Structure and dynamics of a dual bore event during IHOP as revealed by remote sensing and numerical simulation

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ABSTRACT

The International H_20 Project (IHOP_2002) offered an extensive array of ground-based and airborne remote sensing systems for producing what is probably the most complete set of observations ever collected of the evolving structure and dynamics of bores solitons, and solitary waves. Data were collected of a dual bore event on 4 June 2002 by spaced-antenna radar, FM-CW radar, S-band radar for deriving refractivity fields, interferometer, Raman lidar, Doppler lidar, aerosol backscatter lidar, and a surface mesonetwork. These data are synthesized and related to fields from a high-resolution model simulation to shed light on the structure and dynamics of the bores and associated solitary waves. This case offers the opportunity to study bore entrainment, solitary wave generation, wave dispersion, wave trapping and other processes in the evolution of the bore systems.

Keywords: Lidar, radar, interferometer, refractivity, bore, gravity waves, solitary waves, IHOP.

1. INTRODUCTION

The International H_2O Project (IHOP_2002) field experiment took place in the Southern Great Plains of the U.S. for the chief purpose of obtaining an improved characterization of the time-varying three-dimensional water vapor field and to evaluate its utility in improving the understanding and prediction of convective processes. With this purpose in mind, IHOP_2002 brought together many operational and state-of-the-art research water vapor sensors and numerical models. A concentration of instruments at the Homestead Profiling Site in the Oklahoma Panhandle enabled very detailed study of the structure and dynamics of mesoscale phenomena responsible for triggering convection, including undular bores and solitary waves. The NCAR Integrated Sounding System and Multiple Antenna Profiler (ISS/MAPR)[1], an Atmospheric Emitted Radiance Interferometer (AERI)[2], FM-CW radar[3], low-level fields of refractivity derived from measurements made by the NCAR S-POL 10-cm radar[4, 5], a Scanning Raman Lidar (SRL)[6], the GLOW Doppler lidar[7], and the HARLIE aerosol backscatter lidar[8] were collocated at the Homestead site to provide information on water vapor, aerosols, and winds. In addition, a surface mesonetwork and supplementary rawinsondes were deployed in the region, and the University of Wyoming King Air aircraft delivered flight-level data and 95 GHz radar depictions of the bore. Numerical simulations of the event were performed using a "full-physics" 2-km nested version of the MM5 mesoscale model initialized with all of the operational data plus mesonetwork, reflectivity and radial velocity fields from multiple WSR-88D radars, and precipitable water fields from geostationary satellite and GPS sensors in the field.

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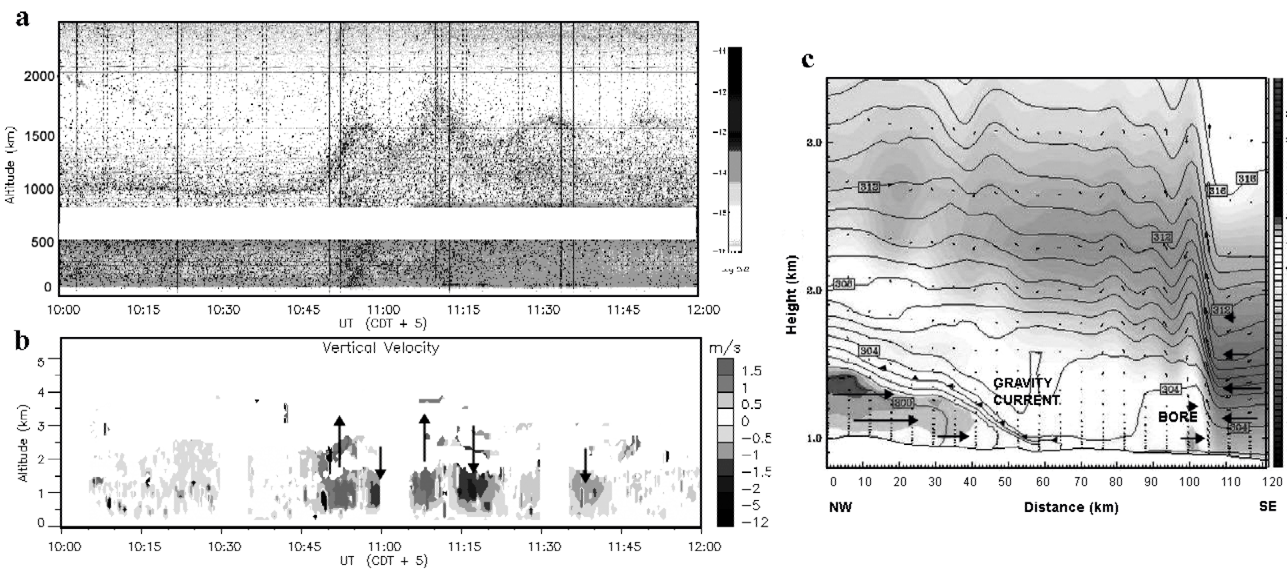

Figure 1. Bore B as depicted by a) FM-CW reflectivity fields (dBZ) and b) MAPR vertical motions (m s^{-1}). Problems exists in the FM-CW data in the 500 – 800 m layer. Bore front passes at 1050 UTC, and results in a sustained boundary layer deepening followed by 4 solitary waves. Compare structure of bore to that simulated by MM5 model from a 9.5-h forecast valid at 0930 UTC in (c), which shows potential temperature (1K interval isentropes), vertical circulation relative to the movement of the gravity current, and magnitude of horizontal motions relative to the motion of the gravity current (shaded). Note positive front-relative "feeder flow" behind the gravity current, but also a remnant at very low levels beneath the bore head. Time axis of the observations may be flipped in order to make direct comparison with the model results, which is a vertical cross section taken perpendicular to bore motion.

2. OBSERVATIONS OF THE BORE STRUCTURES

Two particularly well-documented bore events occurred on 4 June 2002. Bore A occurred in association with an outflow boundary, whereas bore B (which occurred ~4h later) was generated along a southward-advancing cold front. Multiple deep convective cells ahead of the front appeared to have been initiated by the second bore. S-POL radar data showed evidence of several solitary waves (a soliton) with a spacing of ~10 km in both bore events. Synthesis of all the remote sensing data reveals that the solitary waves were amplitude ordered with well-defined vertical circulations and multiple-layered structures or filaments. The FM-CW and MAPR data indicate that the influence of the bore on the atmosphere was felt to 2 – 3 km AGL (Fig. 1). A quadrature phase relation between the MAPR vertical motions and the oscillations of the inversion surface supports the solitary wave interpretation of these data. HARLIE better revealed the multiply stratified nature of the atmosphere perturbed by the wave disturbances (not shown).

AERI measurements revealed that cooling and moistening aloft attended the passage of both bores. Wyoming King Air in-flight measurements detected similar moistening and cooling as it passed through the upper parts of the wave crests of bore B. In addition, the aircraft data showed a quadrature phase relation between fluctuations in potential temperature and vertical motions, with updrafts leading cooling periods, and vice versa, as expected for gravity waves (or solitary waves). By contrast, surface-layer refractivity fields estimated from the S-POL data revealed a narrow band of pronounced warming and/or drying along the leading fine line for bore A that disappeared once solitary waves began to develop within the bore system. The S-POL derived changes in refractivity are consistent with computed changes from the mesonetwork station time series data for bore A. A reverse sequence of events occurred with bore B, in that the refractivity signature became apparent only as the soliton devolved into a single line suggestive of an undular bore. These observations suggest the hypothesis that drying near the surface (the warming was rather insignificant) and cooling and moistening at the tops of wave crests were the consequence of entrainment processes within the turbulent bore head and adiabatic lifting processes aloft, respectively. However, the refractivity changes with bore B were not nearly as evident, so additional processes were apparently at work with that bore.

3. HYPOTHESIS TESTING AND FUTURE WORK

Tentative hypotheses resulting from the synthesis of the observations can be tested with high-resolution fields from the MM5 model, which was successful in producing the bore and several solitary waves within the bore (Fig. 1c). The model suggested that the cold front acting as a gravity current generated bore B. Future work will determine the actual origin of the bores from the data, and will attempt to reconcile differences in wave characteristics (wavelength, number, etc.) and inversion layer details existing between the remote sensing systems. It is also desirable to understand why the number of waves within the soliton varied with the life cycle of the bore. The actual cause(s) for the observed temporal changes in the refractivity fields are also unclear at this time. Future plans include the need to understand the nature of the entrainment process, the height dependency of the waves, and the cause for the waves behind the bore head. The latter waves in both the profiling observations and the model appear to be lee-wave types, similar to what has been modeled in another bore-gravity current case[9], as opposed to theoretical predictions of dispersive waves related to the intrinsic nonlinear dynamics of bores.

4. REFERENCES

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