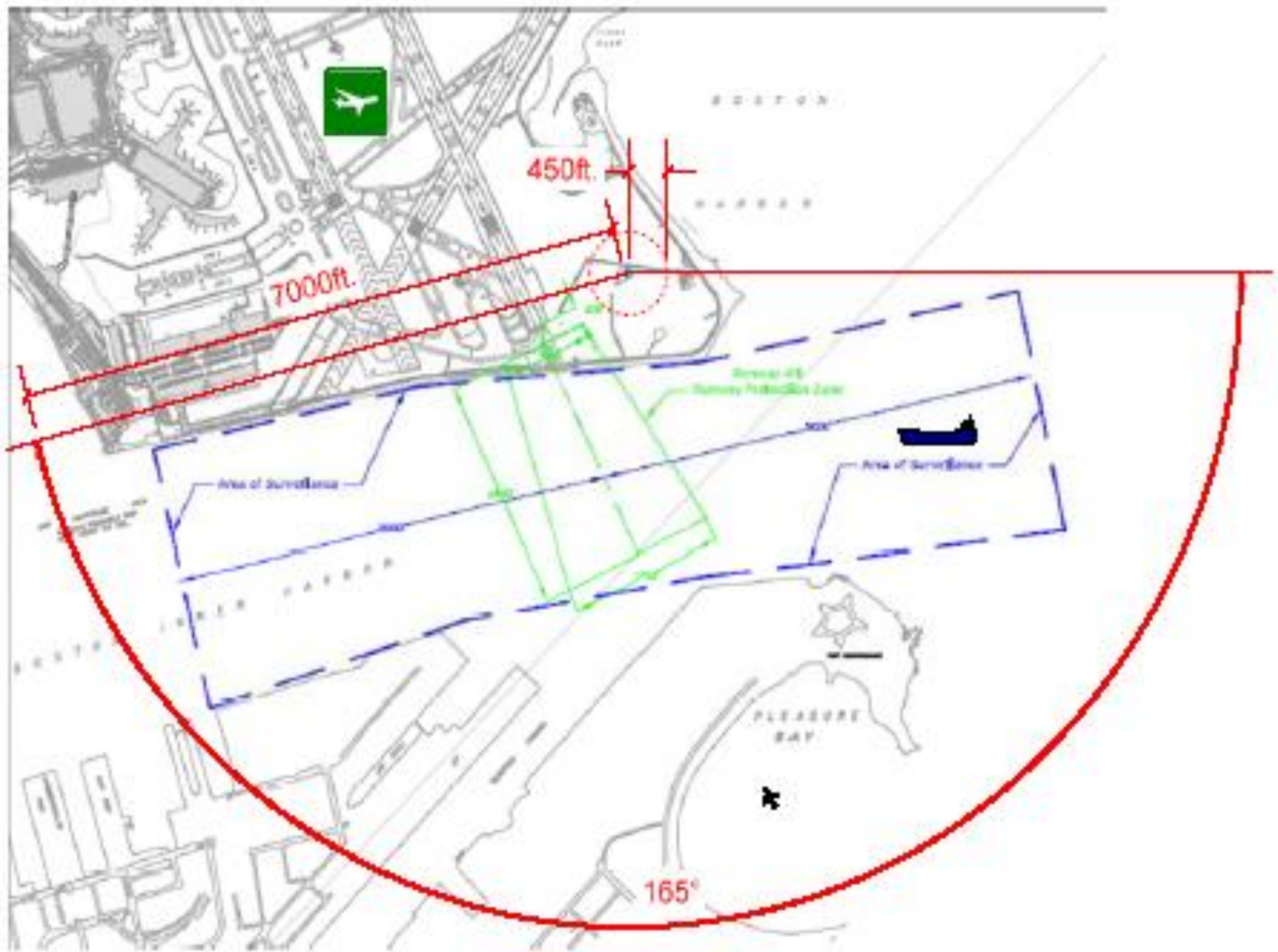
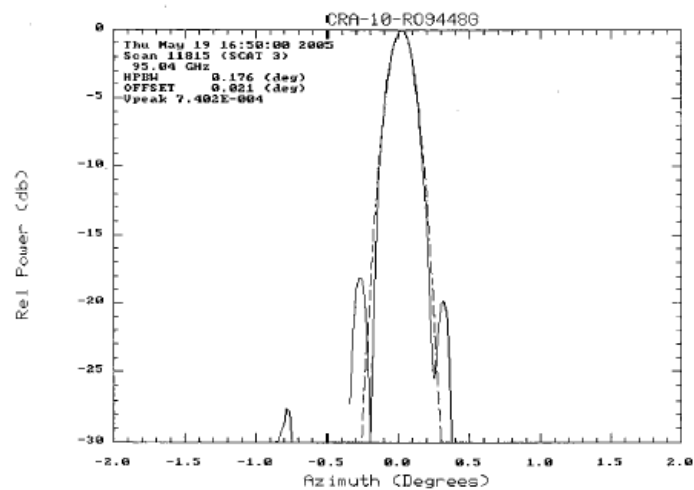
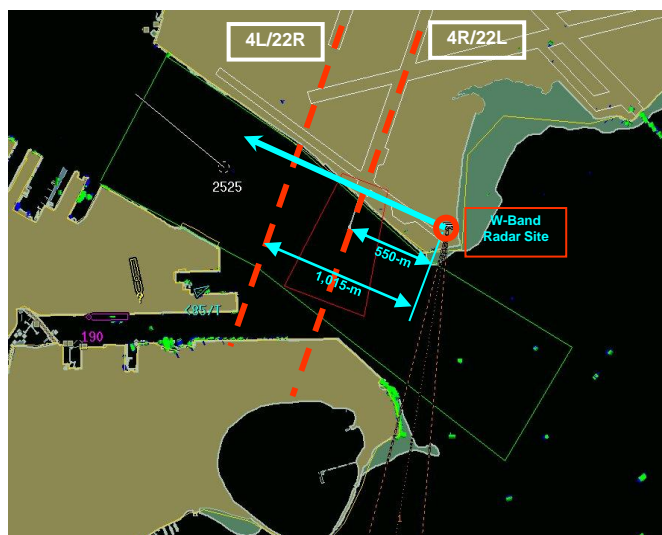


High Resolution W-Band Radar Detection and Characterization of Aircraft Wake Vortices in Precipitation

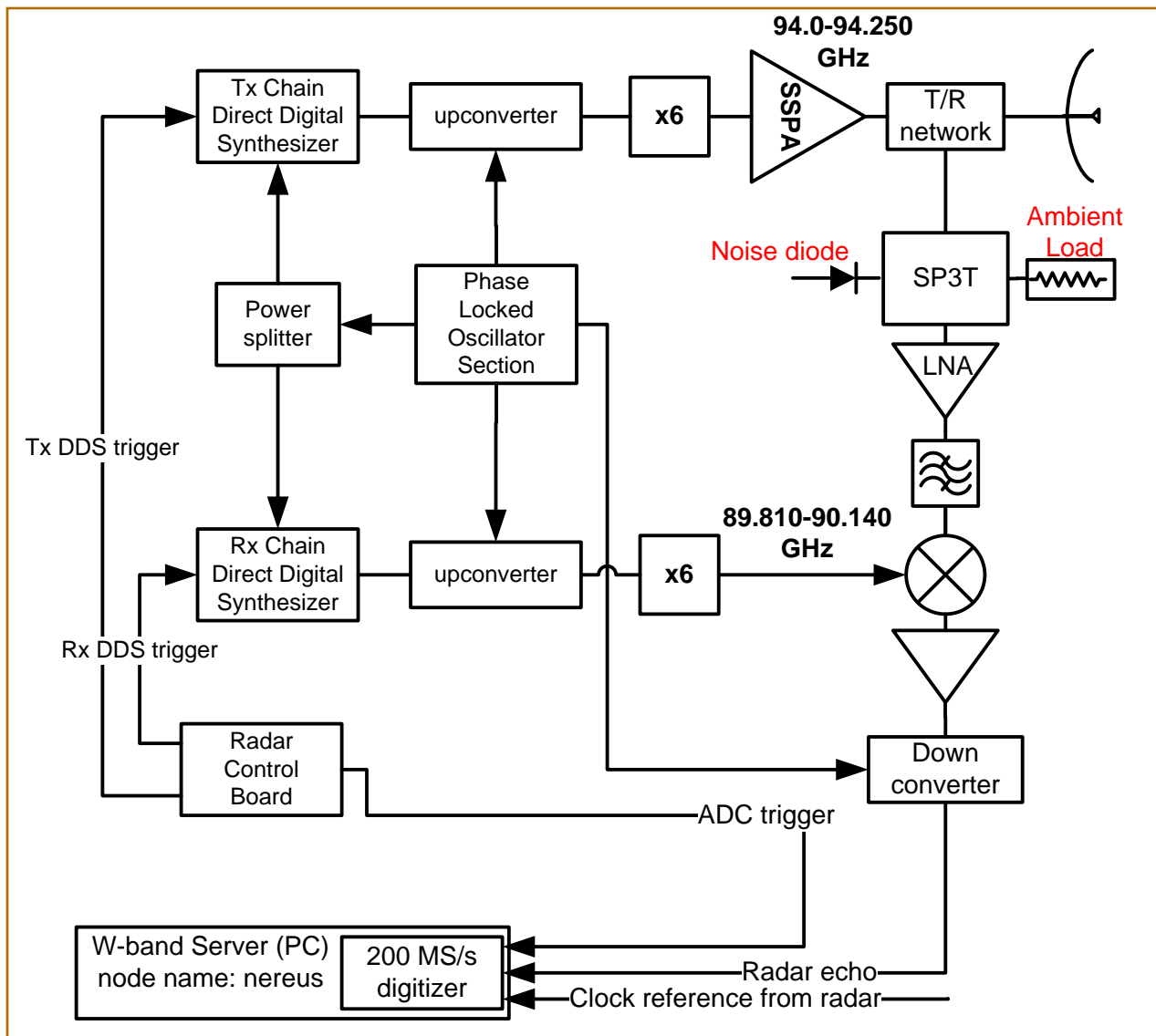
**Thomas A. Seliga
and
James B. Mead**







The W-Band Radar System at Boston's Logan Airport



Block Diagram of the W-Band Radar System.

RADAR ATTRIBUTES

- Secure Shelter located on the airfield
- Able to scan in azimuth and elevation (programmable)
- Ideally located for detection of wake vortices (RW₄R/22L and RW₄L/22R)
- Internet connectivity for continuous monitoring, data archiving and maintenance
- Reference Reflector for monitoring and gauging system performance
- Antenna is a Parabolic Cassegrain Feed with nominal gain of 59-dB and HPBW of 0.18° ; 2-Way sidelobe suppression > 60-dB beyond ±3-beamwidths
- TX Signal is a long-duration, linear FM chirp waveform, with duration configurable from 1-10-μs

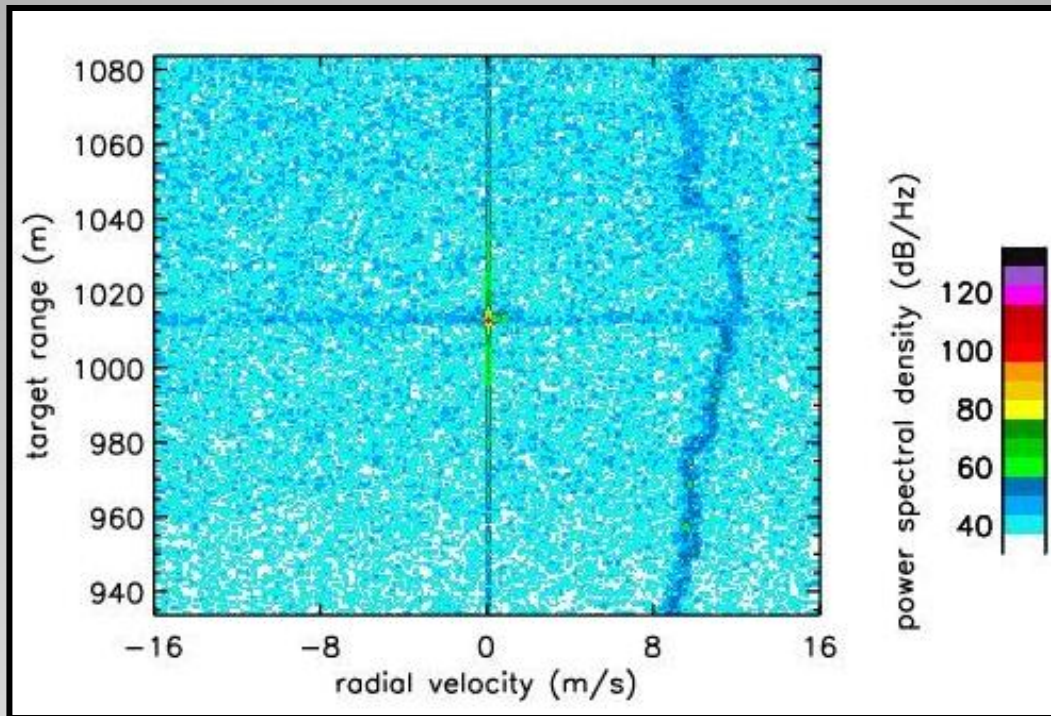
RADAR ATTRIBUTES

- RX Signal is multiplied by time-delayed RX local oscillator signal of the same slope in the modulation domain (f vs t) used for the TX Signal. Sampling is at 200-MHz-s⁻¹, followed by first-level FFT processing to generate a range profile with 1-m range resolution (configurable)
- 20-kHz PRF yields an unambiguous Doppler velocity interval of ± 16 -m-s⁻¹ and allows for a large number of samples to be coherently integrated for improving sensitivity.
- The typical coherent integration length is 256 samples (512 and 1,024 also selectable), implemented by a second-level FFT at each range gate for Doppler processing. (Doppler velocity resolution ~ 0.12 m-s⁻¹)
- Velocity spectra are power averaged to reduce fading

Parameter	Value
Frequency of Operation	94.0-94.25 GHz
Peak Transmit Power	100 mW
Waveform Type	Linear FM chirp
Range Resolution	1.0 m
Pulse Repetition Frequency	20 kHz
Pulse Duration (min- max)	1-10 μ s
Antenna Diameter & Type	48" Cassegrain
Antenna Beamwidth	0.18°
Antenna Gain	59 dB
Front-end Noise Figure	12 dB

W-Band Radar Specifications.

SAMPLE VALIDATION OF DOPPLER VELOCITY MEASUREMENTS

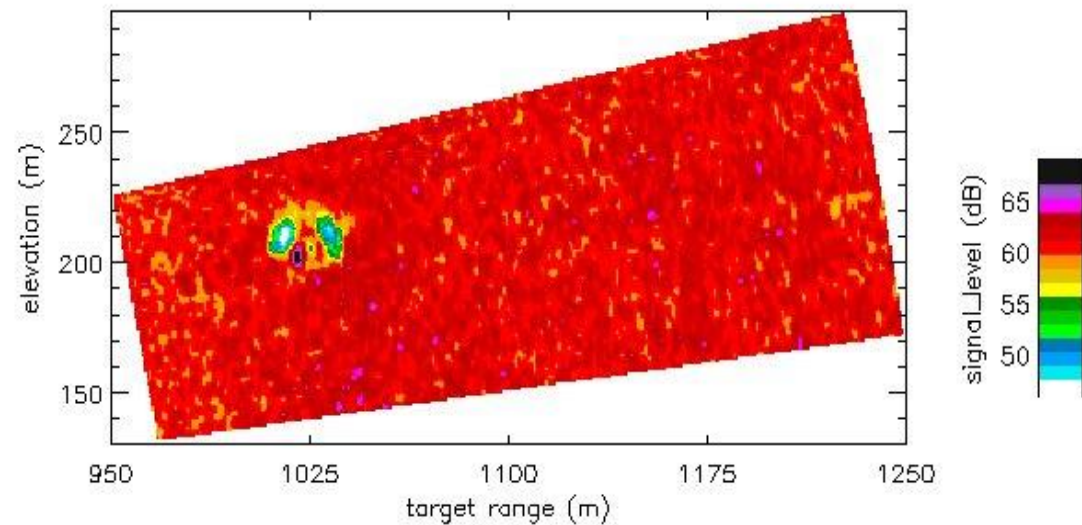


ASOS-based wind speed in the direction and at the height of the radar Doppler measurements were $\sim 9.3\text{-}10.8\text{-m-s}^{-1}$ in good agreement with the 10.7-m-s^{-1} average Doppler velocity measurement obtained from the measurements shown above.

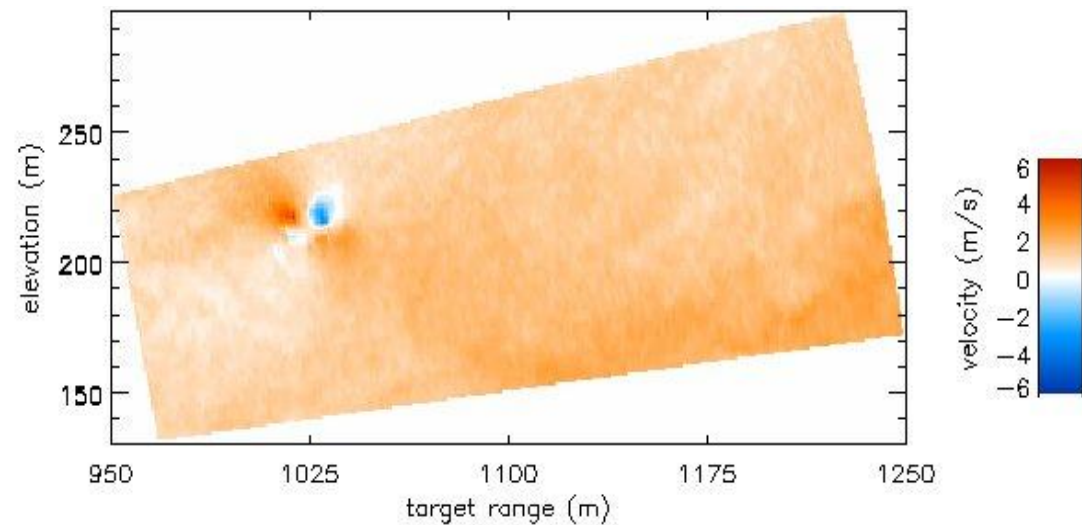
SAMPLE VALIDATION OF DOPPLER VELOCITY MEASUREMENTS

FIRST ATTEMPT TO DETECT WAKE VORTICES

***RELATIVE
POWER***



***DOPPLER
VELOCITY***



**First measurements of wake vortices made with the W-Band Radar on
March 26, 2009 at Logan International Airport.**

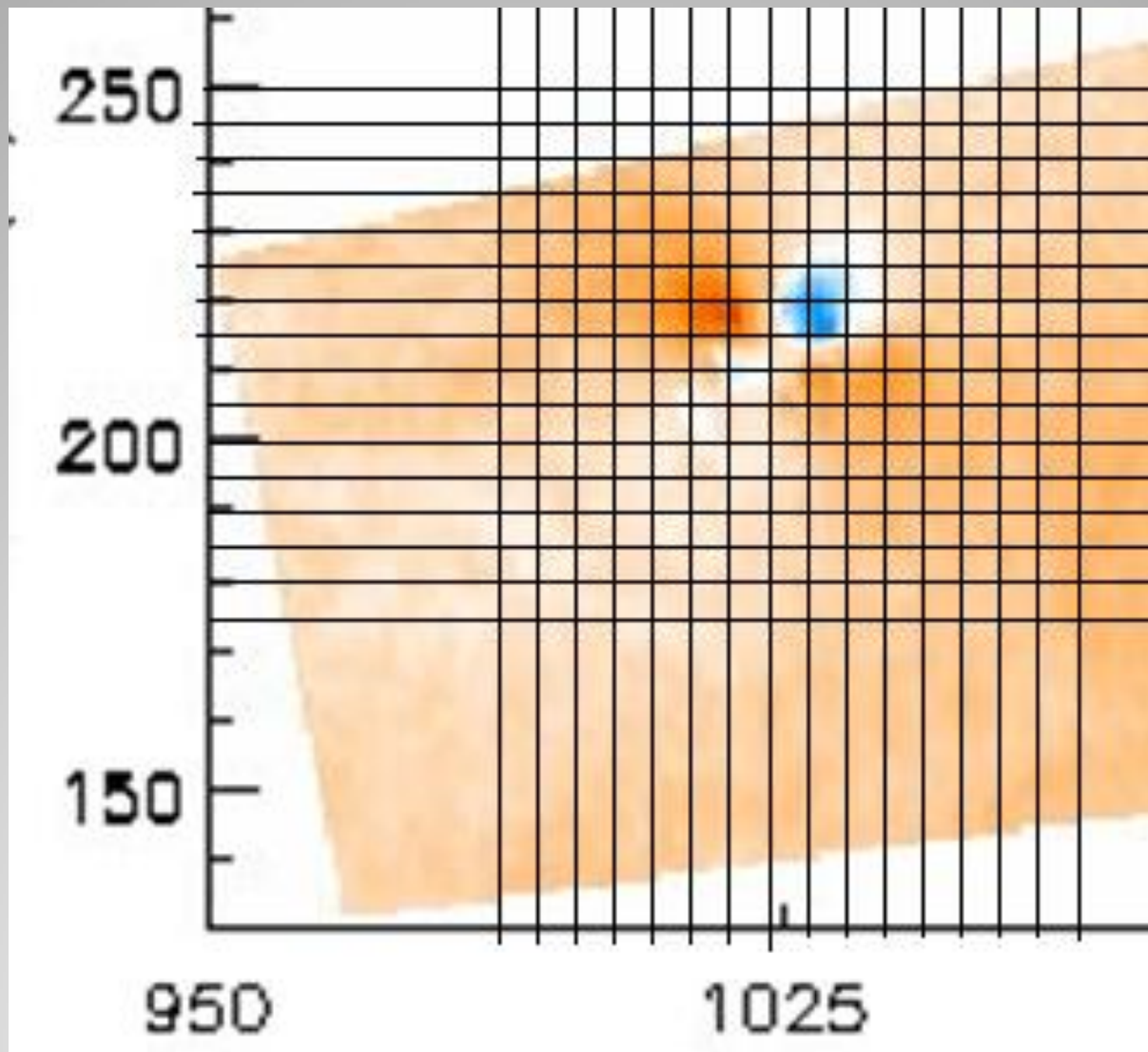
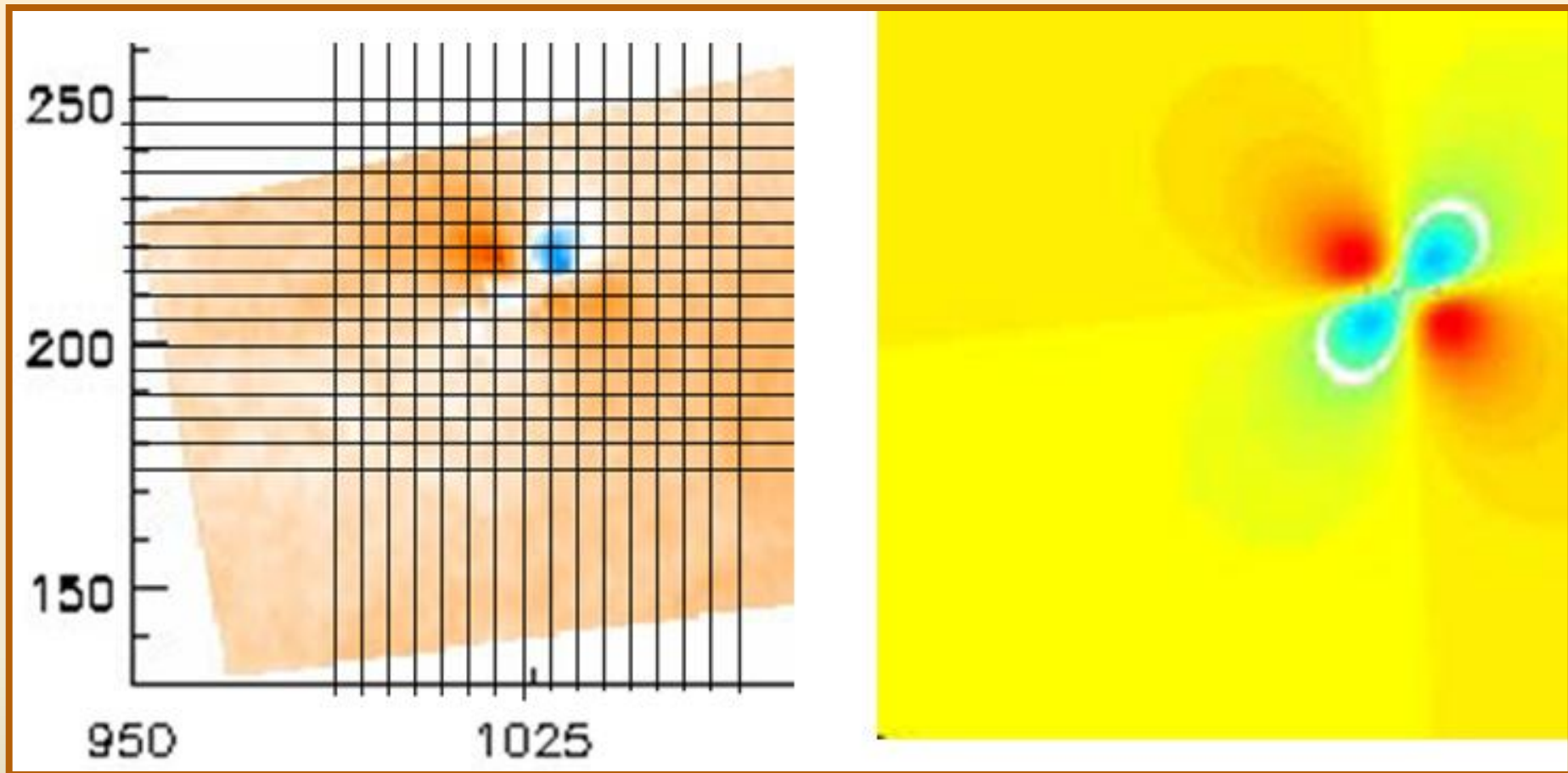
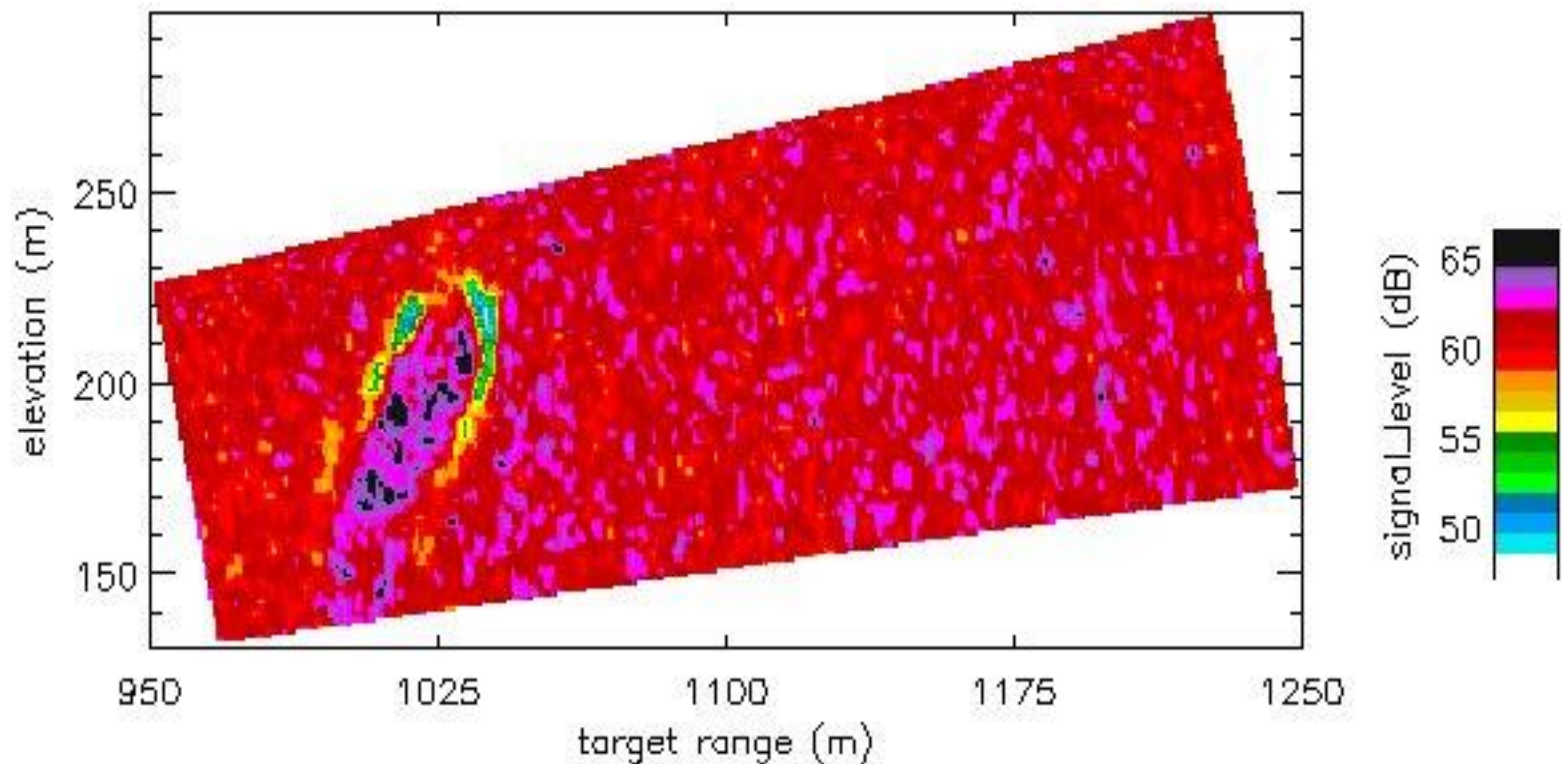


ILLUSTRATION OF THE RADAR'S SPATIAL RESOLUTION (3-m)
GRIDS: HOR @ 5-m; VER @ 5-m



**COMPARISON OF RADAR MEASUREMENTS WITH A SIMULATED
PAIR OF VORTICES, INCLUDING EFFECTS OF A CROSS WIND**



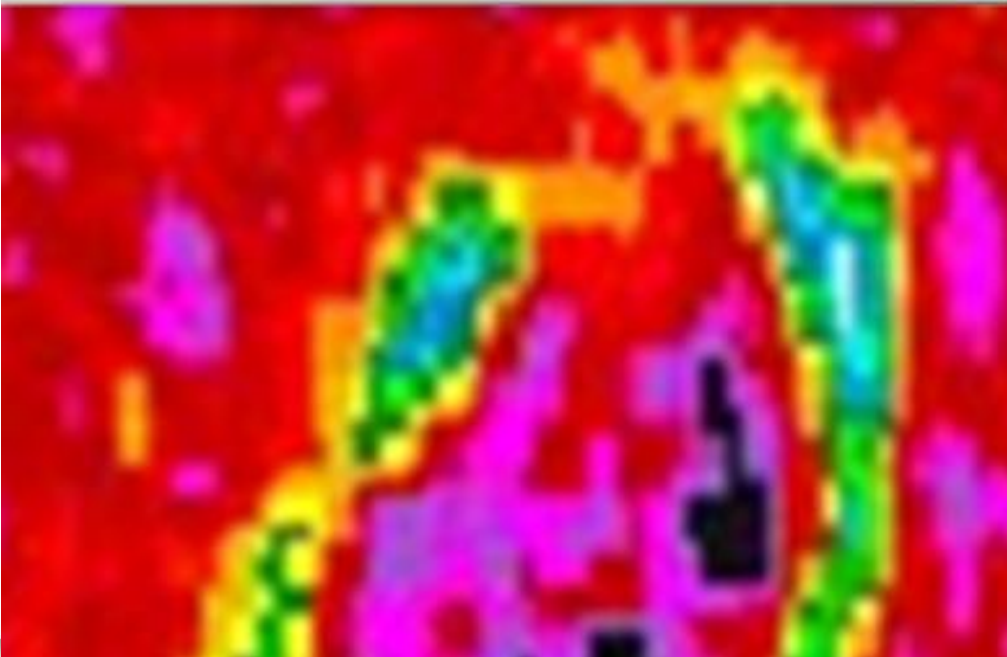
RHI RELATIVE POWER PROFILE INDICATING BOTH REDUCED AND ENHANCED PRESENCE OF HYDROMETEORS RESULTING FROM THE PRESENCE OF THE WAKE VORTEX PAIR SHORTLY AFTER THEIR FORMATION (~28-s)

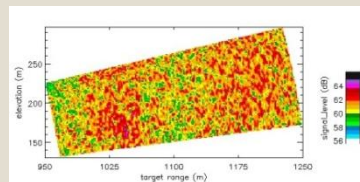
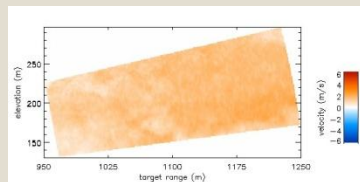


**SIMILARITY OF
CLOUD-BASED
PHOTOGRAPH**

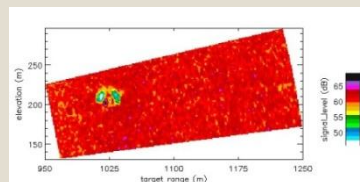
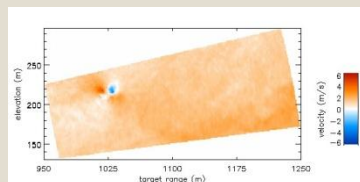
AND

**HYDROMETEOR-
BASED RADAR
RELATIVE
POWER
RESPONSE**

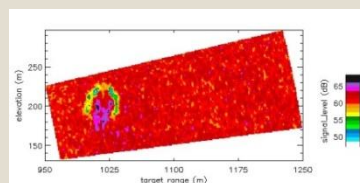
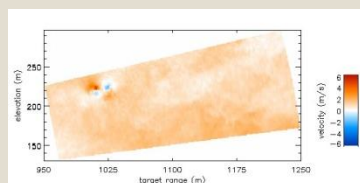




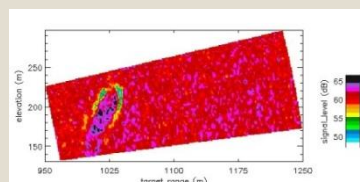
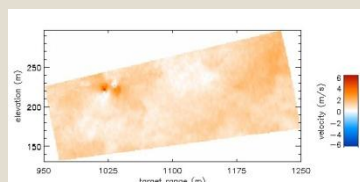
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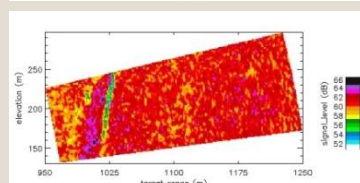
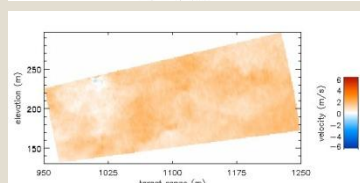
1217



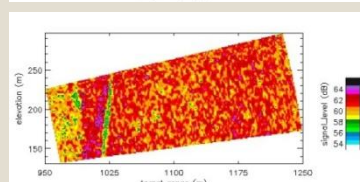
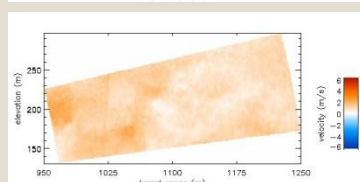
1229



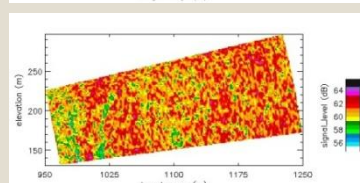
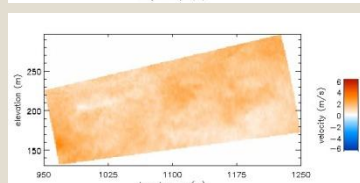
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1253



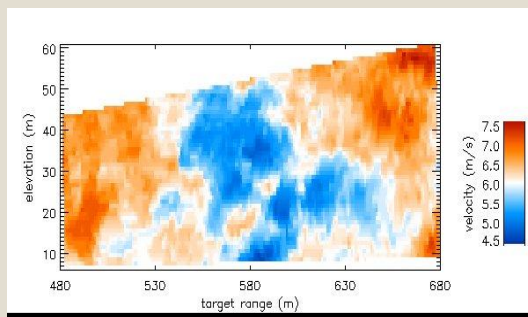
1305



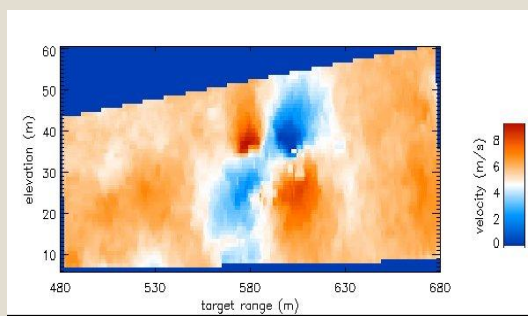
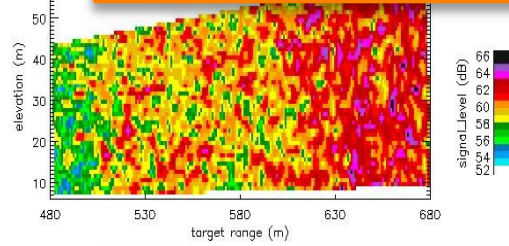
1317

Time history of wake vortices detected by the W-Band Radar on March 26, 2009. The block numbers correspond to MMSS after 19:00 EDT.

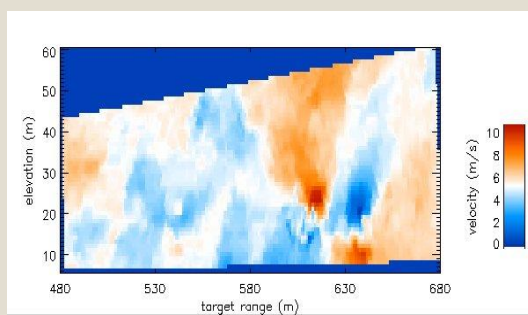
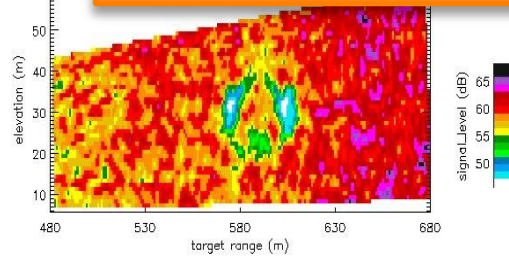
IN THIS EXAMPLE, THE WAKES ARE TRANSPORTED UPWARDS, MOST LIKELY DUE TO THE PRESENCE OF AN UPDRAFT



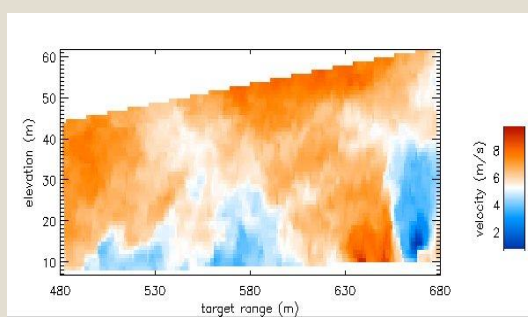
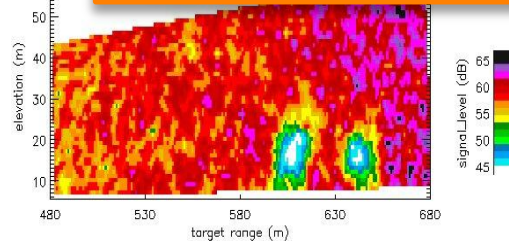
05_05_103147 EDT



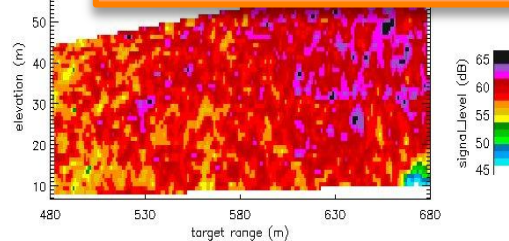
05_05_103155 EDT



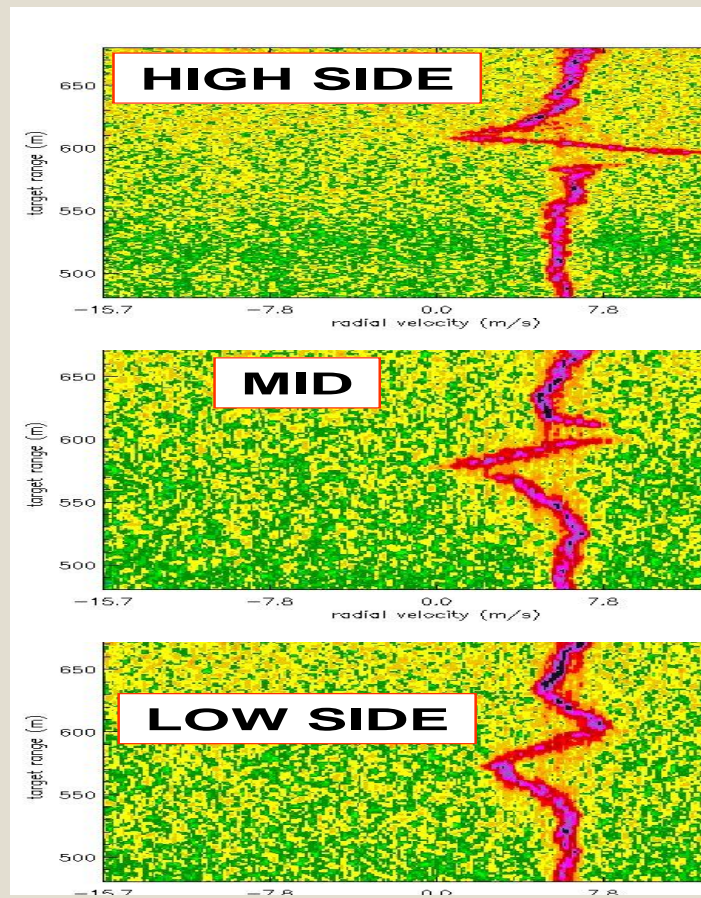
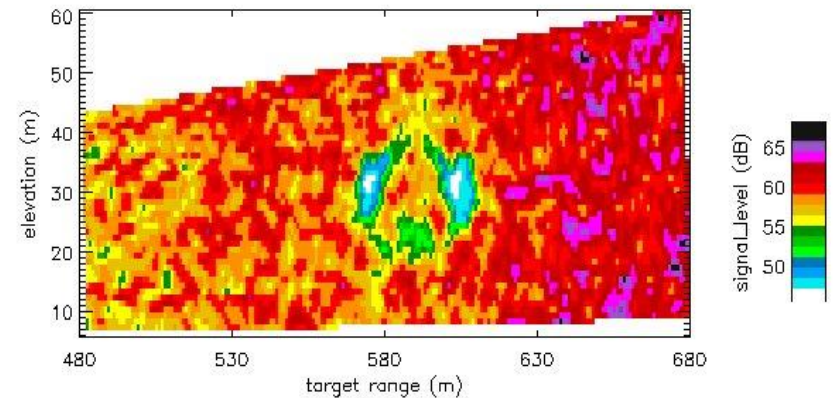
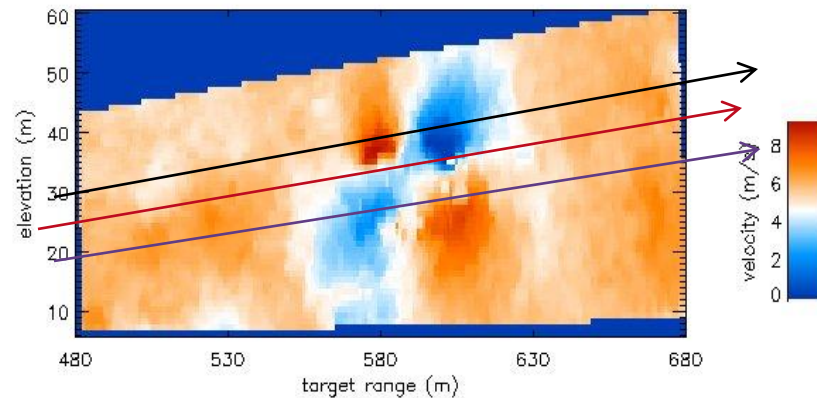
05_05_103203 EDT



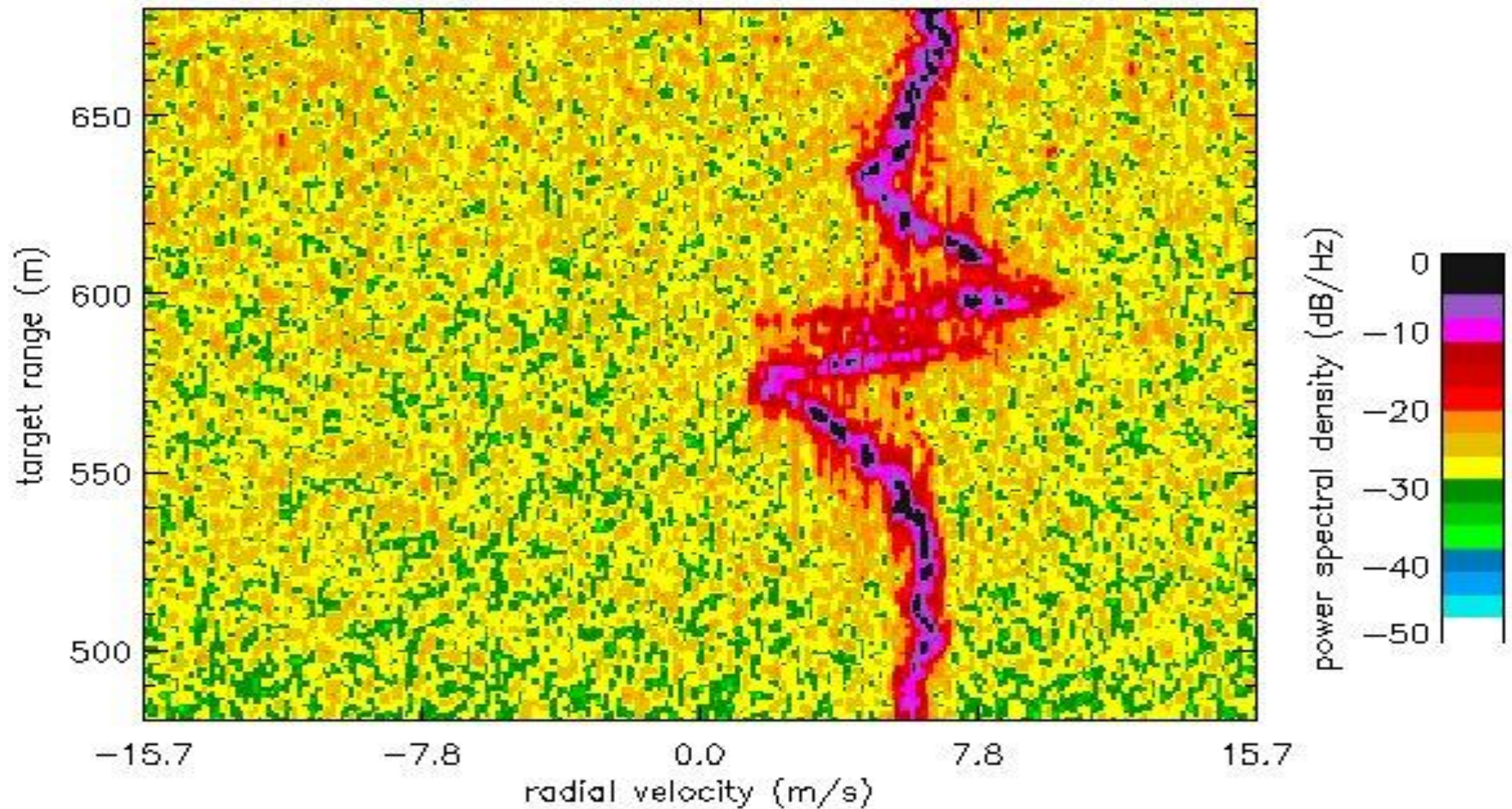
05_05_103211 EDT



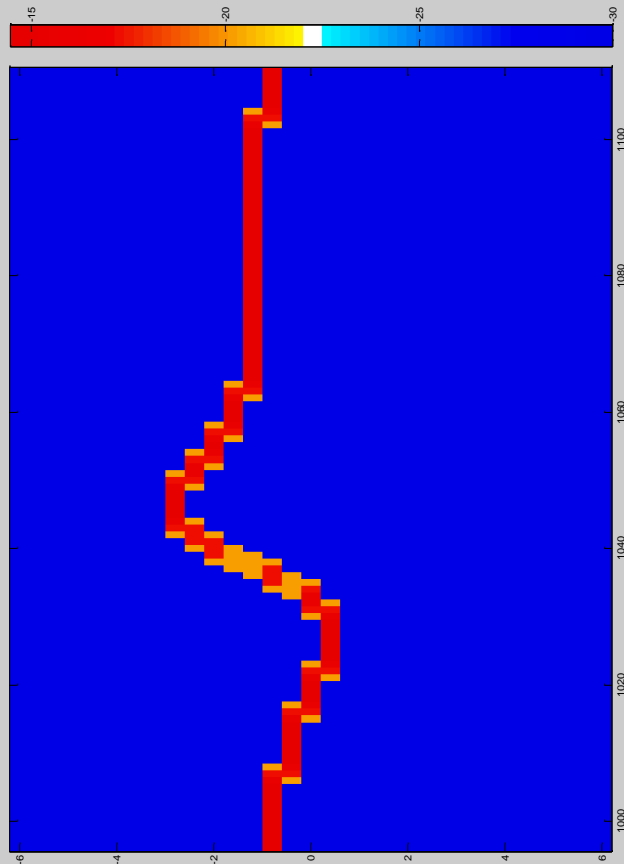
**Time history of wake
vortices detected by the
W-Band Radar on May 5,
2009.**



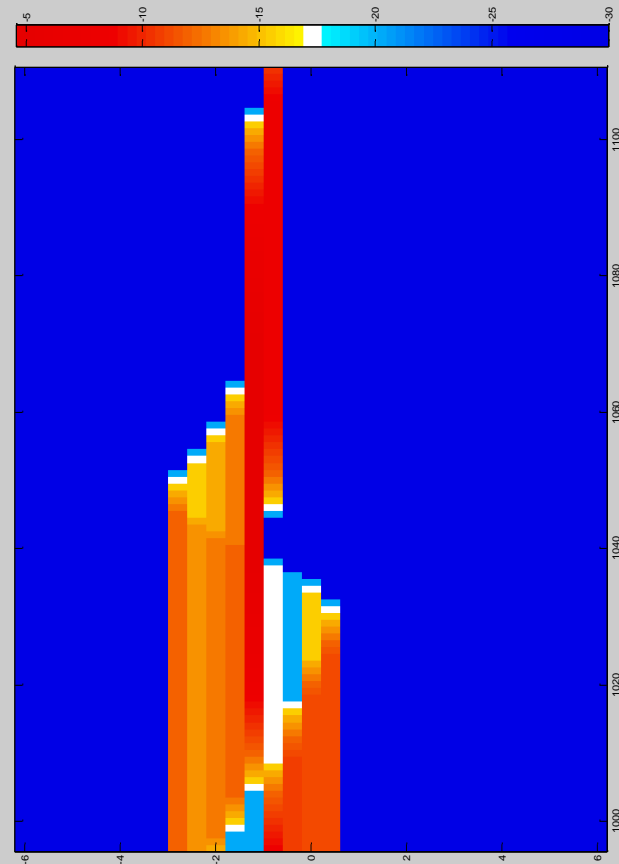
**DOPPLER SPECTRA ALONG
RADIALS PASSING THROUGH
THE WAKE VORTEX PAIR
May 5, 2009.**



Example of Doppler velocity spectra for a ray below (Low Side) the center of the vortex pair indicating considerably greater amounts of turbulence.

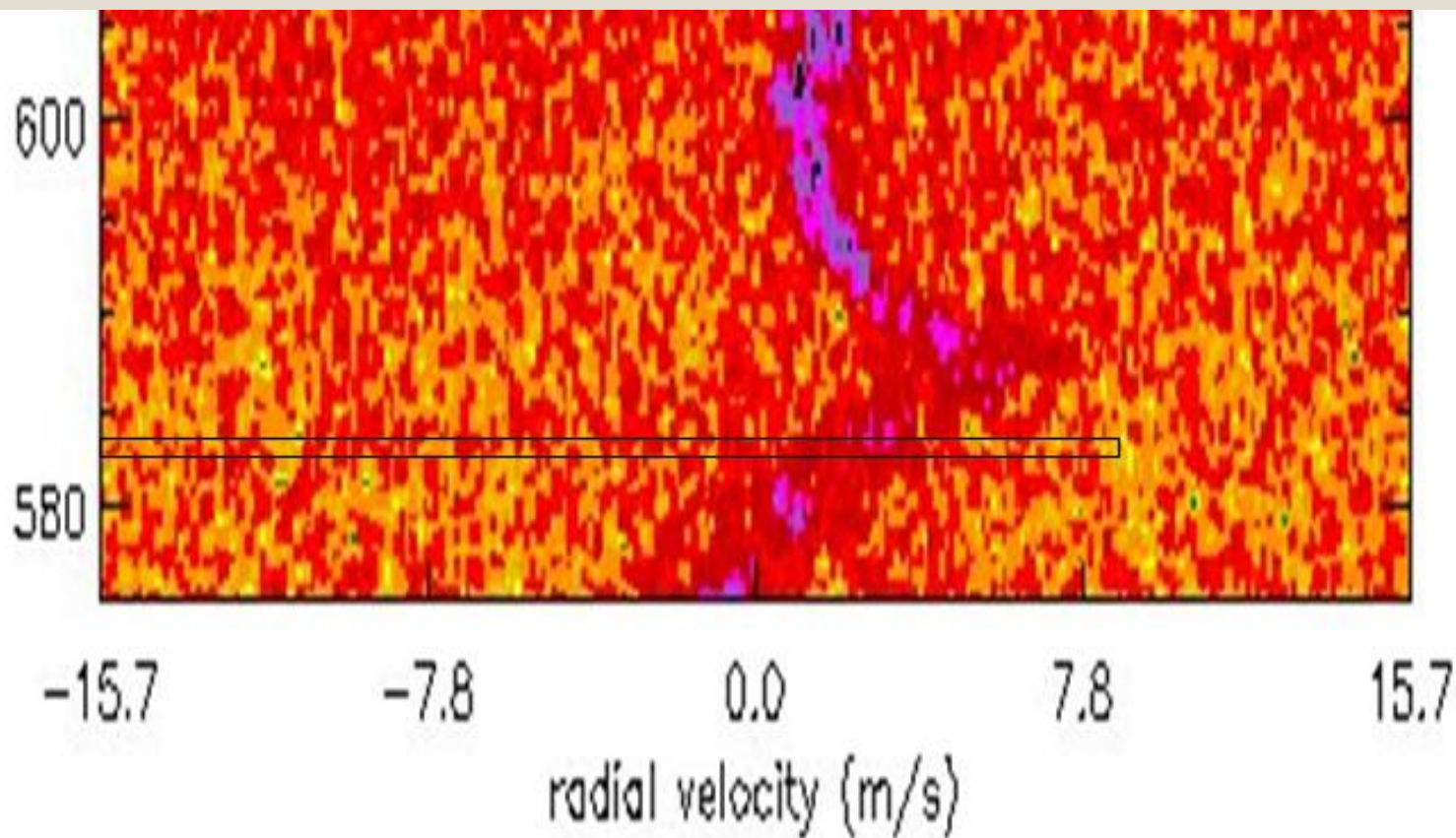


RANGE RESOLUTION = 3-m

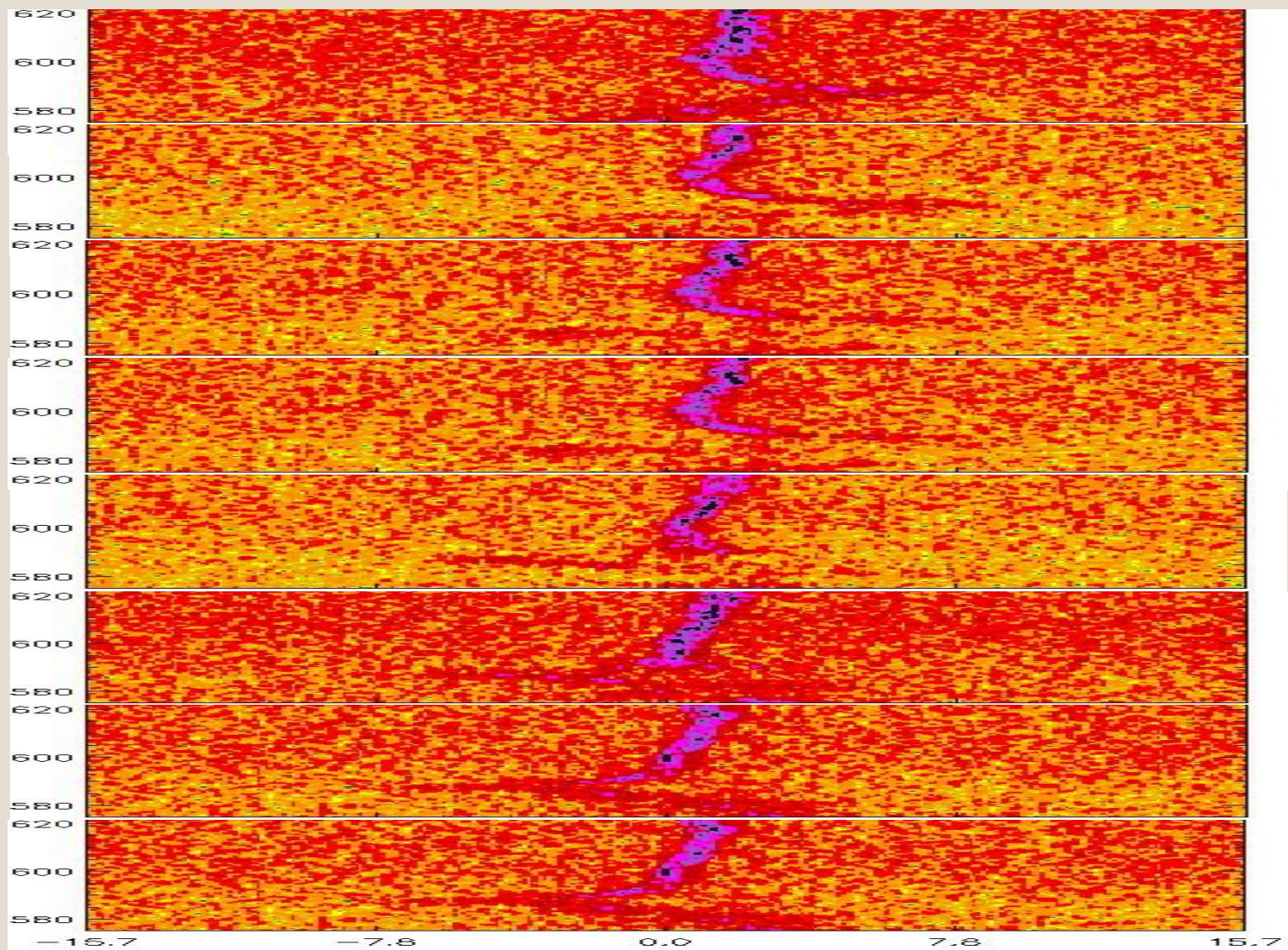


RANGE RESOLUTION = 60-m

**Simulated Illustration of the Differences in
Doppler Velocity Spectra at Range Resolutions
of 3- and 60-m.**

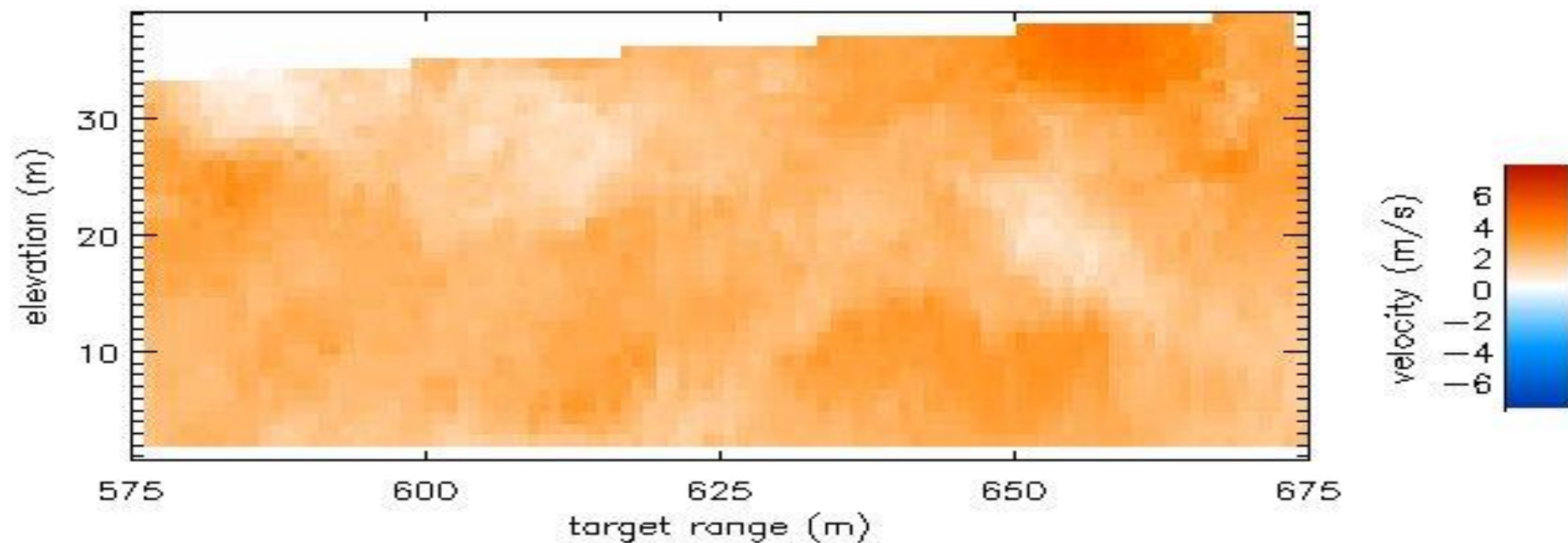
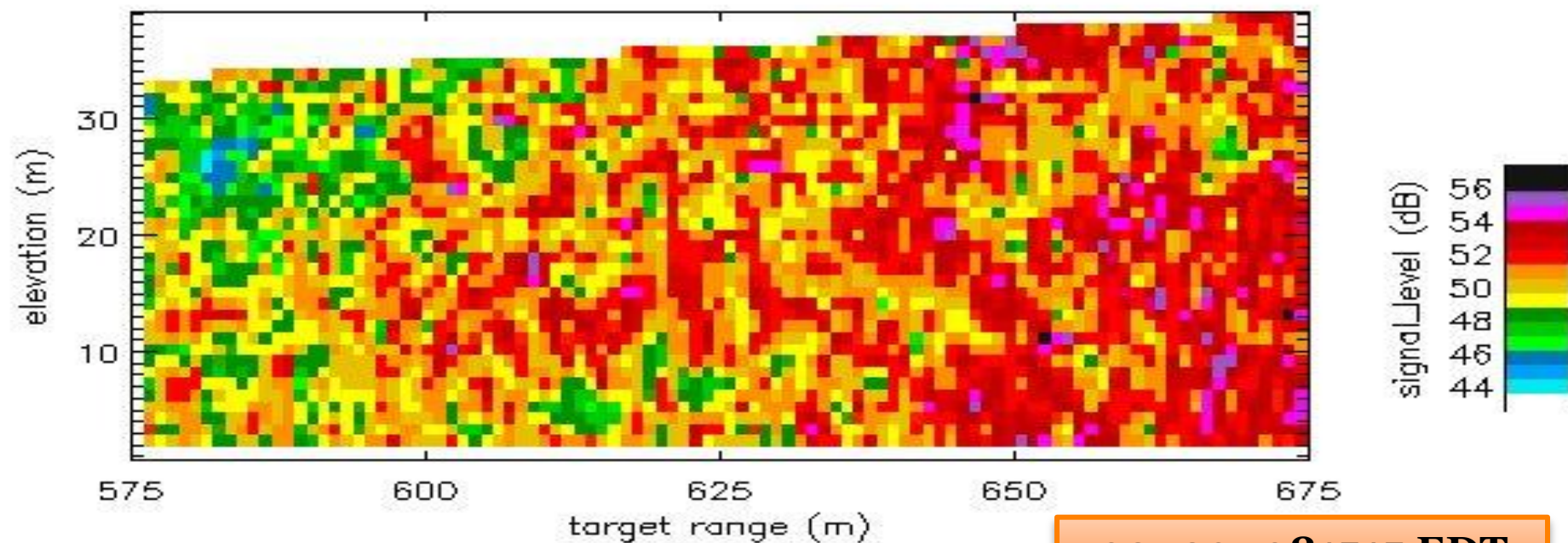


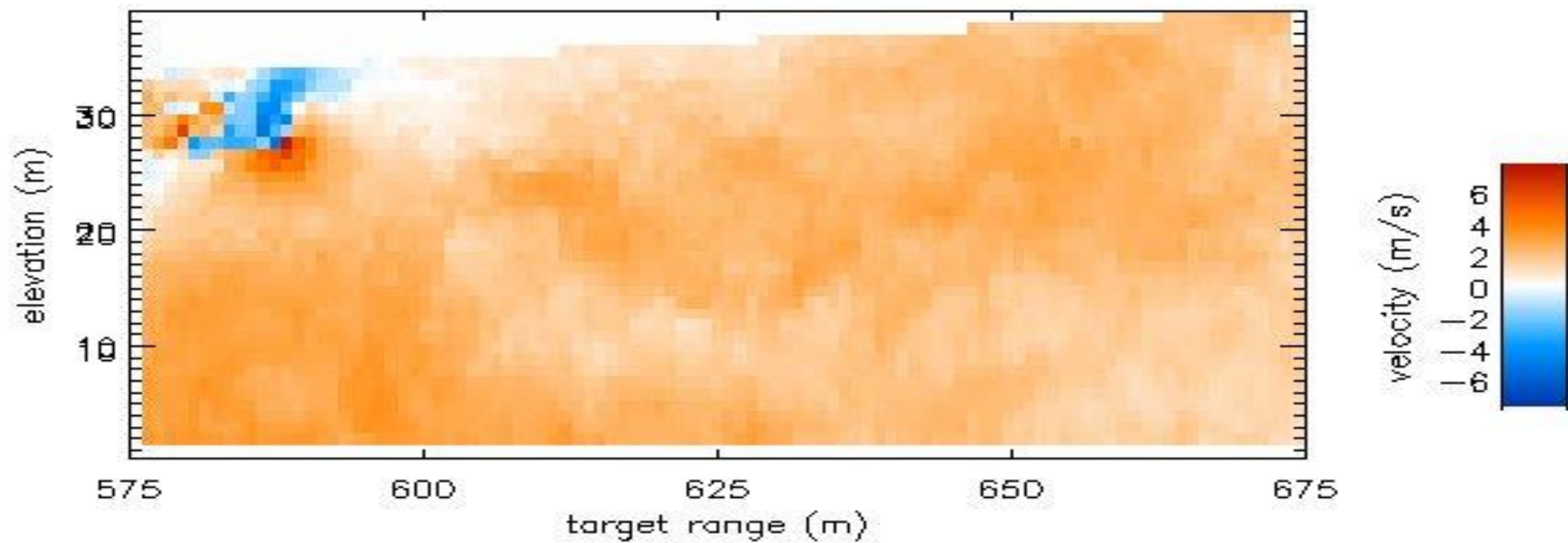
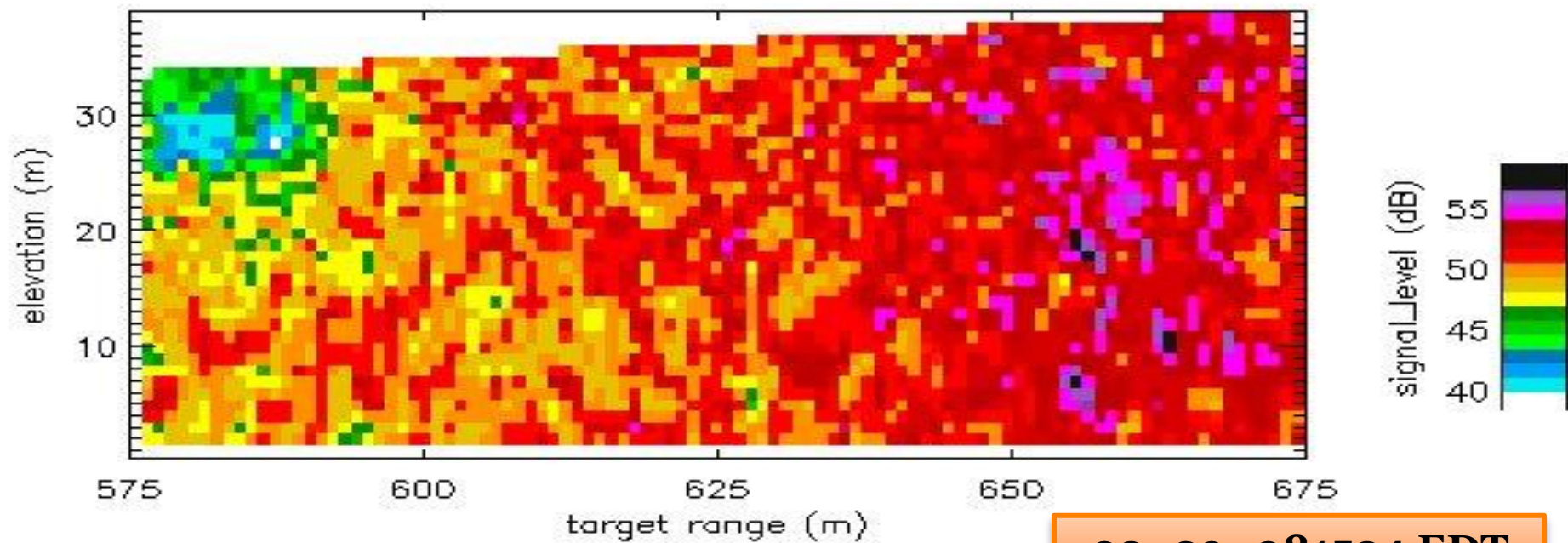
**Sample Doppler Spectra Obtained at a
Range Resolution of 1-m**

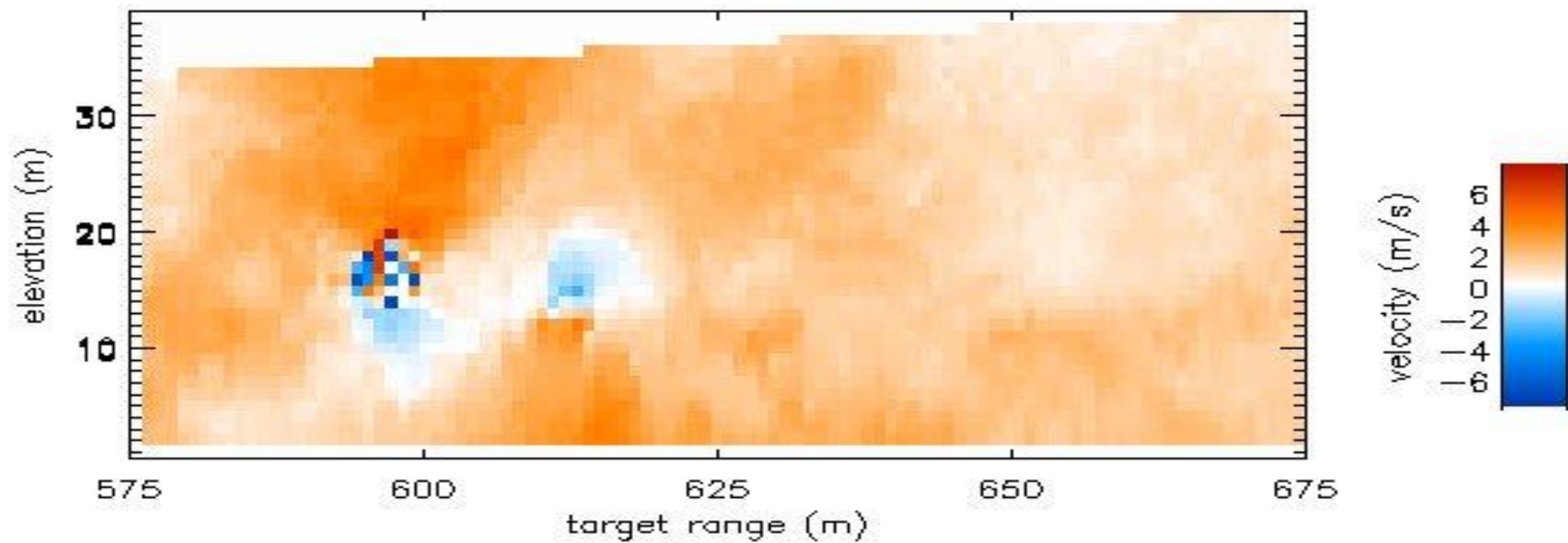
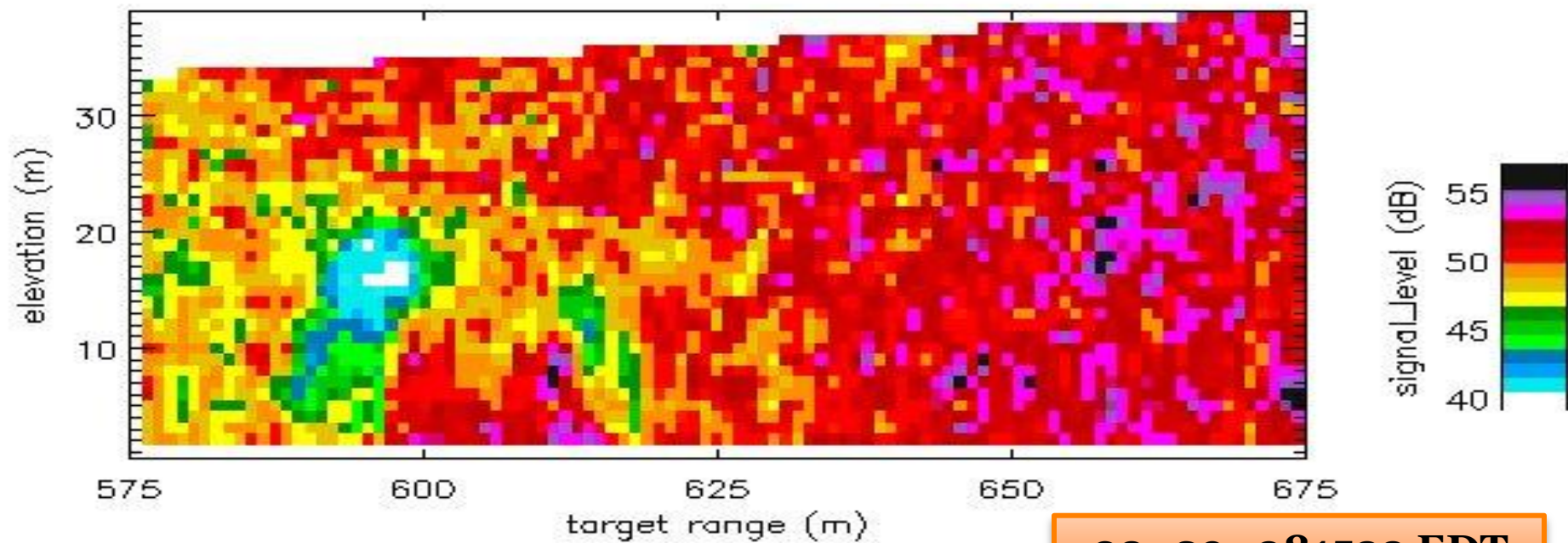


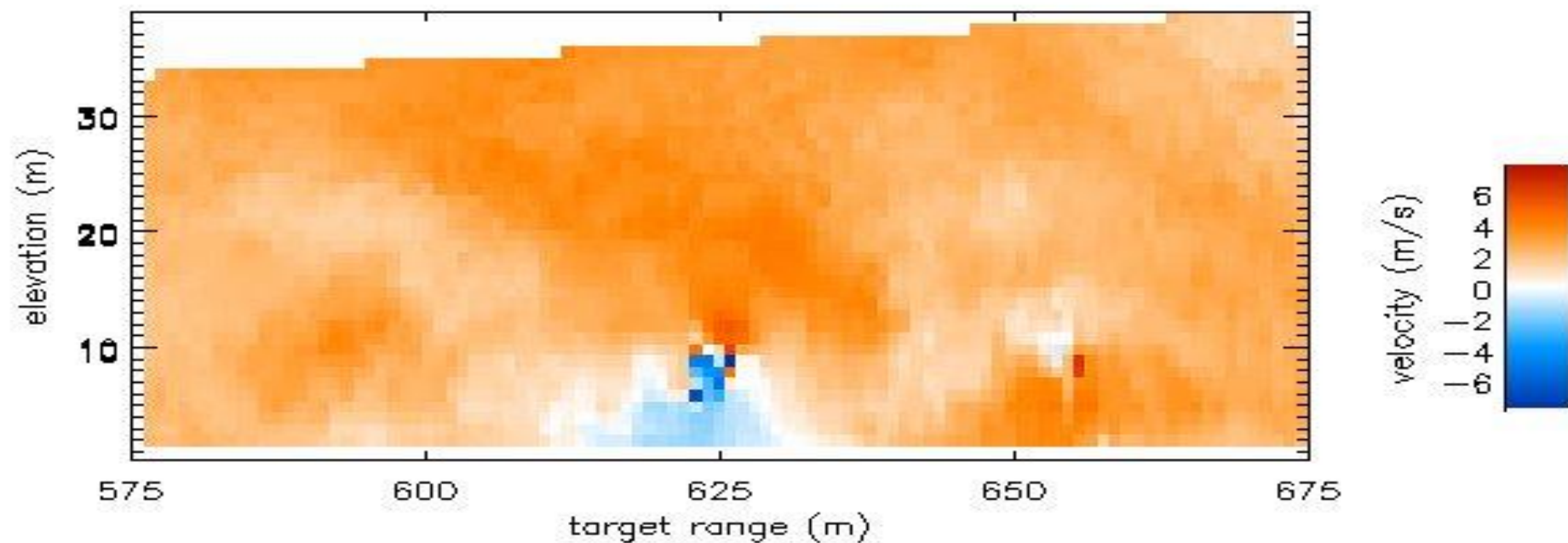
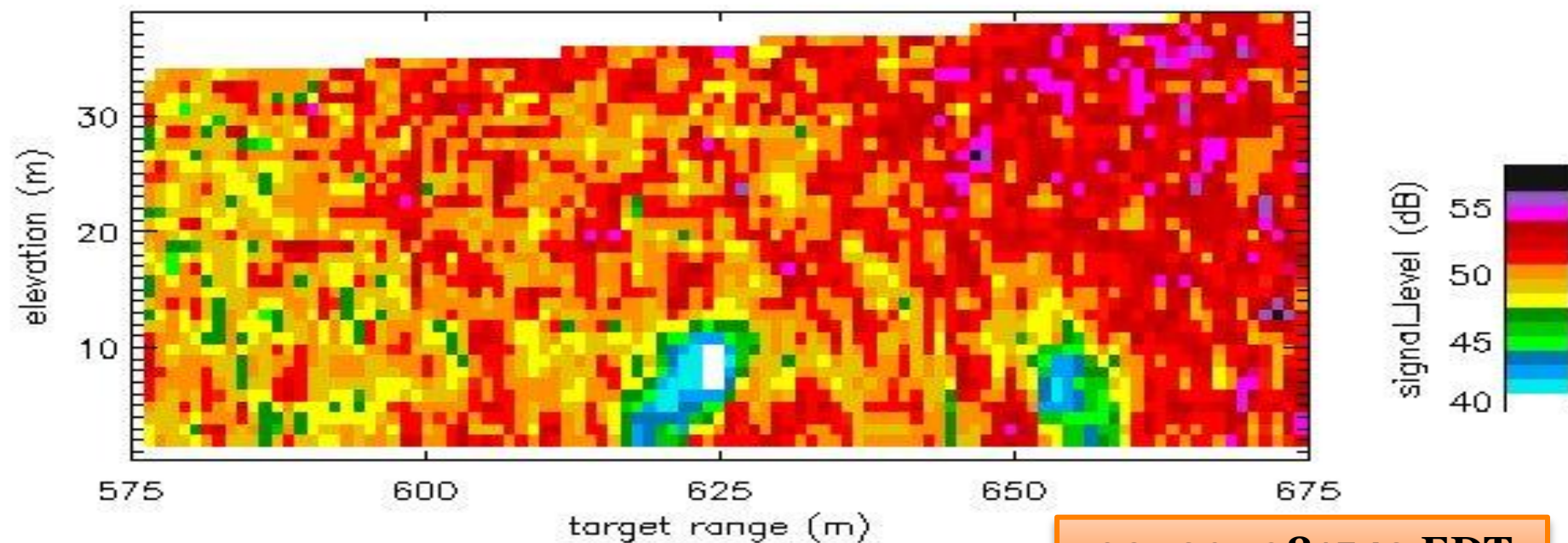
Sample Doppler Spectra of a Sequential Set of Rays Obtained at a Range Resolution of 1-m

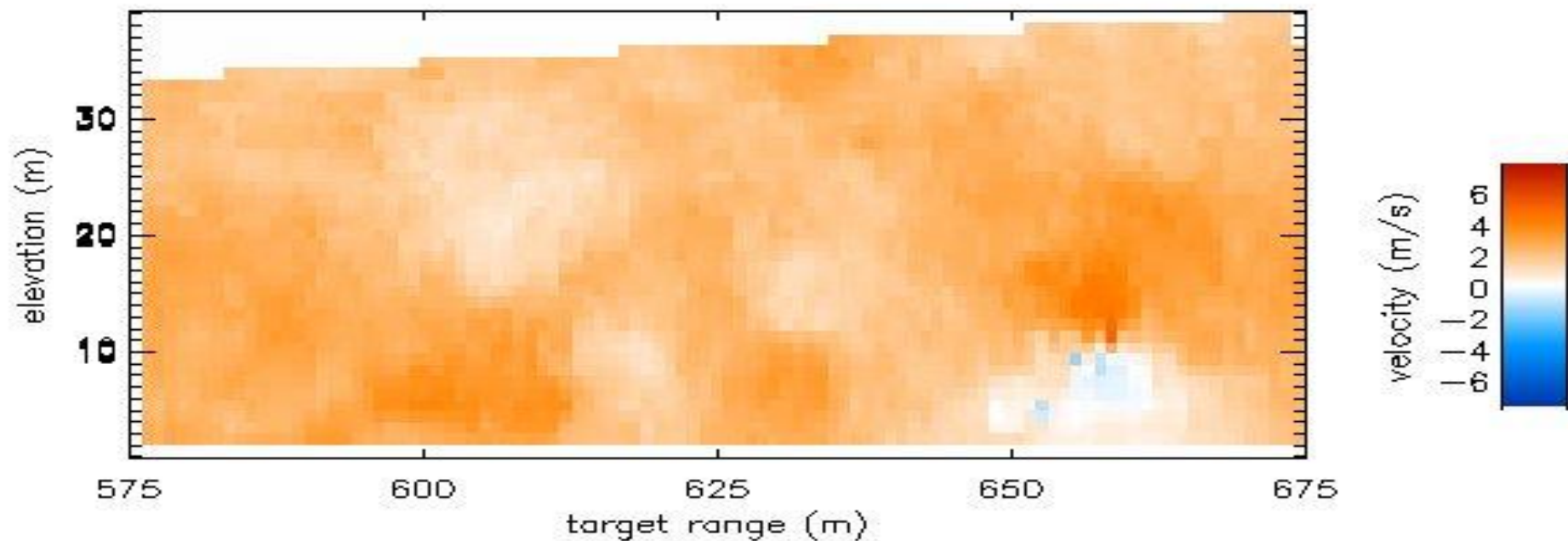
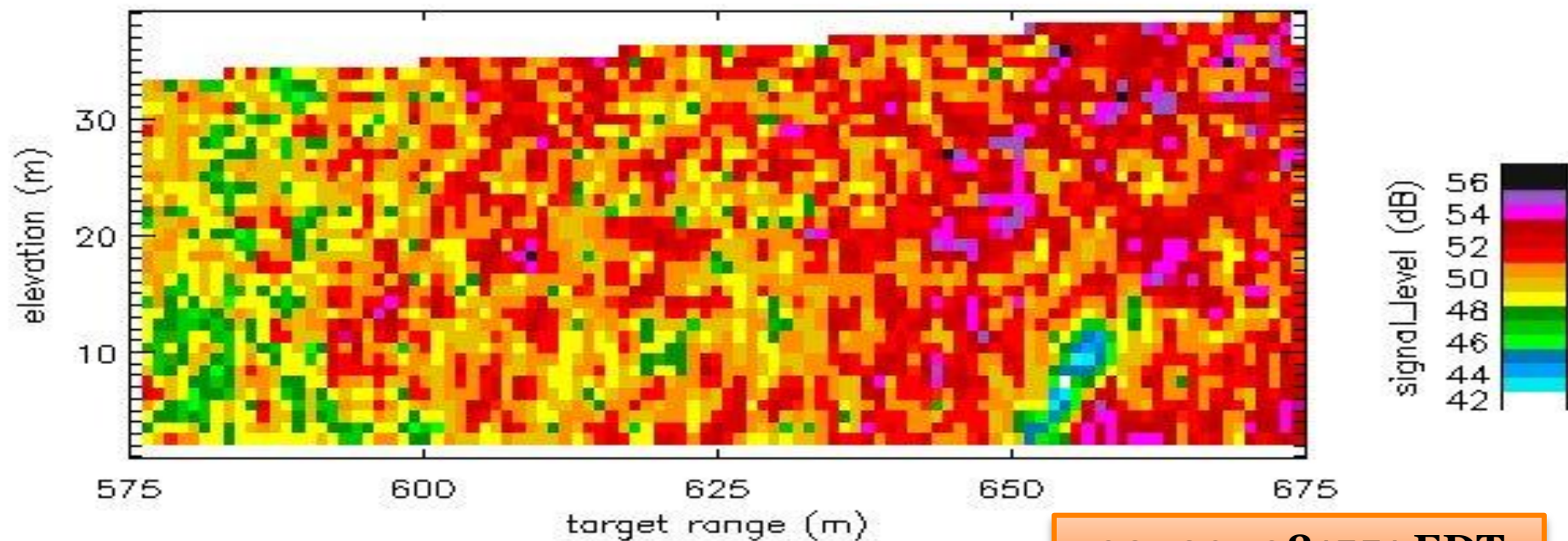
**SET OF WAKE VORTEX RHI
PROFILES OBTAINED ON
MARCH 29, 2009. THE WAKES
WERE GENERATED BY AN
AIRCRAFT LANDING ON
RW04R AT LOGAN
INTERNATIONAL AIRPORT**

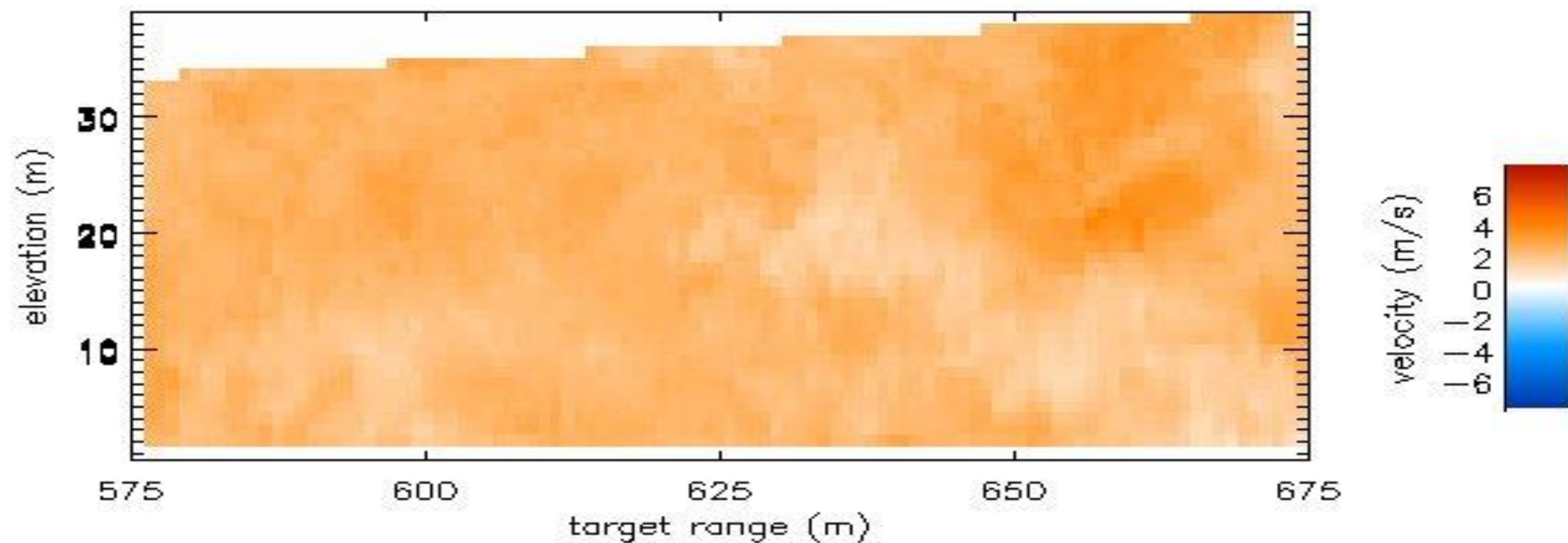
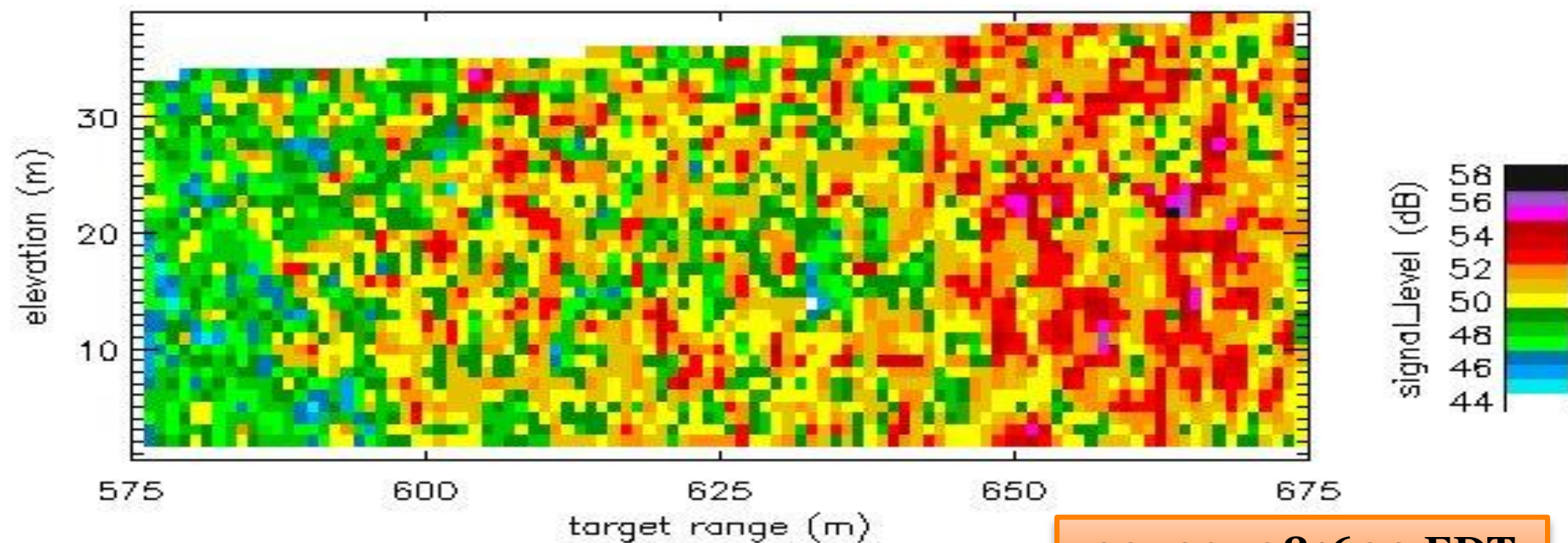




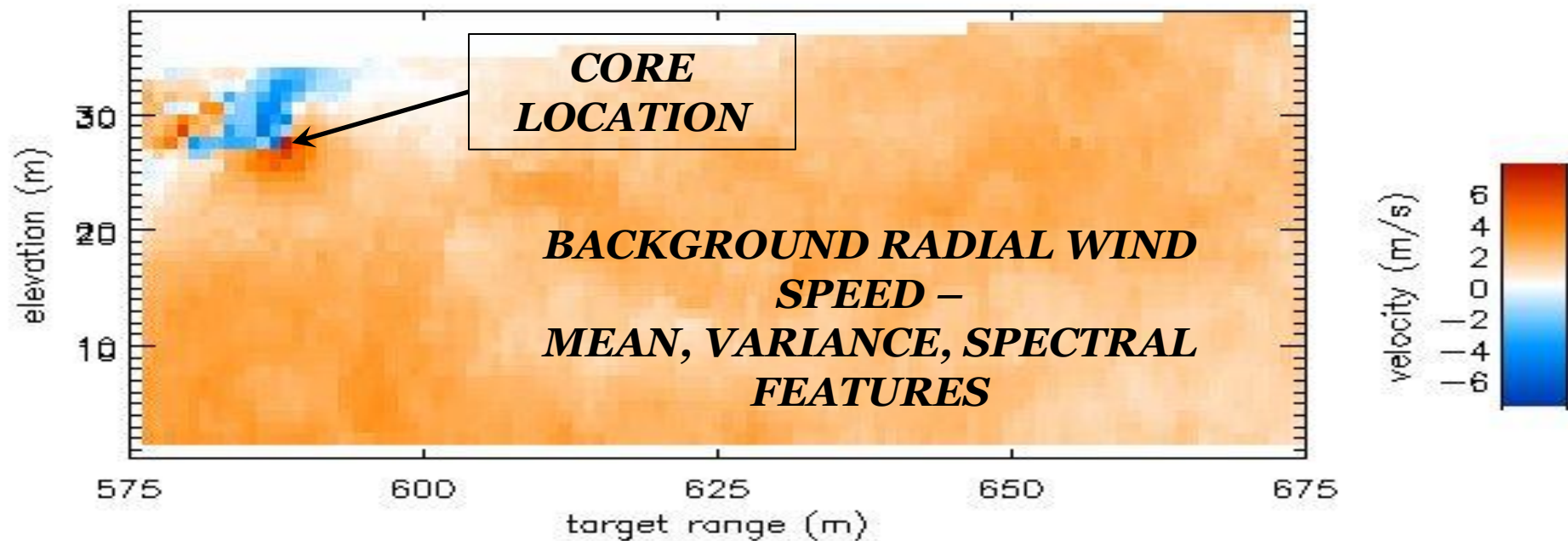
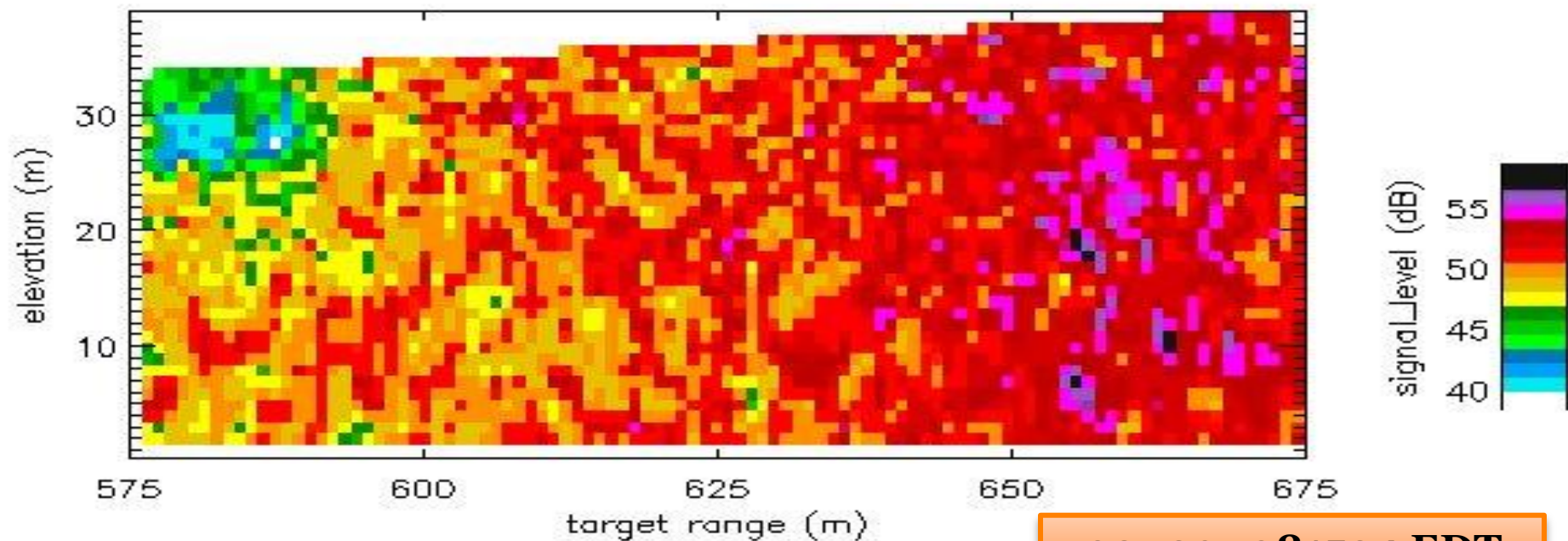


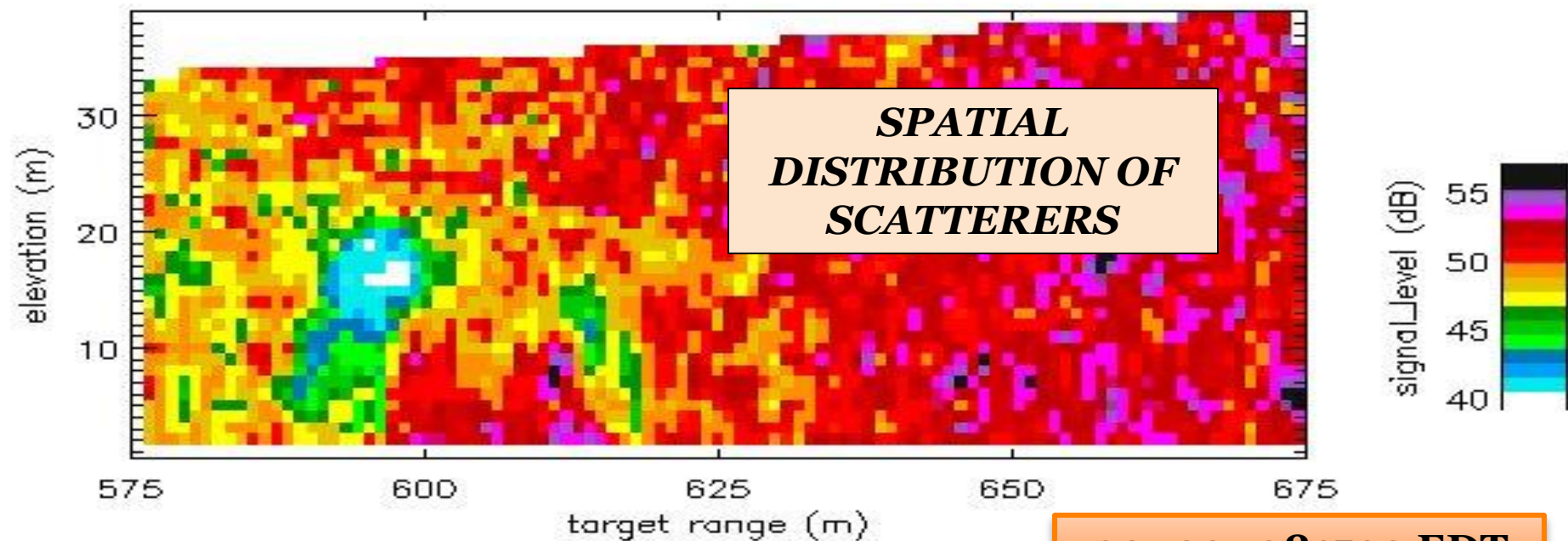




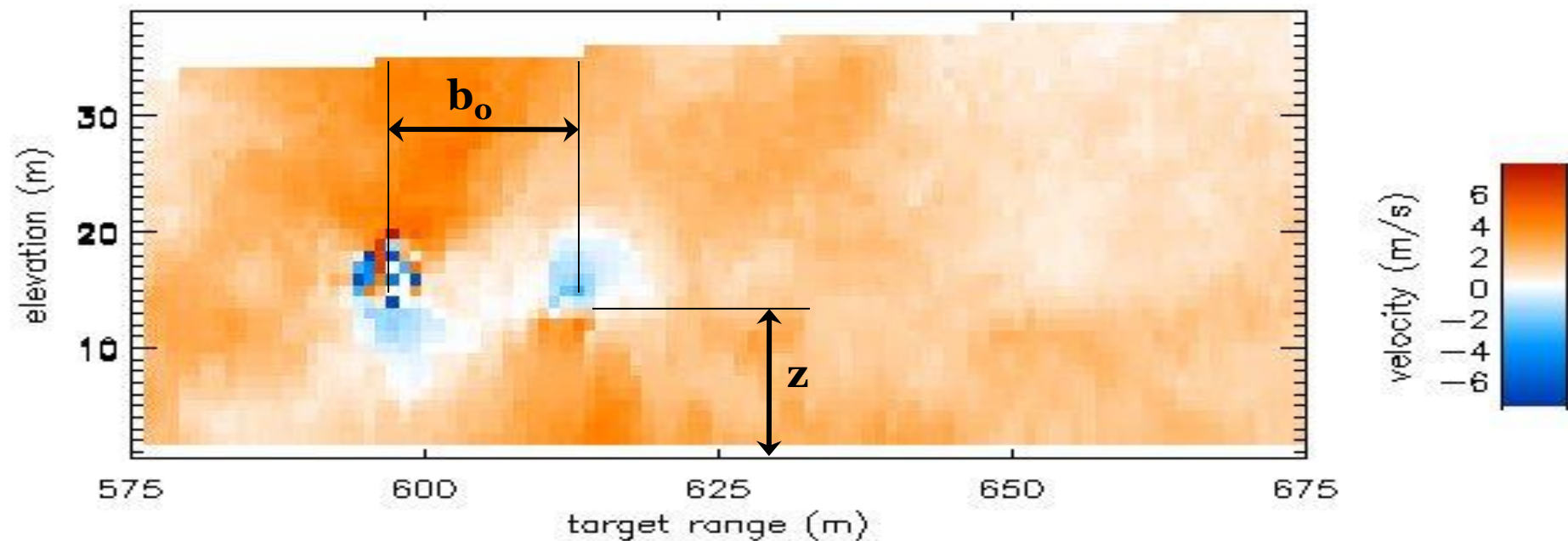


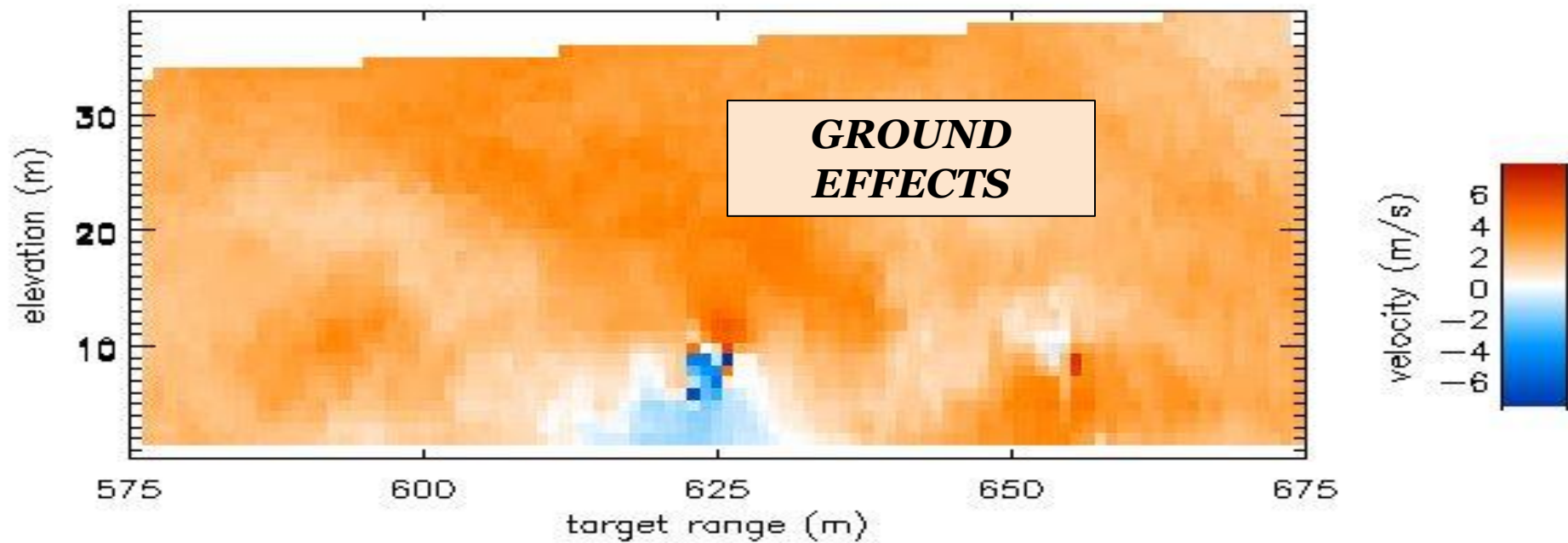
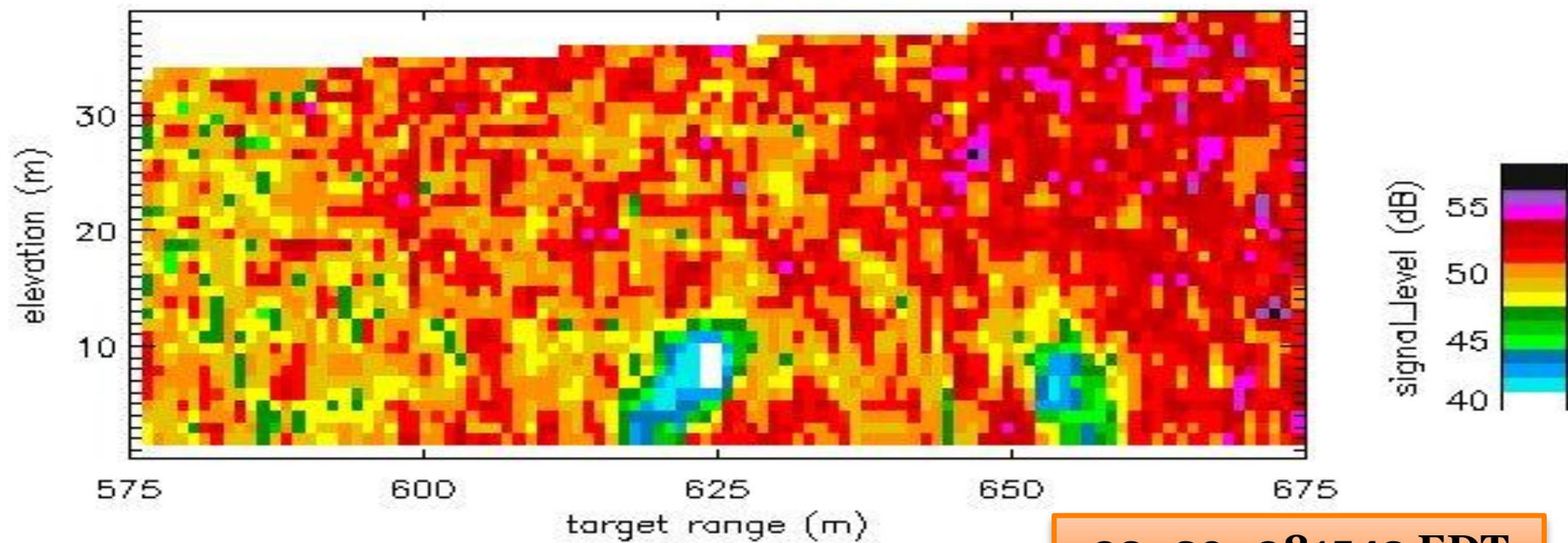
**EXAMPLES OF READILY
OBSERVED
WAKE VORTEX - RELATED
FEATURES OF INTEREST**



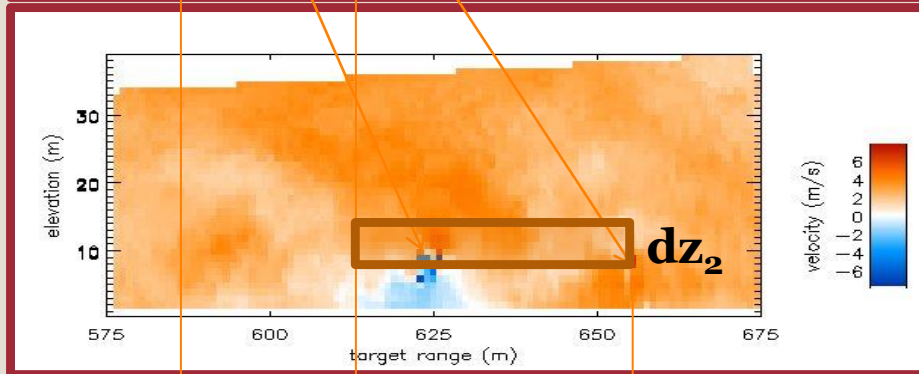
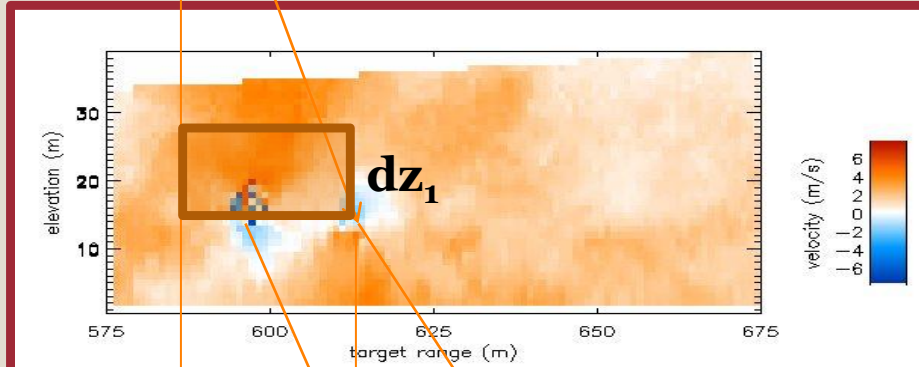
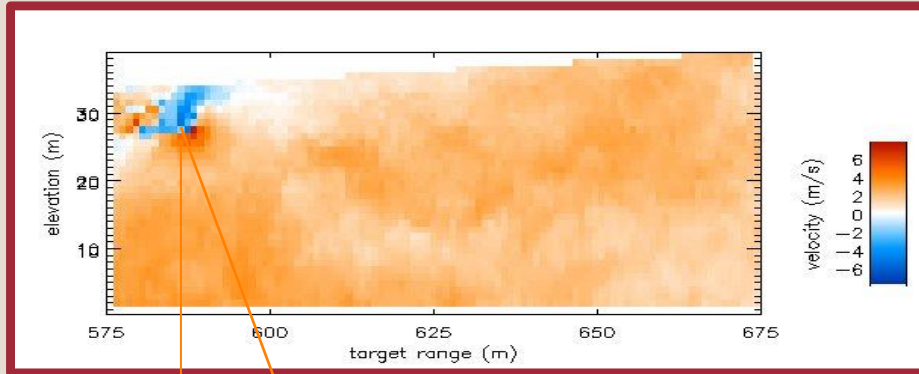


03_29_081533 EDT





HORIZONTAL AND VERTICAL VELOCITIES



Horizontal distance markers: dy_1 and dy_2 .

$$\frac{dy_1}{dt} \approx \frac{26.1}{8} = 3.3 m \cdot s^{-1}$$

$$= 10.7 ft \cdot s^{-1}$$

$$\frac{dz_1}{dt} \approx \frac{-15.5}{8} = -1.9 m \cdot s^{-1}$$

$$= -6.4 ft \cdot s^{-1}$$

$$\frac{dy_2}{dt} \approx \frac{40.6}{8} = 5.1 m \cdot s^{-1}$$

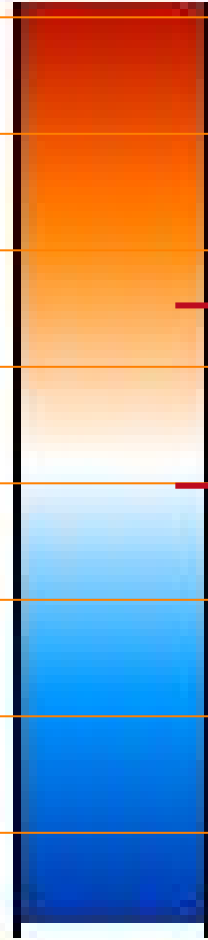
$$= 16.7 ft \cdot s^{-1}$$

$$\frac{dz_2}{dt} \approx \frac{-6.2}{8} = -0.78 m \cdot s^{-1}$$

$$= -2.5 ft \cdot s^{-1}$$

velocity (m/s)

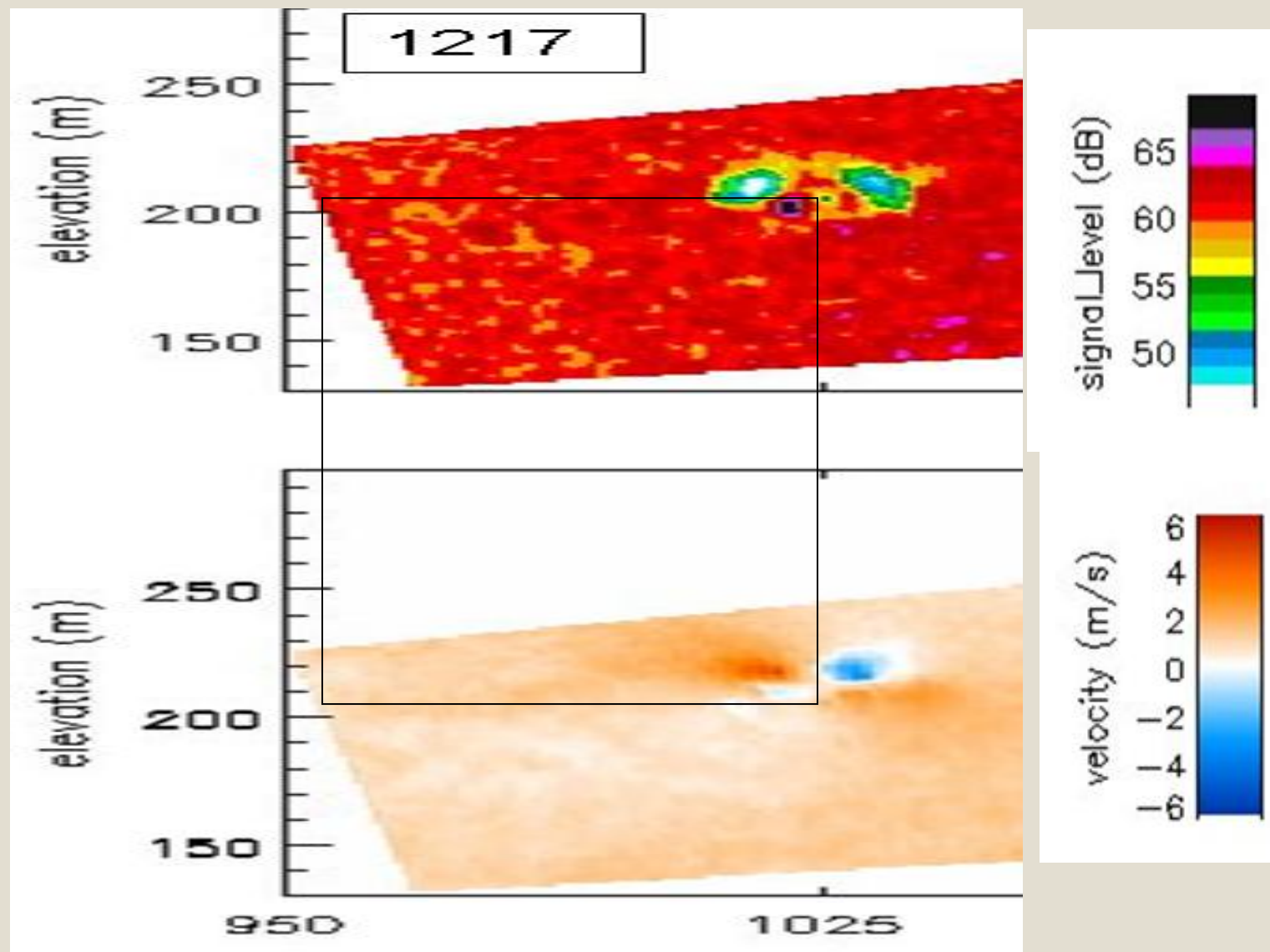
0 4 8 12 16 20 24 28



**RADIAL VELOCITY
IN VICINITY OF
WAKE**



3.3 ms⁻¹



Spatial Correlation of Power and Velocity Profiles for Insights into Understanding Related Physical Phenomena

**POTENTIAL OF THE W-BAND
RADAR SYSTEM FOR WAKE
VORTEX RESEARCH AND
AVIATION-RELEVANT
APPLICATIONS**

- ❑ More precise understanding of the physics of wake behavior under landing and takeoff conditions.**
- ❑ Basis for learning about differences in wake behavior in precipitation and non-precipitating regimes.**
- ❑ Means of determining how hydrometeors of different types behave in complex flows such as wakes.**
- ❑ Basis for understanding how atmospheric winds and boundary layer turbulence affect wake behavior.**
- ❑ Means of ascertaining wake behavior caused by interactions with the ground (both solid and liquid), i.e., contrasting above ground level (AGL) , near ground effect (NGE) and in ground effect (IGE).**
- ❑ Detecting and characterizing wakes in low visibility conditions (rain/fog/haze).**
- ❑ Investigations of other aircraft turbulence such as thrust stream turbulence (jet blast), propeller wash and rotor wash.**

SOME ADDITIONAL TOPICS OF POSSIBLE RELEVANCE

- ❑ Classifying differences in wake behavior as related to aircraft type, speed and weight.**
- ❑ Improved understanding of differences in wakes and their behavior relative to aircraft type, speed, and atmospheric conditions.**
- ❑ Contribute to improving rationale for ICAO and other standards for separation of aircraft.**
- ❑ Contribute to standards for closely spaced parallel runways (less than 2,500-ft).**
- ❑ Contribute to the evolution of new concepts of operations of airports.**
- ❑ Provide valuable information on wake behavior that will help test the hypothesis that airport capacity can be safely increased through dynamic or standardized means of aircraft separations.**
- ❑ Contribute to IFALPA concerns regarding: Safety Assurance; Testing and evaluation of airborne wake turbulence detection technologies; Ground-based detection of location, movement, intensity and duration of wake turbulence.; Ground-based detection of winds and atmospheric turbulence.**

❑ Investigating effects of flaps and their influence on the primary wake generation, their contribution to additional secondary wake formation and the subsequent interactions between primary and secondary wakes.

❑ Specific attributes of interest: core size (in to ft in diameter); speed of air movement inside the core (up to ~ 300-fps or 92-mps); extent of the outer region of the vortices (out to ~ 100-ft or 30-m); descent and ascent rates; and wake persistence or lifetimes.

❑ Improve understanding of the atmospheric environment that in turn can improve understanding of its effects on wake vortex behavior. Atmospheric parameters of interest include: ambient wind, turbulence, wind shear, thermal stratification and the presence of hydrometeors.

❑ Aviation-relevant mechanisms include: horizontal transport; downward vertical transport; vortex tube deformation or loss of vortex alignment; and wake vortex decay.

❑ Under Ground Influence –horizontal transport is reduced; downward vertical transport is not effective or is reversed; vortex tube deformation is increased; and wake vortex decay is increased.

❑ Aviation-Relevant Concerns: functionality; stability; reliability; area of applicability; etc.

The design of the W-Band Radar is currently being enhanced for the US Department of Energy. This new system will provide dual polarization capabilities, mobility and TX power levels ~ 25-dB higher than the Logan Airport Radar. The company will also have a system of its own available to support a variety of field programs and experiments.



ProSensing is a systems engineering firm specializing in custom-built radar and radiometer systems for a wide range of remote sensing applications.

ProSensing provides widespread expertise in electromagnetic scattering and propagation, microwave systems, antenna design, radiometric techniques, radar oceanography, radar meteorology, high speed data acquisition, digital signal processing and remote sensing systems. Our customers include government research laboratories, university research groups and large corporations in North America, Europe, and Asia.

Types of Sensor Systems

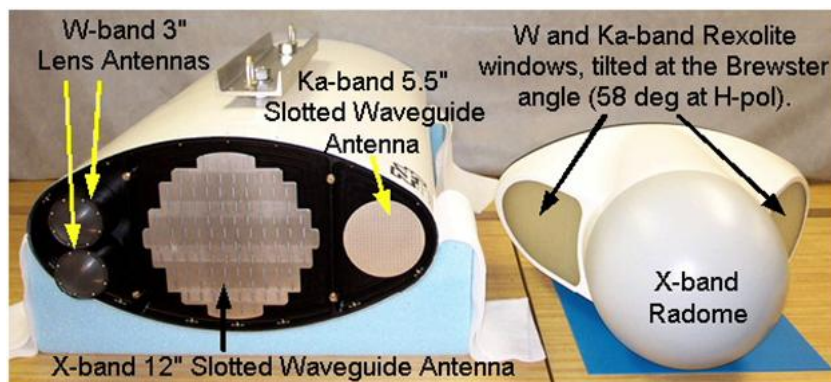
W-Band Cloud Radars
Ka-Band Cloud Radar
X-Band Weather Radars
L-Band Imaging Radiometer
C-Band Stepped Frequency Microwave Radiometer
Millimeter Wave (183 GHz) Water Vapor Radiometer
Synthetic Aperture Radiometers
Polarimetric Radars
L-Band Salinity Mapper
Digital Beamforming Antennas
C-Band Scatterometer
X-Band Ocean Surface Imaging Radar
Ship Height Detection and Reporting Radar System



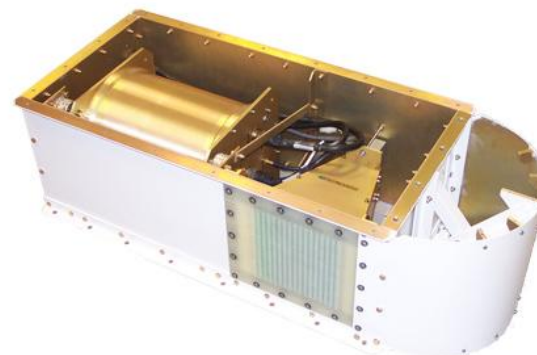
W-BAND CLOUD RADAR



FMCW AIRBORNE RADAR



**MULTI-FREQUENCY AIRBORNE
RADAR (X-, Ka-, W-Band)**



**STEPPED FREQUENCY MICROWAVE
RADIOMETER (4.5-7.0 GHz)**