Weather Radar Range Oversampling: Addressing Users' Needs for Faster Updates and Better Data Quality

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In a Nutshell

- **Weather radar range oversampling** is a **signal processing technique** that can lead to
  - **Faster updates**
    - Improved observation/tracking of phenomena
    - Timely warnings
  - **More accurate measurements**
    - Precipitation
    - Wind fields

Outline

- Weather radar signal processing

- Faster updates and better accuracy

  - Motivation

  - Fundamental trade-offs

- Range oversampling
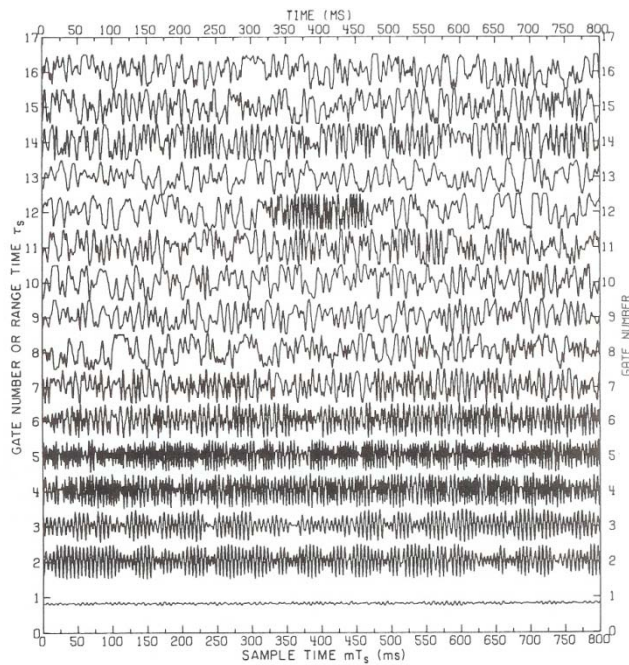
- Accomplishments and future activities
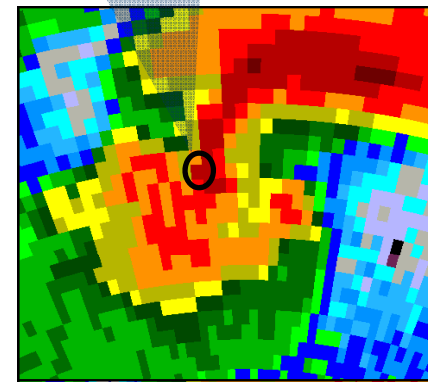
Signal Processing
What is it?

Time series data

- *Large amounts of data*
- *Unintelligible*

Weather Radar Signal Processing

Why does this pixel have this color? What does it represent?

Meteorological variables

- *Smaller amounts of data*
- *Understandable*

**Separation and classification of echoes
Mitigation of sampling artifacts**

- ## NOAA Strategic Goals

  - "Increase lead-time and accuracy for weather and water warnings and forecasts"

  - "Improve predictability of the onset, duration, and impact of hazardous and severe weather and water events"

  - "Increase development, application, and transition of advanced science and technology to operations and services"

United States
National Doppler Radar Sites
158 Operational

All **weather-radar-centric** endeavors benefit

Signal Processing
for Improved Weather Observations

- Four basic needs to **improve weather observations**
  - **Effective** quality control
  - **Faster** updates
  - **Better** accuracy
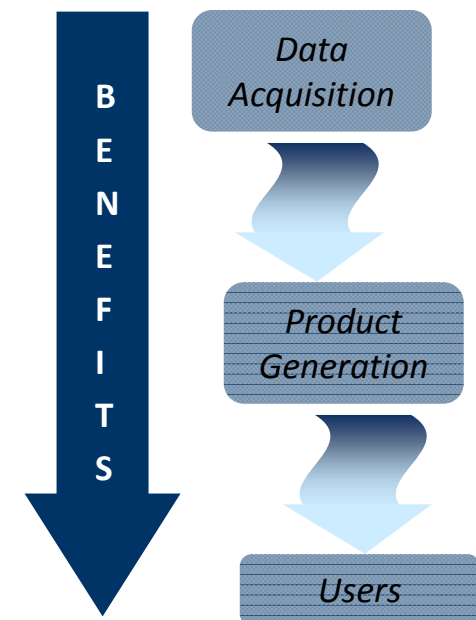 - **Greater** coverage
- Improvements at the source
 - Benefits carry over downstream
- Enabled by technology
  - Feasible real-time implementation

BENEFITS

Data Acquisition

Product Generation

Users

Research to Operations
Signal Processing Advancements on the NEXRAD Network

- Legacy system did not allow for signal processing upgrades (mid-1980s technology)

- NEXRAD Product Improvement (NPI) program established in the late 1990s to meet evolutionary tri-agency needs

  - Open Radar Data Acquisition (ORDA) (2005)

    - **Phase Coding**: volume coverage patterns, Doppler dilemma (2007)
    - **Super Resolution**: tornado detection (2008)
    - **Clutter Mitigation Decision**: automatic clutter management (2009)
    - **Dual Polarization**: rainfall estimates and data quality (2011)
    - **Staggered PRT**: volume coverage patterns, Doppler dilemma (2012?)
    - **Range oversampling**: faster updates and data quality (2013?)
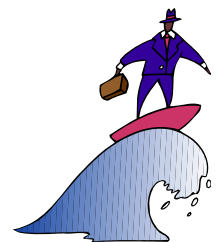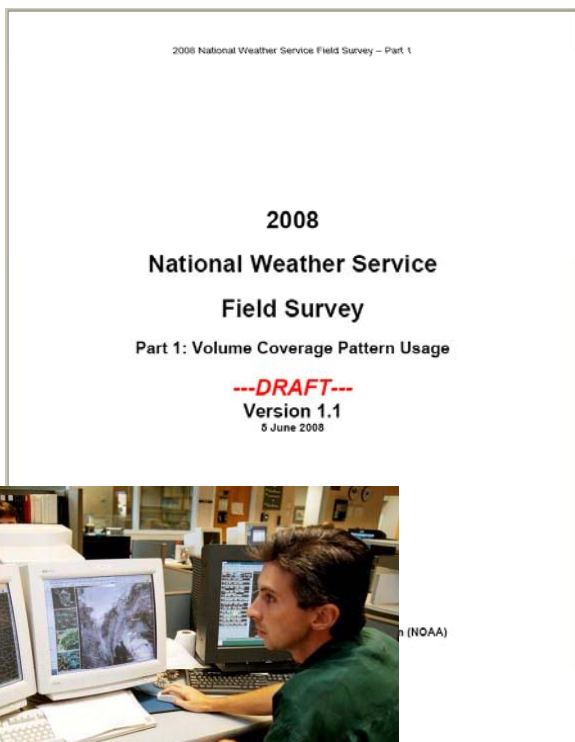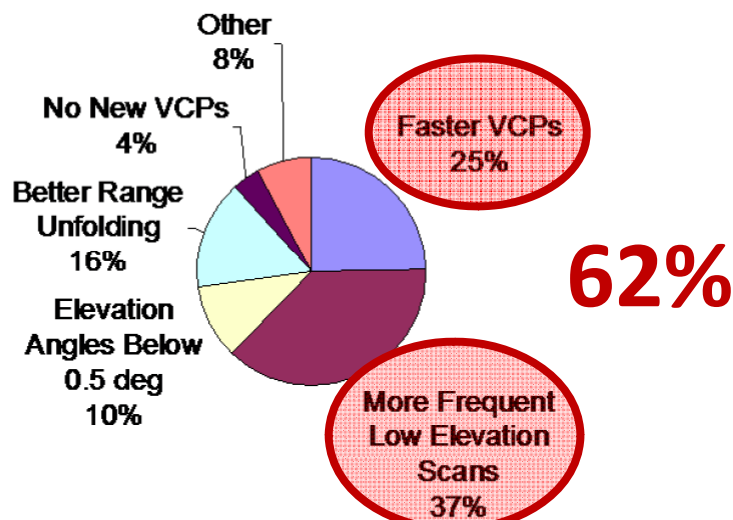
Faster update times are needed to provide forecasters a greater opportunity to see **first signs** of potentially severe weather from **quickly evolving phenomena**

2008 National Weather Service Field Survey – Part 1

2008

National Weather Service

Field Survey

Part 1: Volume Coverage Pattern Usage

---DRAFT---
Version 1.1
5 June 2008

(NOAA)

Which type of scanning strategy improvement do you consider most important?

Other 8%

No New VCPs 4%

Better Range Unfolding 16%

Elevation Angles Below 0.5 deg 10%

Faster VCPs 25%

More Frequent Low Elevation Scans 37%

62%

Courtesy of Radar Operations Center

- **Reduce coverage**
  - Limit radar volume coverage
    - e.g., remove upper tilts
  - Use coarser vertical sampling
    - e.g., double the spacing between tilts
- **Rotate antenna faster**
  - Degrade azimuthal resolution
    - e.g., 2-deg radials
  - Reduce number of pulses per radial
    - Variance of estimates increases
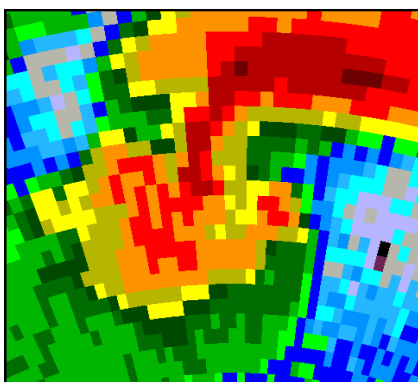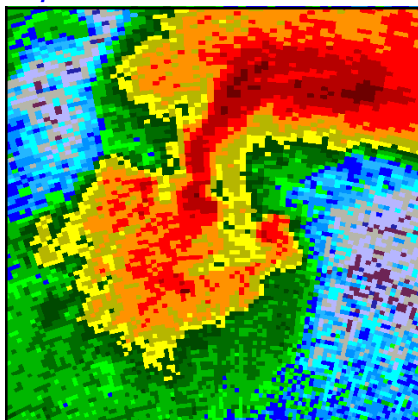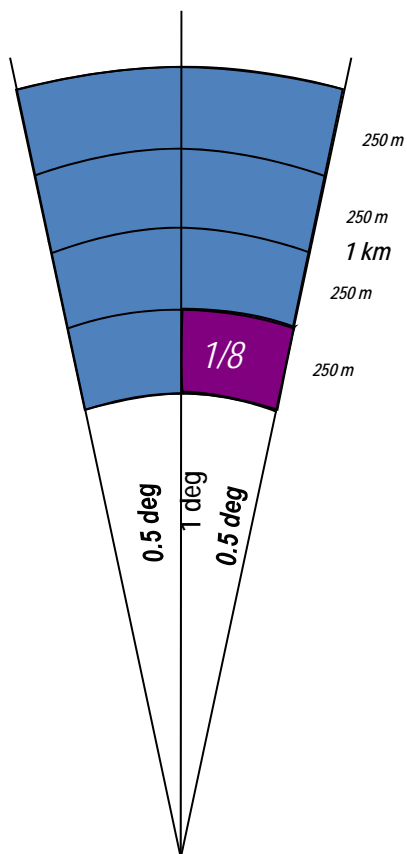 - Reduce time between pulses (PRT)
    - Loss of coverage in range

Volume Coverage Pattern
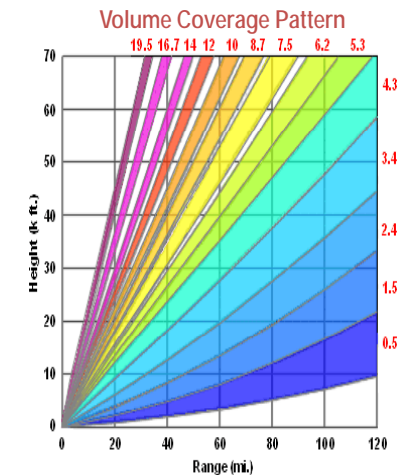
Better Accuracy
Motivation

Super-Resolution

Legacy Resolution

Super-Resolution

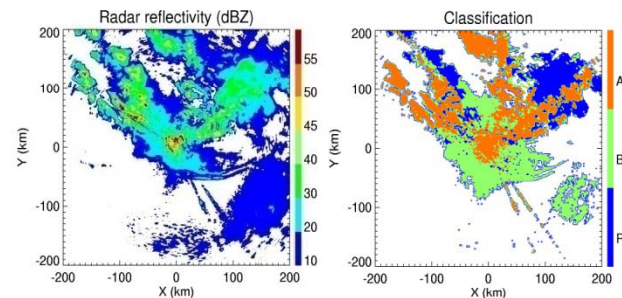Tornado outbreak in Oklahoma City, 9 May 2003
from Curtis et al. (2003)

250 m

250 m

1 km

250 m

1/8

250 m

0.5 deg **1 deg** **0.5 deg**

Dual Polarization

Rainfall Estimation

Rainfall Amount (inches)
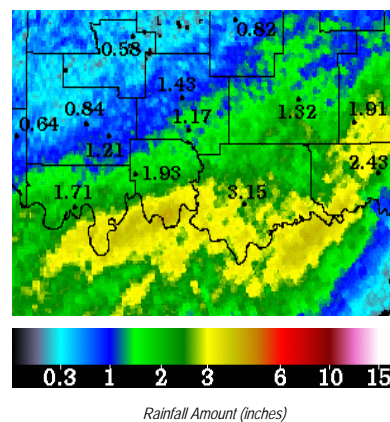
Hydrometeor Classification

Joint Polarization Experiment (JPOLE), 2003

Better Accuracy
How can it be done?

- **Reduce spatial resolution**
  - Average in range
    - e.g., average every four 250-m estimates and get a more accurate field with a 1-km range resolution
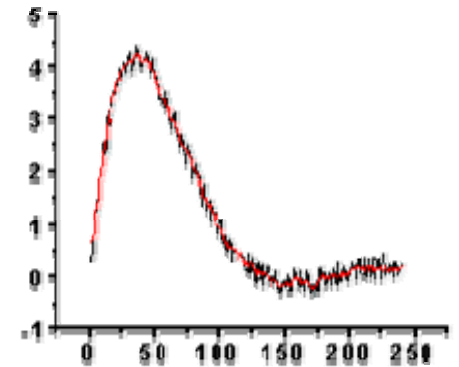 - Average in azimuth
    - e.g., super-resolution data recombination for the algorithms

- **Increase number of samples**
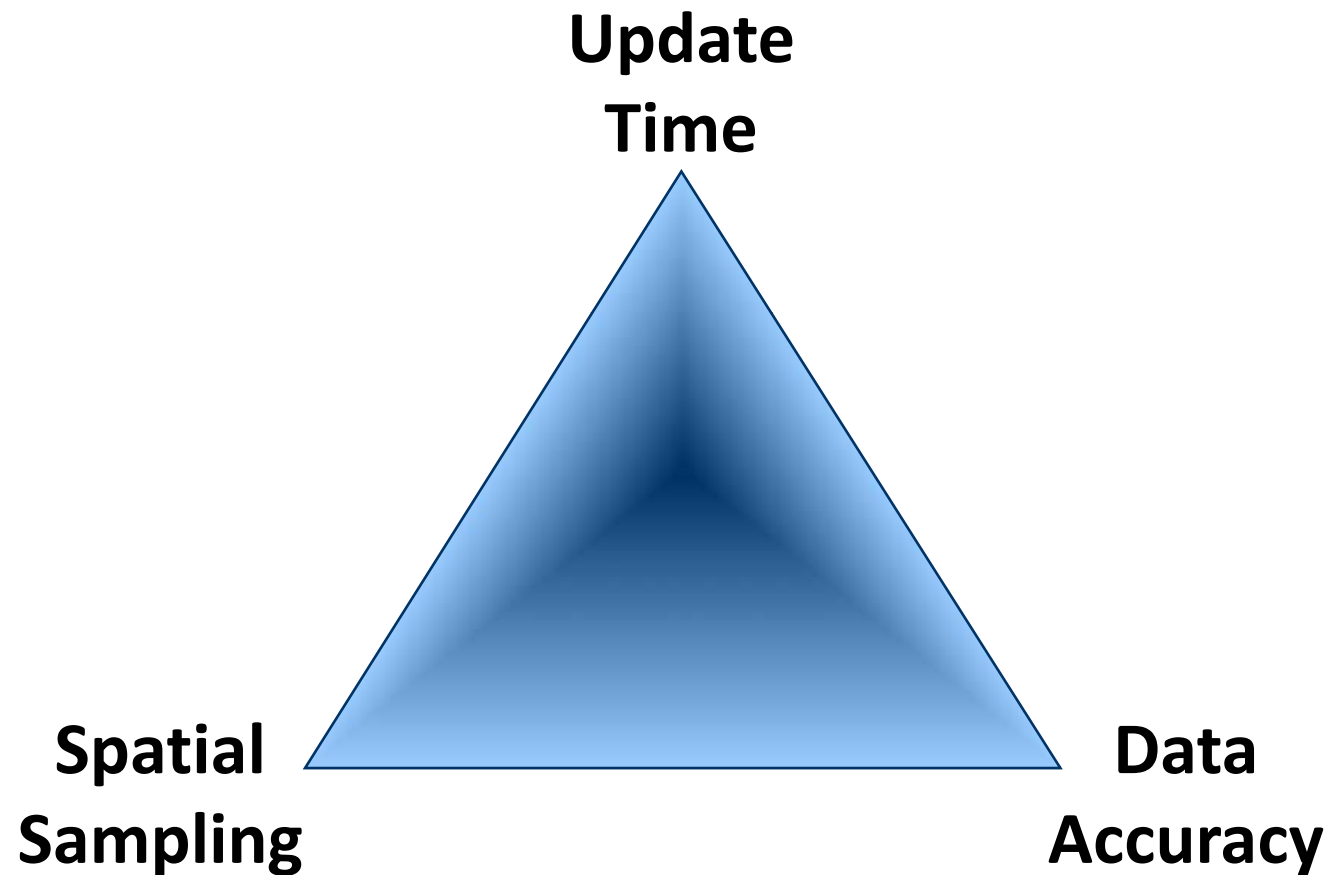 - Reduce antenna rotation rate
    - Increased update time
  - Degrade azimuthal resolution
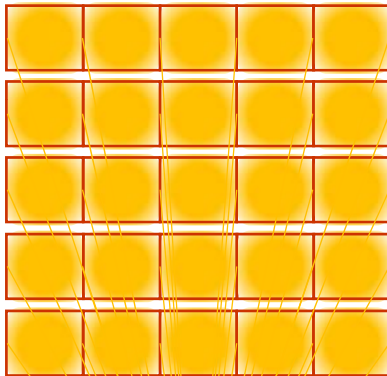
Fundamental Trade-Offs

Update Time

Spatial Sampling

Data Accuracy

If you want faster updates, you can't have <u>both</u> better spatial coverage and better accuracy

Fundamental Trade-Offs
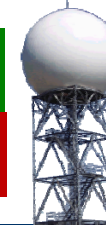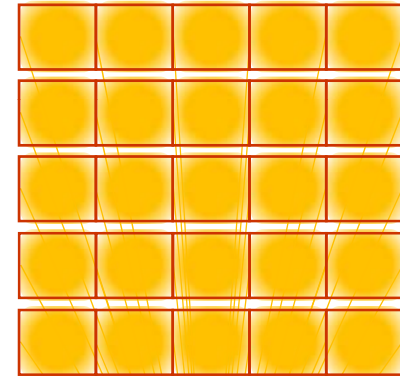
There's no such thing as a free lunch

Full Scan	Partial Scan	Full Scan Short Obs. Time
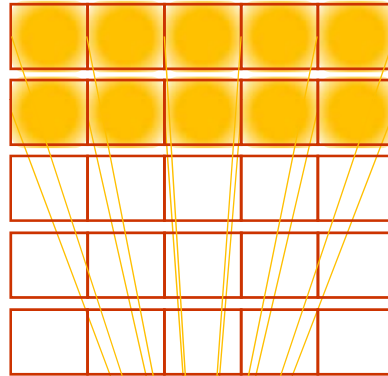
Faster updates
Less coverage

Faster updates
Less accuracy

- ## Range oversampling (RO) adds more information (samples) without increasing the observation time
  - ### RO leads to overlapping radar volumes (gates)

$c\tau/2L$

range

range

$c\tau/2$

$c\tau/2$

Traditional Sampling
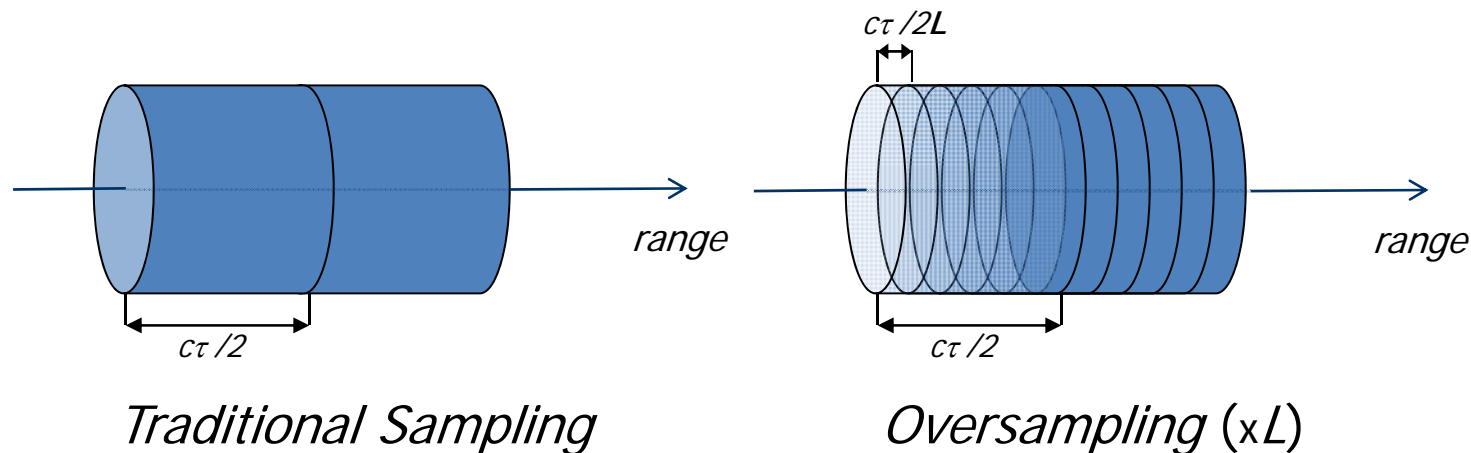
Oversampling ($\times L$)

  - ### RO data are correlated and correlation **is known**
    - #### Set of *L* oversampled data can be **decorrelated/whitened**

Range Oversampling
Benefits and Limitations

- **RO benefits**
  - More samples ($_xL$)
    - without increasing data collection time
    - with minimal reduction in range resolution
  - Can run with current radar transmitter/receiver

- **RO limitations**
  - More computations are needed ($_xL$)
    - May require upgrade to digital signal processor
  - Data decorrelation process adds "noise"
    - Not usable at low signal-to-noise ratios
    - Adaptive scheme controls decorrelation vs. noise enhancement

Range Oversampling
How can it be exploited?

- Range oversampling provides *L*-times more samples
  - For **maximum data accuracy**:
    - Maintain number of pulses
      - Variance of estimates is reduced by a factor of *L*
      - Update time does not change
  - For **minimum update time**:
    - Reduce number of pulses by a factor of *L*
      - Update time is reduced by a factor of *L*
      - Variance of estimates does not change
  - For **better data accuracy** <u>and</u> **shorter update time**:
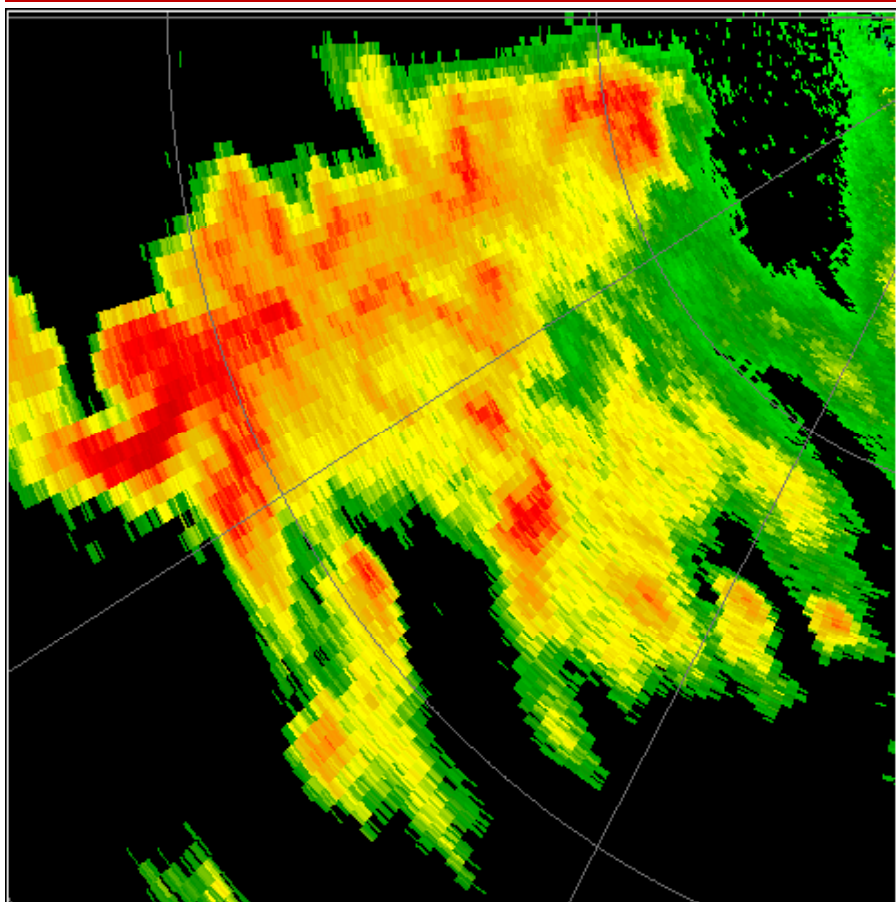   - Reduce number of pulses by a factor 2 $(1 \leq L' \leq 5)$
      - Update time is reduced by a factor of 2
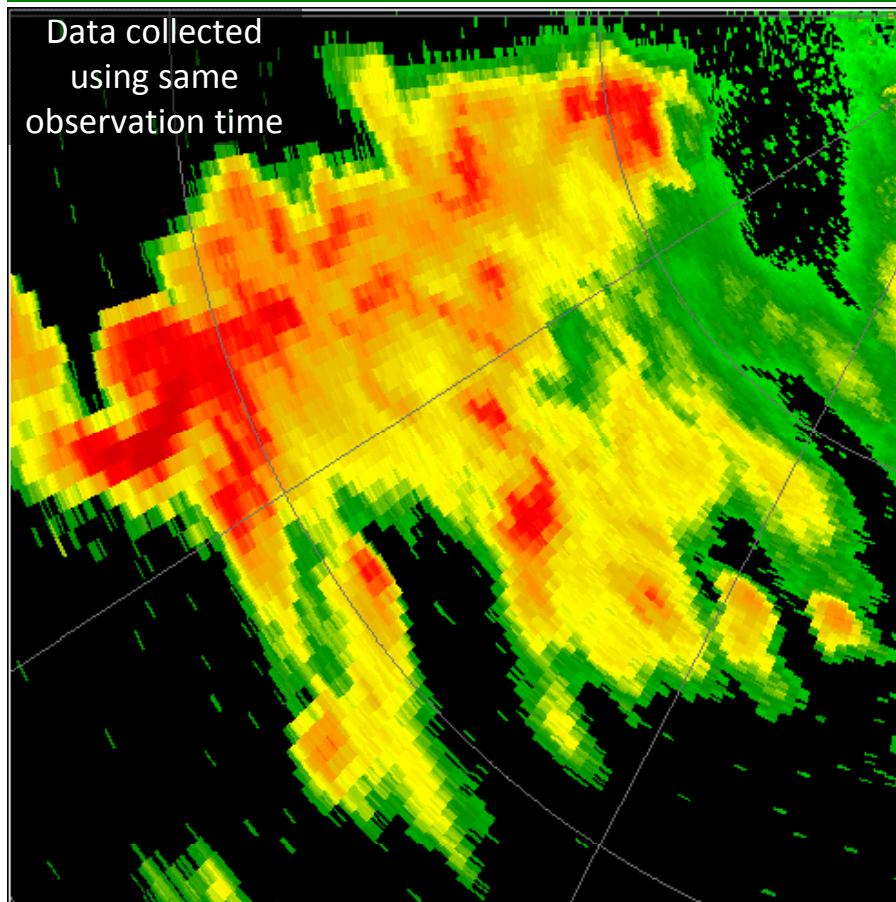   - Variance of estimates is reduced by a factor of 2.5

Range Oversampling
Performance Demonstration

Standard Processing	Range Oversampling Processing

Data collected using same observation time

A smoother field with no loss of detail is an indication of more accurate data

Accomplishments

- **Theoretical** developments
  - Developed fundamental technique: oversampling and whitening
  - Improved performance: oversampling and adaptive pseudo-whitening
- **Simulation** analyses
  - Quantified improvements and validated theory
  - Presented to the NWS Radar Operations Center (ROC)
- **Real-data** analyses with **off-line** processing
  - Data collection experiments
    - Research WSR-88D radar (KOUN)
    - National Weather Radar Testbed Phased-Array Radar (NWRT PAR)
  - Validated theoretical and simulation results
  - Presented to the NEXRAD Technical Advisory Committee (TAC)
- **Real-time** implementation on the NWRT PAR
  - Inserted into existing signal processing pipeline
  - Exploited for faster updates and improved data quality

Standard

Range Oversampling

Range Oversampling
50% observation time
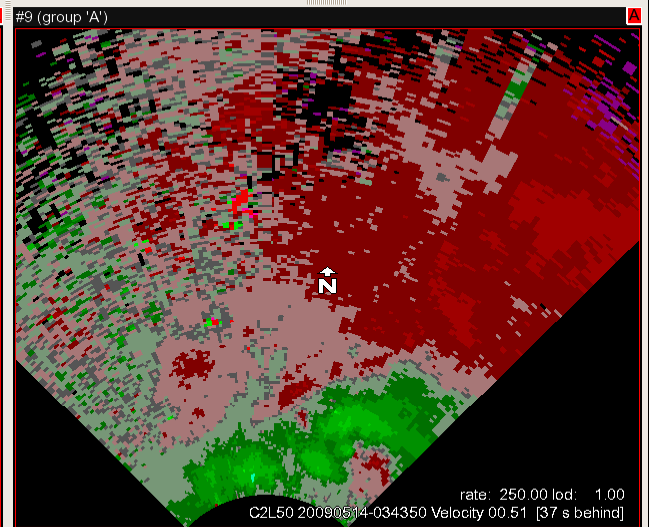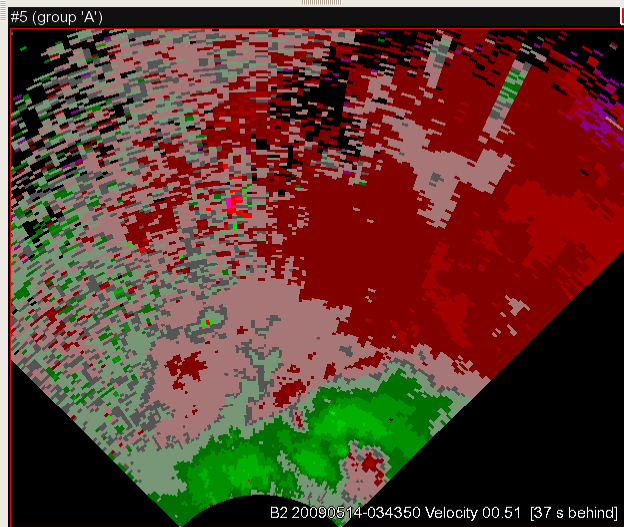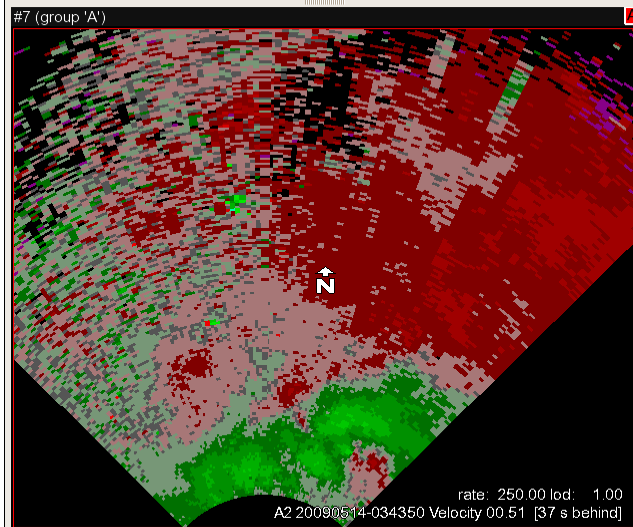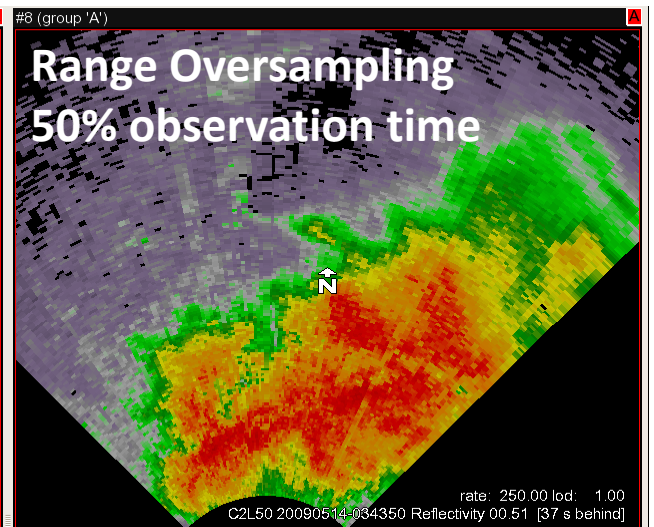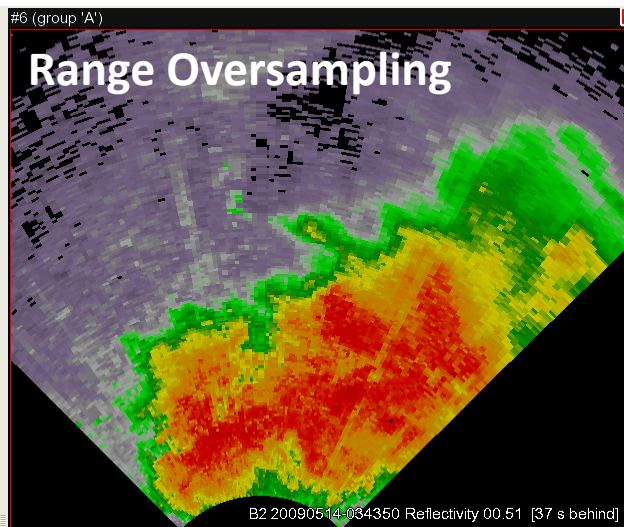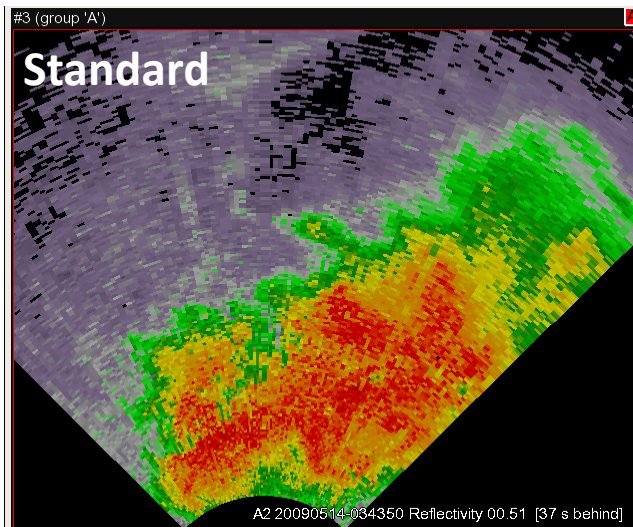
Future Activities

- Continue to work on **integration** with **existing** and **evolutionary** techniques
  - Phase coding
  - Dual polarization
- Analyze **data cases** collected with the NWRT PAR
  - Quantify actual performance improvements
  - Identify data quality/integration issues
- Present again to **NEXRAD TAC**
  - Digital signal processor upgrade required for operational implementation on the NEXRAD network
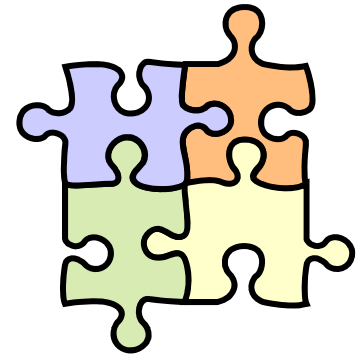
And the Bottom Line is...

- Weather Radar **Range Oversampling** can lead to
  - **Faster updates**
    - Improved observation/tracking of phenomena
    - Timely warnings
  - **More accurate measurements**
    - Precipitation
    - Wind fields

Questions?

Tornado in Central Oklahoma, USA

How much lead time would YOU need?

Want to know more?

- **For more information**
  - Email me:
    - Sebastian.Torres@noaa.gov
  - Find me on the web:
    - http://cimms.ou.edu/~torres/range_oversampling.html