Weather Surveillance with Phased-Array Radar

Dr. Pam Heinselman
NOAA National Severe Storms Lab

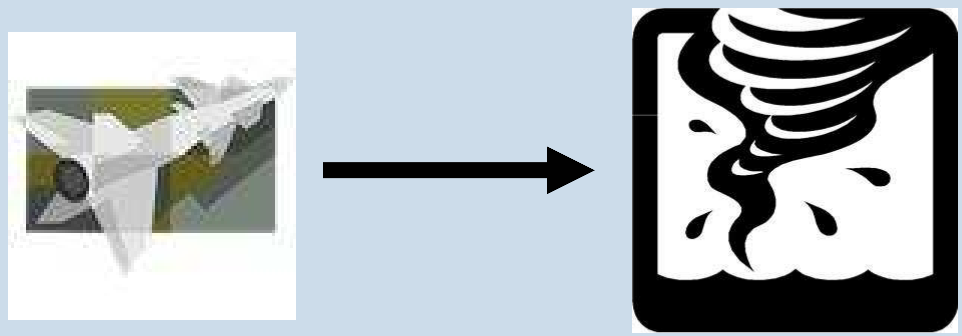
Great Plains Weather Conference, 12 Aug 2010

Acknowledgements

THANKS FOR/TO:

Signal processing techniques and software development

- **Sebastian Torres**
- Ric Adams
- Chris Curtis
- Eddie Forren
- Igor Ivic
- Dave Priegnitz
- John Thomson
- David Warde



Acknowledgements

THANKS FOR/TO:

Contributing to 2010 Phased-array Radar Innovative Sensing Experiment:

- **Daphne LaDue & Heather Lazrus**
- Kim Klokow & Heather Moser
- Rick Hluchan, Jen Newman
- Adam Smith & David Priegnitz

Social science

- Charles Kerr
- Kevin Manross
- Travis Smith
- Greg Stumpf

Hardware and software; EWP leadership

What’s Unique to PAR?

Parabolic Antenna

- Single radiation element
  - Single transmitter
  - Single receiver
- Non-conformal
- Fixed beam pattern
- <u>Mechanical steering</u>

Phased Array Antenna

- Multiple radiation elements
  - Multiple transmitters
  - Multiple receivers
- Conformal
- Variable beam pattern
- <u>Electronic steering</u>

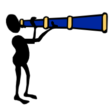
Unique Capabilities

Why a PAR at NSSL?

The WSR-88D (NEXRAD) is ~20 years old

- End of life around the year 2020
- Investigating replacement technology

  - Affordability of new technology vs. operating costs for obsolete technology



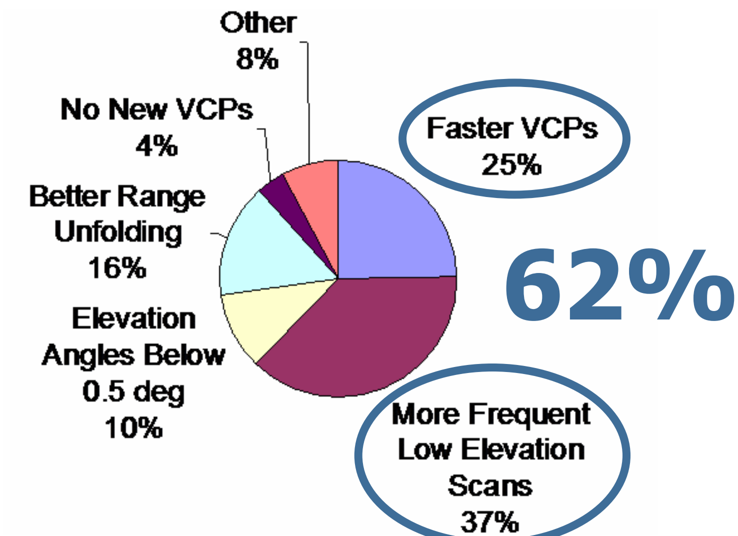
  - Improved weather surveillance capabilities
    - e.g., faster updates

  - Combine weather and aircraft surveillance networks
    - Reduce number of radars
    - Reduce maintenance costs

The MPAR Concept

Why Faster Updates?

Stakeholders' needs: **Faster Updates**



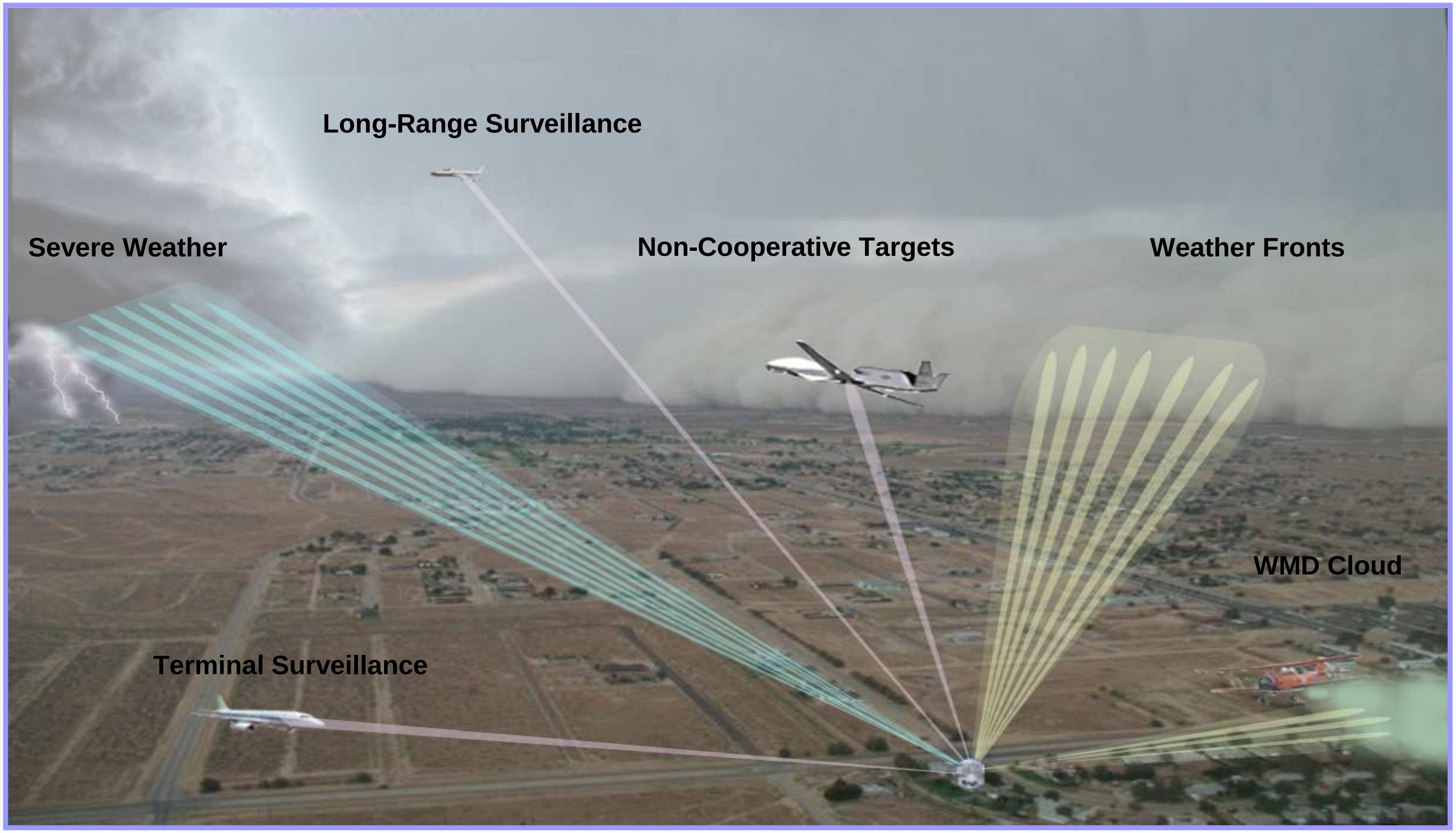
Source: Radar Operations Center

Why are faster updates needed?

1) Tornado cyclone and mesocyclone evolution can occur in 10s of seconds
2) Significant storm evolution and transition between storm types can occur between WSR-88D scans
3) Mid and upper-level signatures indicative of downbursts are not reliably detected

Source: LaDue et al. 2010, Newest BAMS!!!

Multi-function PAR Concept



What is the NWRT PAR?

SPY-1A Antenna + Partnership = National Weather Radar Testbed Phased-Array Radar

U.S. Navy

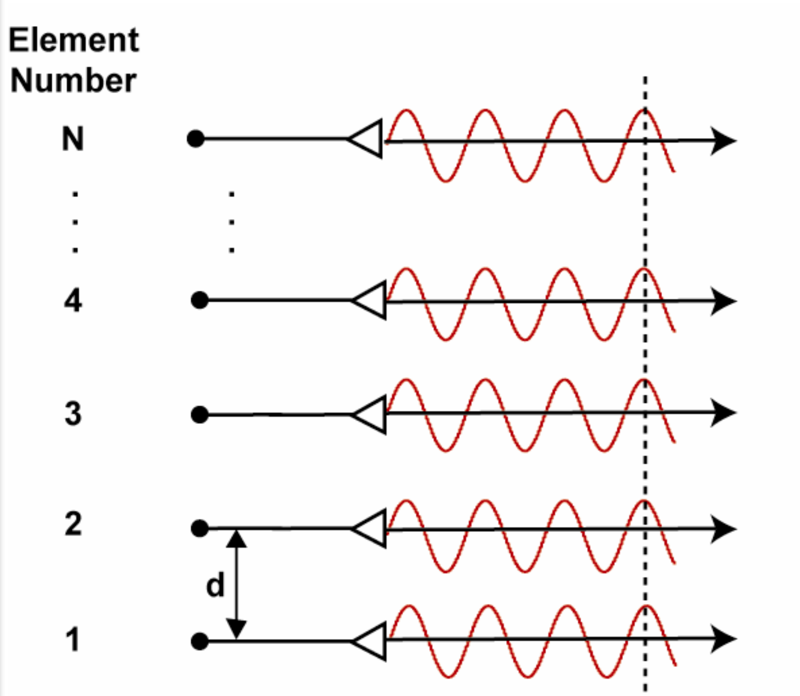
Government
Academia
Private Industry

NWRT PAR

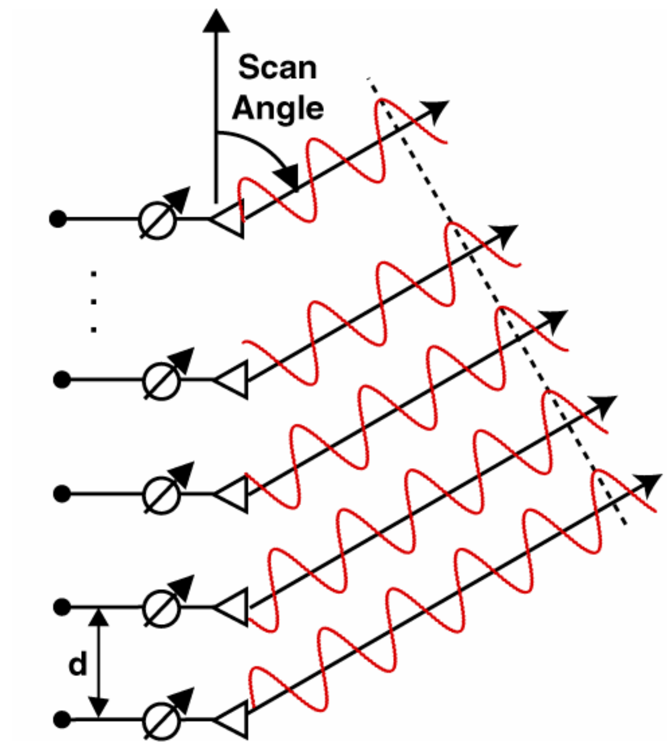
PAR → Electronic Beam Steering

Want fields to interfere constructively in desired directions, and interfere destructively in the remaining space

Beam Perpendicular to the Array



Scan To 30 deg

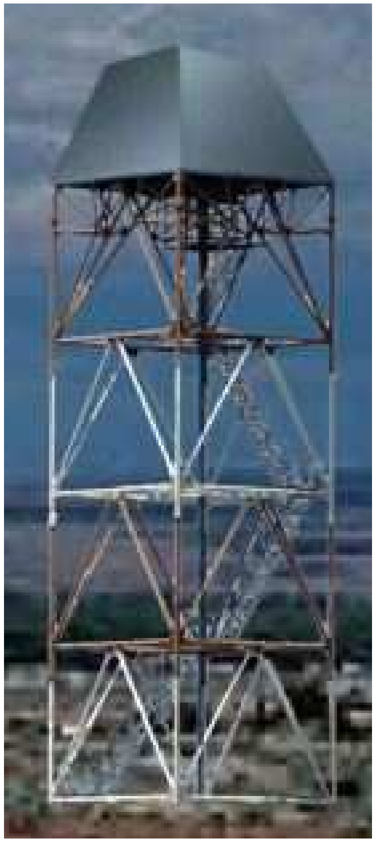


Adapted from Jeff Herd, MIT LL

Future PAR Design?

What we have now

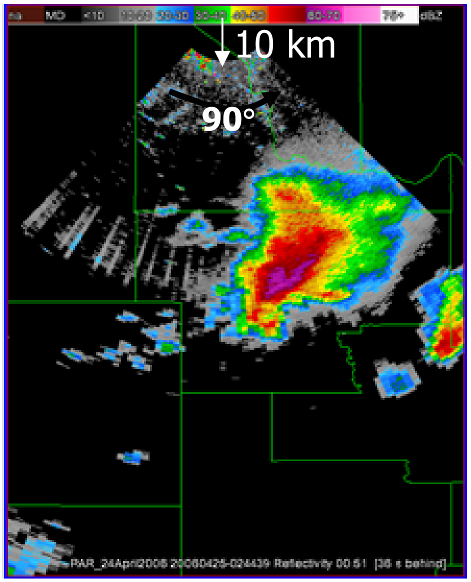
Ultimate Goal



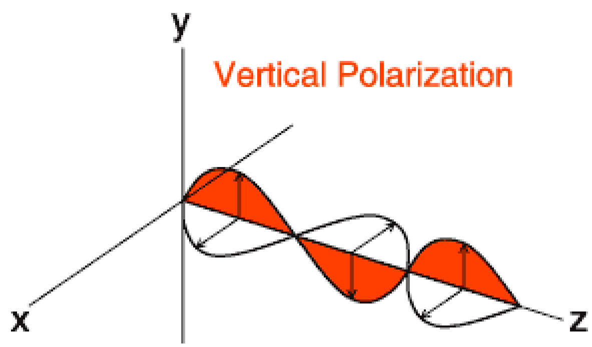
NWRT PAR Characteristics

Characteristics Different from WSR-88D

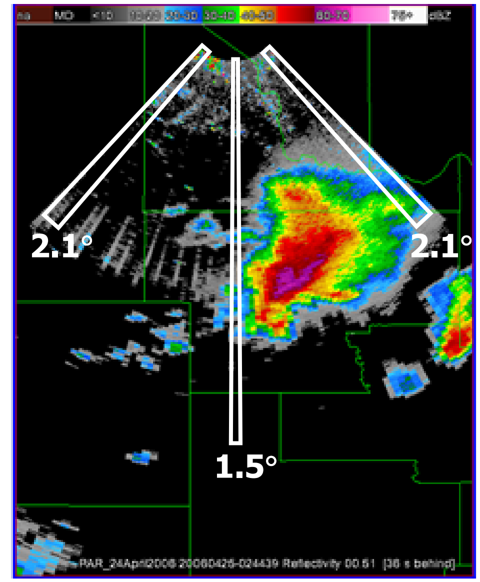
Sector Scans



Polarization



Beam Width



Characteristics Similar to WSR-88D

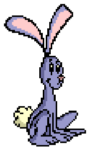
Wavelength: PAR = 9.4 cm / WSR-88D = ~10 cm (S-band)

Range Resolution: PAR = 240 km / WSR-88D = 250 km

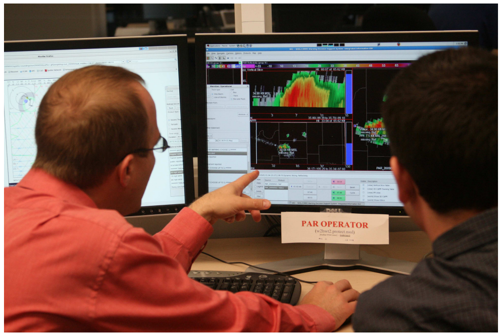
Research Objectives

Determine how to best capitalize on PAR capabilities to address 21st century forecast and warning needs

Tornado in Central Oklahoma, USA



Develop, demonstrate, and test rapid sampling techniques



Investigate how rapid updates may improve understanding of storm processes

Study impact of rapid updates on warning decision process

Signal Processing Upgrades

- **Data Quality**: brings performance closer to that of operational radars
  - Artifact removal
    - Ground clutter, interference, DC bias, point targets
  - Range and velocity ambiguity mitigation
  - Calibration
- **Evolutionary**: demonstrates PAR technology for weather applications
  - Faster updates
    - Sector scanning
    - Beam Multiplexing
    - Elevation Prioritization
    - Adaptive scanning
    - Range oversampling

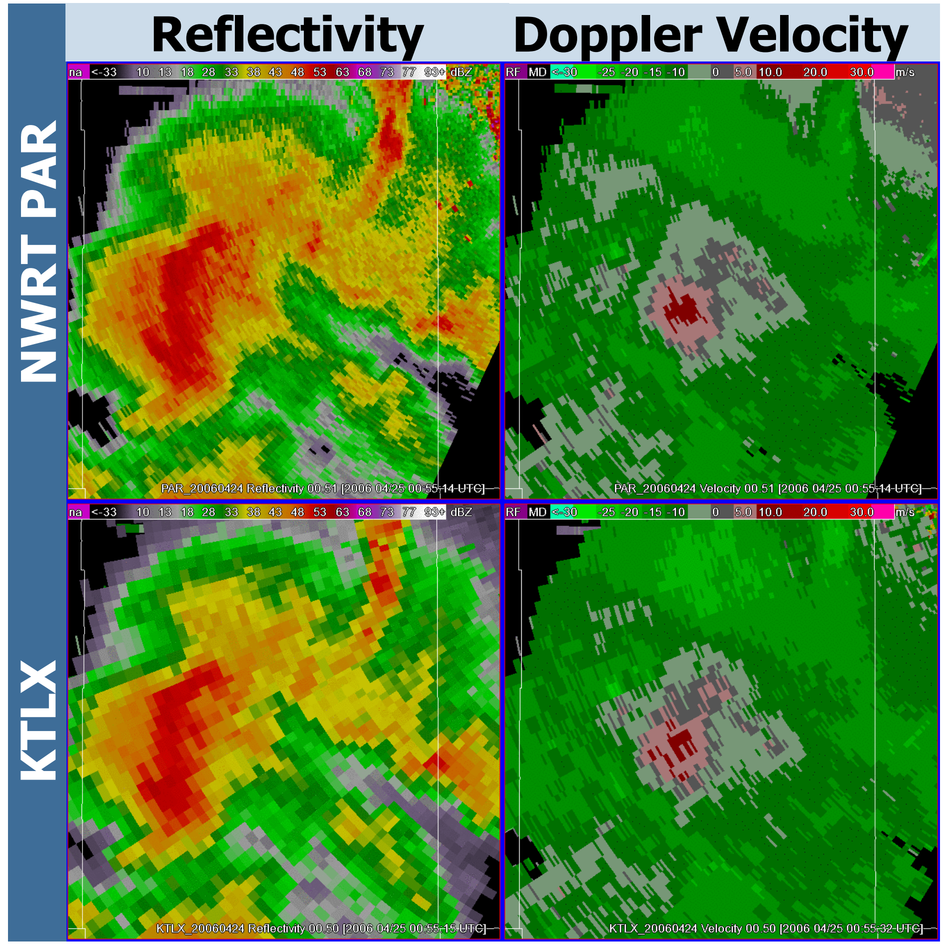
Photo by M. Benner

Method for Increasing Update Time

Technique	Increase in Sampling Rate	Tradeoff
Sector Scanning	≥ 4 times	Coverage

Update time for VCP 12-like scan

- Strategy yields fast update times by scanning a 90° sector
  - NWRT PAR
    - 90 deg sector
    - 58 s updates
  - NEXRAD
    - Conventional scan
    - 4.1 min updates



24 April 2006

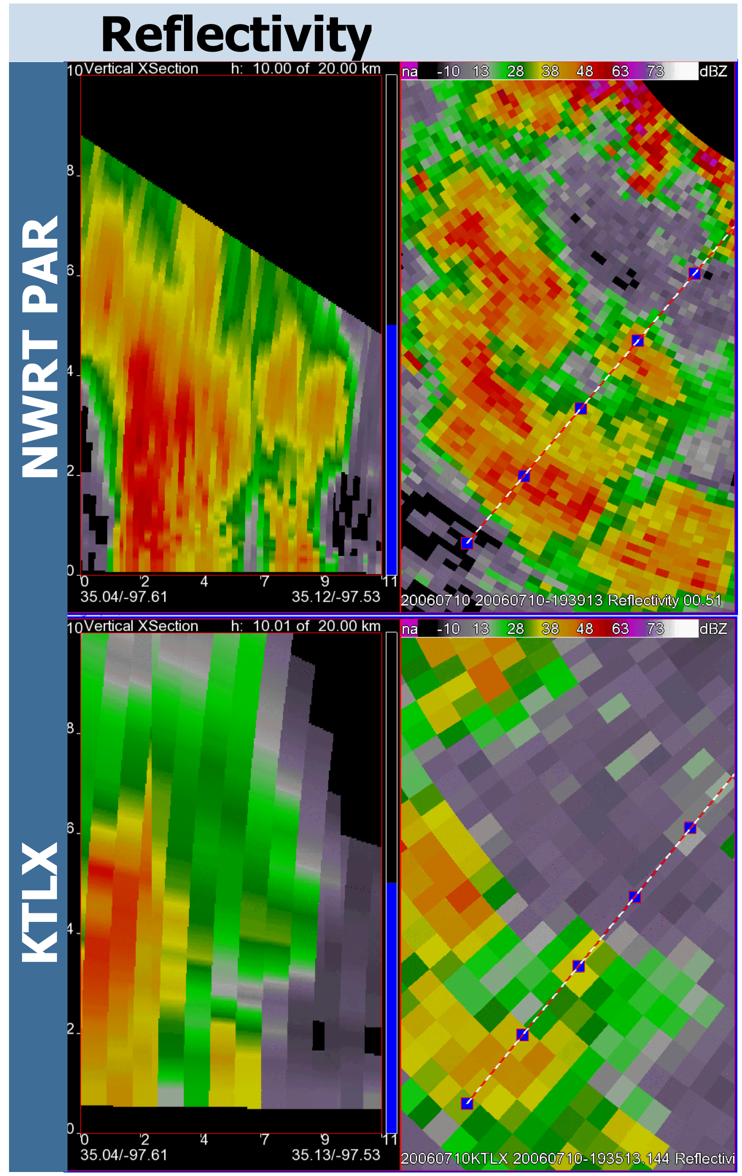
Method for Increasing Update Time

Technique	Increase in Sampling Rate	Tradeoff
Beam Multiplexing	2 times	Ground Clutter Mitigation

Beam Multiplexing: 34 s Updates

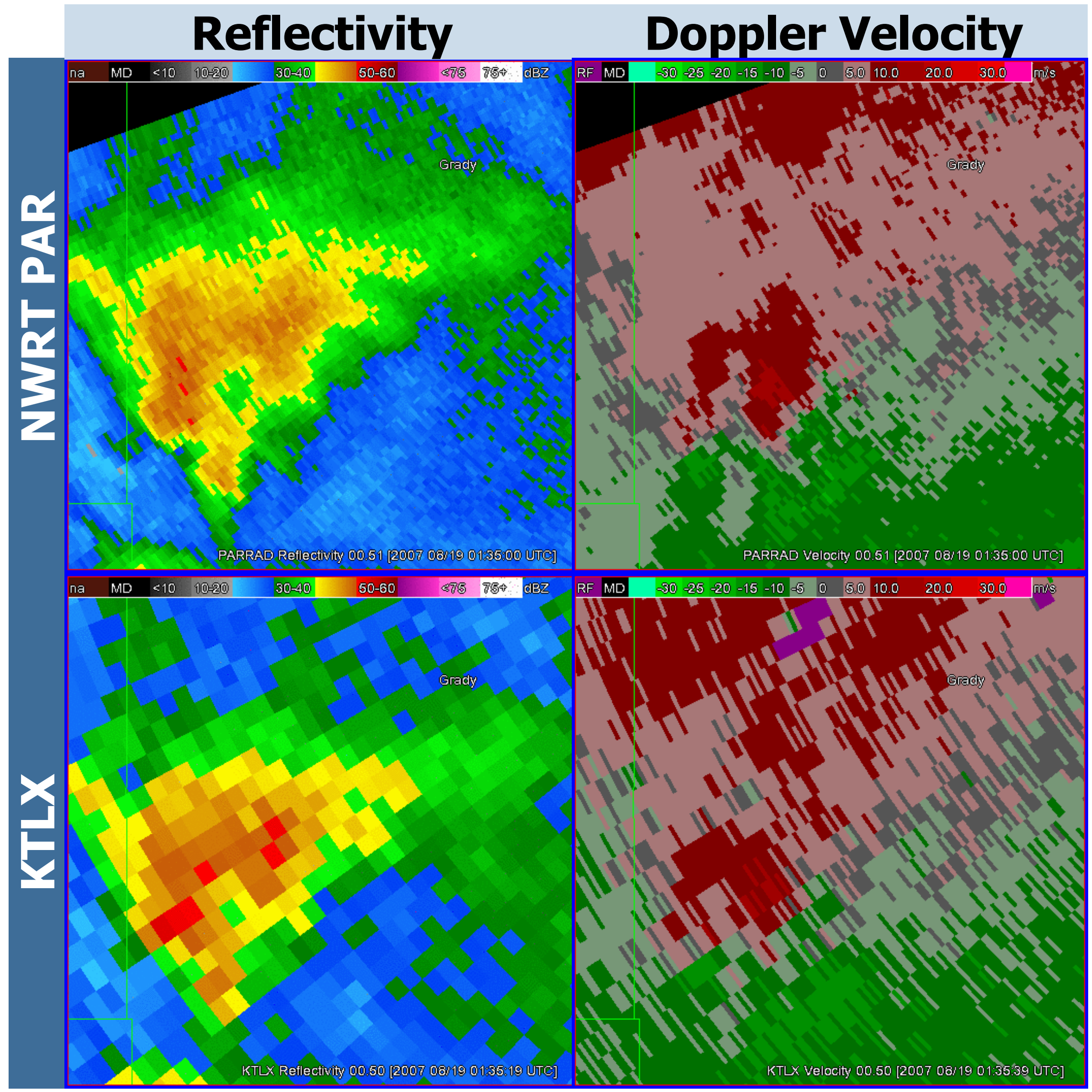
10 July 2006

- Strategy yields fast update times by using beam multiplexing
  - NWRT PAR
    - 90 deg sector
    - 34 s updates
  - NEXRAD
    - Conventional scan
    - 4.1 min updates



Beam Multiplexing: 43 s Updates

- Strategy yields fast update times by concentrating on a sector and using beam multiplexing
  - NWRT PAR
    - 60 deg sector
    - 0.5 deg az oversampling
    - 43 s updates
  - NEXRAD
    - Conventional scan
    - 4.1 min updates



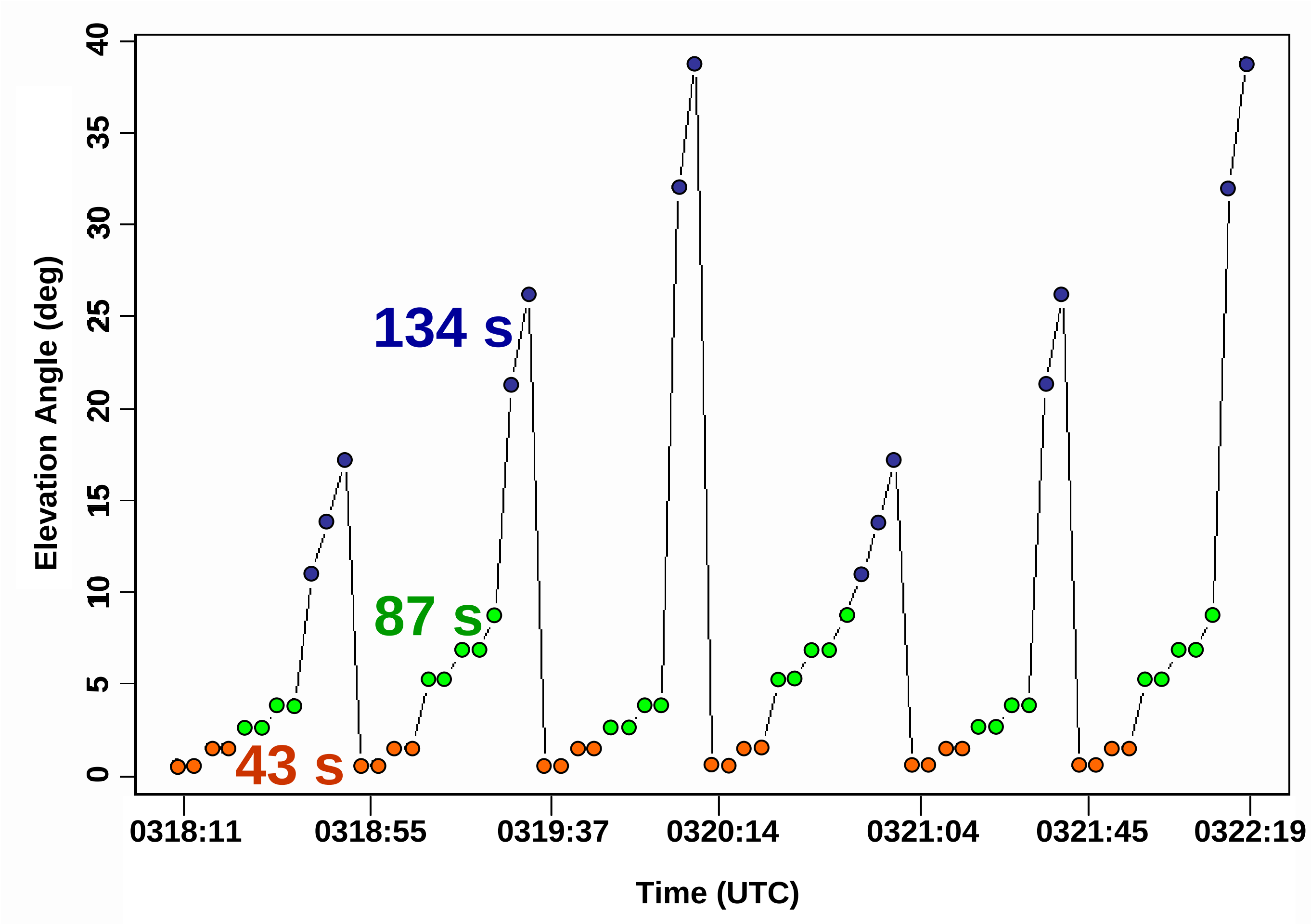
19 Aug 2007

Method for Increasing Update Time

Technique	Increase in Sampling Rate	Tradeoff
Elevation Prioritization	Variable	Slower sampling at some elevations

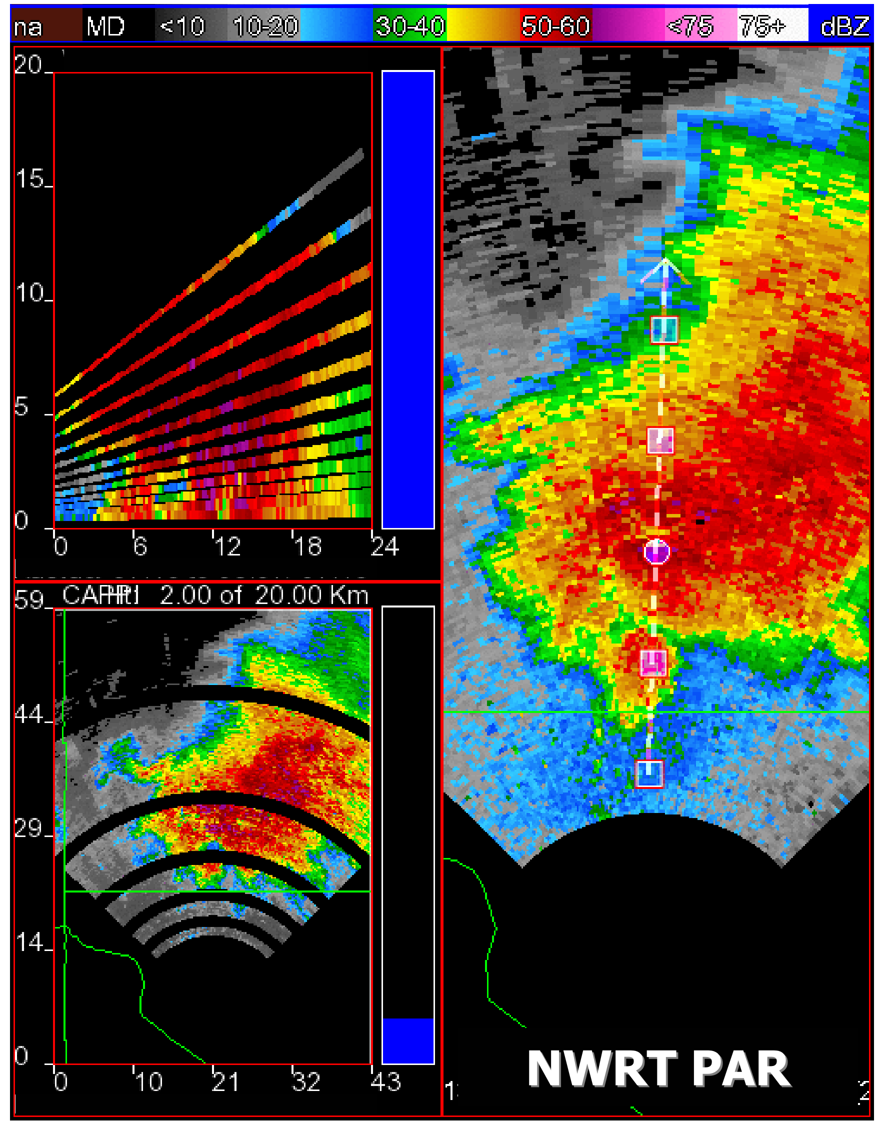
Elevation-Prioritized Scanning

Strategy yields different update times at different elevations by scheduling 14 tilts in a non-sequential manner



Elevation-Prioritized Scanning

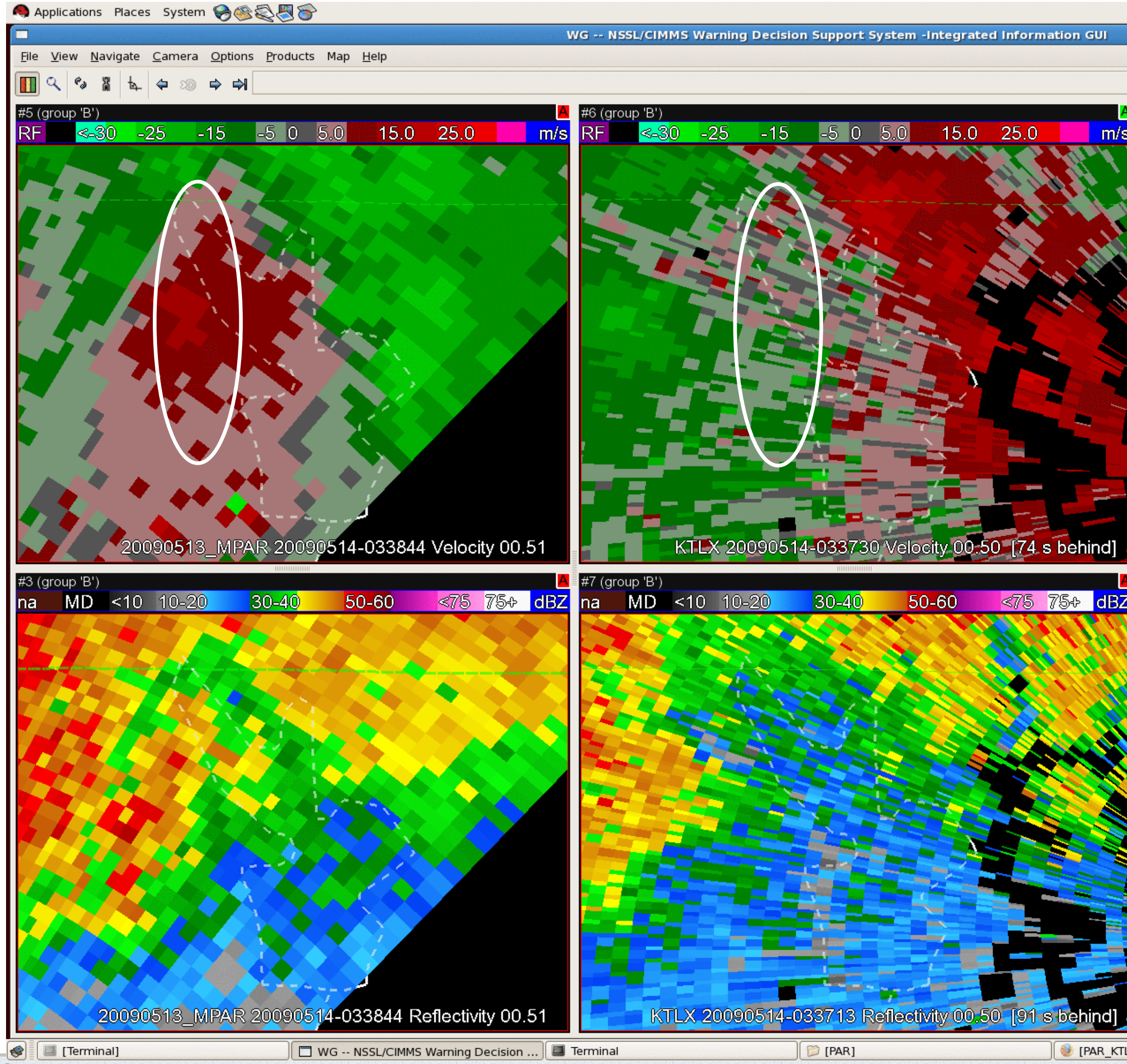
- Strategy yields different update times at different elevations by scheduling 14 tilts in a non-sequential manner
  - **Low-levels: 43 s updates**
  - **Midlevels: 87 s updates**
  - **Upper-levels: 134 s updates**



14 May 2009

13 May 2009 EF0 Tornado

PAR: 43 s Updates **KTLX: 4.2 min Updates**



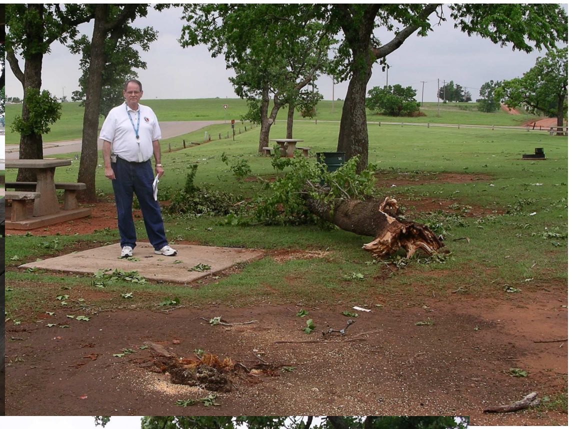
Damage Survey

Tornado Track (~0.5 mile)

Lake Draper Marina

Damage Survey

Tornado Track (~0.5 mile)



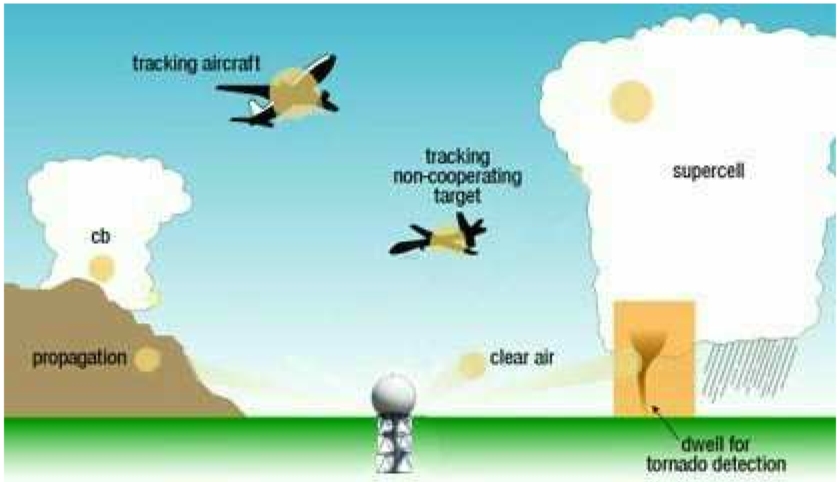
Method for Increasing Update Time

Technique	Increase in Sampling Rate	Tradeoff
Electronic Adaptive Scanning	Variable	Rapid, New Development Aloft

Electronic Adaptive Scanning

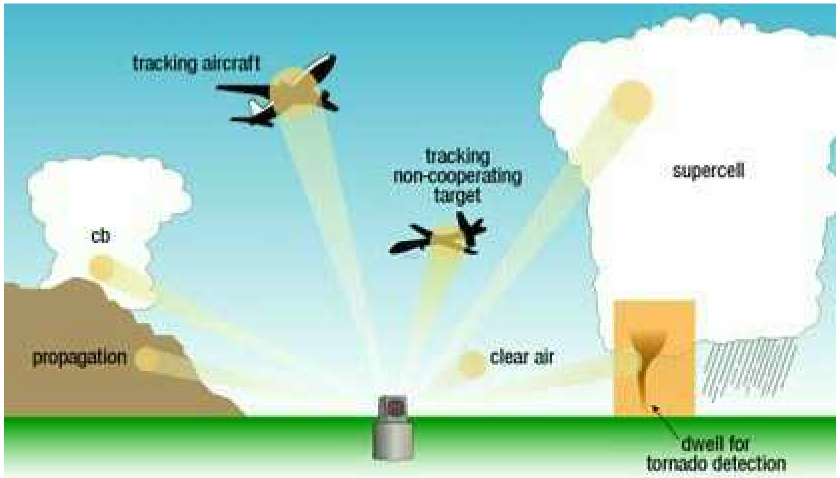
Conventional scanning

Everywhere
Sequential



Adaptive scanning

Areas of interest only
Arbitrary

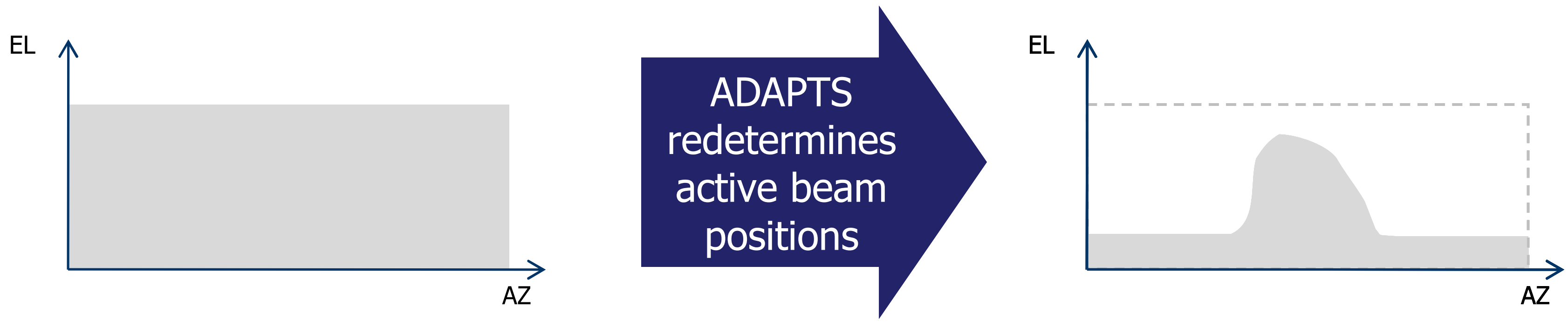


Courtesy of Chris Curtis

Goal: Faster Updates

What is ADAPTS?

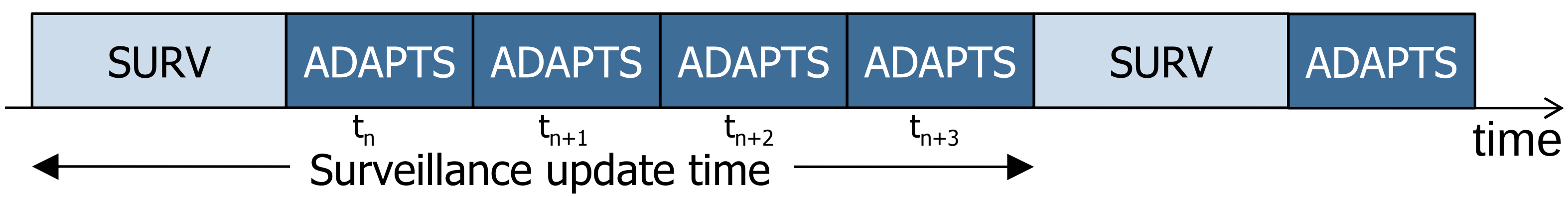
- <u>A</u>daptive <u>D</u>SP <u>A</u>lgorithm for <u>P</u>AR <u>T</u>imely <u>S</u>cans
  - Beam positions are classified as **active** or **inactive**
    - Only **active** beam positions are scanned
      - Active beam positions are updated after every scan
      - Full surveillance volume scans are scheduled periodically



Radar scans
full surveillance volume

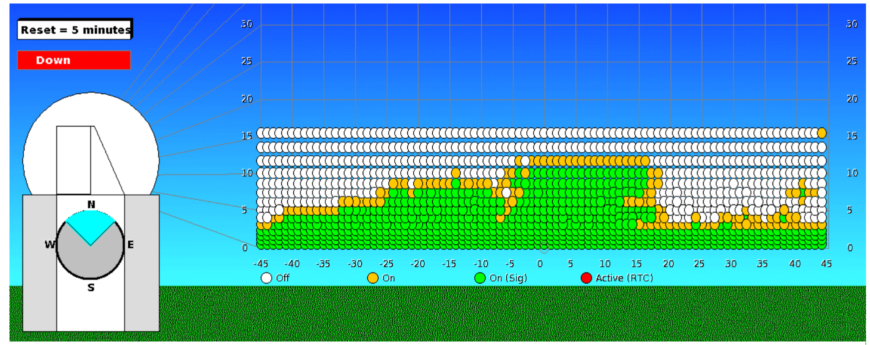
Radar scans
active beam positions

Scanning strategy schedule:

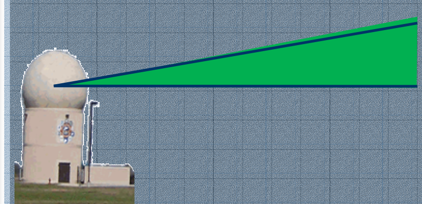


How does ADAPTS work?

- Active beam positions meet one or more criteria
  - Elevation angle
  - Continuity and coverage
  - Neighborhood

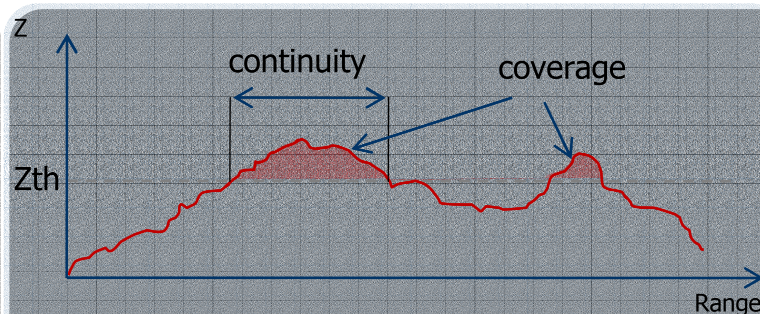


Real-time display of active beam positions



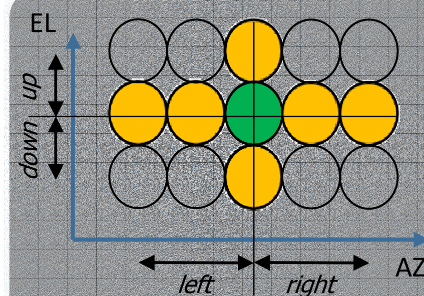
Always scan at the lower elevations

1st Criterion



Determine significant weather signals

2nd Criterion



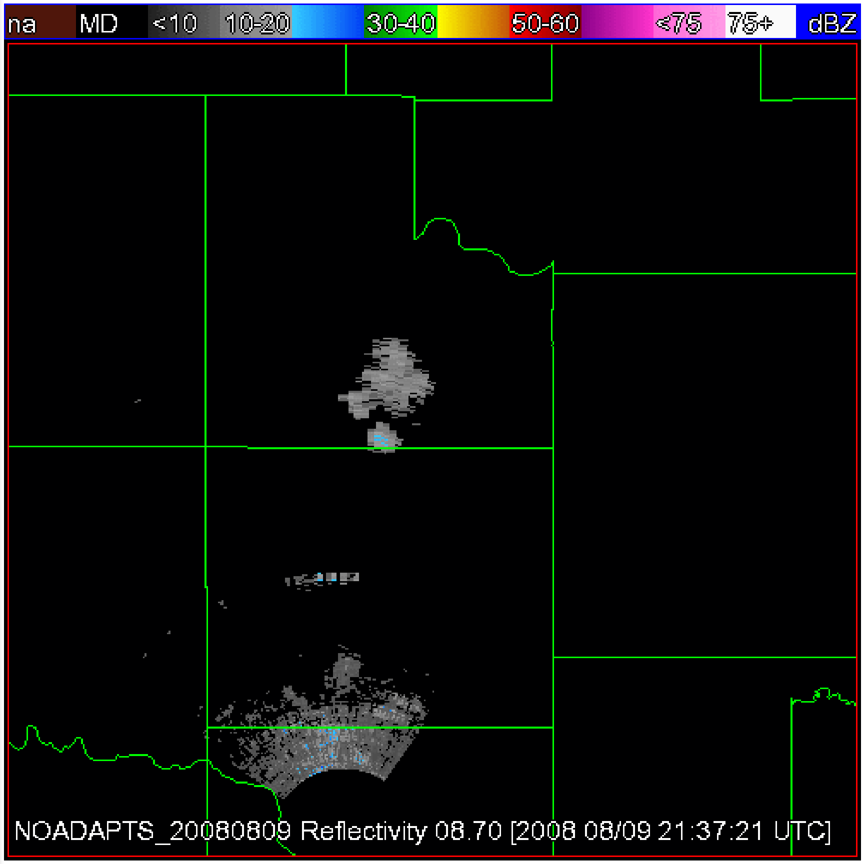
Look around to respond to storm evolution

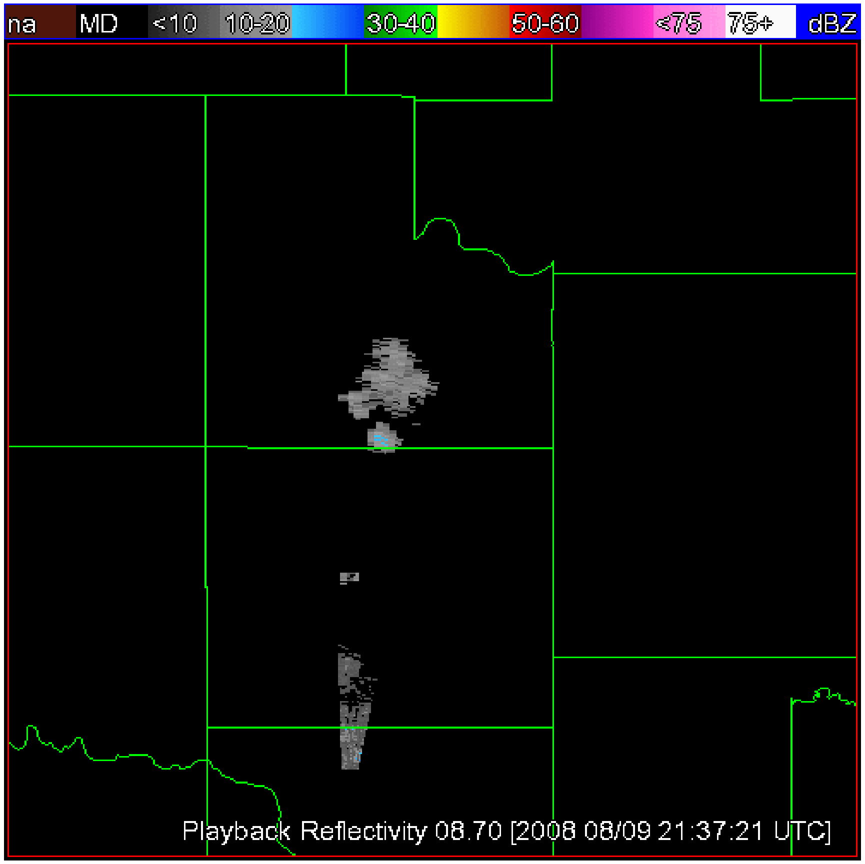
3rd Criterion

ADAPTS Performance

Qualitative Evaluation

ADAPTS is OFF	ADAPTS is ON

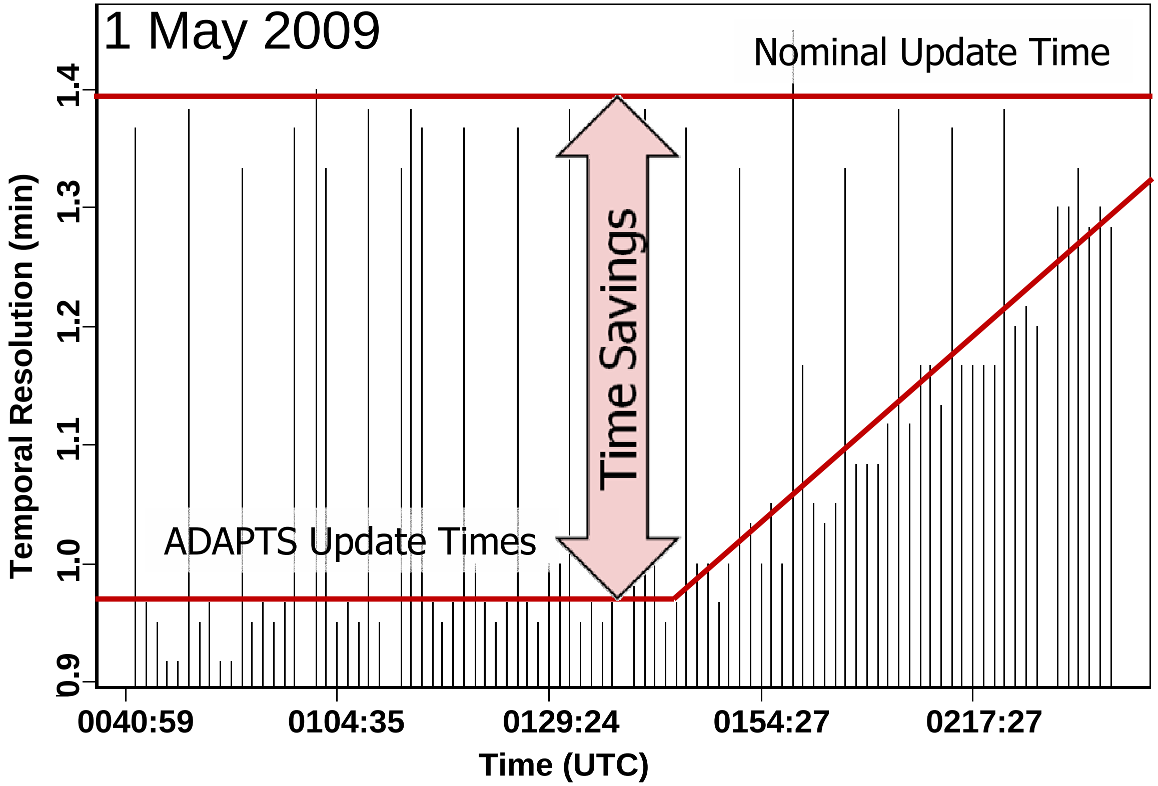


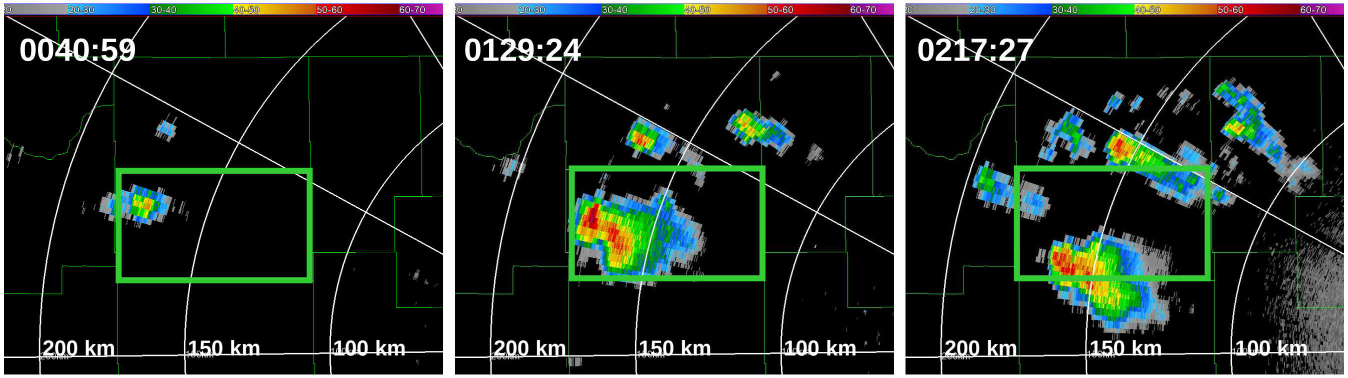


09 AUG 2008 – Reflectivity - 8.7 deg

ADAPTS Performance

Quantitative Evaluation

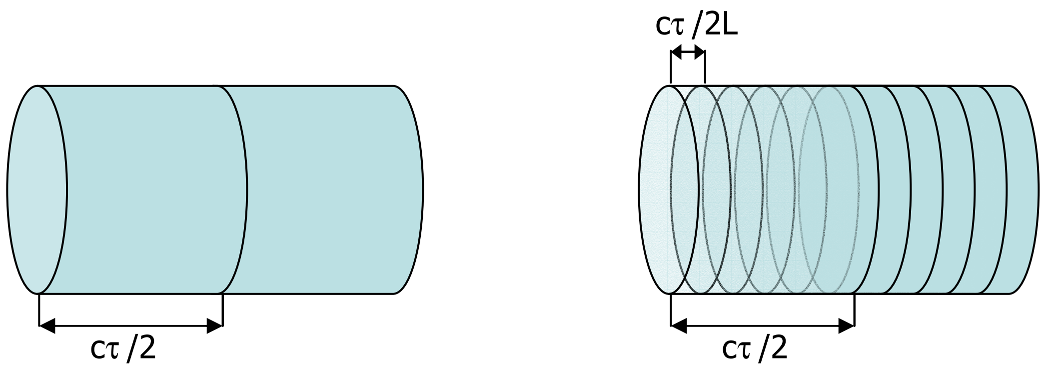




Range Oversampling

A Signal Processing Solution

- Range oversampling (RO) adds more information <u>without increasing</u> the observation time
  - RO leads to overlapping radar volumes



Traditional Sampling

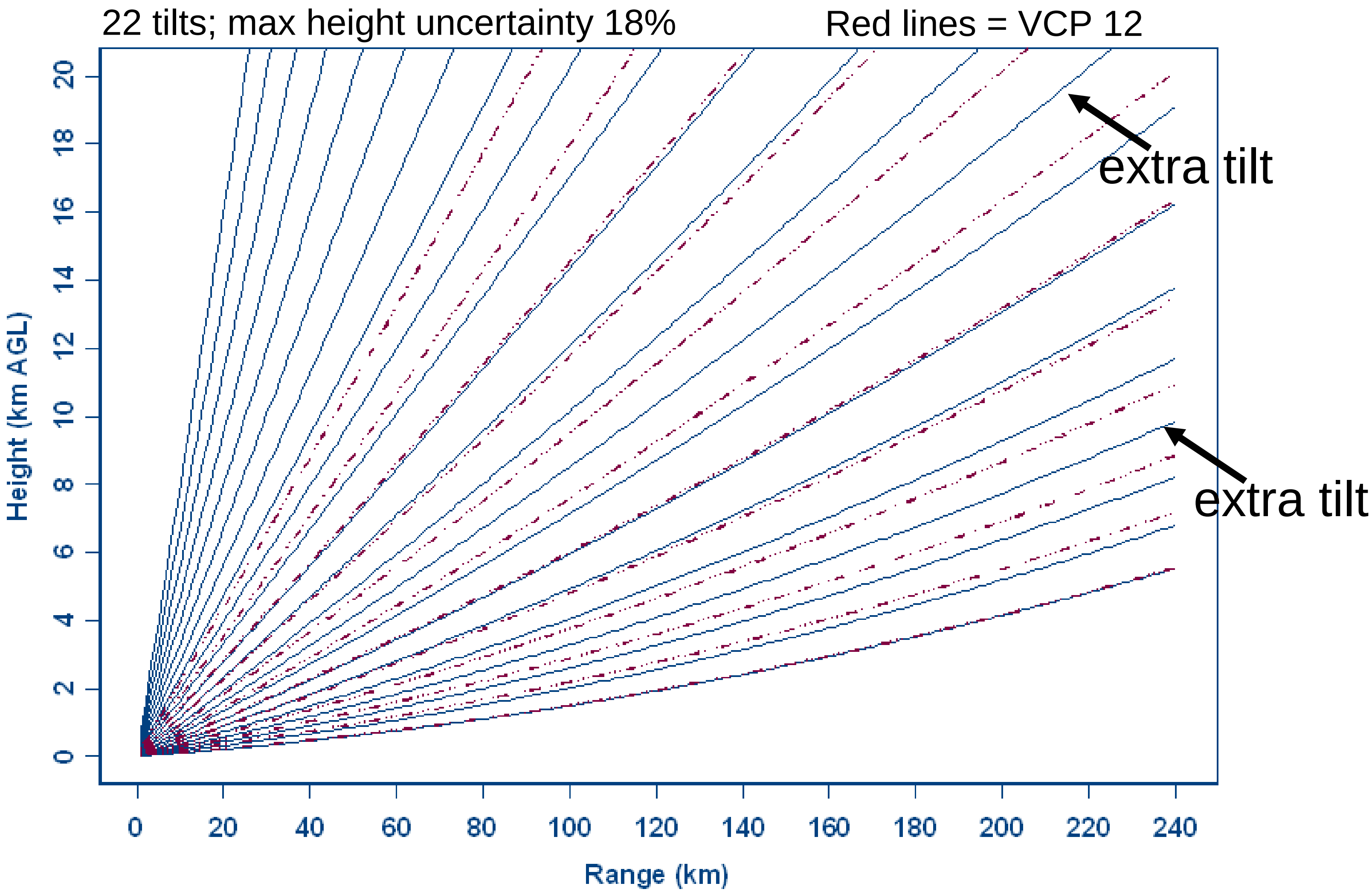
Oversampling

These are **cleverly** combined for improved accuracy

  - RO results in **more accurate estimates** and/or **faster updates**

2010: Oversampled VCP

Update Time: ~~2 min~~ **1 min**

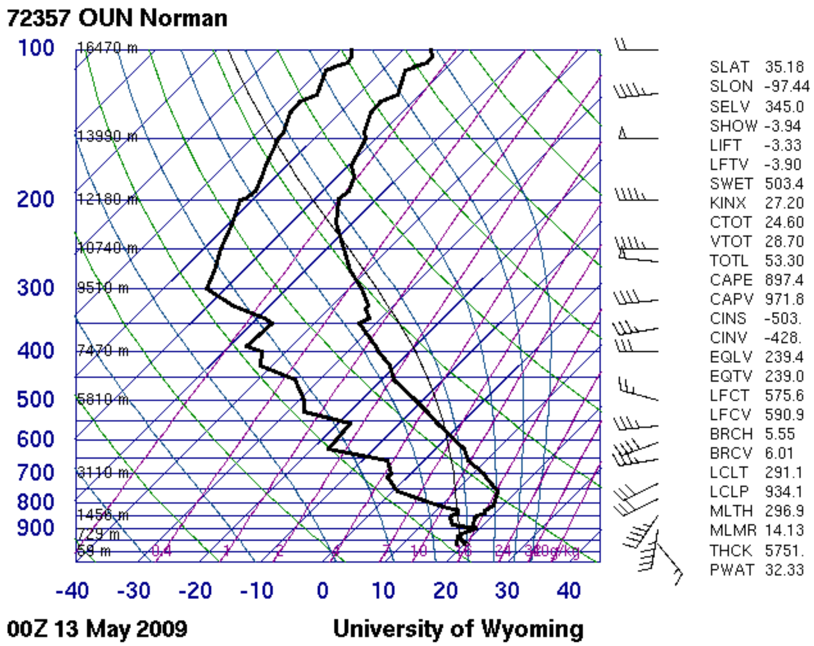


NEXT…

Investigating how rapid updates may improve understanding of storm processes

13 May 2009 Heat Burst

Environment at 0000 UTC 13 May 2009

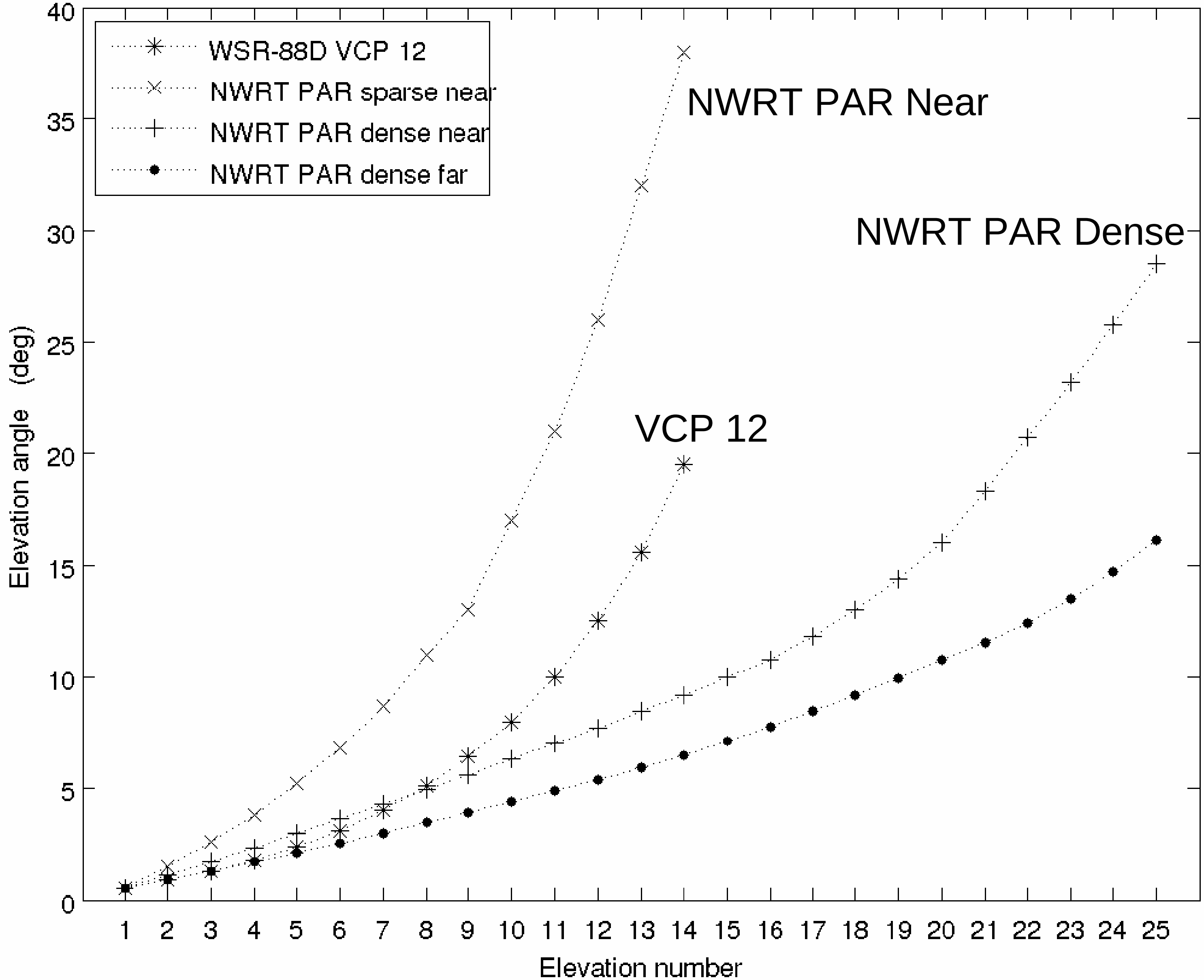


Available data

- Heat bursts observed at 41 sites of the Oklahoma Mesonet
- Event sampled by two WSR-88D radars:
  - Frederick, OK (KFDR)
  - Twin Lakes, OK (KTLX)
- The NWRT PAR sampled this event for 2.5 hours using the dense vertical sampling strategy

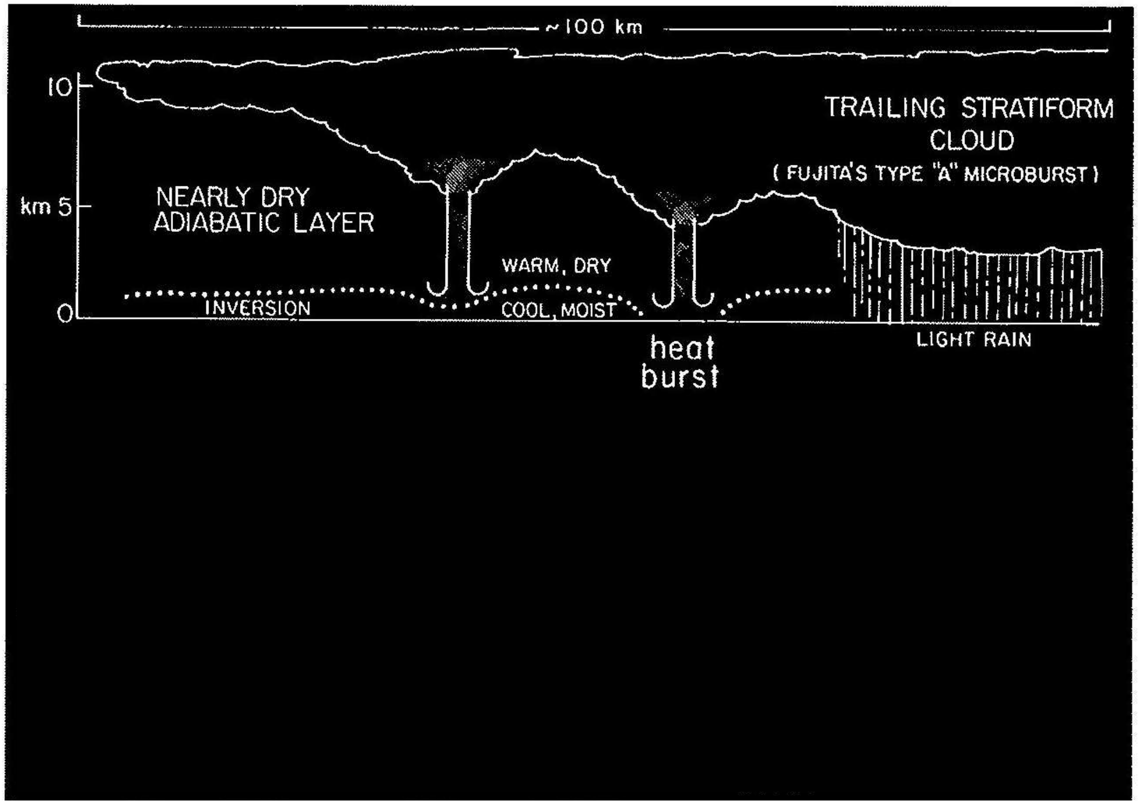
Collaborators: Adam Smith and Dr. Phil Chilson (OU SoM)

Scanning Strategies

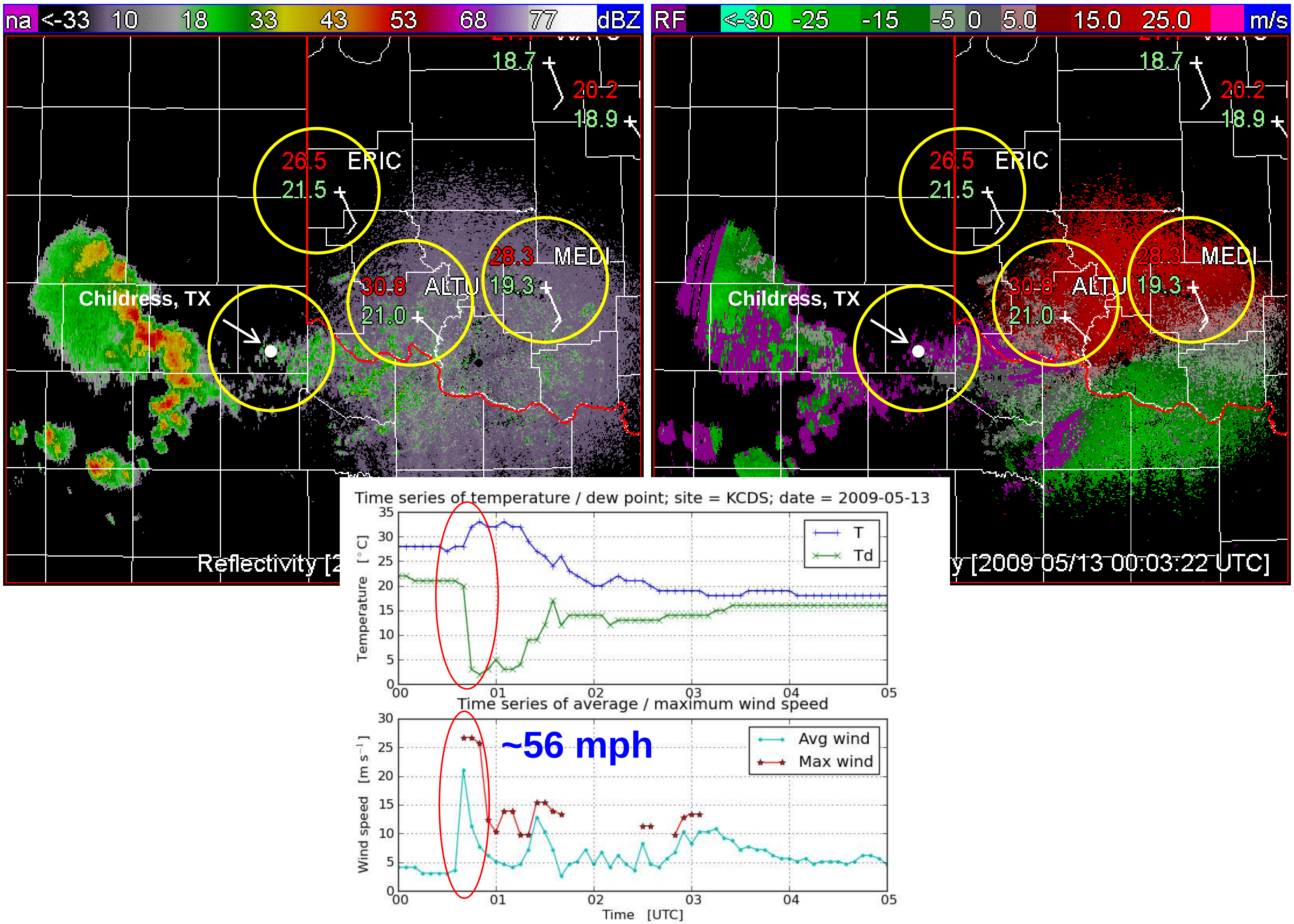


Heat burst mechanisms

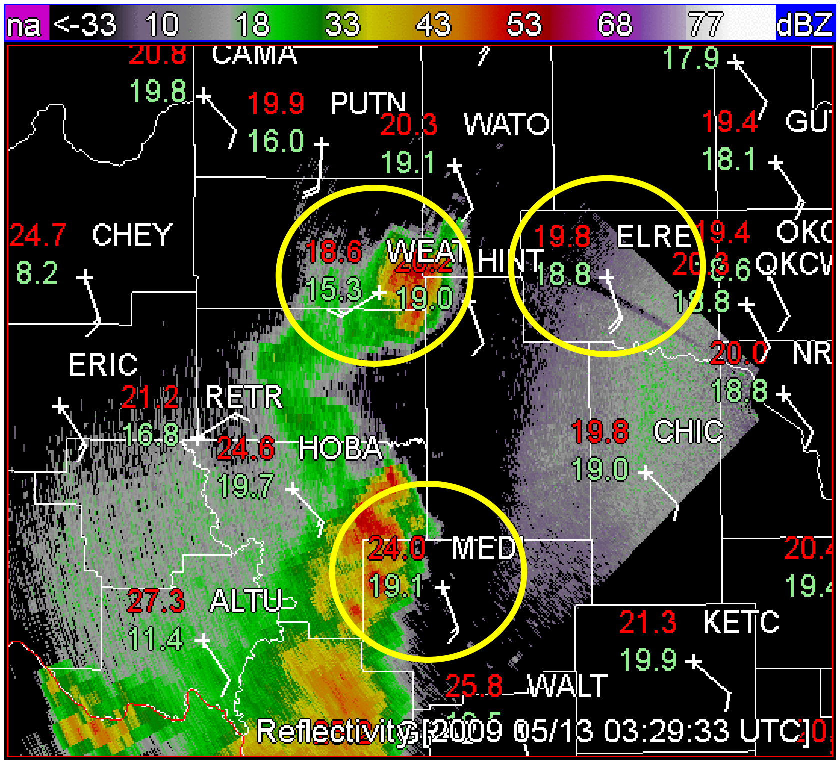
From Bernstein and Johnson 1994, *Mon. Wea. Rev.*

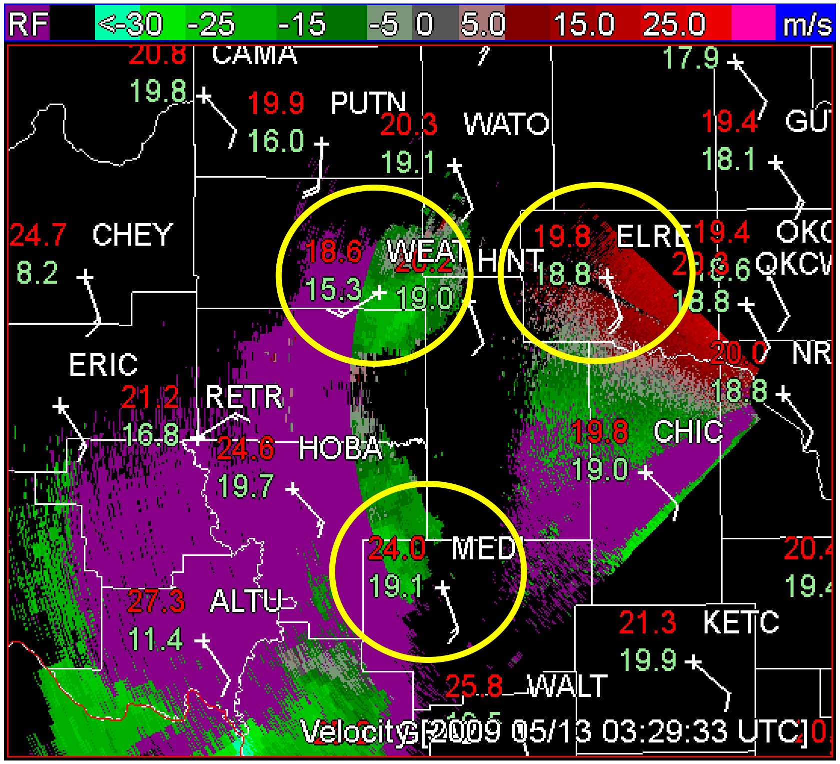


13 May 2009 heat burst: 0329–0519 UTC

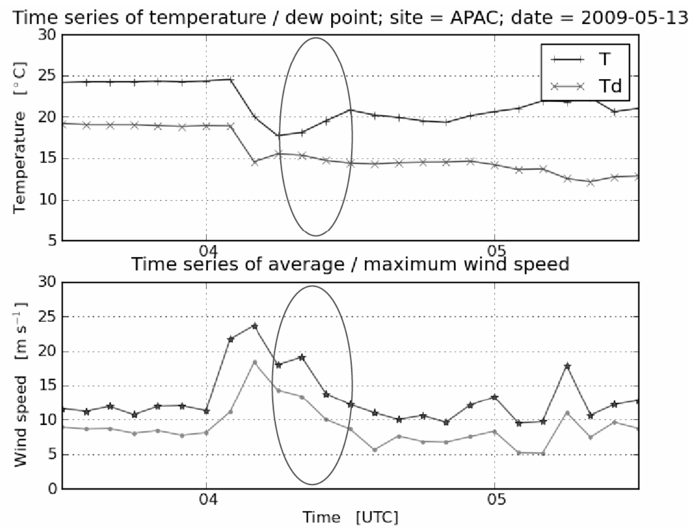


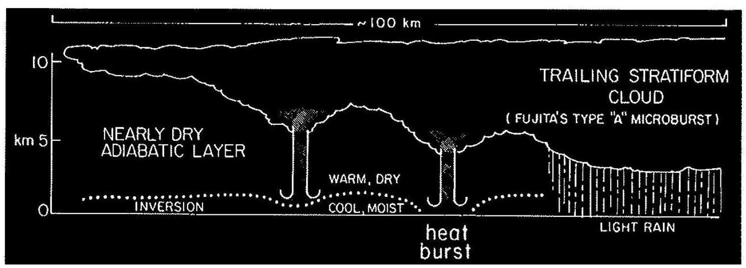
13 May 2009 heat burst: 0329–0519 UTC

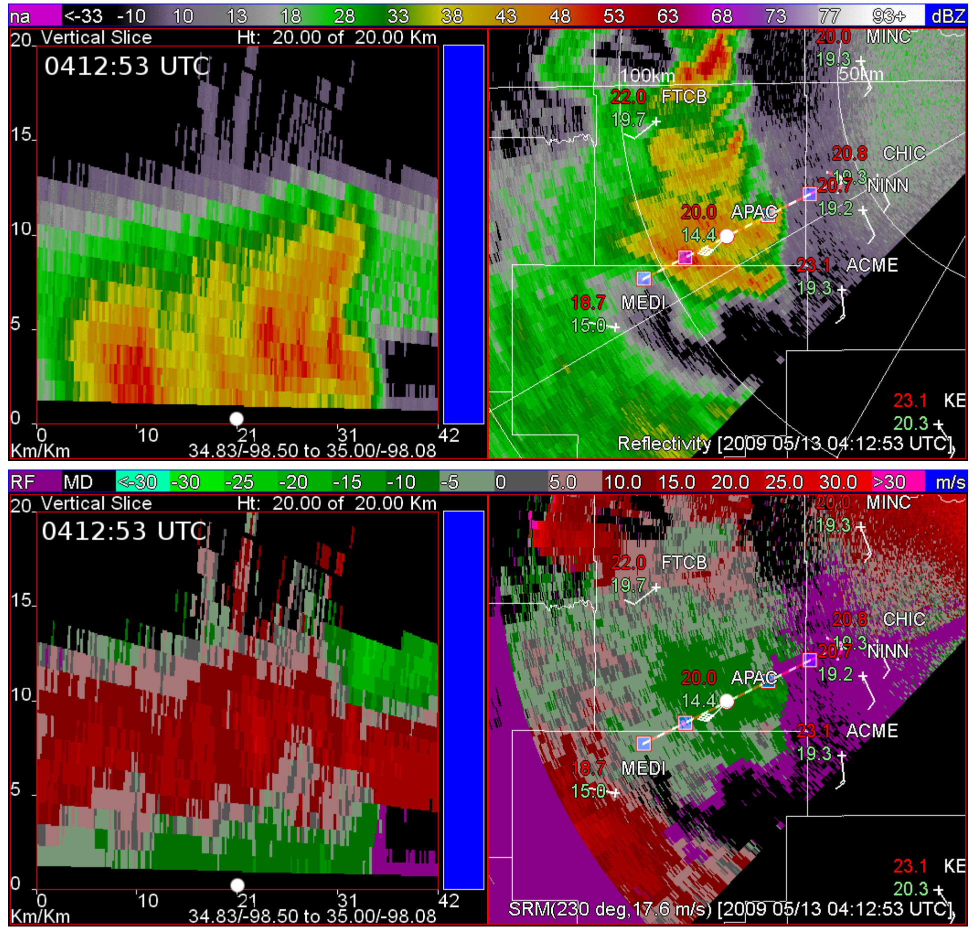




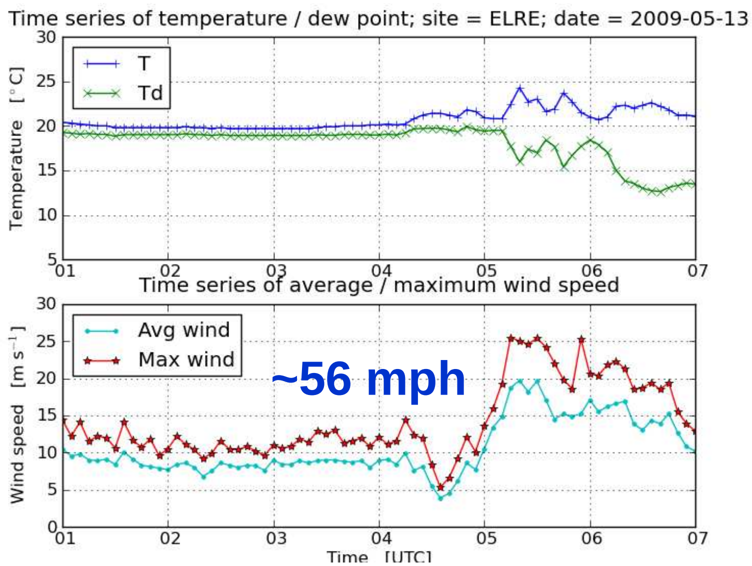
Apache Heat Burst: 0413–0427 UTC

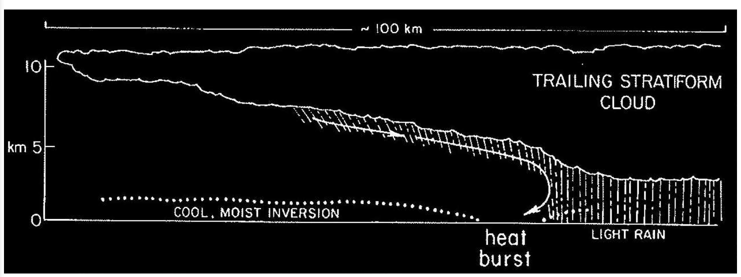


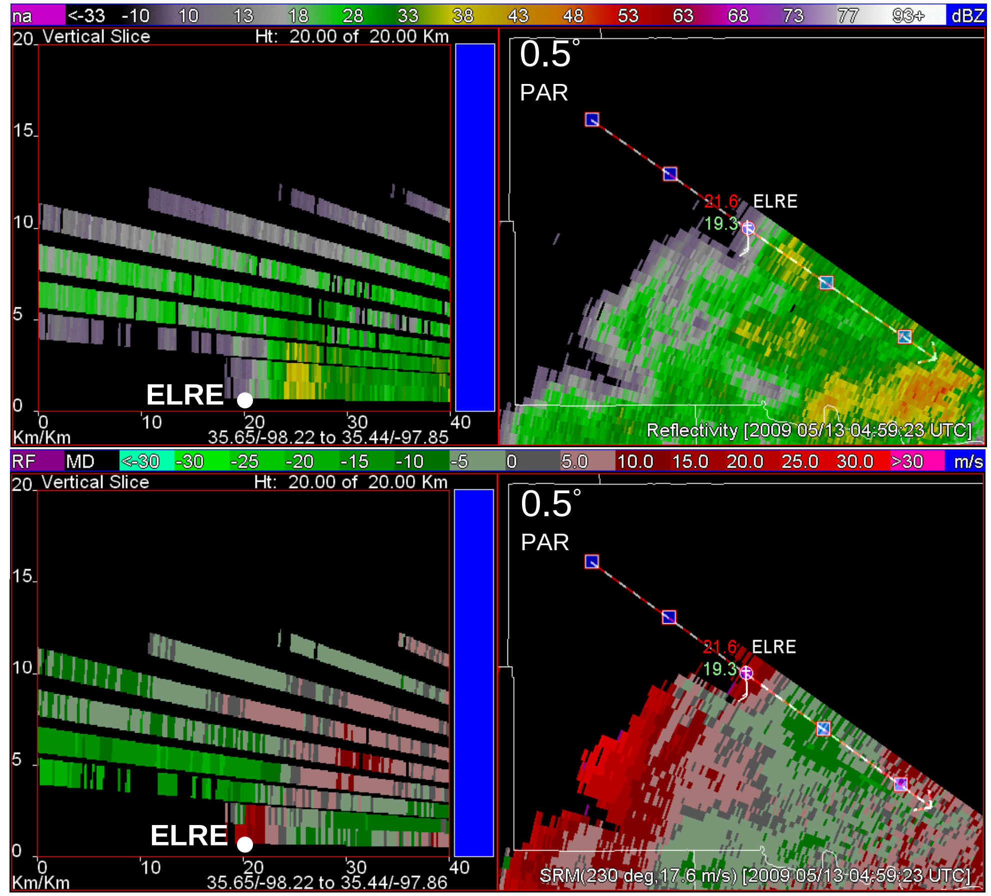




El Reno Heat Burst: 0459–0519 UTC

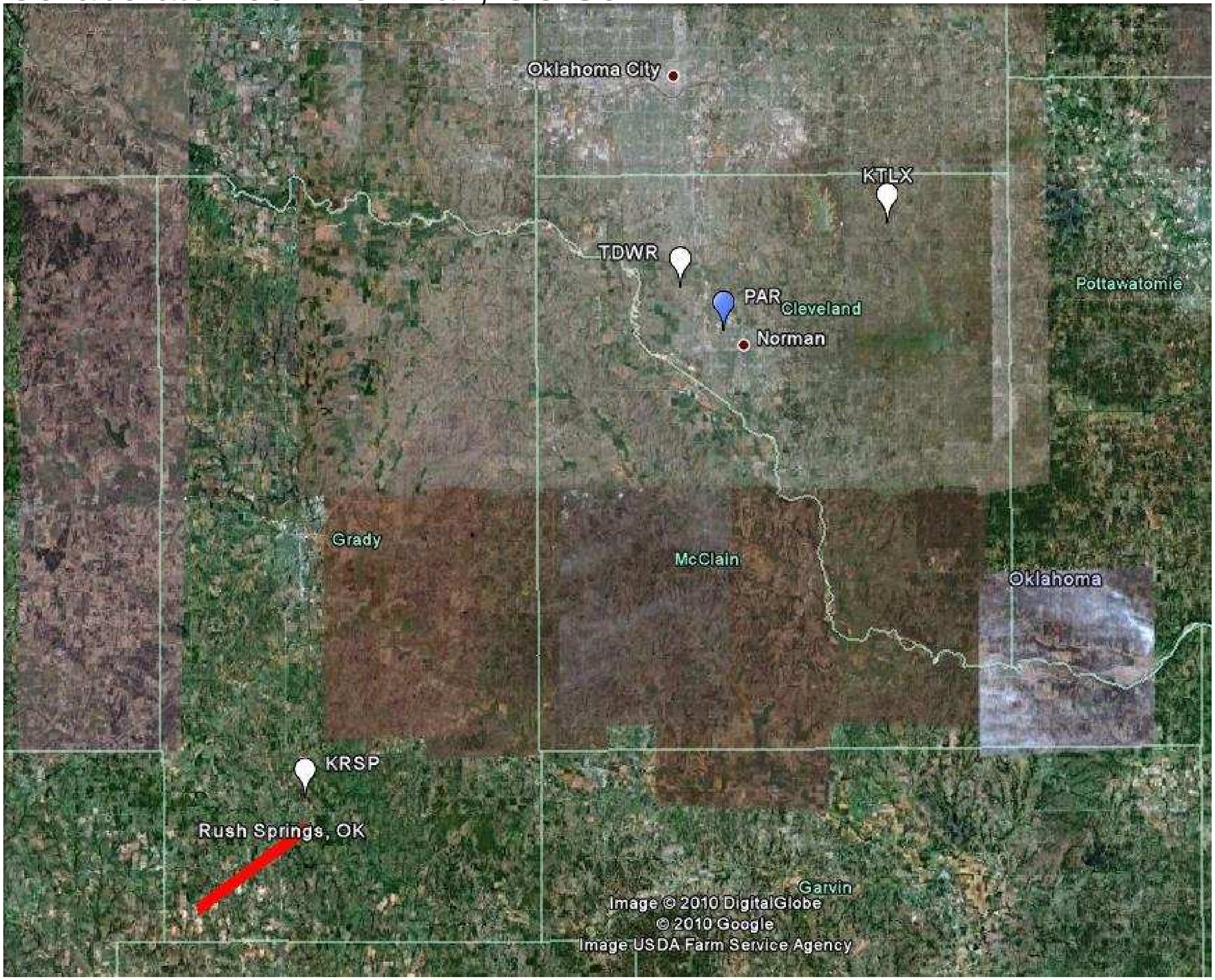






2 April 2010 – Rush Springs, OK Tornado

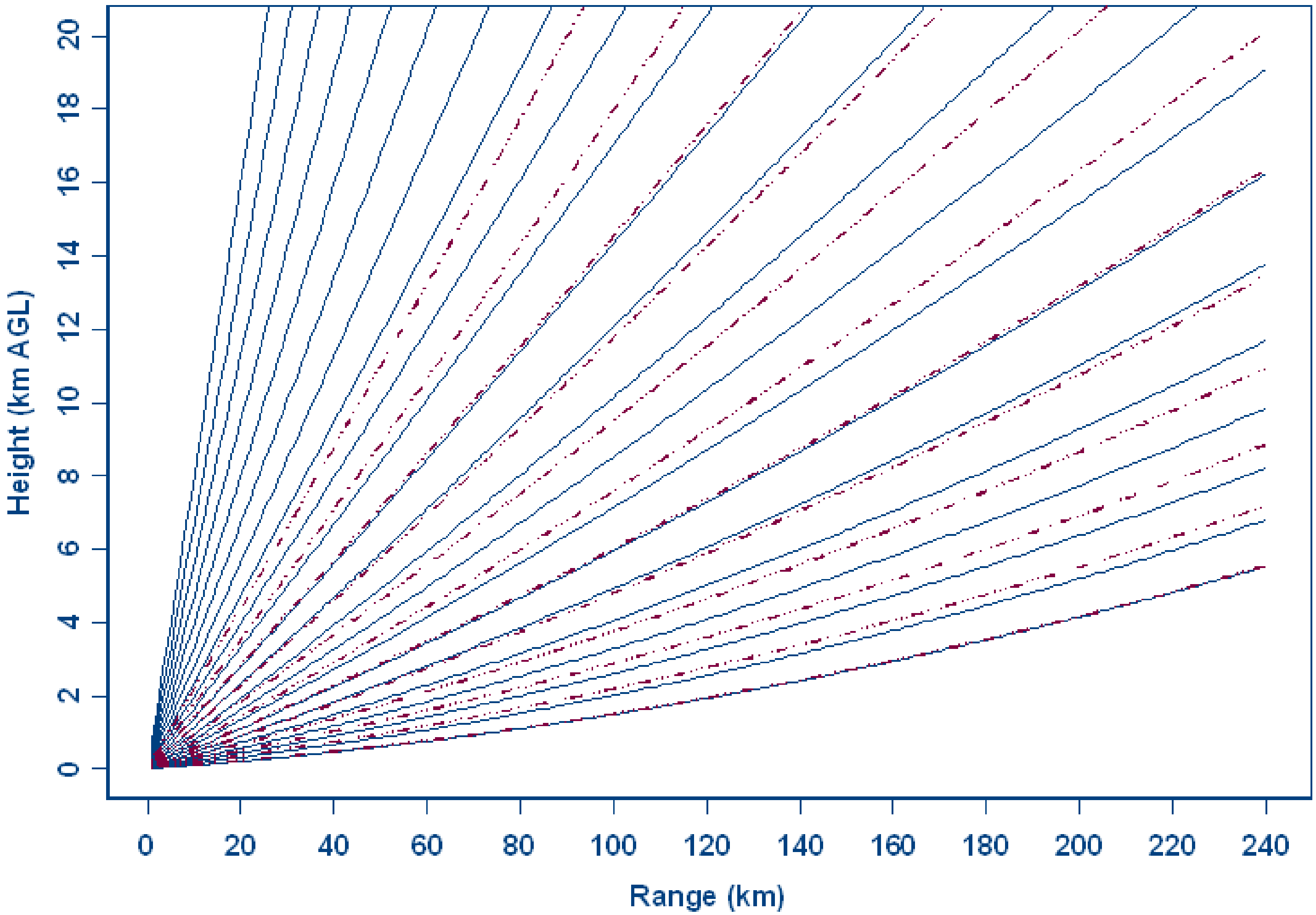
Collaborator: Jen Newman, OU SoM



Scanning Strategy

Update Time: 2 min

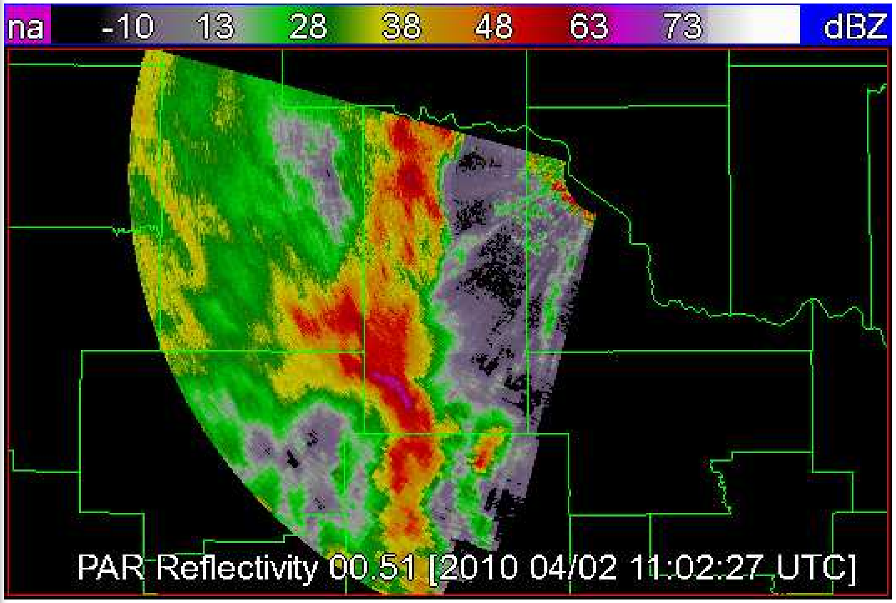
22 tilts; max height uncertainty 18% Red lines = VCP 12

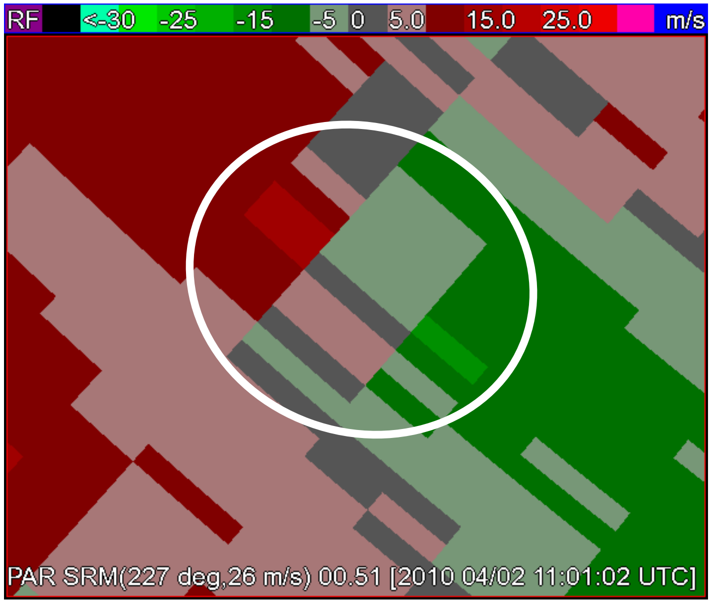


PAR sampled QLCS in central Oklahoma

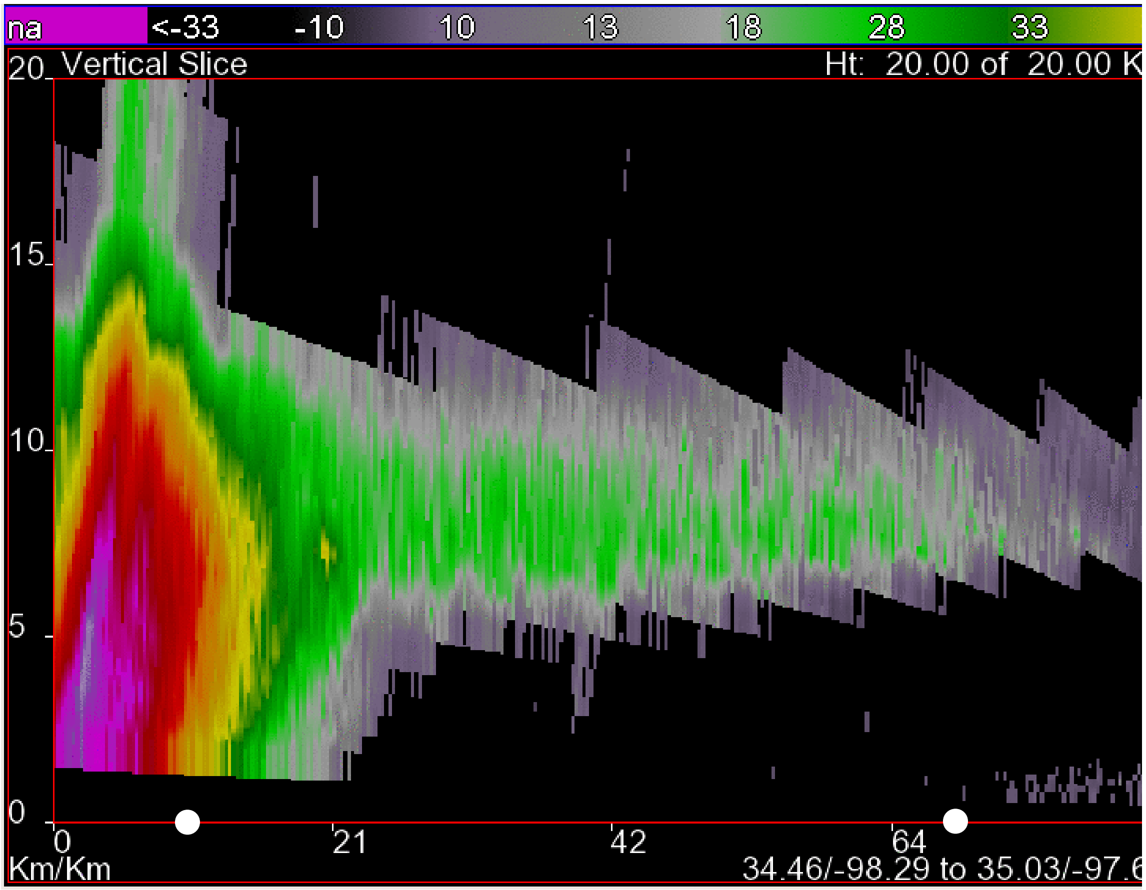
- Sampled 2 microbursts, multicellular storm evolution, intensifying rear-inflow jet, Rush Springs circulation

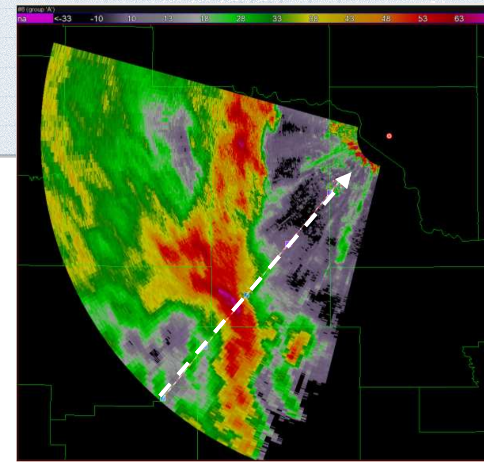
- Damage in Rush Springs was likely associated with a tornadic mesovortex along leading edge of QLCS (verified by high-resolution CASA data)





Evolution of individual cells





NEXT…

Studying impact of rapid updates on warning decision process

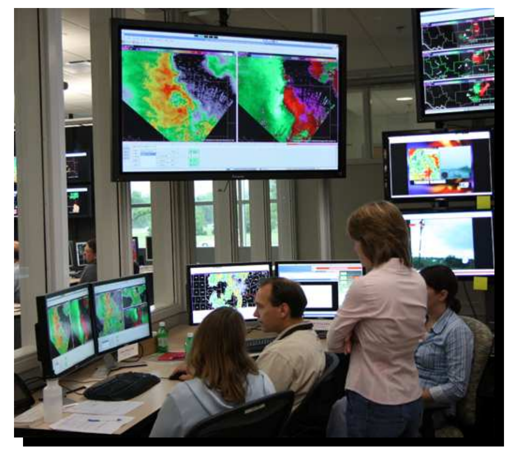
Forecaster Evaluation of PAR

2007 – 2009

Forecasters evaluate utility of PAR & WSR-88D via side-by-side comparisons

Evaluations via written survey following playback and real-time cases

Experiment design limited by sharing 2 or 3 other groups

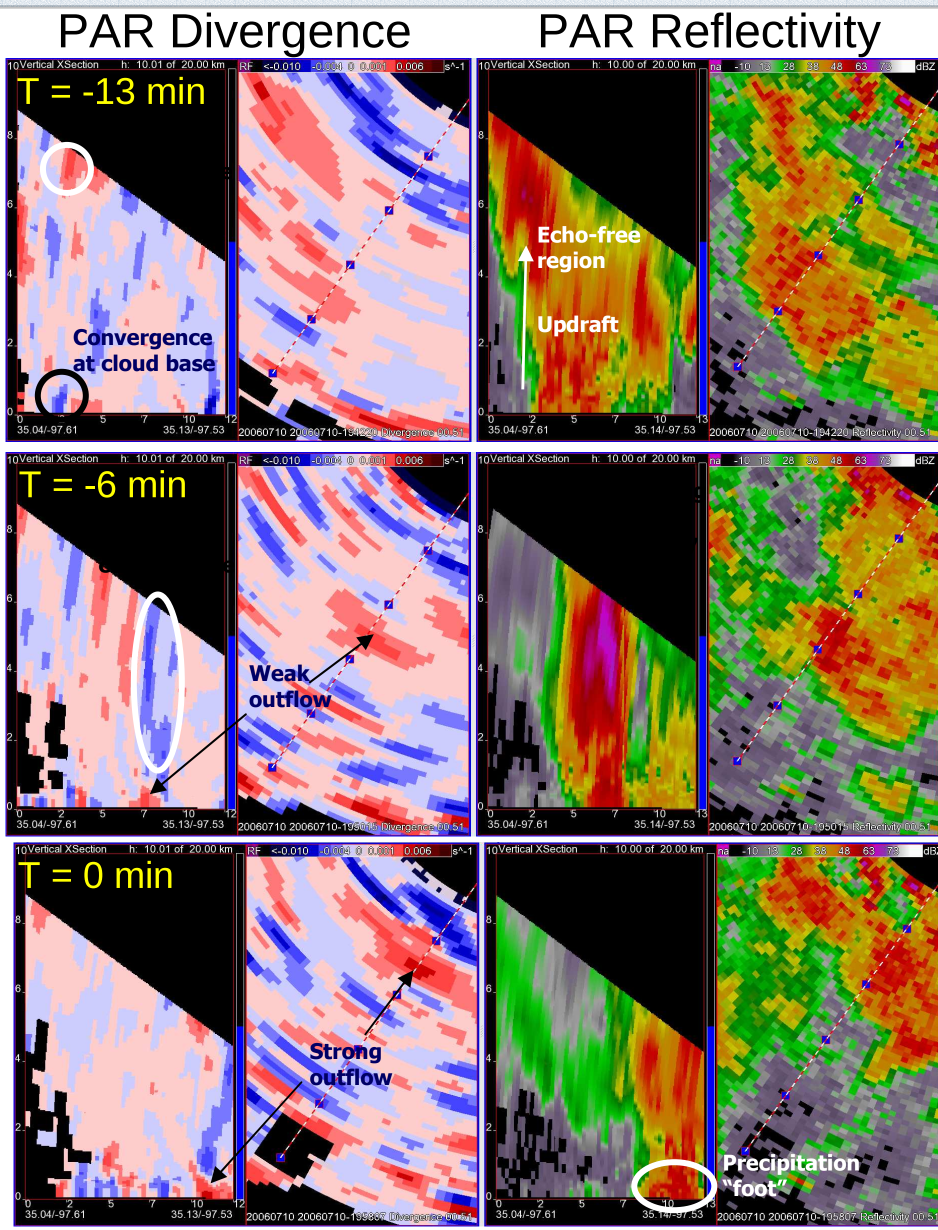


Forecaster Evaluation

“High temporal resolution of PAR allowed me to ***identify near-ground-level severe winds which were considerably under-played by KTLX*** (27 kt vs 57 kt).”

“You can diagnose better what’s going on so you can have ***more confidence in issuing or not issuing warnings***.”

“Rapid updates will ***help get the warning out period***. We have many missed pulse storm hail and wind warnings.”

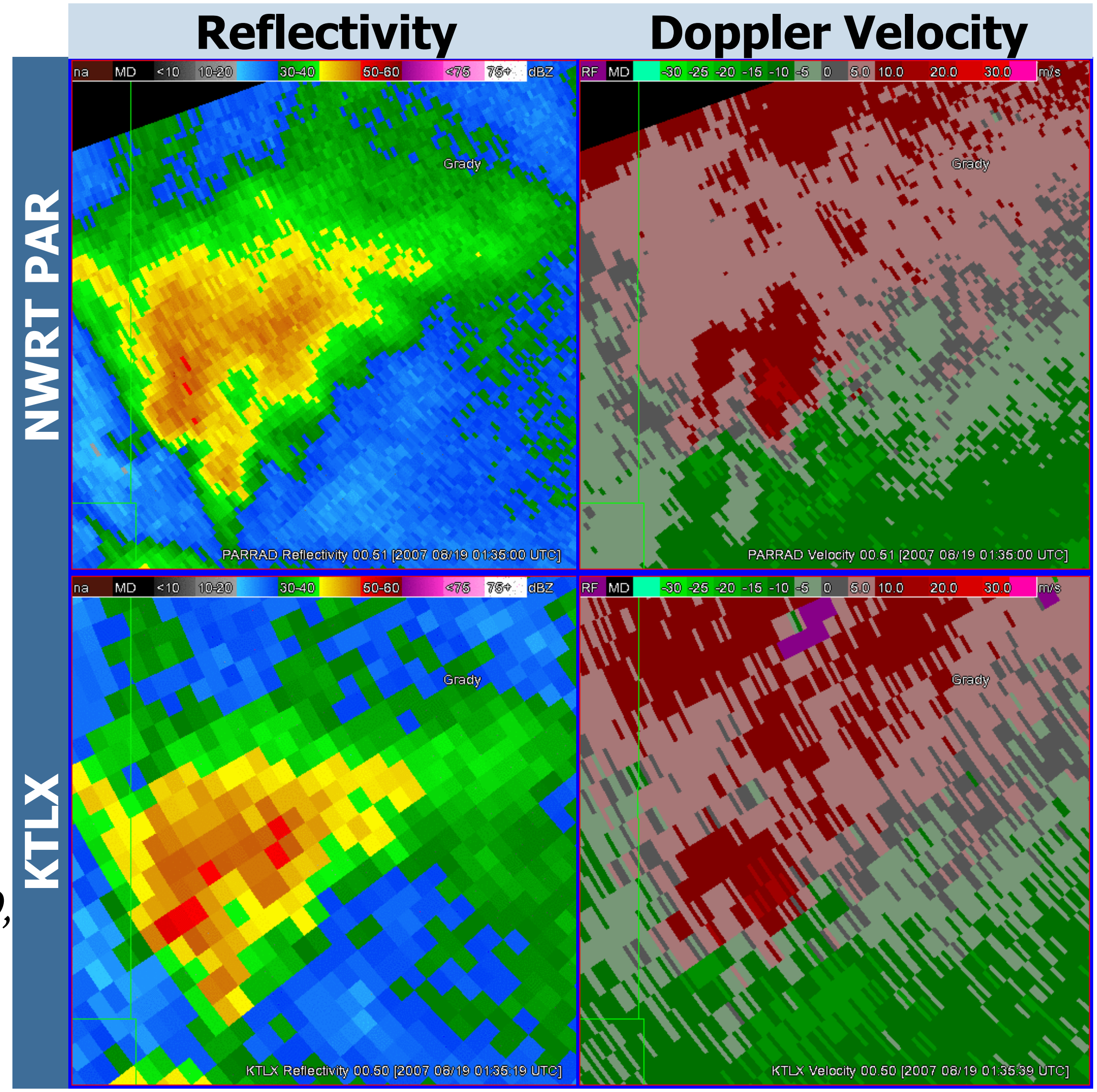


Forecaster Evaluation

*"**Superior** to KTLX **for identifying mini-supercell features.**"*

*"**Rapid updates** at the 0.5° tilt **were critical** in this case; **rotation and TVS features were very fast moving and very fast to evolve.**"*

*"Allowed the **tornado warning to be issued 3 – 4 min before the signature appeared on 88D,** and **with higher confidence.**"*



19 Aug 2007

Findings: 2008 – 2009 Experiments

Collaborators: Daphne LaDue and Cristal Sampson

High-temporal resolution showed continuity of significant, transient features, making them easier to identify

↓

Continuity of features led to greater confidence

Note: No questions asked about confidence

↓

Warnings were issued earlier, increasing lead time over conventional radars

Concept of Operations

Recalibration of the warning decision process

Need to gain experience as to how many consecutive scans need to be examined prior to issuing a warning

Forecaster Evaluation of PAR

2007 – 2009

Forecasters evaluate utility of PAR and WSR-88D via side-by-side comparisons

Evaluations via written survey following playback and real-time cases

Experiment design limited by sharing forecasters w/ 2 or 3 other groups

2010

Forecasters evaluate impact of temporal resolution on warning decision making using PAR data

Discussions of warning decision process in team and group debriefings

Experiment design ~limitless; perform better social science research

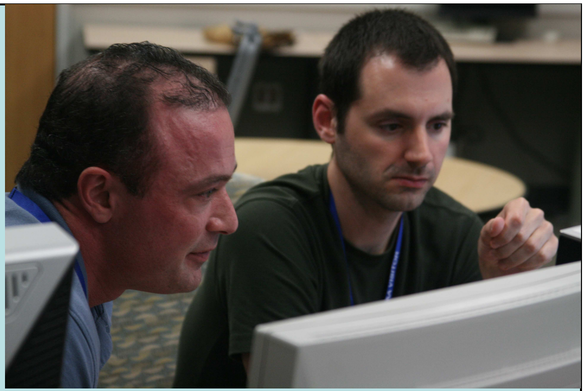
2010 PARISE

Who: 12 forecasters: Central, Southern, Eastern Regions

When: 12-30 April 2010

<ins>**What**</ins>

Tuesday Afternoon
Introduction to PAR and training on WDSS-II



Tuesday Evening and Wednesday
Gain experience interrogating PAR data and issue warnings as you would in your office: playback and real time (if wx permits)

After each event, discuss warning decision process

Thursday: Impact of Temporal Resolution Experiment

Impact of Temporal Resolution on Decision Making

Collaborators: Daphne LaDue and Heather Lazrus

Purpose

Determine potential operational impact of temporal resolution on warning decision process

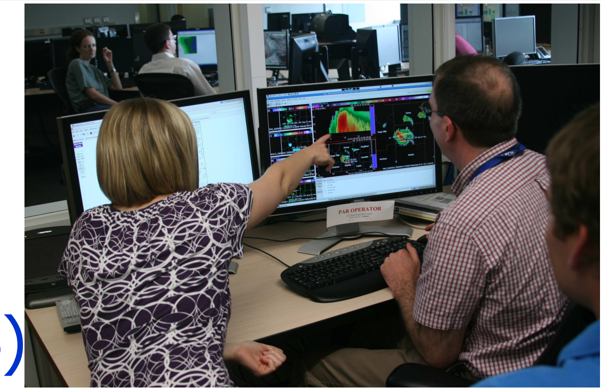
Method

Two groups

- Group 1: PAR data degraded to WSR-88D update time
- Group 2: PAR data with full-temporal resolution

Matched groups: Produce pairings that result in equivalent radar-interpretation skills

What was done during experiment



- Formed two teams
- Worked through two cases
  - Gained situational awareness (WES)
  - Wrote an short-term forecast
  - Worked through the case in displaced real time
  - Issued warning products as needed
  - Discussed experiences within each team
  - Contrasted experiences with other team
- Broke for lunch / worked through 2nd case / final debrief to end the day

Preliminary Findings

Impacts of rapid updates on warning decision making

- 12 participating forecasters agreed it was far easier to apply conceptual models

- Experienced much less uncertainty regarding storm severity and evolution

- Reported they continued to adapt their normal approach to analyzing radar data throughout the week

    - *Some discovered rapid updates allowed easier use of cross sections, while others mentioned the possibility of greater fatigue*

Summary

- **Capabilities of the NWRT PAR are well-suited for the high-temporal resolution data desired by users**

  Sector scanning: ≥ 4x increase

  Beam Multiplexing: 2x increase

  Elevation-Prioritized: *Increase is f(elevation)*

  Adaptive Scanning: *36% increase in temporal resolution in case shown*

  Range Oversampling: 2x increase w/ improved data quality

- **High quality, rapid-update data "fills in the gaps" to improve understanding of storm evolution**

- **Involving users in the developmental stage of PAR technology is helping us build an understanding of how rapid update data may impact warning decision making**

El Reno Heat Burst: 0459–0519 UTC

Wet Microburst Study

- Four days from July and August 2007-2008
- These days qualify as "microburst days" as defined by Atkins and Wakimoto (1991)
- 25 storms were analyzed, 10 were microbursts
  - Reflectivity
  - Divergence

Courtesy Steve Irwin and Travis Smith

Lead time Comparison