cells. The derived velocities showed that these extensions were updrafts, the strongest of which was located about 10 km north of the latitude of MHR and exhibited updraft velocities in excess of about 0.5 ms^{-1}. The cross-section contained a low-level region of reflectivity greater than 25 dBZ, and low-level band-relative inflow of about 5 to 6 ms^{-1}. The leading edge of the region greater than 25 dBZ exhibited a layer of convergence about 2 km deep.

The maximum surface convergence analysed for this LA would produce an updraft of only about 0.05 ms^{-1}, based on continuity using a representative depth of 500 m. Using the slopes of the θ_e surfaces documented by aircraft measurements in and around B2, upglide along these surfaces with an inflow of 5ms^{-1} would produce a vertical velocity of 0.3 ms^{-1}, or a factor of two less than the dual-derived velocities in Fig. 4. Thus it is certainly possible that convection was significant, given the lack of significant larger-scale (e.g. frontal) lifting in this case and the fact that low-level convergence was present. Soundings measured in the vicinity of the band supported this scenario.

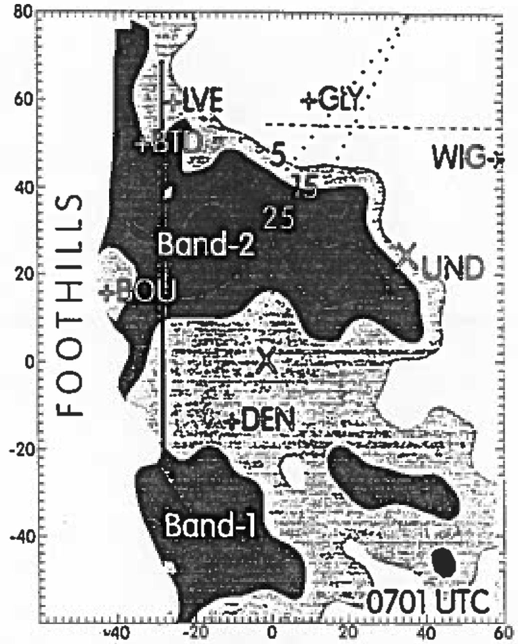

Figure 3. 2.0 km MHR CAPPI at 0700

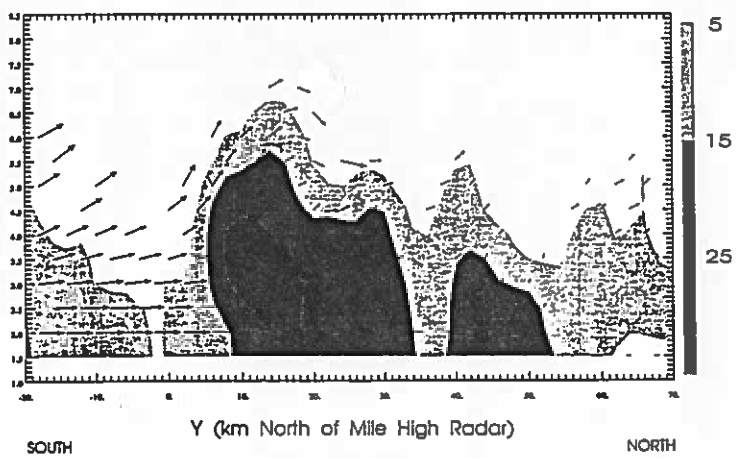

Figure 4. Cross-section of dual-derived radar velocities and reflectivity at 0705 through snowband B2

3. DISCUSSION

The Longmont Anticyclone (LA) is a local feature downstream of a modest, sloping east-west ridge, and is typically characterised by low-level convergence within ambient postfrontal northerly flow, in contrast to the Denver Cyclone which forms within ambient southerly or southeasterly winds. Winter Icing and Storms Project (WISP) measurements, both at the surface and aloft, were analysed in detail for the event of 16 January 1991. In this case the LA was present for more than ten hours and featured low-level convergence and snowbands. Snowfall rates were occasionally moderate to heavy. Unlike typical Denver Cyclone cases, the low-level winds did not exhibit organised return (i.e. southerly in this case) flow. Snowband propagation was approximately 10-12 ms^{-1} to the south, and the strongest band resembled a long-lived convective line. To the east of the WISP domain, little or no snowfall was reported during this event, while 4 to 9 cm accumulated in the western and southwestern portions of the domain. Synoptic-scale forcing was considered weak. Surface measurements in this storm indicated highly ageostrophic low-level wind components, though not of the same magnitude as in the Johnson *et.al.* (1984) case study. Based on detailed examinations of low-level radar reflectivity scans during the snowy period of 00-12 UTC 16 January, a preferred zone of reflectivity intensification was located over the western South Platte River Valley. This region was located just downstream of the area of highest convective instability and low-level convergence (as specified from time-averaged wind fields) and was verified using time-averaging of reflectivity scans.

A possible direct mechanism leading to mesoscale upward motion in association with the LA is convergence of northerly flow over the Cheyenne Ridge with weak northeasterly or nearly calm winds in the western portion of the South Platte River Valley. An indirect mechanism for mesoscale upward motion in this case was differential low-level thermal advection between the lighter winds over the west end of the South Platte Valley and the stronger winds over the plains to the east. Convectively unstable conditions were observed only over the western South Platte Valley. This area appeared to retain warm, moist low-level conditions and weak winds during a period of large-scale advection of cooler and drier air. These weak winds are inherently a part of the LA wind pattern and occur in a convergent region. The LA-induced precipitation intensification led to maximum enhanced snowfall approximately 50 km south of the maximum surface convergence. Mesonet and sounding data also indicated that convergence of westerly flow in the foothills northwest of Denver with weak northeasterly or calm winds over the western South Platte River Valley may have contributed to ascent in this case.

The unimpeded low-level north-northwesterly flow over the eastern South Platte River Valley strongly inhibited cloud and precipitation formation in that region, as drier and more stable upstream conditions quickly replaced the air mass in the vicinity of the cold front. It is plausible that the anticyclonic turning in the low levels in this case can be explained by negative vorticity generation on the downstream left side of a three-dimensional obstacle, the Cheyenne Ridge. The presence of a reduced NW-SE-oriented surface pressure gradient over the western South Platte River Valley corresponded with the warm and decelerated portion of the anticyclonic LA wind pattern. However, the lack of sounding and surface measurements upstream of this feature prevented a conclusive assessment of the mechanisms leading to this pressure anomaly (e.g. blocking associated with low-Froude number flow). The relative importance of low-level convergence in generating precipitation as opposed to convective instability due to differential thermal advection is unclear at this time, although convection appeared to be critically important in this event. The exact nature of the role of the terrain in generating the LA will require further analysis of WISP datasets, and possibly numerical model simulations. With another year of WISP intensive field operations during the winter of 1994 in this region, perhaps these questions can be answered.

4. REFERENCES

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