Wind Mapping with Doppler Lidar Using a New Approach for Increased Measurement Range

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AMS Annual Meeting

29 January 2024

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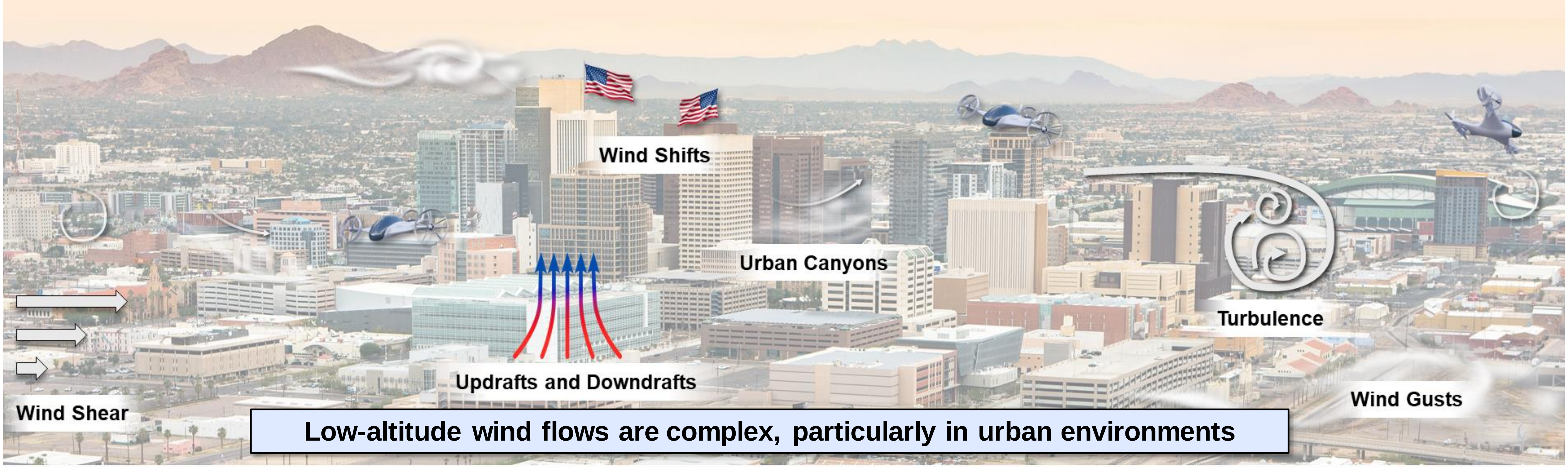
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

This material is based upon work supported by the Department of the Air Force under Air Force Contract No. FA8702-15-D-0001. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Department of the Air Force.

Motivation

- Winds are expected to be highly impactful to emerging AAM operations
  - Low airspeeds
  - Limited battery reserves
  - Operations at low altitudes where winds are turbulent and highly variable



Low-altitude wind flows are complex, particularly in urban environments

AAM = Advanced Air Mobility

Wind Sensing Technology Overview

Sensor	Approximate Cost Per Sensor	Horizontal Coverage	Vertical Coverage	Sensor Shortfalls
Anemometers (ASOS)	$10K	1000 across U.S. (1 per 3000 sq mi)	Surface only	Surface (10 m) only
Weather Balloons	$1K	92 sites across U.S. (1 per 56,000 sq mi)	Ground to 100 kft	Manpower intensive
Aircraft Observations	N/A	Varies, along flight tracks	Ground to 50 kft	Poor low-altitude coverage
Satellite	$1B	Most of globe	Typically > 10 kft	Inferred from cloud motion
Weather Radar (NEXRAD)	$25M	250 nmi per radar, 159 radars across U.S .	Ground to 50 kft	Poor coverage outside precipitation
Doppler Lidar	$300K	3 nmi per lidar, only a few operational at airports	Ground to 10 kft	Currently limited range

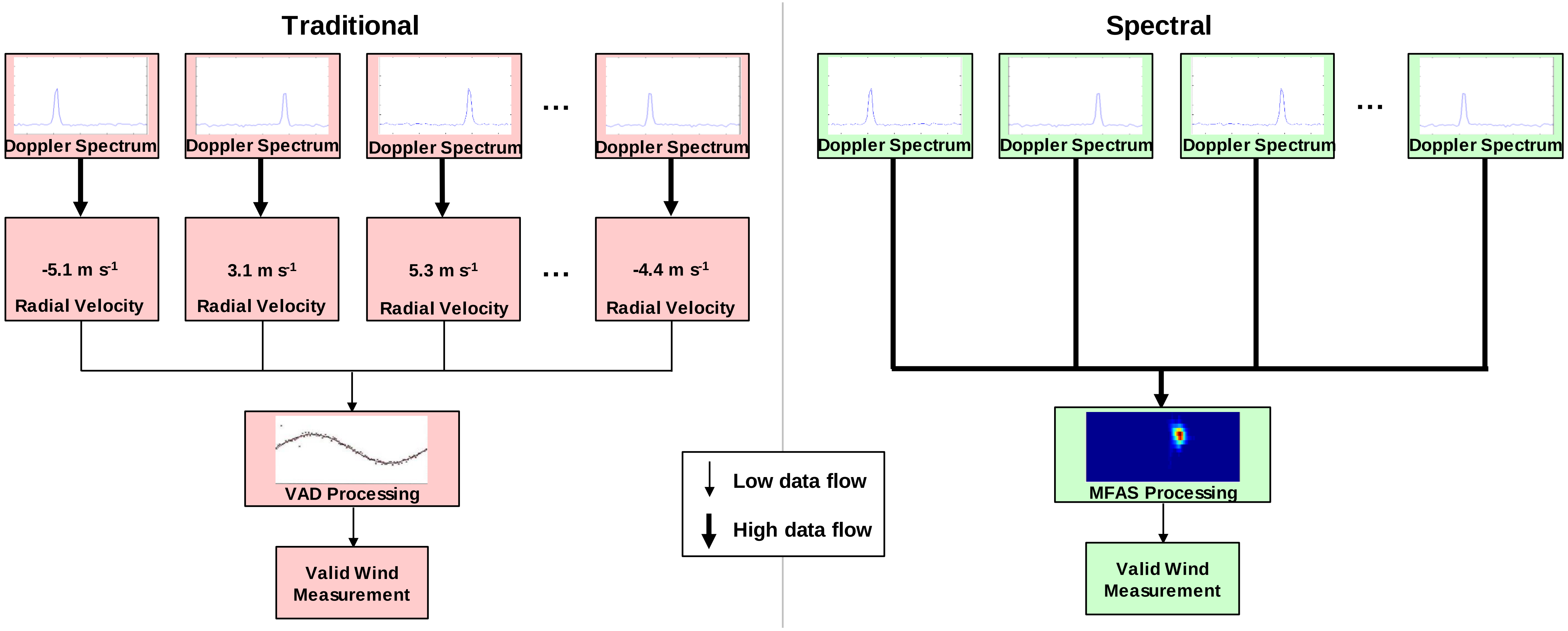
Low-altitude winds impactful to AAM are poorly sampled, but lidars could be leveraged to fill gap if range improves

ASOS = Automated Surface Observing System
NEXRAD = Next-Generation Radar

Outline

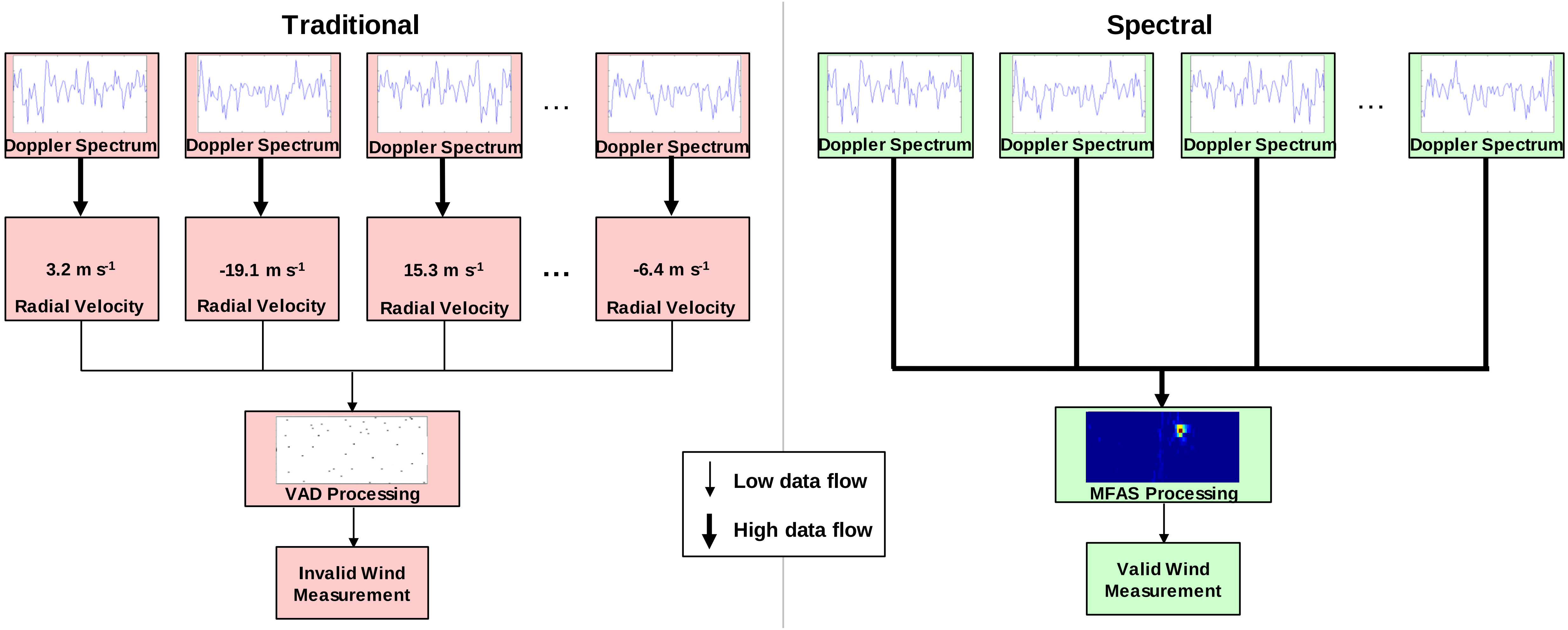
- **Motivation and Introduction**
- **New Dual-Doppler Approach**
- **Wind Mapping Example**
- **Verification**
- **Summary and Future Work**

Traditional vs Spectral Wind Measurement (High SNR)



SNR = Signal-to-Noise Ratio
VAD = Velocity-Azimuth Display
MFAS = Maximum Function of Accumulated Spectra

Traditional vs Spectral Wind Measurement (Low SNR)



Noise characteristics are retained in spectral approach, enabling wind measurement at lower SNR and longer range

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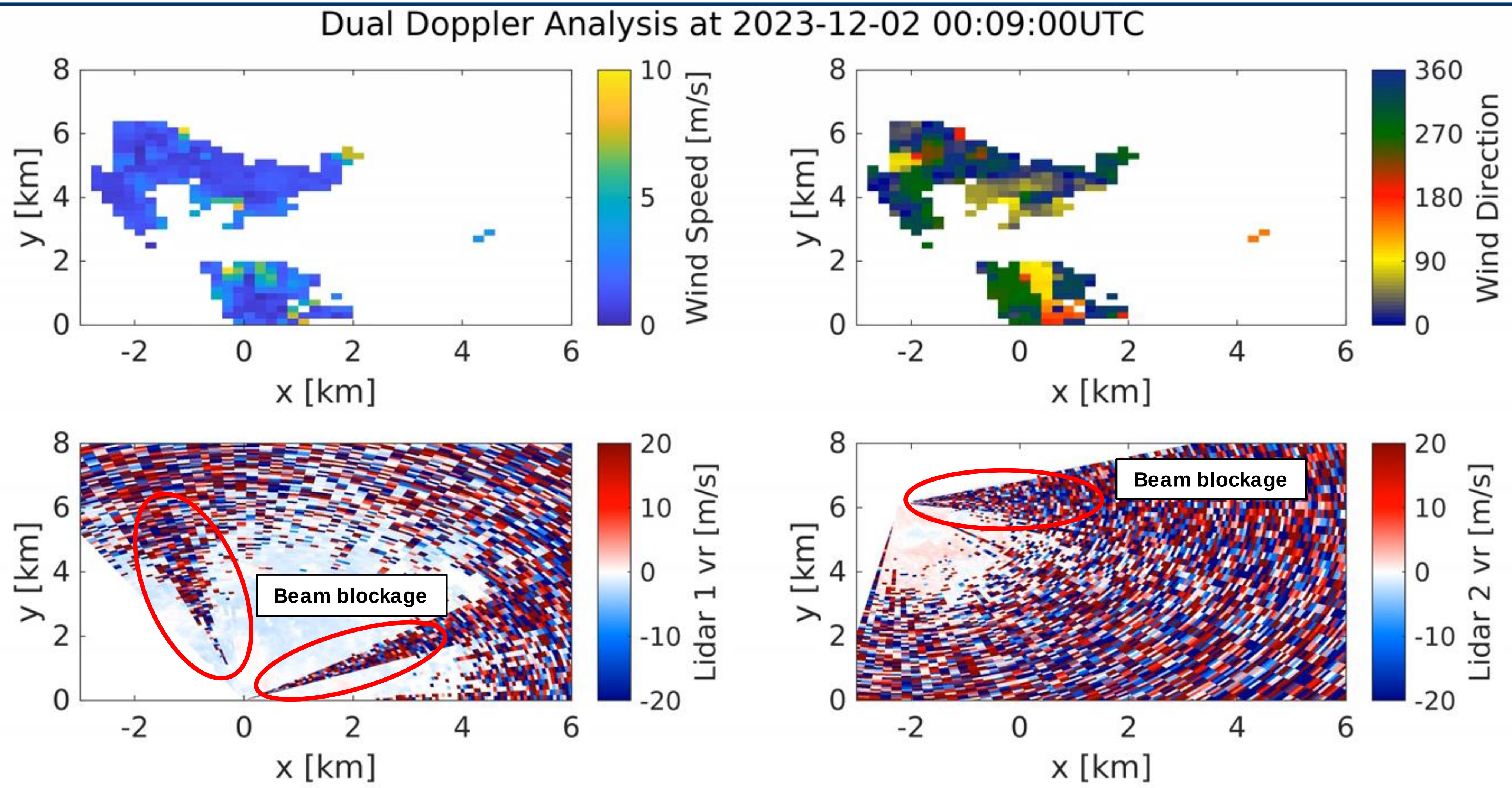
Dual-Doppler Experiment in Norman

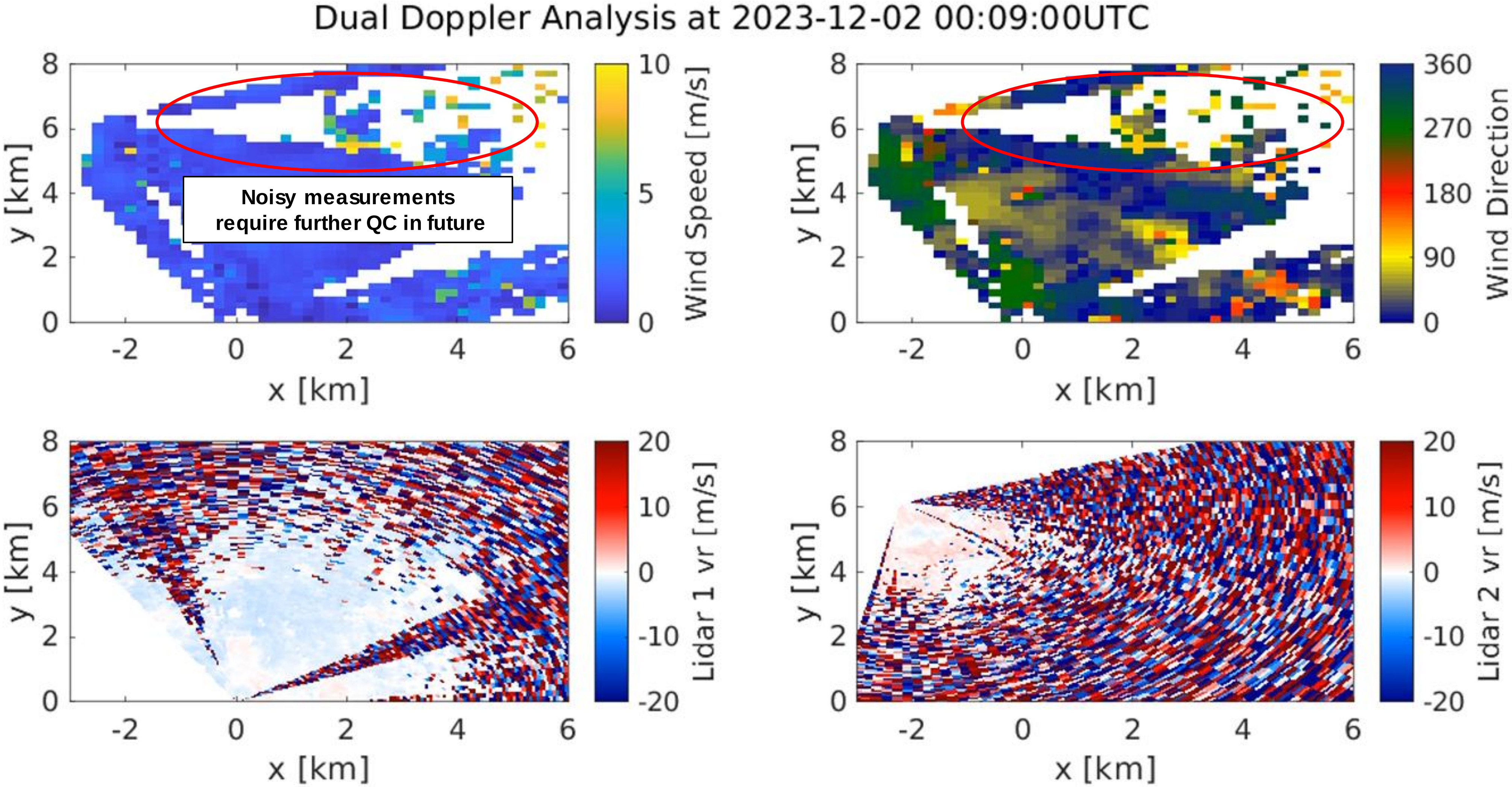
- Custom data collection needed as no existing dataset suitable for testing algorithm
  - Most Doppler lidar users save moment data, but not the spectra or autocovariance
- Coordinated with NSSL on a data collection in Norman, Oklahoma
  - Deployed two Halo Streamline lidars 6.6 km apart
    - One on top of the National Weather Center
    - One on north side near Max Westheimer Airport
  - Northern lidar has low sensitivity and reduced range
- Data collection of approximately 1 ½ months (30 Nov 2023 – mid-January 2024)
  - Sector scans between two lidars
    - Beam blockage from buildings limited useable azimuthal range
  - Three weeks each of:
    - Continual low-elevation scans
    - Stacked sector scans for 3-D volumes

NSSL = National Severe Storms Laboratory
NWC = National Weather Center

Preliminary Traditional Dual-Doppler Results



Preliminary Spectral Dual-Doppler Results



Spectral dual-Doppler wind mapping has increased coverage compared to traditional approrach.

QC = Quality Control

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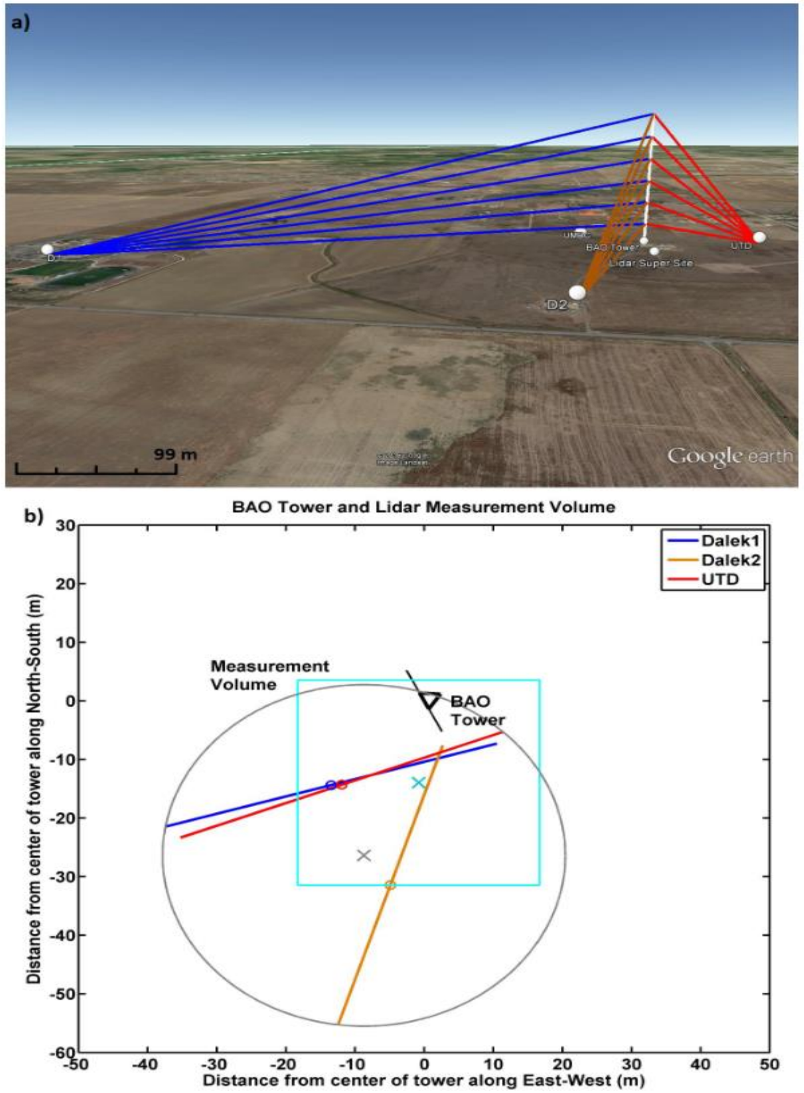
Verification

- **Used available archived data from the XPIA field campaign funded by the Department of Energy in 2015**
  - **Conducted near a 300-m tower with sonic anemometers at six heights**
  - **Objective of this XPIA was to quantify the accuracy of different wind and turbulence measurements**

- **Multiple lidars pointed just to the south of the tower**
  - **Two Vaisala WindCube 200S systems (named Dalek 1/2) archived the required raw spectral data**
    - **One system (UTD) only saved moment data**

- **Verification objective:**
  - **Evaluate if new technique is as accurate as traditional dual-Doppler approach**



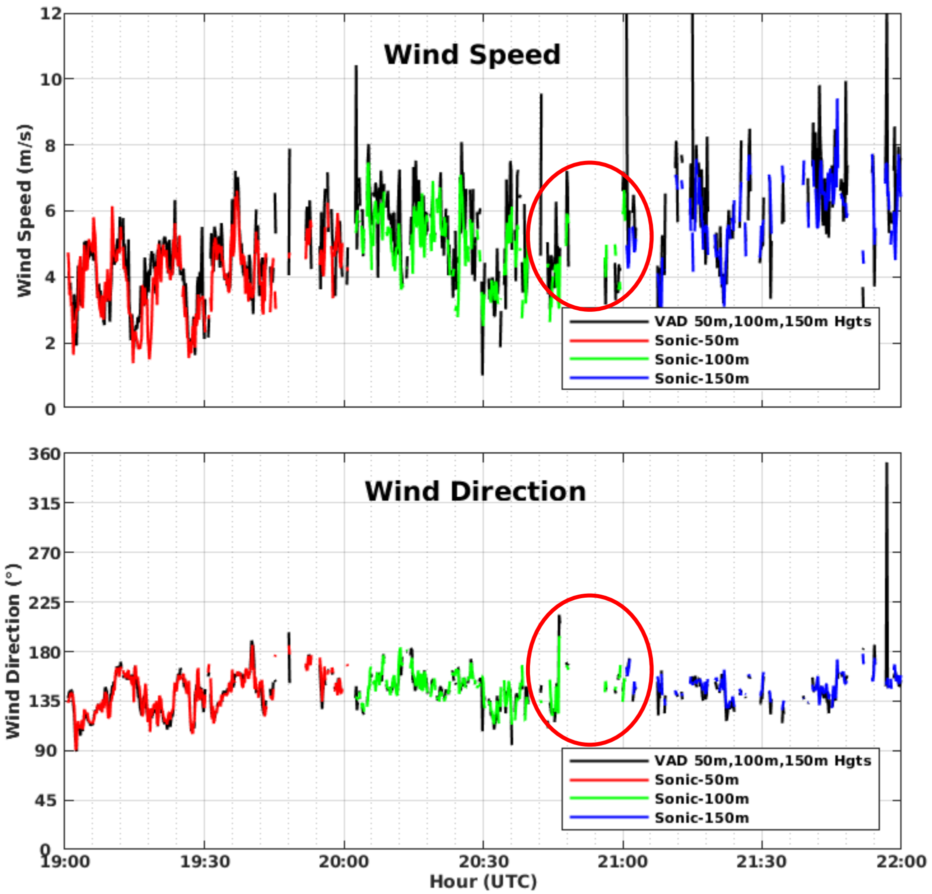
(from Choukulkar et al 2017)

XPIA = eXperimental Measurement Campaign (XMC) for Planetary Boundary Layer (PBL) Instrument Assessment
BAO = Boulder Atmospheric Observatory
UTD = University of Texas at Dallas

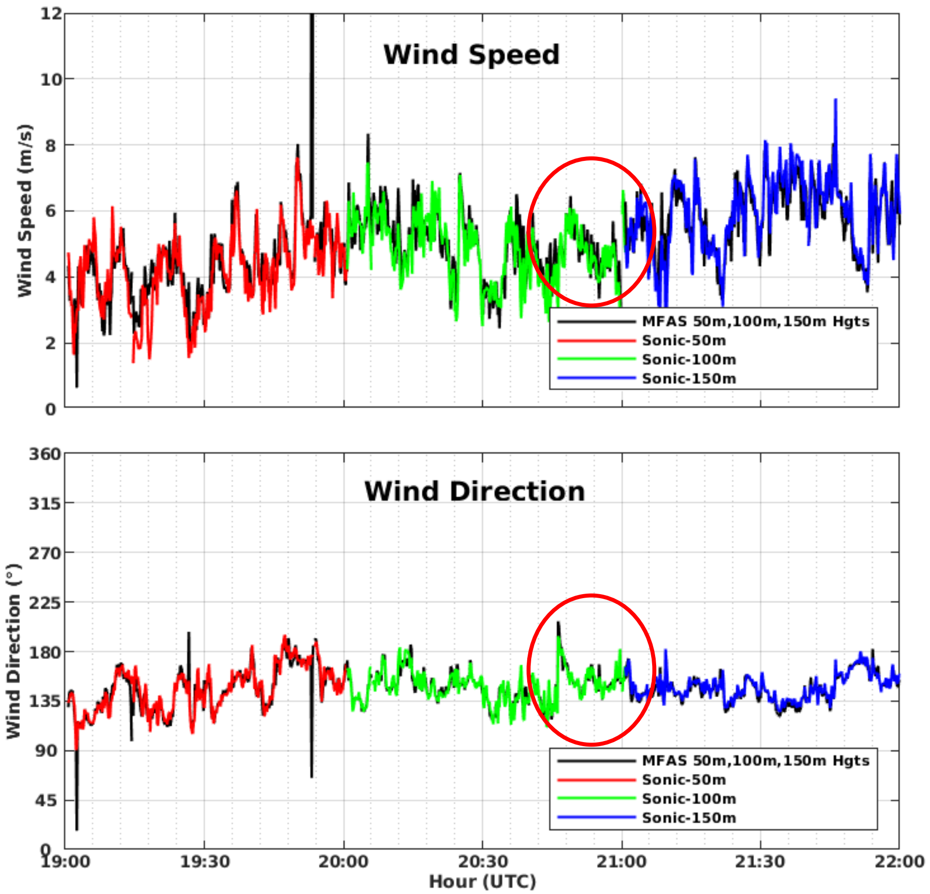
Choukulkar, A., et al., 2017. Evaluation of single and multiple Doppler lidar techniques to measure complex flow during the XPIA field campaign. *Atmospheric Measurement Techniques*, **10**, 247-264.

Sample Time Series Verification

Traditional Dual-Doppler vs Sonic Anemometer



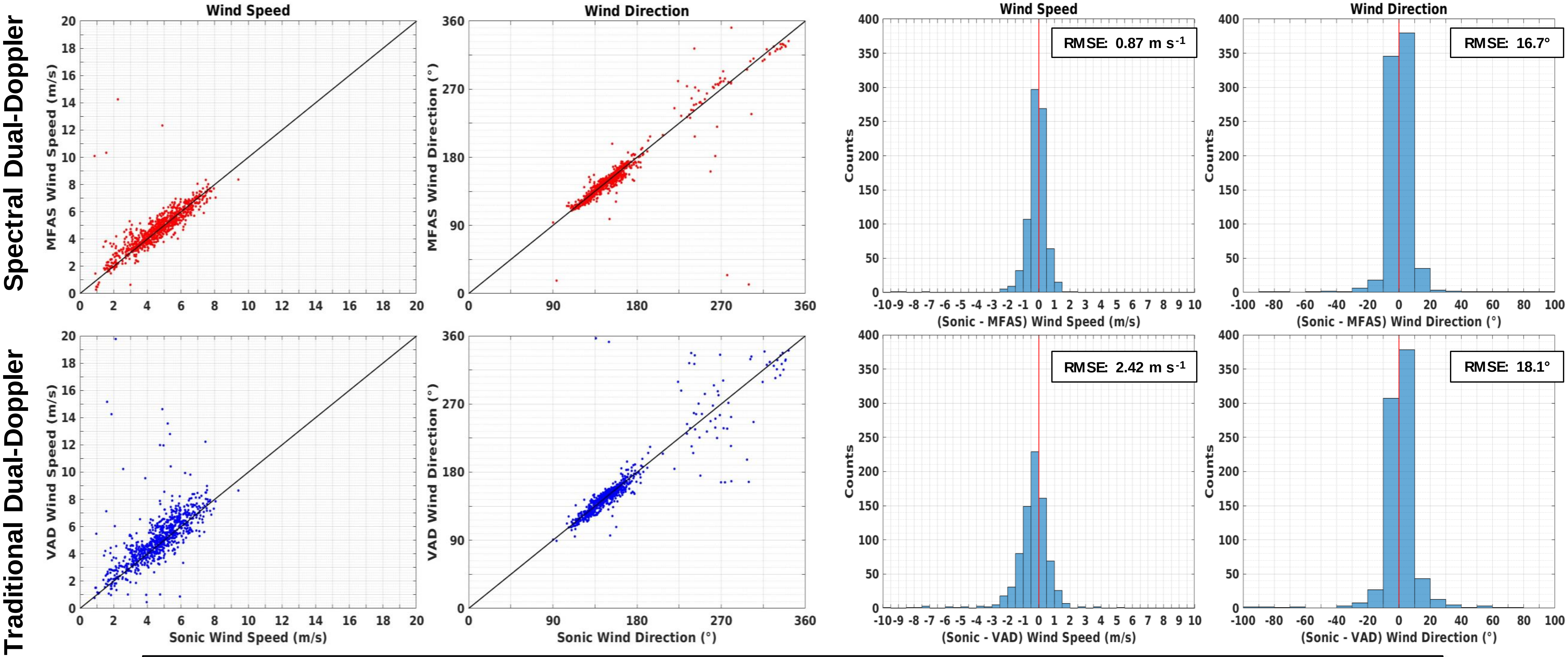
New Spectral Approach vs Sonic Anemometer



New technique able to take measurements at lower SNR where traditional approach fails.

For visualization, anemometer data were removed when no wind measurement was possible.
Additional quality control procedures are not applied to MFAS results.

Quantitative Verification



Spectral dual-Doppler method is more accurate than traditional approach using radial velocities.

Summary and Future Work

- MIT Lincoln Laboratory has developed a new approach to map the winds from Doppler lidar measurements
  - Expected to be applicable to weather radar as well
  - Initial results show improvement in wind measurement range at low SNRs
  - Preliminary verification shows accuracy is better than traditional methods

- Ongoing and future enhancement of algorithm
  - Further develop quality control procedures
  - Establish and verify methods to measure unresolved turbulence
  - Add capability to process and create 3-D wind fields
  - Enable adaptable/flexible grid spacing
    - Currently use customizable fixed grid (nominally 200 m resolution)
    - Adaptable grid spacing will allow high-resolution near the lidar and lower resolution at far ranges
  - Optimization for efficiency