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THE LIFE CYCLE OF A BORE EVENT OVER THE US SOUTHERN GREAT PLAINS DURING IHOP _2002

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1. INTRODUCTION

The International H_20 Project (IHOP_2002, Weckwerth et al., 2003) was a large field experiment held in the southern High Plains for the purpose of obtaining an improved characterization of the time-varying three-dimensional water vapor field and to determine its importance in the understanding and prediction of convective processes. One objective of IHOP_2002 was to investigate the role played by bores in the initiation and the maintenance of nocturnal convection.

On 20 June 2002, a remarkable bore was sampled in the course of night time mission during which 2 aircraft (one equipped for launching dropsondes and one flying the water vapor differential absorption lidar LEANDRE 2) and a number of ground-based facilities (including the S-POL radar and other profiling instruments), located in the lower Oklahoma panhandle, were deployed. The generation mechanisms for the bore have been documented by S-POL and the Dodge City WSR-88D radars. The evolution of the structure and dynamics of the bore into a soliton was well captured by LEANDRE 2 (onboard the NRL P-3) and S-POL measurements. Finally, as the wave train broke down during its passage over the Oklahoma panhandle, the dissolution of the soliton was also well documented. Hence, this case offers the opportunity to examine the evolution of a gravity current into a bore, then a soliton, and its dissipation.

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2. SYNOPTIC SITUATION ON 20 JUNE 2002

The 20 June 2002 low-level jet mission was designed to study the mesoscale circulations associated with the development and maintenance of nocturnal convective systems. The experiment was designed to retrieve the three-dimensional time-varying water vapor field while sampling the low-level jet and pre-mesoscale convective system (MCS) environment. It was designed to study the pre-MCS environment which impacts the nocturnal precipitation maximum.

Two MCSs were present in extreme western Kansas at 0000 UTC on 20 June 2002. No other significant precipitation systems existed at this time. The northernmost MCS quickly propagated northeastwards into Nebraska and did not play a role in the bore event. The second MCS was initially located along the Colorado border and did play a role in the generation of the bore. MCS-2 did not show much signs of propagation until 0900 UTC, when it propagated slowly northeastwards until it eventually dissipated at 1700 UTC. The bore first appeared in the DDC WSR-88D display at 0248 UTC near the radar.

3. THE 20 JUNE 2002 BORE EVENT

The most revealing data pertaining to the possible generation mechanism for the bore may be the S-POL/88D composite radar displays, since these show reflectivity as low as –15 dBZ from the multiple radars. A remarkable fine line (actually, a bowed arc) was present to the south of MCS-2 as early as 0100 UTC (Figure 1). The bowing nature to this fine line suggests that it is an outflow boundary (hereafter referred to as OB1) produced by cold downdrafts from MCS-2, yet it is coincident with the location of the surface cold front. However, the front extends much farther beyond the limits of the fine line.

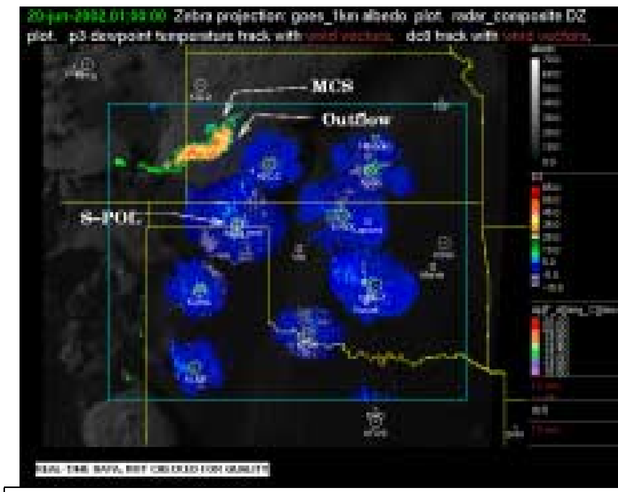

Figure 1: S-POL/WSR-88D radar composite at 0100 UTC showing the mesoscale convective system (MCS, redish colors) and the outflow boundary that triggered the bore further to the south.

As the outflow boundary propagated and expanded southward and eastward, it induced a bore and an accompanying wave train. The wave train propagated slowly southward from the northern Oklahoma Panhandle at 0400 UTC to the Oklahoma-Texas border by 0600 UTC where S-POL and the other profiling instruments were operating (further referred to as Homestead). The wave train began to break down after 0630 UTC, and really could not be discerned at all on S-POL/WSR-88D radar composites after 0730 UTC. The wave train that developed to the rear of OB1 was very impressive in terms of its structure, longevity, and coverage. Waves were even present in the composite radar display in central Kansas after 0400 UTC which means that at least half of the state of Kansas was affected by this event.

4. BORE STRUCTURE AND EVOLUTION OVER THE SOUTHERN GREAT PLAINS

The structure of the bore and its temporal evolution over southwest Kansas and the Oklahoma panhandle was observed by S-POL and LEANDRE 2.

4.1 *LEANDRE 2 observations*

The vertical structure of the bore was investigated with nadir pointing DIAL LEANDRE 2 (Bruneau et al., 2001) from an altitude of 4.5 km MSL. The evolution of the bore was best captured along the westernmost north-south oriented leg passing over S-POL (Figure 2). Three passes were made along that leg: 0329-0352 UTC, 0408-0427 UTC, and 0555-0616 UTC (see vertical cross sections of water vapor mixing ratio in Figure 3).

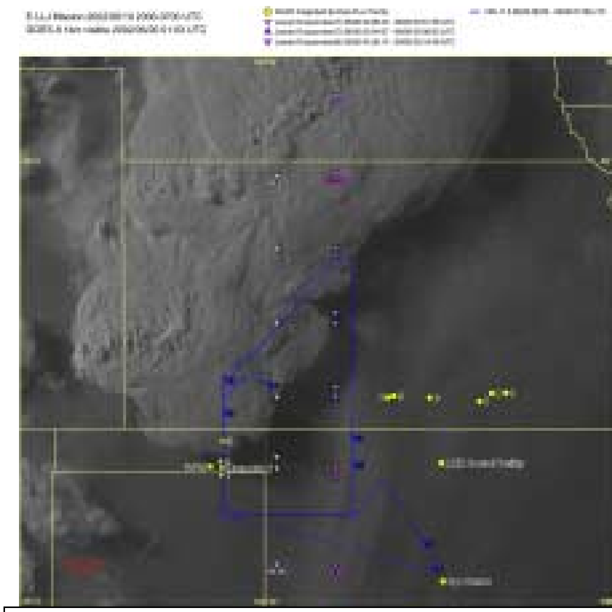

Figure 2: NRL P-3 flight track (blue) during the 20 June 2002 mission. The water vapor mixing ratio vertical cross sections shown in Figure 3 were acquired on the westmost (shortest) north-south oriented leg.

On the first of the three overpasses (0329-0352 UTC), the wavelike signatures were fully developed just north of the Kansas-Oklahoma border (the P-3 passed above the boundary at 0340 UTC). The LEANDRE water vapor mixing ratio cross section (Figure 3a) clearly shows an undisturbed inversion layer at a height of 1.7 – 2.7 km MSL. This layer descends 0.5 km in elevation just ahead of the bore as the aircraft penetrated the leading fine line at 0340 UTC. Two or three perturbations are evident in both the reflectivity and mixing ratio displays at precisely this time. This is then followed by a continuous rise in the height of the inversion layer to an altitude of 2.5 – 3.5 km by 0355 UTC. At least 3 distinct solitary waves are present within the inversion surface at about this time. The crest-to-crest spacing of the waves was ~15 km.

On the second overpass (0408-0427 UTC), the NRL P-3 crossed over the bore at 0415 UTC in essentially the same relative location as it had traversed 35 min earlier. The same 3 waves appear in the data with a horizontal wavelength of 17 km, though at a lower altitude (1.8 – 2.1 km MSL). The waves are amplitude-ordered, the leading one (the bore head) displaying h_1~0.7 km amplitude, and the second and third ones showing h_1=0.4 km (crest-to-trough).

For the final leg (0555-0616 UTC), the pass through the bore occurred at 0602 UTC. During this period the ground observing systems at Homestead were also sampling this feature very intensively (see Section 4). Perhaps the most beautiful of all the wave patterns captured by the LEANDRE 2 on this day occurred with this pass through what is apparently a very well-defined soliton composed of no less than 9 waves, with a spacing of 11-12 km wavelength. Another interesting feature seen in this display is the suggestion that the amplitude-ordering seen earlier is no longer present, but instead that the inversion surface is lifted successfully higher by each passing wave, from 1.3 km to 1.7 km MSL with the first wave, to eventually 2.1 km MSL by the 4th wave, after which the depth of the layer remains essentially the same. This gives valuable information about the length scale of the transition region and suggests an interesting hypothesis that the demise of the soliton was brought about by the flattening of the leading wave in the wave train. Also of considerable interest is the appearance of “ghost” oscillations at 3.2 km altitude in phase with those much lower. These features may actually be clouds induced by lifting below that altitude. The lack of any vertical tilt reveals that these are trapped waves occupying a deep layer from ~ 1.3 – 3.3 km MSL.

Besides the wave patterns, other remarkable features observed by LEANDRE 2 concerned the structure of the water vapor field in the lower tropopshere. Figure 3 evidences the presence of two moisture laden layers (the layer closest to the surface being the atmospheric boundary layer -ABL- and the other corresponding to an elevated layer) separated by a thin and extremely dry layer. This thin dry layer was also seen on the water vapor mixing ratio profiles measured by dropsondes in this area. Back trajectory analyses conducted with the NOAA HYSPLIT4 Model (Draxler and Hess, 1998) suggest that the origin of air masses sampled in these layers were diverse, i.e. the Gulf of Mexico for the ABL, Canada for the thin dry layer and the US west coast for the elevated moist layer. The thin dry layer could be identified unambiguously well to the south of the bore. This layer was no longer observed to the north of the bore head, possibly due to the enhanced entrainment at the top of the ABL in connection with turbulent eddies within the bore head.

4.2 *S-POL observations*

As the wave train approached the S-POL site, an increasing number of waves became evident. Five waves are dramatically apparent in the S-POL radial velocity displayed from 0500 – 0630 UTC (not shown). The waves in the RHI reflectivity and radial velocity cross-section at 0530 UTC (Figure 4) appeared to have a uniform horizontal wavelength of 10 km (crest-to-crest) atop the inversion surface at 2.5 km altitude.

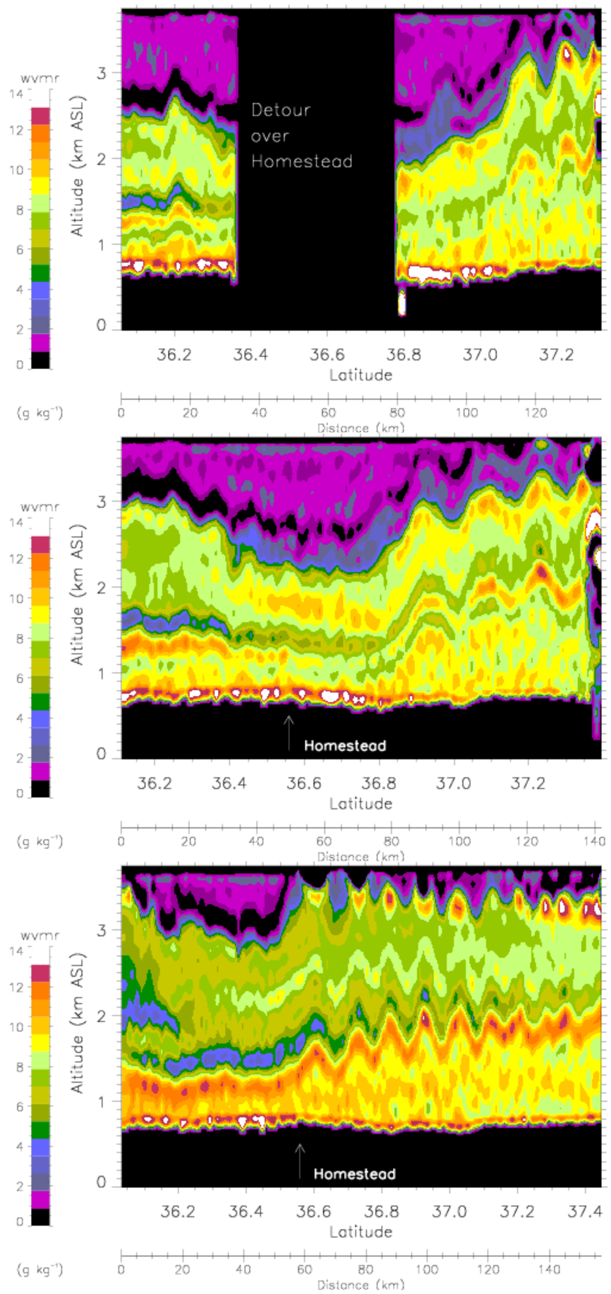

Figure 3: Water vapor mixing ratio vertical cross sections acquired with LEANDRE 2 on the westernmost (shortest) north-south oriented leg between 0329 and 0352 UTC (top), 0408 and 0427 UTC (middle), and 0555 and 0616 UTC (bottom).

Folded Doppler velocities of 18 m s^{-1} directed from the south at a range of 20 km appeared just ahead of the bore and directly north of the radar site at 0400 UTC, suggesting very strong convergence occurred at 200 m agl. This low-level jet appears to ride over the top of the solitary waves, and the RHI display reveals extremely strong vertical wind shear was present between this jet and the winds near the surface.

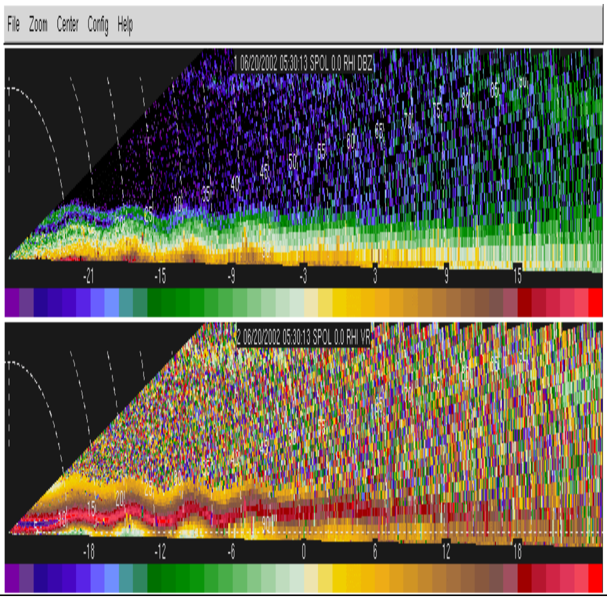

Figure 4: S-POL RHI reflectivity (top) and radial velocity (bottom) displays at 0530 UTC. The RHI is oriented from north (left) to south (right).

5. BORE OBSERVATIONS AT THE HOMESTEAD PROFILING SITE

The bore dissolution after 0630 UTC was observed by numerous surface and profiling instruments (in situ and remote sensing facilities) at the Homestead site.

The high-resolution ISS (Integrated Surface and Sounding System) data between 0500 and 1700 UTC on 20 June 2002 are shown in Figure 5. The bore is characterized by a 2-mb pressure jump at 0600 UTC, though the pressure had already been rising ahead of the bore for several hours. Wind direction shifted only slightly from 150 to 120 degrees with the passage of bore. However, the wind speed dropped abruptly with the passage of bore, from 12 to 3 m s^{-1}. There is no evidence of fluctuations in the wind on the same time scale as the small-scale waves within the soliton, perhaps because the wave train was dissolving as it came over Homestead.

The ISS sounding from Homestead at 0330 UTC indicated a strong inversion at 850 hPa (1.6 km MSL), which apparently was lifted to 800 hPa (2.0 km MSL) by 0600 UTC. The ISS1 sounding provided some evidence that the inversion originally at 850 hPa was lifted and weakened with the passage of the bore (similar to that shown by Koch and Clark 1999).

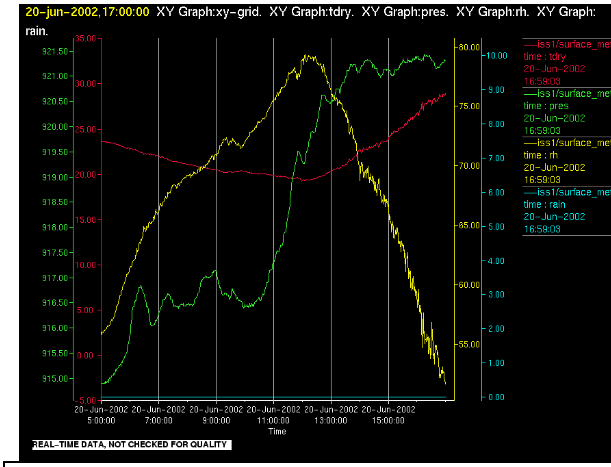

Figure 5: ISS observations of surface pressure (green), temperature (red) and relative humidity (blue) between 0500 and 1700 UTC.

6. CONCLUSION AND PERSPECTIVES

We have presented a first analysis of the life cycle of a bore event observed by numerous instruments on 20 June 2002, in the course of the IHOP_2002 field experiment. Ultimately, the objectives of this study are to:
• study the life cycle of a bore event,
• compare observations with hydraulic theory,
• understand the role of bores in nocturnal convection initiation and maintenance,
• simulate this bore event with a high-resolution numerical simulations.

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