P3.33 WSR-88D GROUND CLUTTER SIGNATURES ASSOCIATED WITH LEE-SLOPE WIND EVENTS

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1. INTRODUCTION

A number of communities located in the lee of mountainous regions of the United States (e.g., Boulder, CO; Juneau and Anchorage, AK; Salt Lake City, UT) experience strong downslope winds that often gust to well above nominal hurricane force (34 m s^{-1}). These high-wind events are frequently responsible for considerable property damage and occasionally serious injury or loss of life. Observational evidence indicates downslope windstorms occur when there is a strong low-level amplification of a terrain-induced gravity wave (e.g. Lilly and Zipser 1972). The resolution of current weather prediction models is too coarse to explicitly predict this mesoscale phenomenon. Furthermore, the highly nonlinear nature of this type of terrain-induced flow makes this phenomenon difficult to forecast without explicit numerical model guidance.

The Denver Weather Surveillance Radar-1988 Doppler (WSR-88D, formerly known as NEXRAD) was installed in 1993 at a location approximately 80 km east of the Rocky Mountains (KFTG in Fig.1). At this location, the radar is able to easily detect the mountains west of the Colorado Front Range Urban Corridor. Due to its close proximity to significant terrain, a rather sophisticated ground clutter suppression scheme is necessary to remove unwanted ground returns. Shortly after the radar's installation, forecasters noticed strange echoes occasionally appear during time periods of little, if any, precipitation despite the fact that clutter suppression is in effect. The near-zero Doppler velocities, low spectrum widths, shape, and location of these high reflectivity echoes suggest they may be due to ground returns. Over time, it has become apparent that these odd echoes are well correlated with the occurrence of strong winds in the foothills and the presence of large-amplitude mountain waves at low levels. In some instances, the location and appearance of these echoes change with time and the surface winds in the vicinity of these echoes exhibit similar time dependencies. Forecasters from a number of other National Weather Service (NWS) offices with a WSR-88D in close proximity to significant terrain have observed similar signatures in their radar data (e.g. Pueblo, CO; Cheyenne and Riverton, WY; Great Falls, MT; and Anchorage, AK). The odd echoes in these locations also appear to be well correlated with the occurrence of strong terrain-induced winds. Forecasting the occurrence, timing, duration, and downstream penetration of downslope windstorms is a challenging forecast problem. Given the correlation between this radar signature and the occurrence of strong terrain-induced winds, understanding the mechanism responsible for this signature could provide a basis for using the WSR-88D as a much needed nowcasting tool for downslope windstorms.

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2. EXAMPLE RADAR SIGNATURE

A grayscale depiction of the terrain features west of the Colorado Front Range Urban Corridor is shown in Fig. 1, as well as the location of the Denver WSR-88D radar (KFTG) and the county boundaries. Noteworthy features pertaining to this study are: a) the high portions of the Continental Divide running from southwest Larimer county southward between Boulder and Grand counties and then extending southwestward; b) the high area in south central Clear Creek county (Mount Evans); c) the high terrain in northeast Park county (Kenosha and Tarryall Mountains); and d) the transition area in Larimer, Boulder, Jefferson and Douglas counties, marking the eastern edge of the foothills of the Rockies. The highest terrain is generally above 10 or 11 thousand feet MSL, while the eastern edge of the foothills roughly follows the 6000 to 6500 foot contour.

Figure 2a shows the Denver WSR-88D reflectivity at 2037 UTC on 7 January 1995 for an elevation angle of 0.5°. Echoes beyond the second range ring are, for the most part, precipitation returns, with the exception of the high reflectivity returns in southwest Larimer and northwest Boulder counties. These high reflectivity returns, as well as those in the remainder of

Boulder county, in the vicinity of Mt. Evans and around the Kenosha and Tarryall mountains match very well with the higher terrain features shown in Fig. 1. Reflectivities in these returns are generally greater than 30 dBZ with maxima in western Boulder county in excess of 55 dBZ. These intensities strongly suggest that the radar returns are from the mountains. Further evidence that this signatures are ground returns is shown in Figure 2b, which depicts the Doppler velocity for the same time. The radial velocities of these high reflectivity echoes are very nearly zero, while the radial velocities in the precipitation echoes exceed 40 knots towards the radar. The spectral width data (not shown) for these high returns shows very low values in comparison with those for the precipitation echoes, further suggesting that the echoes are from the stationary terrain in the area.

The Denver WSR-88D reflectivity and Doppler velocity at 2331 UTC on 7 January 1995 are shown in Figs. 2c and d, respectively. Note that the area of high reflectivity has shifted eastward to the base of the foothills, extending from Larimer through Boulder and Jefferson counties into Douglas county. These high reflectivity areas also exhibit near zero Doppler velocities, again suggesting the returns are from stationary ground targets, viz. the eastern edge of the foothills in this case. This shift occurred gradually during the three-hour period, with the high reflectivity area slowly progressing to the east, down the lee slope of the mountains.

The radar reflectivity and velocity patterns shown in Fig. 2 are not unique to this date and time, nor as mentioned above, to the Denver radar. What has become apparent from seeing these returns on a large number of occasions and on a variety of radars is the fact that they appear when mountain wave activity is likely occurring. Indeed, on the day shown in the imagery above, strong west to northwest flow aloft was impinging on the Colorado Rockies, likely generating a strong mountain wave. Moreover, strong terrain-induced winds at the surface were confined to the higher foothills (generally above about 8500 feet) at 2037 UTC, and gradually followed the high reflectivity area down the slope, arriving at locales near the base of the foothills at roughly the same time as the high reflectivity. On this occasion and many others observed since then, the strong winds were confined to locations along and to the west of the high reflectivity region.

3. RAY TRACING

Zamora and Kropfli (1999) used simple ray-trace calculations to explain unusual stationary wavelike echoes observed by an X-band Doppler radar during the San Clemente Ocean Probing Experiment (SCOPE). By calculating ray paths through a perturbed two-dimensional analytical field of modified refractive index, they were able to show that ray bending and focusing/defocusing of the signal due to a strong atmospheric-gravity-wave modulation of the marine inversion height was responsible for the wavelike echoes. The objective of this study is to determine whether perturbations in the refractive index due to the presence of the strong mountain wave signature can explain the anomalous WSR-88D returns by performing simple ray-trace calculations similar to those used by Zamora and Kropfli.

The clutter suppression algorithm for the WSR-88D radars is based on a map of ground clutter obtained during a periodic Radar Data Acquistion System Operability Test performed during quiescent conditions (i.e., weak flow, no strong inversions, no precipitation: essentially homogeneous conditions in refractive index). In contrast, the propagation medium during a downslope windstorm is characterized by a shooting lee-slope flow with tight packing of isentropes at low-levels and a turbulent updraft downstream. Due to the localized nature of downslope windstorms, this hydraulic jump-like feature is located between the Denver WSR-88D and the mountain ridge, creating a medium through which the radar beam propagates that is characterized by large horizontal and vertical inhomogeneities in refractive index. In this ongoing work, this study will use refractive index fields based on output from nonlinear, two-dimensional mountain wave simulations to investigate whether these inhomogeneities are responsible for the odd echoes observed during wind events. Significant ray bending and focusing similar to that found by Zamora and Kropfli could lead to stronger than normal ground returns, which would explain why the clutter suppression algorithm is no longer sufficient to remove all of the ground clutter signature. Changes in the mountain wave structure would lead to changes in the refractive index field, which, in turn, would lead to changes in the location at which the focusing occurs, producing a ground clutter signature that appears to propagate. Such changes in the mountain wave structure would also lead to changes in the terrain-induced winds, which would explain the temporal correlation between the location of the ground-clutter signature and the location of the high winds.

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References

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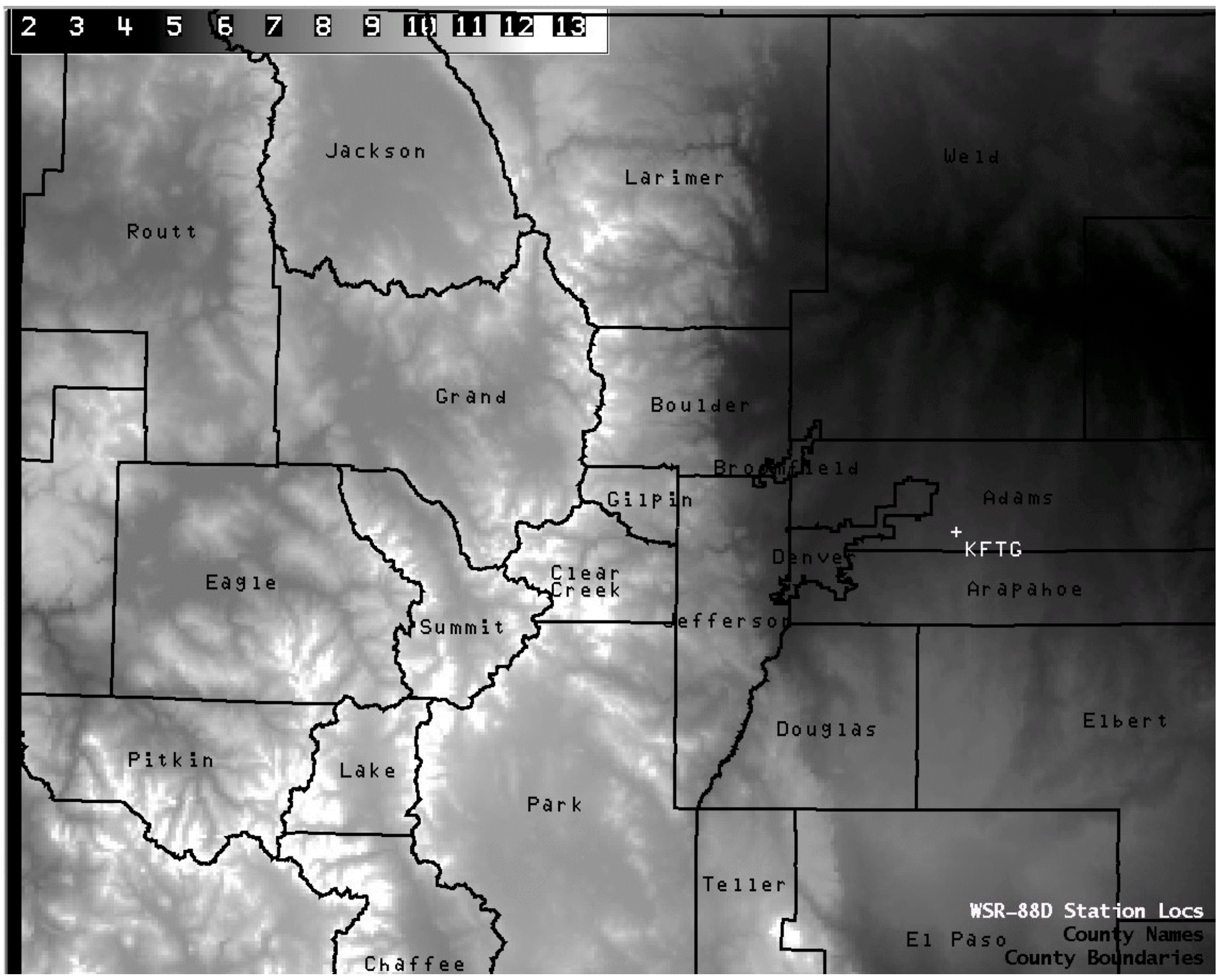

Figure 1: Grayscale depiction of the terrain features west of the Colorado Front Range Urban Corridor (lowest elevations correspond to darker regions, higher elevations correspond to lighter regions). A scale marked in thousands of feet is located at the top of the figure. The location of the Denver WSR-88D radar (KFTG) is indicated by a "+". Black lines depict the county boundaries.

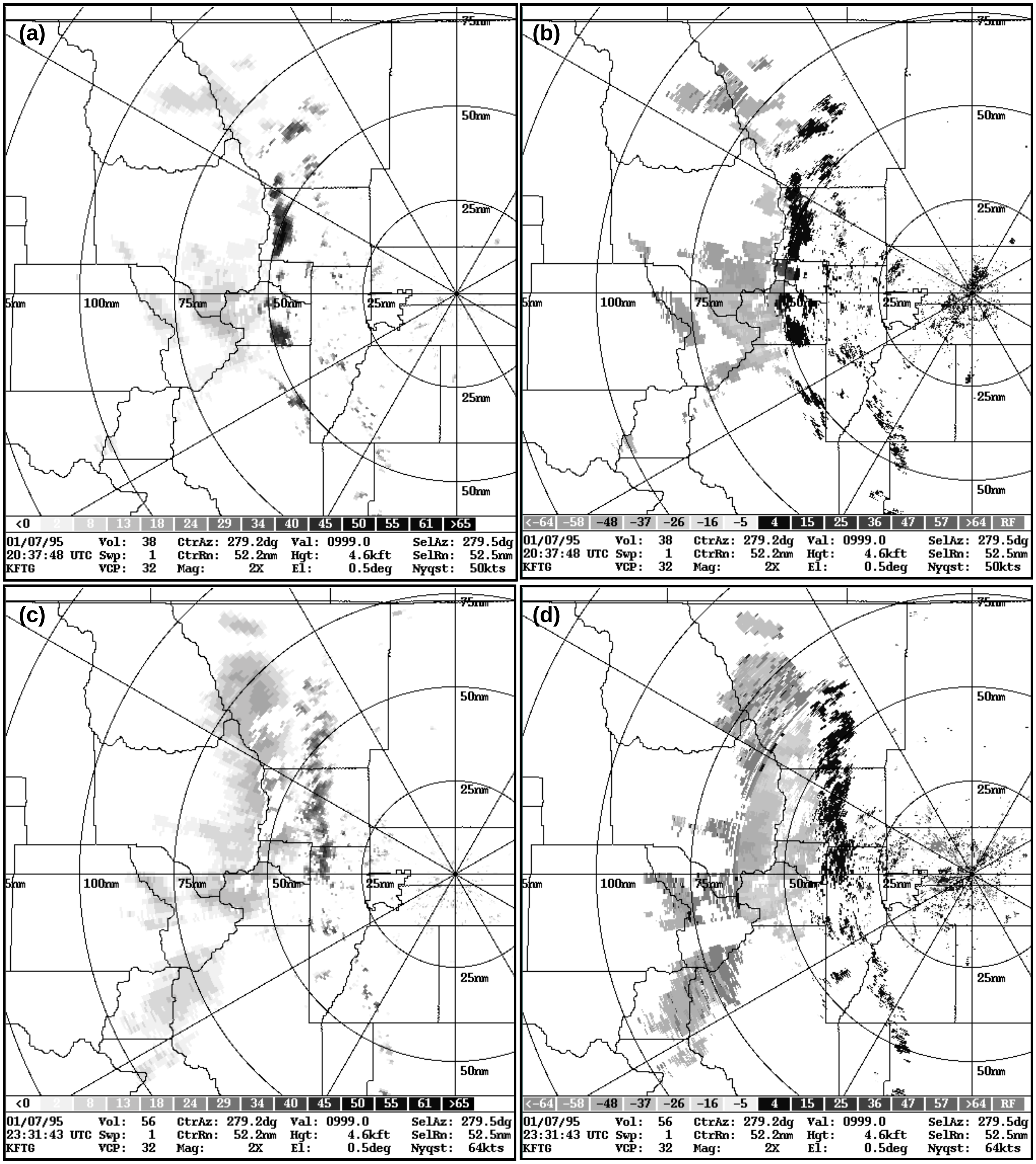

Figure 2: Denver WSR-88D images on 7 January 1995 for an elevation angle of 0.5°: a) reflectivity and b) Doppler velocity at 2037 UTC, and c) reflectivity and d) Doppler velocity at 2331 UTC. A scale is located at the bottom of each image and a polar grid overlain on the image. The Denver radar is located at the center of the polar grid.