NWA *EJOM* Images of Note

A Long-Lived Nocturnal Bore on Radar: Diagnosis and Relevance

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1. Introduction

On the night of 31 May to 1 June 2007, an atmospheric bore moved across most of central Alabama, traversing a distance over 200 km (~125 miles). This bore apparently developed when a cold outflow boundary, left over from afternoon thunderstorms in southern Georgia, impinged on the shallow, stable nocturnal boundary layer (NBL) that developed after sunset.

This development of wave features due to density currents/cold outflow impinging on stable layers is well-documented. Atmospheric bores (propagating hydraulic jumps whose dynamics are based on waves) often form when the cold, dense air in an outflow boundary impinges on a stable layer near the surface, such as the nocturnal inversion (e.g., Crook 1988; Hartung et al. 2010). As noted by Knupp (2006), bores sometimes transition to solitary waves (e.g., Doviak and Ge 1984) before dissipating.

It has also been shown that atmospheric bores may destabilize the boundary layer, because their passage is associated with vertical mixing and permanent upward displacements (e.g., Koch et al. 1991, 2008; Coleman and Knupp 2011). In addition, the moisture flux convergence along the bore may increase the precipitable water in the lower levels of the atmosphere (e.g., Coleman and Knupp 2011). Using 1-minute resolution data from a microwave profiling radiometer, Coleman and Knupp (2011) showed that, immediately after passage of an atmospheric bore at night, surface-based convective inhibition (CIN) was decreased by 50%, from around 180 J kg^{-1} to near 90 J kg^{-1} after bore passage. CAPE, on the other hand, increased as the bore passed. Solitary waves may also, at least temporarily, reduce the stability of the NBL (e.g., Rottman and Einaudi 1993; Coleman and Knupp 2011).

The purpose of this note is to show the appearance of a bore, possibly transitioning to a solitary wave, in radar reflectivity imagery. Since the characteristic fine line that bores or waves produce on radar is similar to that produced by outflow boundaries, surface observations will be shown. This will help forecasters to determine the causes of similar reflectivity fine-lines. This is important because outflow boundaries typically produce convective initiation (CI) near or

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within 10 km of their leading edge (due to mechanical lifting and moisture flux convergence) *while bores may produce or enhance CI at, in addition to well behind, their leading edge*. This is likely due to the mechanical lifting at the leading edge of the bore (e.g., Locatelli et al. 2002), the increase in low-level precipitable water, and also the destabilization of the atmosphere behind the bore, including an increase in CAPE and, more significantly, a decrease in CIN. CI behind bores is still not completely understood, and CI did not occur in this case. However, it is important for operational meteorologists to identify bores and watch closely for CI.

2. Discussion

Figure 1 is an animation of radar reflectivity over most of Alabama and western Georgia. The data in the first 3 hours are from the WSR-88D at Robins AFB, GA (KJGX). These images show decaying convection over western Georgia, to the east of Columbus (KCSG). Also note local sunset at KJGX at 0032 UTC. Beginning at 0058 UTC, the data are from the WSR-88D at Maxwell AFB, AL (KMXX). By 0102 UTC, a NE to SW oriented fine line in reflectivity can already be discerned to the south and southeast of Auburn, AL (KAUO). The fine line becomes better defined as it gets closer to the radar. This is due to the shallowness of the reflectivity fine line; higher elevation scans (not shown) indicate that the fine line was only barely discernable up to 1 km AGL. (The 0.5° elevation scan was also likely over-refracted in the developing inversion.) Using extrapolation to determine the time, the feature associated with the fine line passed over KCSG between 0000 and 0020 UTC. At KCSG, pressures were rising steadily around 0000 UTC, probably in part due to the atmospheric tidal increase (e.g., Lindzen 1990) to be expected in synoptically tranquil conditions in early evening. However, there was an increase in $\partial p/\partial t$ around 0015 UTC, likely coinciding with an outflow boundary passage. Temperatures at KCSG dropped about 3°C (5°F) while dewpoints rose about 3°C (5°F, Fig. 2). This drop in temperature and rise in dewpoint is consistent with the cool, moist air behind a thunderstorm outflow boundary.

The outflow boundary speed of motion gradually slowed during the first hour it was discernable on radar. The speed decreased from 7.8 m s^{-1} (16 kt) at 0129 UTC to 4.6 m s^{-1} (9 kt) at 0222 UTC. According to Seitter (1986), the speed of an outflow boundary is directly related to the depth of the cold air, so one would expect such a boundary to slow down with time, as its cold pool spreads out horizontally. However, the fine line accelerated between 0230 and 0430 UTC, reaching a speed near 11 m s^{-1} at 0430. This acceleration is not typical for an outflow; *this indicates that the main forcing for motion transitioned from the pressure gradient associated with the cold outflow before 0230, to wave propagation by 0430 UTC.* The outflow boundary apparently generated a bore in the stable NBL after 0230 UTC.

By the time the fine line reached Calera (KEET) and Birmingham, AL (KBHM), surface data show that it was clearly a bore. At KBHM (Fig. 2), the pressure jumped 0.2 mb in 4 min, and the pressure remained elevated for about 30 min. This quasi-permanent pressure jump is characteristic of a bore (e.g., Locatelli et al. 1998). Also, *a steady or rising surface temperature and a decrease in dew point often distinguishes the passage of a bore from that of an outflow boundary in surface observations* (e.g., Knupp 2006; Hartung et al. 2010). This is due to the low-level mixing of the NBL. At KBHM, the temperature increased 3°C (6°F) and the dewpoint decreased 1°C (2°F), both in about 20 min. At KEET, the temperature warmed 2°C (4°F) during the 30 min following bore passage (indicated by a 0.3 mb pressure jump), and the dewpoint dropped 1°C (2°F) in the 15 min after bore passage. The bore passage was also accompanied by scattered low clouds when it passed the author's residence northeast of KBHM.

When the fine line reached Tuscaloosa, AL (KTCL) around 0835 UTC, its pressure pattern was more similar to that of a solitary wave, with very small changes in temperature and dewpoint (not shown). According to radar data from the Columbus, MS radar (KGWX), the fine line dissipated between TCL and the AL/MS border.

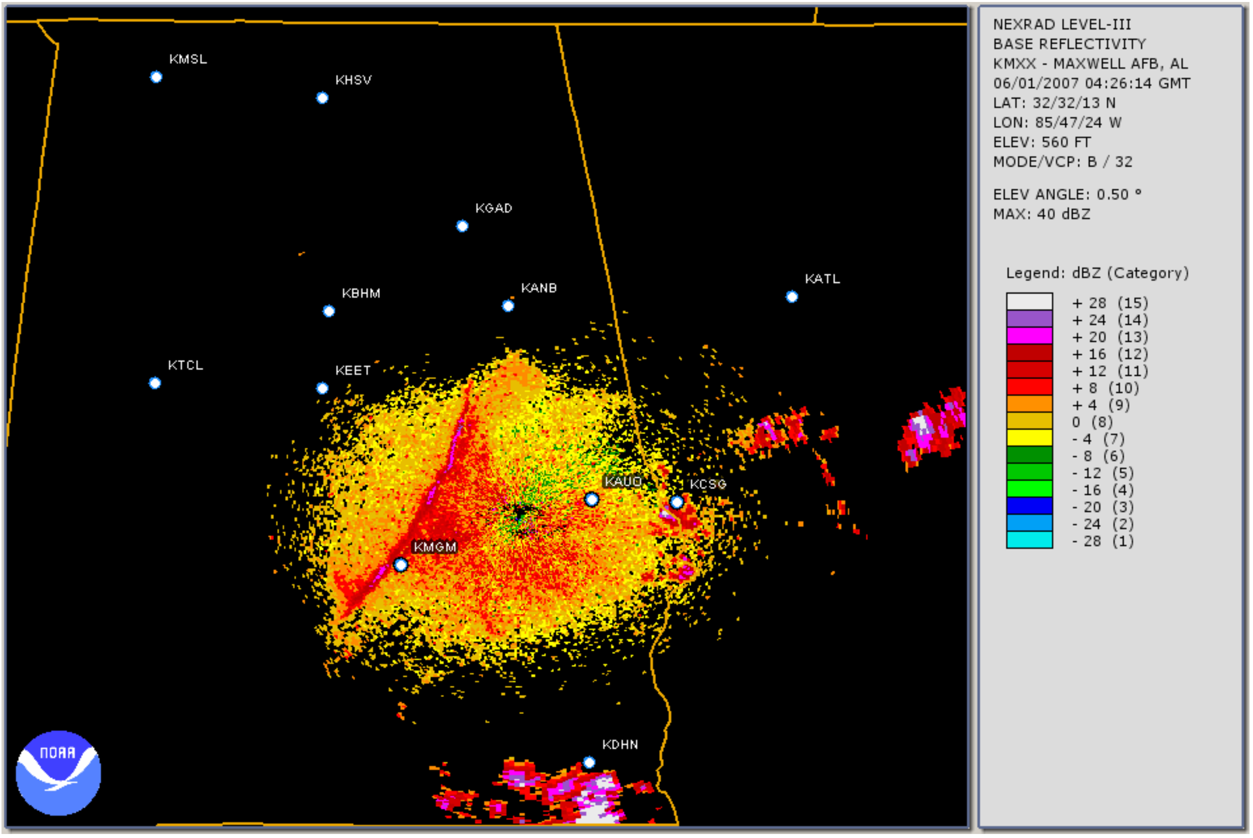

Figure 1. Loop of radar reflectivity from the WSR-88D at KJGX (31/2204 UTC through 01/0055 UTC), KMXX (0058 through 0445 UTC) and KBMX (0452 through 0903 UTC). The timing of the radar loop is adjusted to maintain consistency as a switch from VCP 12 to 32 resulted in a change in frequency of radar images. ASOS locations are shown.

3. Summary

This note illustrates, using radar and surface data, the generation of a bore due to an outflow boundary impinging on the nocturnal boundary layer. As the radar fine line transitioned to a bore, it accelerated. Surface data showed that the bore was associated with a pressure jump, a temperature rise, and a dewpoint drop due to mixing of the NBL. The distinction of the character of radar fine lines, between outflow boundaries and bores, is important because bores have been shown to destabilize the NBL, increase low-level PW, and decrease CIN, sometimes allowing convection to form in their wake.

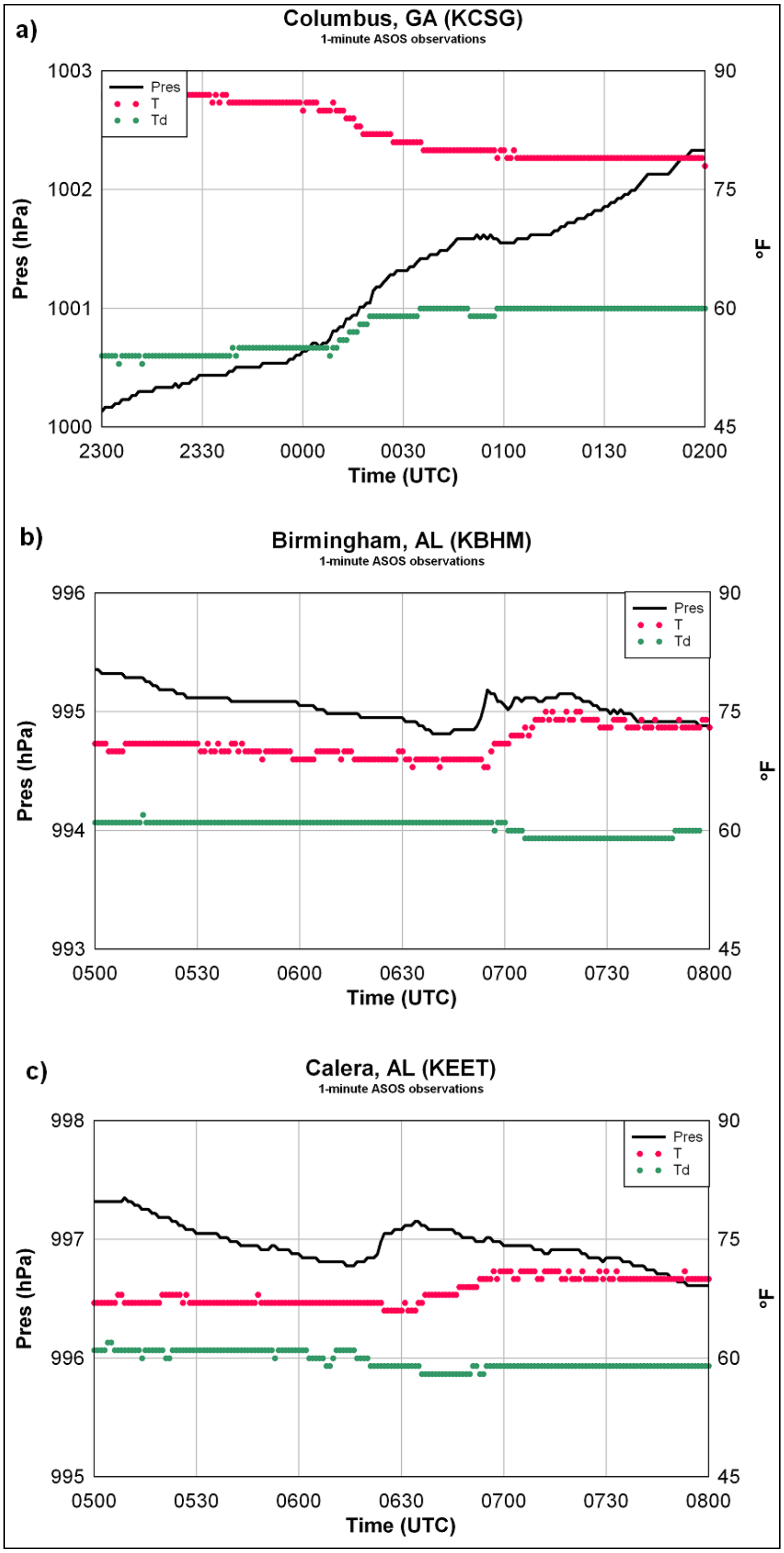

Figure 2. Time-series plots of pressure (mb, solid dark curve), temperature (°F, red dotted curve), and dewpoint (°F, green dotted curve) at a) Columbus, GA (KCSG), b) Birmingham, AL (KBHM), and c) Calera, AL (KEET).

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REFERENCES

Coleman, T.A., and K.R. Knupp, 2011: Radiometer and profiler analysis of the effects of a bore and a solitary wave on the stability of the nocturnal boundary layer. *Mon. Wea. Rev.*, **139**, 211–223.

Crook, N. A., 1988: Trapping of low-level internal gravity waves. *J. Atmos. Sci.*, **45,** 1533–1541.

Doviak, R. J., and R. Ge, 1984: An atmospheric solitary gust observed with a Doppler radar, a tall tower and a surface network. *J. Atmos. Sci*., **41**, 2559–2573.

Hartung, D. C., J. A. Otkin, J. E. Martin, and D. D. Turner, 2010: The life cycle of an undular bore and its interaction with a shallow, intense cold front. *Mon. Wea. Rev.*, **138**, 886–908.

Koch, S. E., P. B. Dorian, R. Ferrare, S. H. Melfi, W. C. Skillman, and D. Whiteman, 1991: Structure of an internal bore and dissipating gravity current as revealed by Raman lidar. *Mon. Wea. Rev.*, **119,** 857–887.

———, W. Feltz, F. Fabry, M. Pagowski, B. Geerts, K. M. Bedka, D. O. Miller, and J. W. Wilson, 2008: Turbulent mixing processes in atmospheric bores and solitary waves deduced from profiling systems and numerical simulation. *Mon. Wea. Rev.*, **136**, 1373–1400.

Knupp, K. R., 2006: Observational analysis of a gust front to bore to solitary wave transition within an evolving nocturnal boundary layer. *J. Atmos. Sci.*, **63**, 2016–2035.

Locatelli, J. D., M. T. Stoelinga, P.V. Hobbs, and J. Johnson, 1998: Structure and evolution of an undular bore on the High Plains and Its effects on migrating birds. *Bull. Amer. Meteor. Soc.*, **79**, 1043–1060.

———, M. T. Stoelinga, and P. V. Hobbs, 2002: A new look at the Super Outbreak of tornadoes on 3–4 April 1974. Mon. Wea. Rev., 130, 1633–1651.

Rottman, J. W., and F. Einaudi, 1993: Solitary waves in the atmosphere. *J. Atmos. Sci.*, **50**, 2116–2136.

Seitter, K. L., 1986: A numerical study of atmospheric density current motion including the effects of condensation. *J. Atmos. Sci.*, **43**, 3068–3076.