Volumetric Supercell and Tornado Analysis with Six-Second Temporal Resolution Using the Atmospheric Imaging Radar

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Abstract

The Atmospheric Imaging Radar (AIR) is a mobile imaging weather radar system designed and built by the Advanced Radar Research Center (ARRC) at the University of Oklahoma. By utilizing a vertical 20-degree fan beam on transmit, as well as 36 receiving elements, digital beamforming techniques can be used in order to form simultaneous RHI scans. Horizontal pedestal rotation allows for sector scans in quickly evolving weather situations, resulting in full volumetric updates on a storm of interest every six seconds. This unprecedented combination of spatial and temporal resolution was deployed on a series of tornadic supercells near Carmen, OK on April 14, 2012, resulting in the full observation of tornadogenesis and dissipation of two tornadoes at close range. With volumetric data at such short intervals, a number of supercellular and tornadic structures and evolutionary characteristics were observed in new ways. A discussion of features that were unobservable with previous methods of radar scanning techniques is presented. Specifically, volumetric vortex tilt, as well as highly detailed storm evolutions, such as mesocyclone occlusion occurring on the order of seconds, are shown.

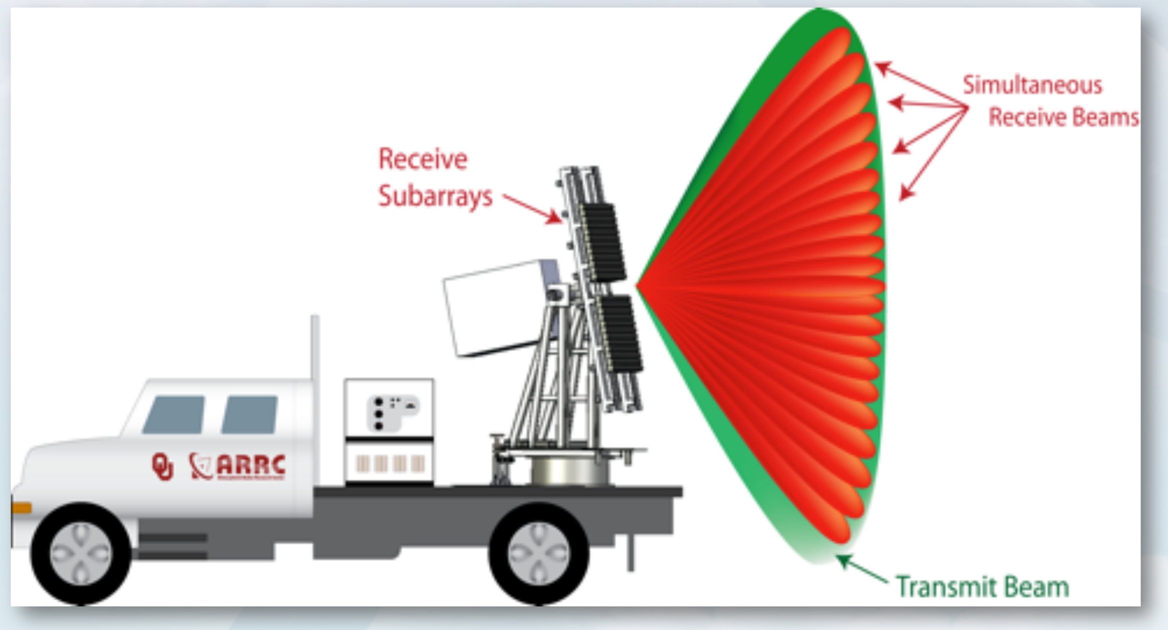
The Atmospheric Imaging Radar

The Atmospheric Imaging Radar (AIR) is an X-band (9730 MHz) 20 kW mobile weather radar platform which specializes in extremely high temporal resolution observations of severe convective storms. The AIR was built entirely by University of Oklahoma students, faculty, and staff affiliated with the OU Advanced Radar Research Center (Isom et al. 2012, JTECH).

The Atmospheric Imaging Radar in front of the National Weather Center in Norman, OK. The system uses a fan-shaped transmit beam, and forms pencil beams on receive using digital beamforming.

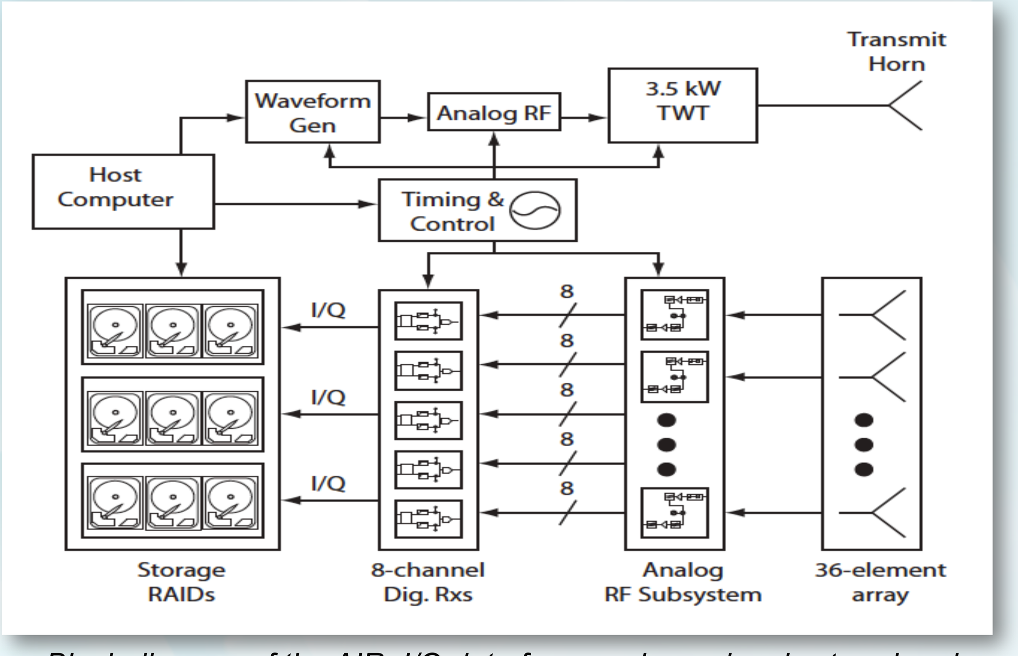
Scanning and Processing Methods

The AIR utilizes a fan beam on transmit, and uses 36 individual sub-arrays to form pencil beams on receive using digital beamforming. This technique allows for instantaneous RHI scans covering 20 degrees in elevation, and 1 degree in azimuth. Typically, a fan beam in the vertical would result in a loss of critical elevation data, but the digital beamforming method allows for an infinite number of pencil beams to be formed, making for a very high resolution RHI image.



Simultaneous receive beams are possible using digital beamforming, allowing for instantaneous collection of RHI scans.

Applying different weights to each of the 36 receiving sub-arrays allows the direction of the beam to change. Digital beamforming is performed after data collection in post-processing, meaning that I/Q data are recorded for all 36 receive channels, allowing for advanced signal processing after collection. For more information on the AIR and beamforming methods, please see paper 7B.3 (*Nai et al.*) at 11:00 AM in Room 12A on Wednesday.



Block diagram of the AIR. I/Q data from each receiver is stored and can be summed with designed weights to form beams.

By acquiring instantaneous RHI scans, the pedestal only needs to be rotated in azimuth to cover the entire storm volume. A sector scan is used, and temporal resolution as high as 3.5 seconds can be achieved.

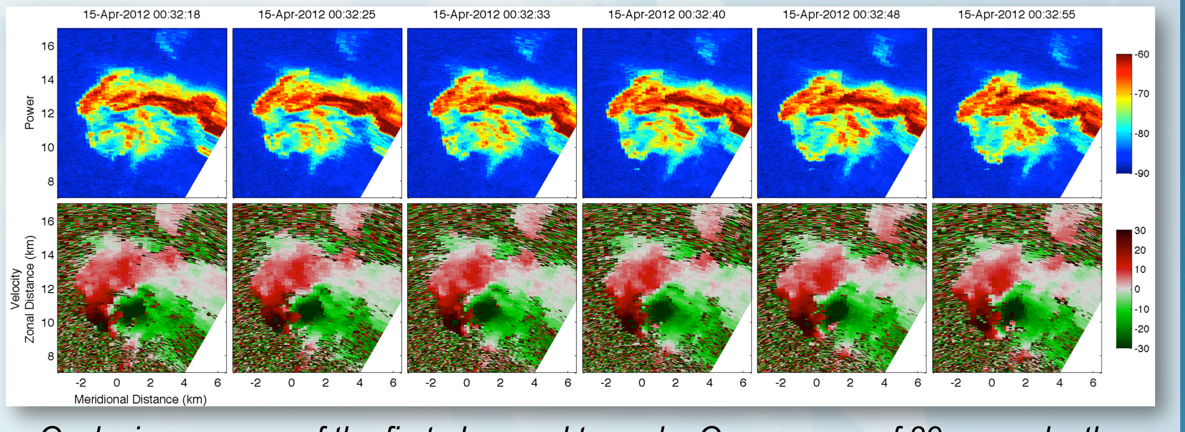
14 April 2012 Tornadoes

On April 14, 2012, multiple large tornadoes occurred across Northwestern Oklahoma. The AIR observed two of these tornadoes at close range, including the full tornadogenesis and dissipation of an extremely short-lived tornado, and the tornadogenesis of a long-lived tornado shortly after. The AIR recorded volumetric scans of both storms at a temporal resolution ranging from 3.5 - 8 seconds.

The AIR collecting 3.5 second volumetric samples of a tornado on 14 April 2012.

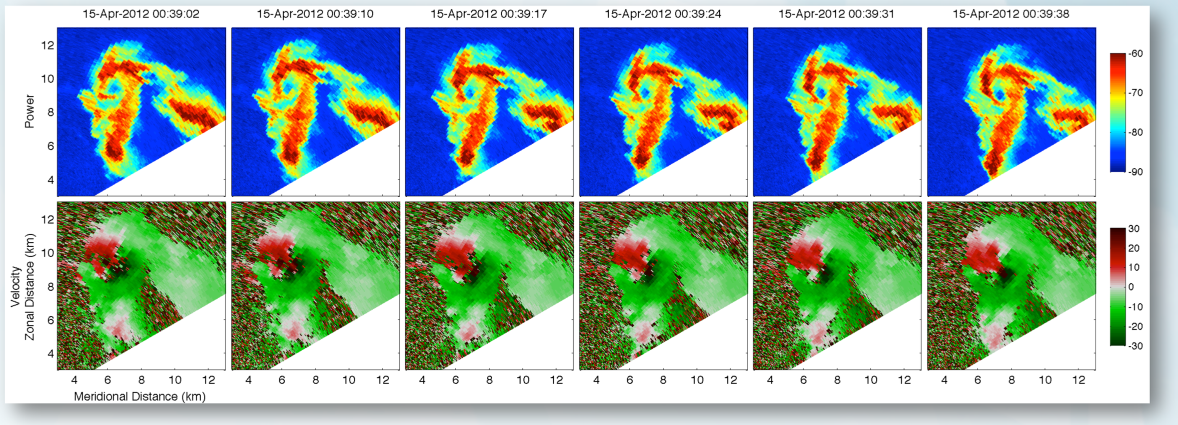
Below are data from the 14 April 2012 tornadoes. Note the extremely high temporal resolution, leading to observations of subtle storm features and rapid occlusions.

Tornado 1



Occlusion process of the first observed tornado. Over a span of 39 seconds, the tornado occludes and dissipates. This tornado had a visual ground circulation for only approximately 10 seconds, making it virtually invisible to traditional scanning radar systems.

Tornado 2

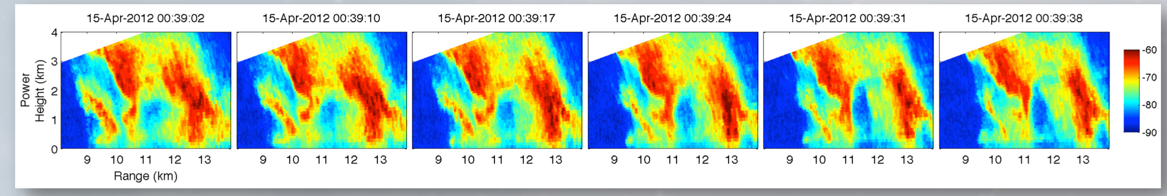


Mature stage of the second observed tornado, approximately six minutes after the first tornado. Images are 6.5 - 8 seconds apart.

Unique Meteorological Analysis

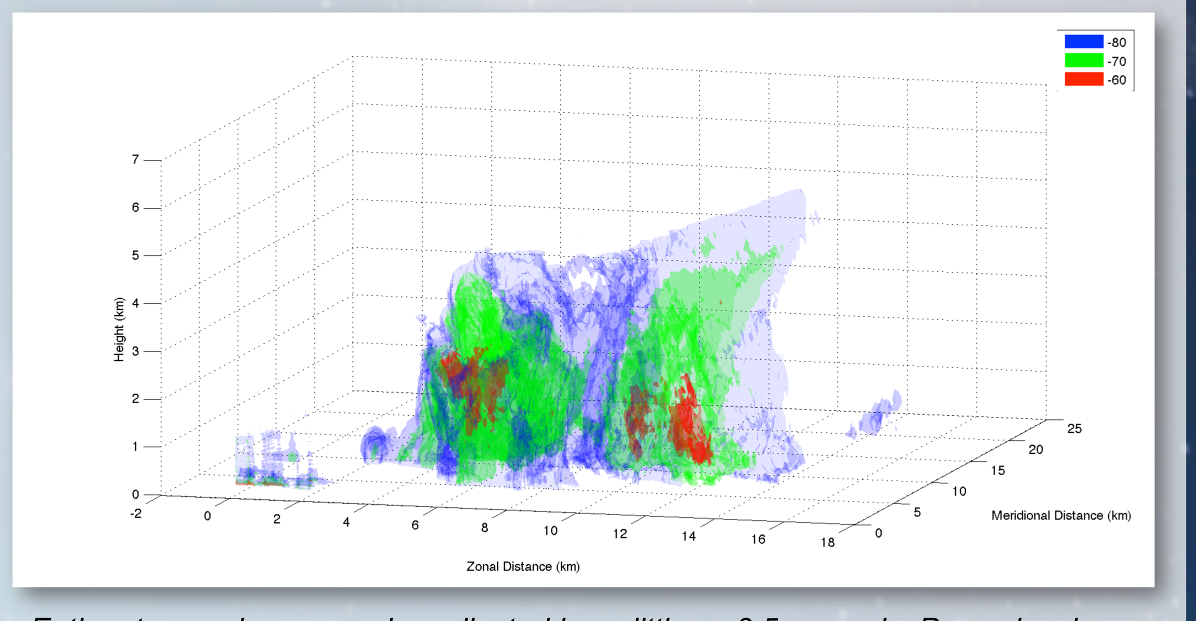
A number of unique analyses can be completed using instantaneous RHI and very high temporal resolution volumetric data. A few of these are shown below.

RHI/BWER Observations



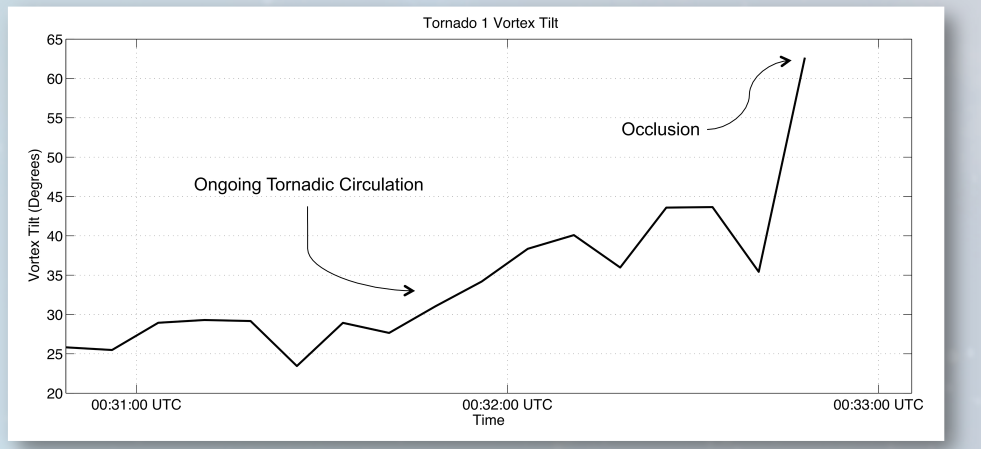
Instantaneous RHI observations allow for high temporal resolution cross sections through the tornado. The bounded weak echo region between 11 and 12 km range is the core tornadic vortex, and can be seen growing in height over 36 seconds.

Volumetric Analysis



Entire storm volumes can be collected in as little as 3.5 seconds. Power levels are shaded as isosurfaces in order to see detailed storm structure and evolution.

Vortex Tilt



With rapid volumetric updates, an accurate representation of vortex tilt can be calculated. At the occlusion point, the vortex tilt increases considerably as the tornado dissipates.

Conclusions and Future Work

Future plans for these data include volumetric analysis of vortex tilt and other features involving rapid tornadogenesis and dissipation. Plans for the AIR in 2013 and beyond include the application of advanced pulse compression waveforms for increased sensitivity, improved beamforming methods, optimal array spacing, and pedestal improvements. For more information regarding future pulse compression applications to the AIR and other systems, please see paper 7B.4 (*Kurdzo et al.*) at 11:15 AM in Room 12A on Wednesday.

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