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MAPR Observations of the Boundary Layer using RIM and Spaced Antenna Techniques at IHOP

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1. INTRODUCTION

IHOP (International H2O Project) was a large experiment carried out in the spring of 2002 involving many researchers and a large variety of instruments on a study of water vapor and convective weather. The experiment was centered on the Kansas and Okalahoma area and is described in Weckwerth et.al. 2003. The IHOP home page is www.atd.ucar.edu/dir_off/projects/2002/IHOP.html

NCAR (National Center for Atmospheric Research) deployed an Integrated Sounding System (ISS, Parsons et. al. 1994) in the Oklahoma panhandle. This ISS included a surface met tower, radiosondes, sodar and the advanced UHF wind profiler MAPR (Multiple Antenna Profiler Radar). MAPR is a spaced antenna 915 MHz wind profiler capable of making rapid wind measurements (Cohn et.al. 1997, 2001). At the same site were NASA lidars (the Raman, GLOW, and HARLIE lidars), the University of Wisconsin AERI (Atmospheric Emitted Radiance Interferometer), and the University of Massachusetts FM-CW S-band vertically pointing radar. The NCAR home page for the ISS at this site is at www.atd.ucar.edu/rtf/projects/ihop_2002/iss/

For an overview of the IHOP project see Weckwerth et.al. 2003, and for more discussion of findings such as water vapor measurements and convective initiation see papers in session 6J of this conference. A preliminary overview of ISS measurements at IHOP was also given in Brown et.al. 2003. This current report will concentrate on MAPR measurements of fine structure, particularly shear rolls, and on the interferometric techniques used to make those measurements.

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Figure 1: The MAPR wind profiler at IHOP in the Okalahoma panhandle.

2. INTERFEROMETRY AND RIM

At IHOP MAPR used the RIM (Range IMaging, Palmer et. al., 1999) technique to greatly enhance the vertical resolution of the radar. The frequency of the profiler is shifted from 915 MHz from pulse to pulse by about 1 – 2 MHz. As the wavelength changes, the phase of echoes change in a manner that can be precisely related to range using frequency domain interferometry techniques. Depending on the application, in principle the technique can improve the range resolution from 100 meters down to around 10-20 meters.

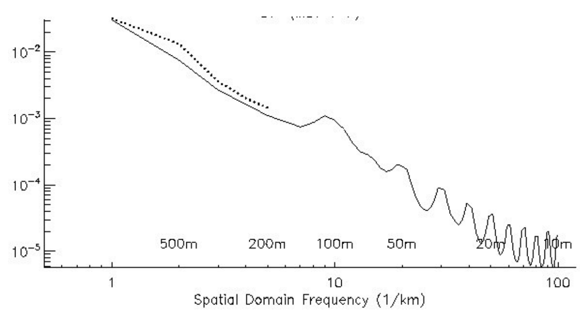

Figure 2: Spectrum in the spatial domain of variance in vertical velocity for standard resolution mode (short, dashed line) and RIM mode (long solid line). 7 June 2002, 17-20 UTC on MAPR.

Rather than using Fourier transform techniques to deconvolve the frequency shifted signals into an enhanced resolution profile, RIM uses the Capon data adaptive transform technique (Palmer et. al., 1999). This technique gives higher resolution profiles with fewer side-lobe contamination than Fourier techniques; however the actual resolution of the resulting profile is difficult to define because of the data adaptive nature of the transform. Figure 2 illustrates one approach to estimating the resulting resolution of the technique. The vertical velocity of both standard mode (at 100 meter sampling) and RIM mode (at 5 meter over-sampling) is spectrally analyzed in the spatial domain (i.e. with altitude rather than in time). As expected, both modes follow a Kolmogoroff trend; however the RIM mode gets noisy at around the 20 meter scale. This suggests that for this data, the resolution of the RIM measurements is around 20 meters.

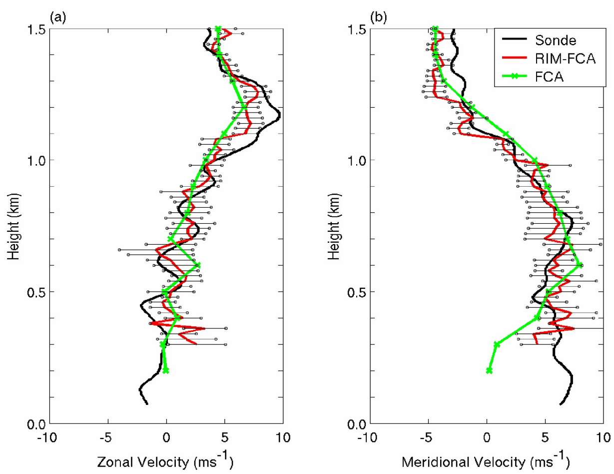

Figure 3: Comparison of radiosonde (black line), RIM (red line), and standard mode (green line) wind measurements at the IHOP MAPR site on 6 June 2002 1740 UTC (Yu, Brown, and Frasier, 2003).

In addition to providing high resolution measurements of reflected signals and vertical velocity, using RIM on MAPR provides the unique ability to also make wind measurements at high range resolution (in addition to the high time resolution normally available to MAPR). RIM analysis is carried out separately for the four receivers of MAPR and an inverse transform is carried out to obtain a time series of raw data at each 20 meter RIM sub-gate (Yu and Brown, 2004). These time series of data are then analyzed in the usual spaced antenna Full Correlation Analysis (FCA) procedure to estimate winds. This technique is referred to here as RIM-FCA. Figure 3 shows a comparison of wind measurements made by standard (100 meter) mode, RIM-FCA, and a nearby radiosonde. As can be seen, the RIM analysis shows small scale features that are similar to those seen by the sounding.

3. WIND SHEAR ROLLS

Small scale structures such as Kevin-Helmholtz rolls were occasionally seen at the IHOP site. MAPR is an ideal tool for studying these rapidly evolving features because of its ability to make rapid wind measurements. The addition of RIM enabled the fine scale structure of these features to be examined.

Figure 4 shows an example of a shear roll as observed by MAPR in standard mode. A nearby sounding showed southerlies near the ground, dropping off to near stationary conditions at around the 3km level. The bulk Richardson number dropped to the ¼ critical levels at about 2.5km. The figure shows echo signal level in the upper panel and the circular structure is suggestive of a roll. The lower panel shows vertical velocity. There appears to be upward motion on the leading edge of the roll as it passed over the radar, followed by downward motion on the trailing edge. This behavior is consistent with might be expected of a roll formed between the southerly wind below, and stationary air aloft.

Figure 5 shows observations made using the RIM technique for the same period as figure 4. The RIM resolution used here is 20 meters. The upper panel shows a brightness image which can be considered a non-linear indicator of (uncalibrated) reflectivity levels. There is additional structure in the features not apparent in the standard mode signal image of figure 4. The lower panel of figure 5 shows wind vectors as estimated using RIM-FCA. There appears to be some convergence of the wind vectors on the leading edge of the roll, and some divergence of the vectors on the trailing edge.

4. SPATIAL INTERFEROMETRY

The multiple receivers of the MAPR radar can also be used for spatial interferometry imaging. This technique uses phase offsets added to the signals received by the spaced antenna to effectively steer the beam of the radar mapping

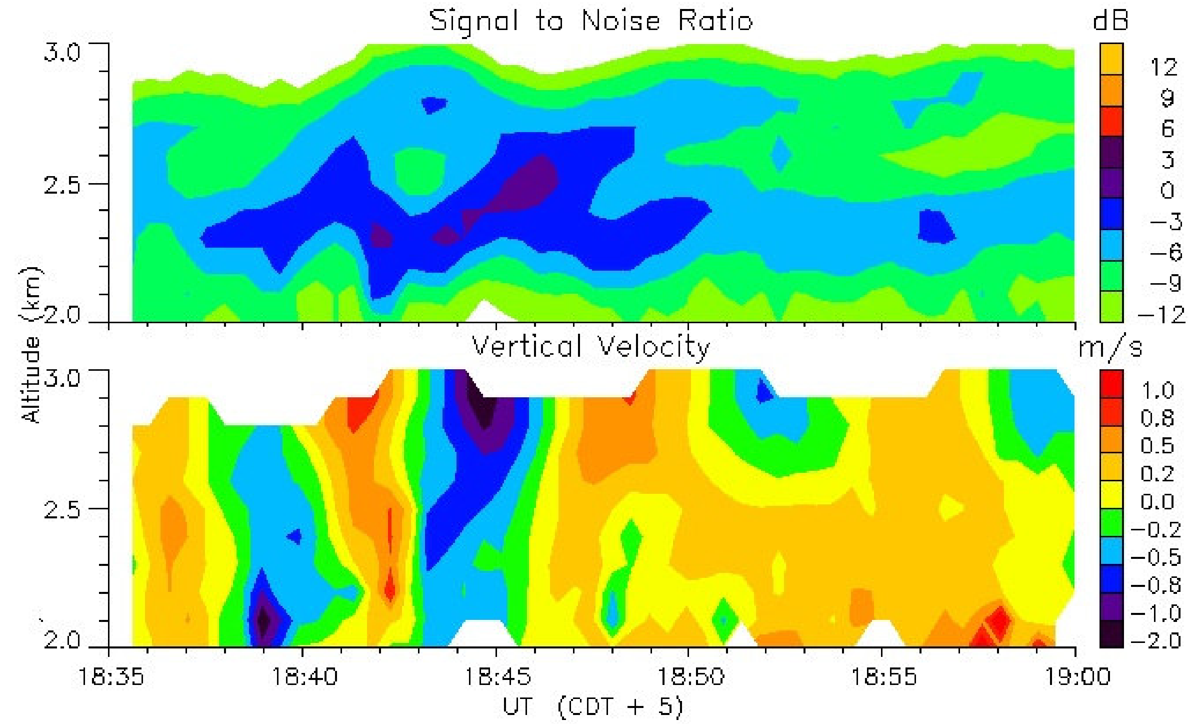

Figure 4: MAPR standard mode observations of a shear roll on 7 June 2002. Reds indicate upward vertical velocity.

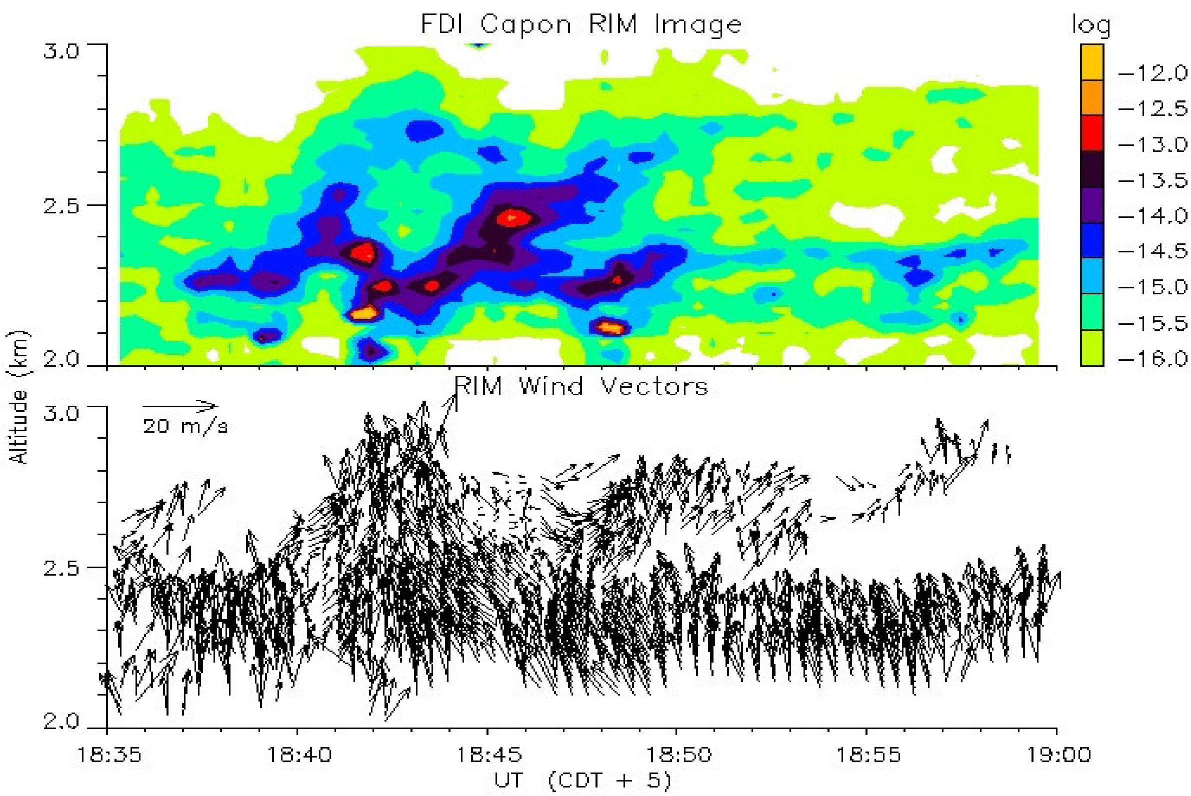

Figure 5: RIM brightness and RIM-FCA wind vectors for the same time and altitude period as figure 4.

out an image of scattering from the atmosphere. MAPR only has four receivers so the image obtained is of low resolution; however the technique can occasionally be useful to examine the orientation of features in the atmosphere. The method of Palmer et. al. 1998 was used.

In general little no structure to the scattering was seen. For example the roll of figures 4 and 5 was larger than the sampling volume of MAPR (about 400 meters across at the 2.5 km level) and so did not produce significant structures in spatial interferometry images.

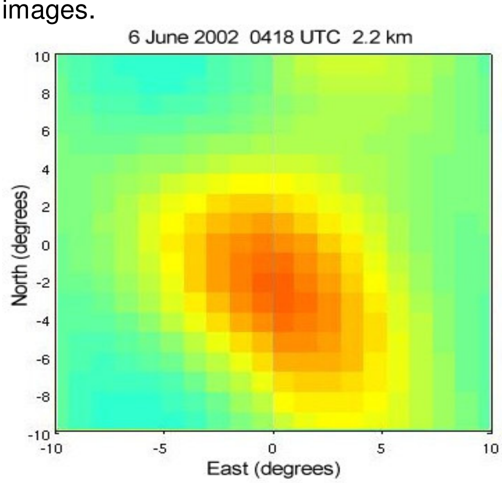

Figure 6: Spatial Interferometry image of a small scale roll.

Figure 6 shows an example of interesting features in observations of another set of rolls. These rolls appear to have been produced by shear between northerlies at around 2km altitude and north-westerlies at around 3km. In this case the rolls were much smaller at around 200 meters across. The figure shows a reflectivity image, with redder colors indicating stronger signal as a function of angular displacement from zenith. Notice how the feature is elongated and aligned approximately NW and SE. This orientation suggests the rolls were traveling in a south-easterly direction with the overlaying wind.

Unfortunately there is only limited phase locking between the multiple receivers on MAPR, which complicates phase calibration of the system. The offset of the feature from directly overhead probably results from the imprecise phase calibration. The phase calibration issue is not expected to significantly impact the orientation of the feature.

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