# Tropical Cyclone Rainbands Over Land in South Florida: Multi-Wavelength Radar Observations and their Educational Applications

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# Main Objectives

- Rainband Observations
  - Study the dynamics of outer stratiform rainbands over land
- Educational Applications
  - Test two lab approaches for using field data in an undergraduate classroom

# Outline

- Rainband Research
  - Motivation/Background
  - Experiment/Methods
  - Results
    - Stratiform Profiles
      - Mean Wind Components
      - Time Series Case
      - Low-Level Wind
    - Variability Cases
  - Summary
- Science Education Research

# Motivation and Background

# Motivation

- Study dynamics of stratiform rainbands over land using a variety of in-situ instruments and radars of different wavelengths

- Focus on:
  - Vertical structure of wind components
    - Location of jets and inflection points
    - Changes during band passage
    - Surface layer
  - Mesoscale/Microscale wind variability

# Motivation

- Why do we care about the wind structure over land?
  - Describe conditions in an urban coastal environment as rainband passes over

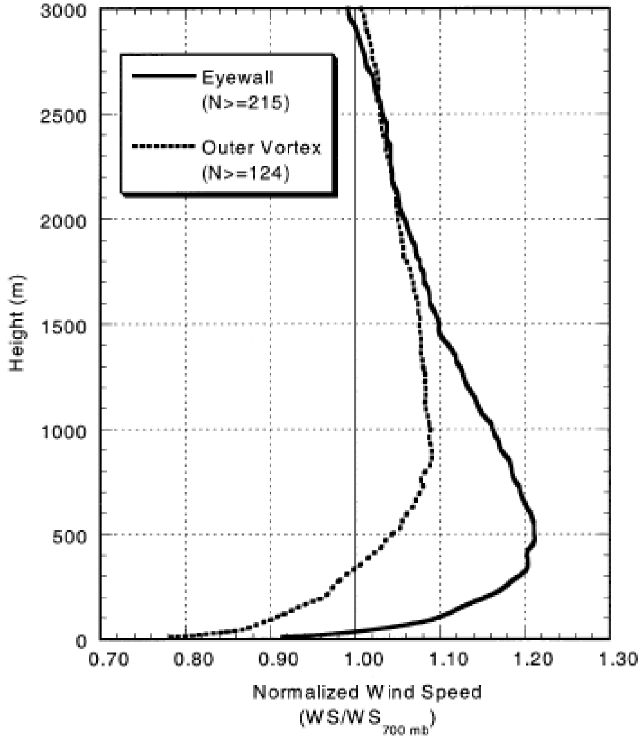
  - Surface layer
    - Impact of wind speeds on tall buildings
    - “Universal” logarithmic slope?
    - Roll structures
      - *Wurman and Winslow 1998; Morrison et al. 2005; Lorsolo et al. 2008;*
    - Tornado genesis
      - *Novlan and Gray 1974; Gentry 1983; Baker et al. 2009*

# Previous Rainband Observations

- Flights over water
  - *Barnes et al. 1983; Jorgensen 1984; Marks 1985; Barnes and Stossmeister 1986; Powell 1990; Hence and Houze 2008*
- Over land with Wind Profiler
  - *May et al. 1994; May 1996; Sato 1991*
- Over land with NEXRAD
  - *Stewart and Lyons 1996; Spratt et al. 1997; Blackwell 2000; Skwira et al. 2005;*

# Observations of Wind Profiles

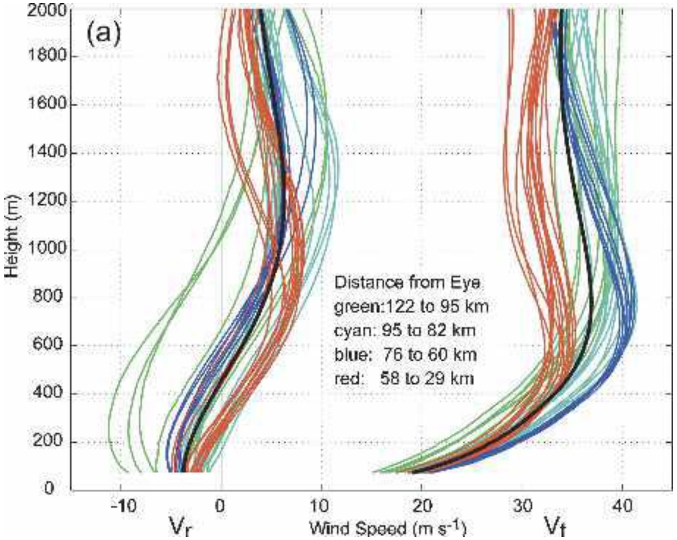
- Previous studies that show wind profiles are done from dropsondes released at 700mb
  (*i.e. Franklin et al. 2003; Schwendike and Kepert 2008; Zhang et al. 2011*)

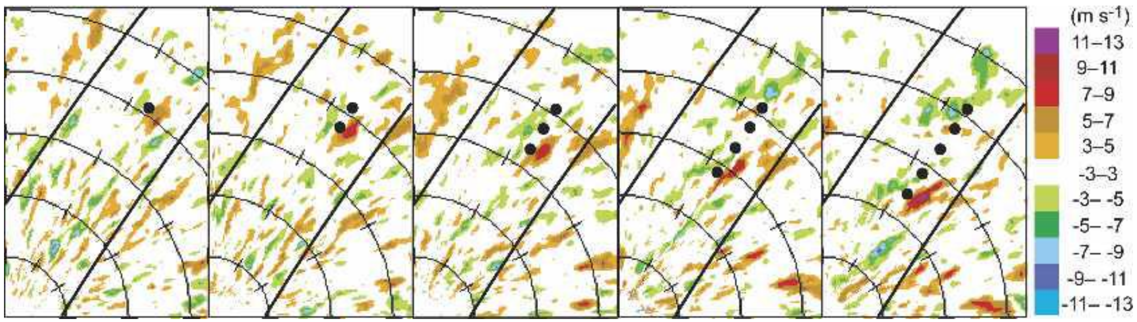



Franklin et al. 2003

# Observations Using VAD Technique

- Using NEXRAD
  - *Marks et al. 1999; Morrison et al. 2005*



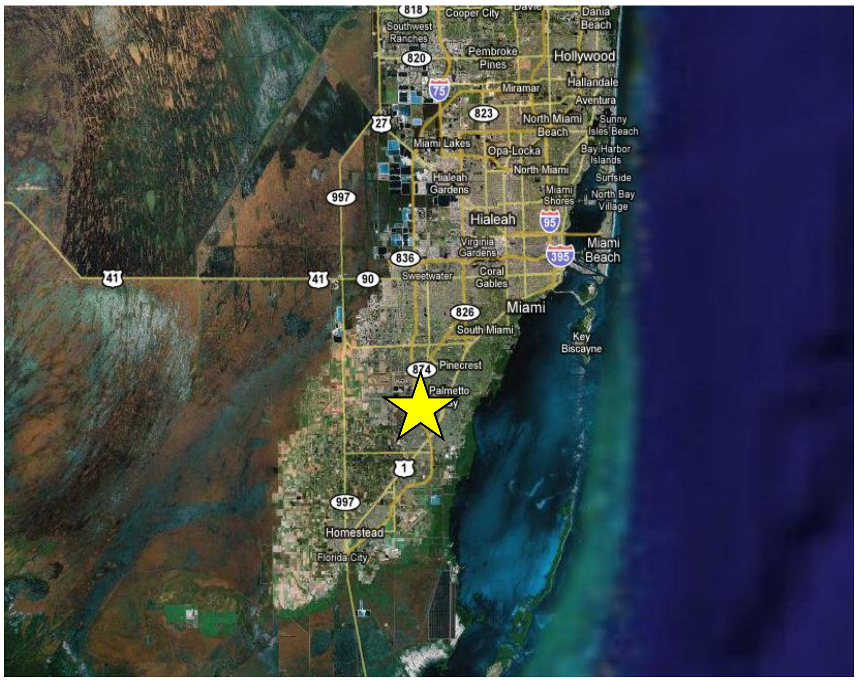




Morrison et al. 2005

# Experiment and Instrumentation

# Experiment Description

- UM South Campus/CSTARS
- Aug-Sept 2008




Images from maps.google.com

★ CSTARS

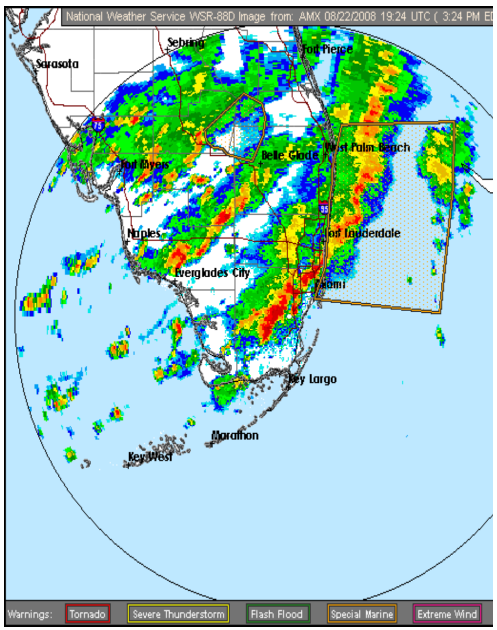

# Rainband Data Set

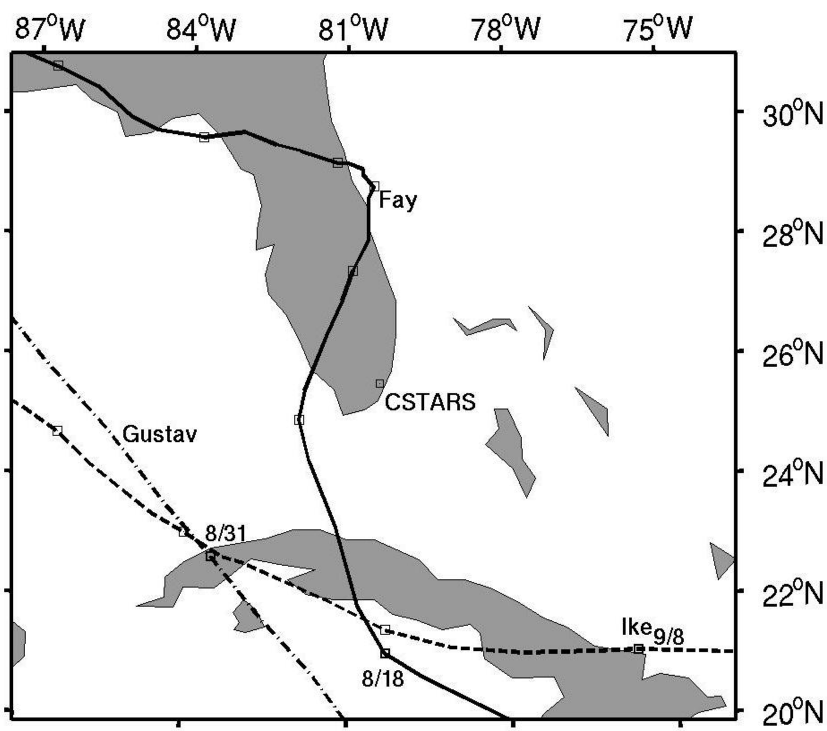
Fay 8/17-8/22
20 bands

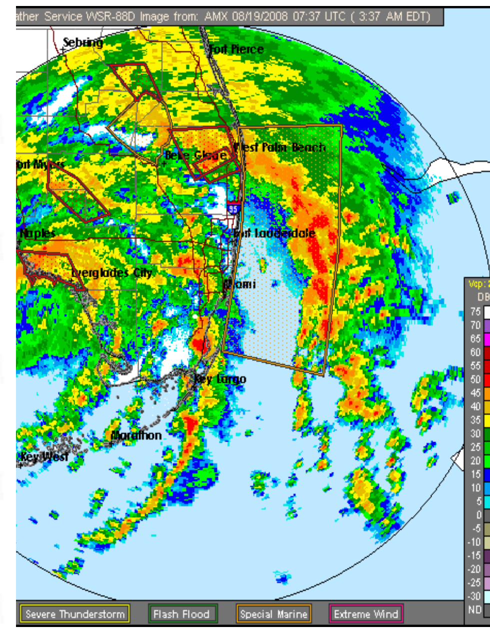
Gustav 8/30-8/31
2 bands

Hanna 9/5
0 bands

Ike 9/9-9/10
2 bands





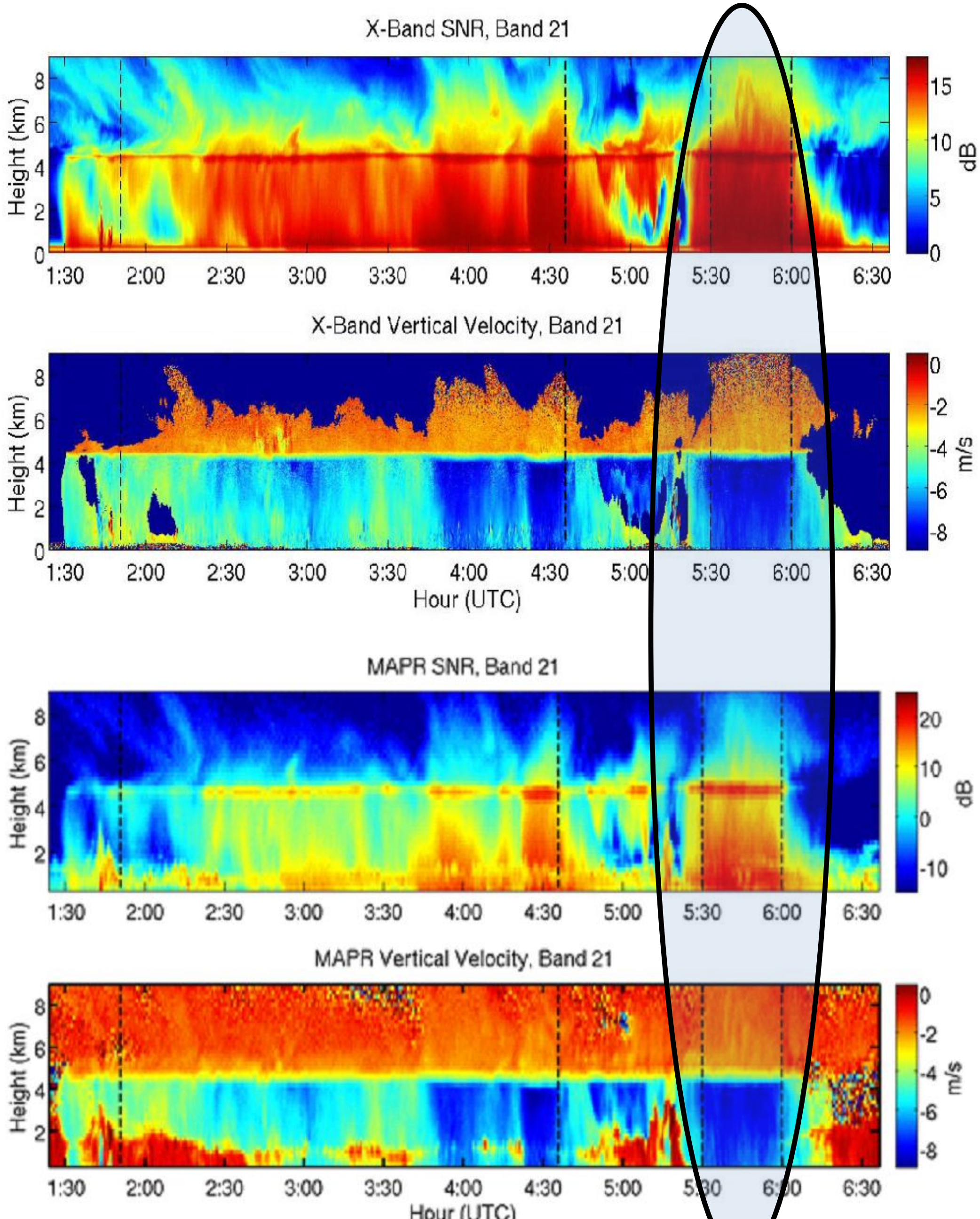



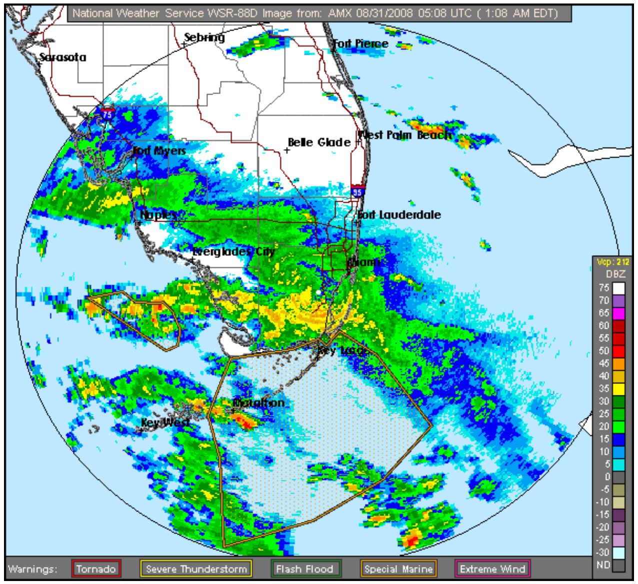
# Stratiform Rainbands

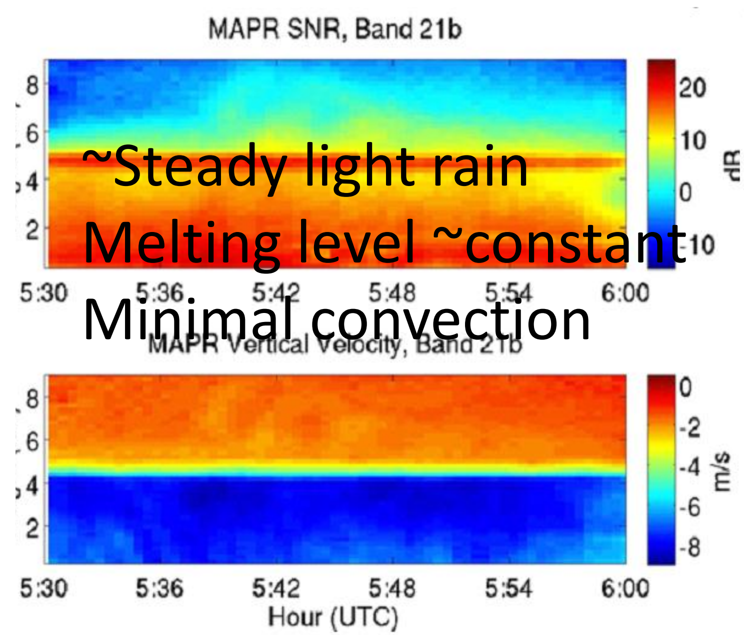
| Storm | Date | Band # |
|---|---|---|
| Fay | 8/17/2008 | 1 2 3 |
| Fay | 8/18/2008 | 4 5 6 7 |
| Fay | 8/19/2008 | 8 9 10 11 12 13 14 |
| Fay | 8/20/2008 | 15 16 17 |
| Fay | 8/21/2008 | 18 19 |
| Fay | 8/22/2008 | 20 |
| Gustav | 8/31/2008 | 21 22 |
| Ike | 9/9/2008 | 23 24 |
| | | |

| Case # | Start Time (UTC) | End Time (UTC) | Length (min) |
|---|---|---|---|
| 4a | 16:40 | 17:40 | 60 |
| 5a | 19:54 | 20:00 | 6 |
| 9a | 2:06 | 3:36 | 90 |
| 9b | 3:53 | 4:11 | 18 |
| 9c | 4:18 | 4:30 | 12 |
| 10a | 5:09 | 5:21 | 12 |
| 10b | 5:27 | 5:48 | 21 |
| 11a | 9:54 | 10:06 | 12 |
| 18a | 17:42 | 18:30 | 48 |
| 18b | 20:00 | 20:42 | 42 |
| 21a | 1:51 | 4:24 | 150 |
| 21b | 5:30 | 6:00 | 30 |
| 23a | 17:27 | 17:38 | 11 |
| 23b | 17:51 | 18:12 | 21 |

14 Stratiform Cases: 8 bands, 8.9 hours




~Steady light rain

Melting level ~constant

Minimal convection

# Instrumentation

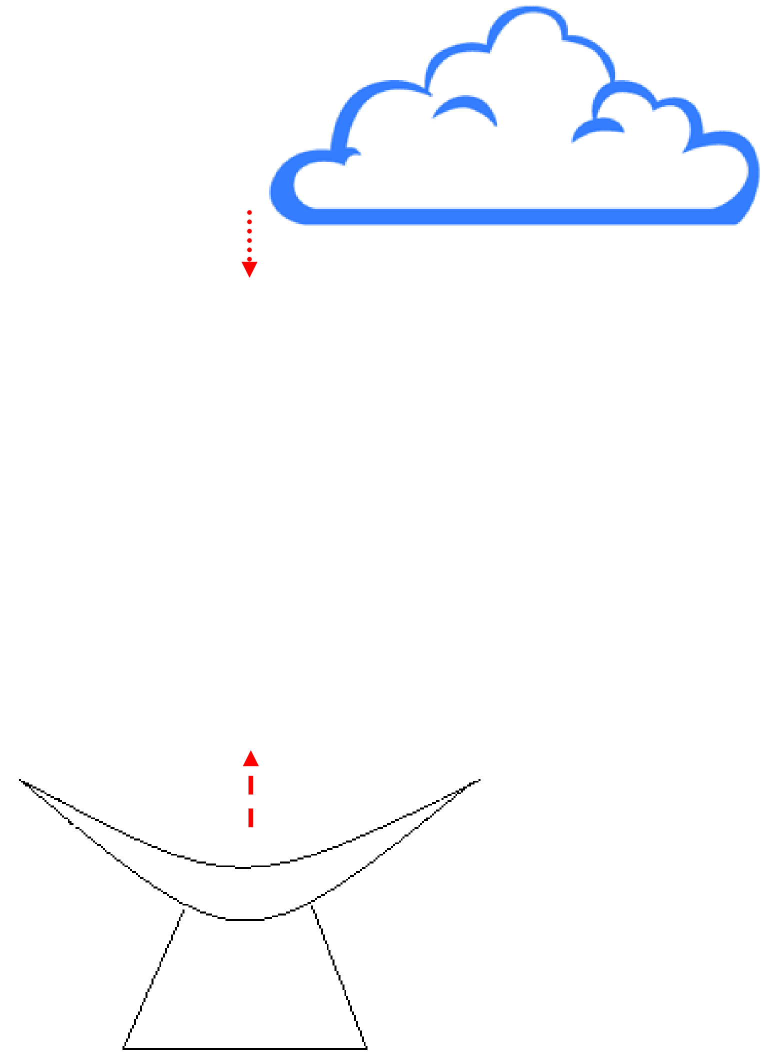
- Surface Instruments
  - Disdrometer
  - Rain gauge array
  - 10 ft met obs
  - 14.5m and 18 m met obs

- Upper-Air
  - Rawindsondes

- Remote Sensing
  - Ceilometer
  - Microwave Rain Radar
  - W-band radar
  - X-band radar
  - Wind Profiler (MAPR)
  - KAMX WSR-88D

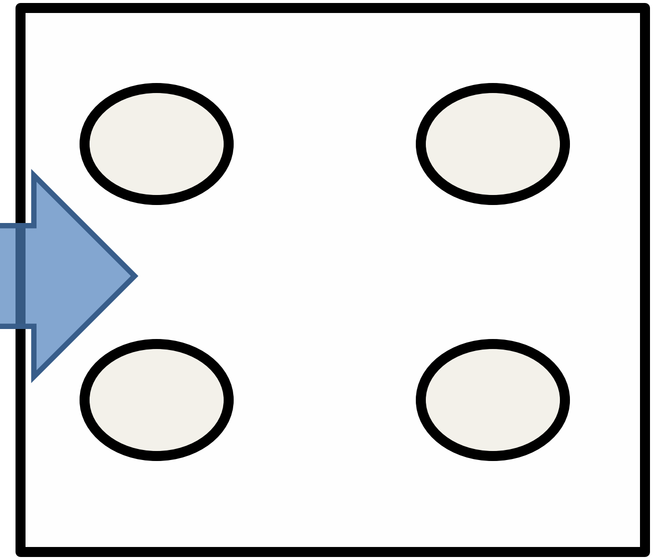

# Remote Sensing: X-BAND

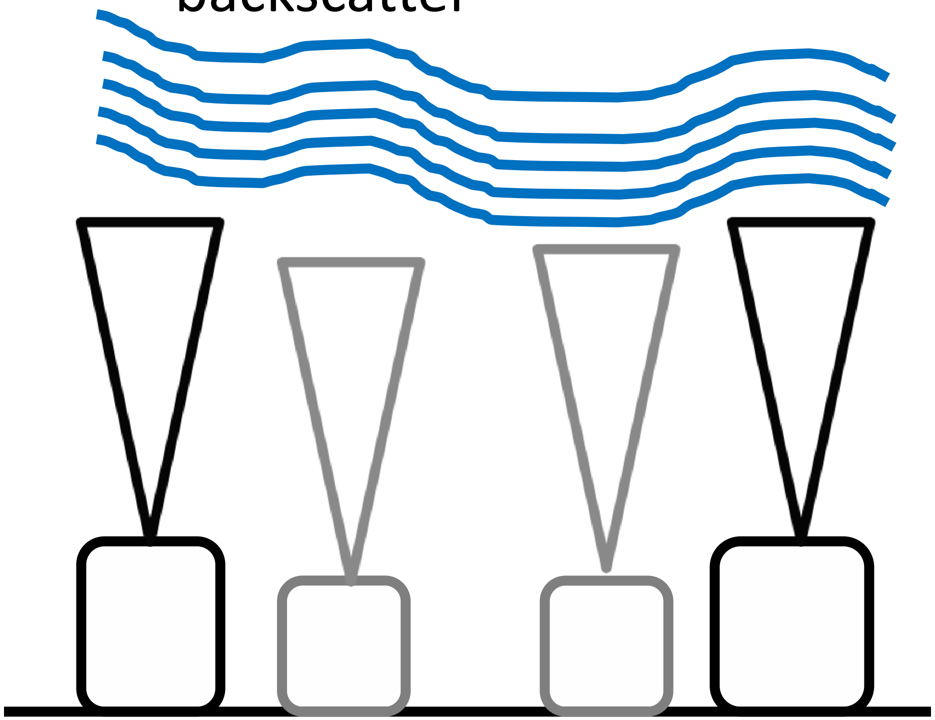
- Vertically Pointing Radar
  - 9.4 GHz
  - 3.2 cm wavelength
  - 60 m vertical resolution
  - Reflectivity and Velocity



# Remote Sensing: MAPR

- Wind Profiler
  - 915 MHz
  - 32.8 cm wavelength
  - 200 m resolution
  - Tracks diffraction pattern of backscatter



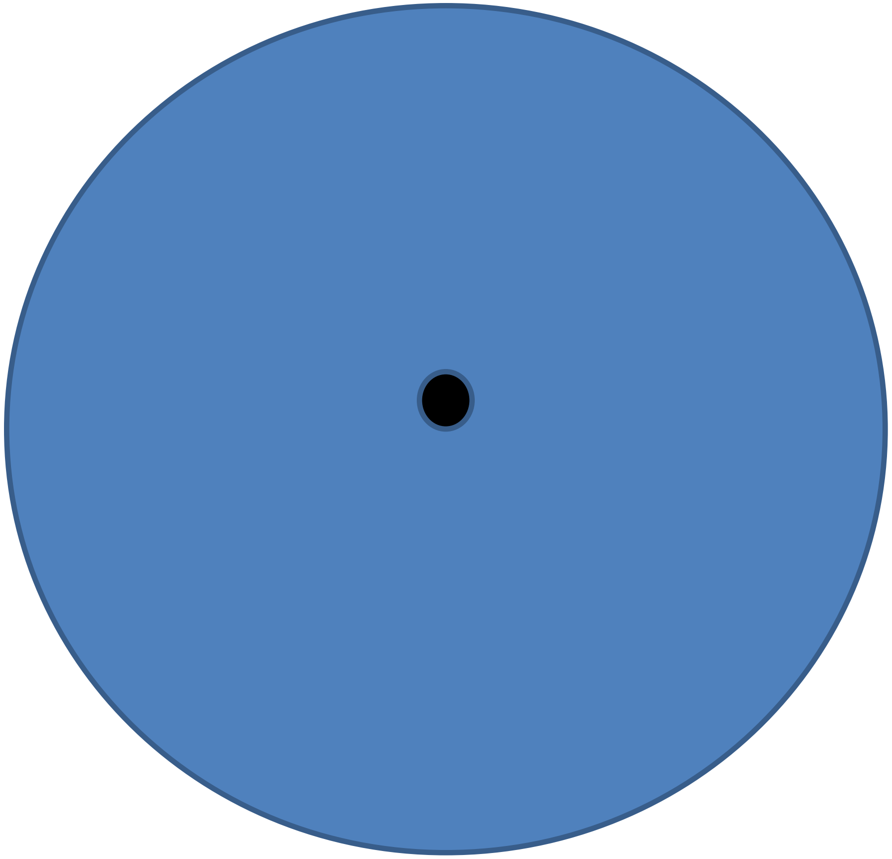


# Remote Sensing: WSR-88D

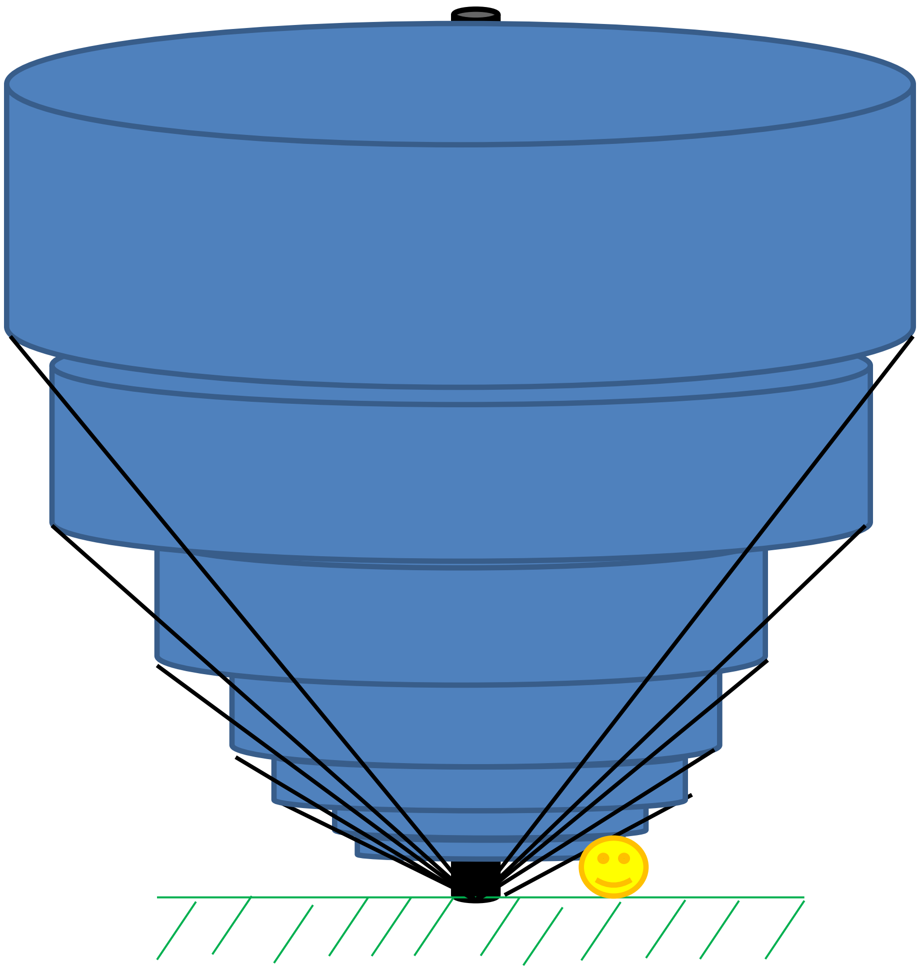
- Weather Surveillance Radar 1988 Doppler
  - NEXRAD (KAMX)
  - Scanning S-band radar
  - 2.8-3.0 GHz
  - 10.0-11.1 cm

# WSR-88D

Overhead View

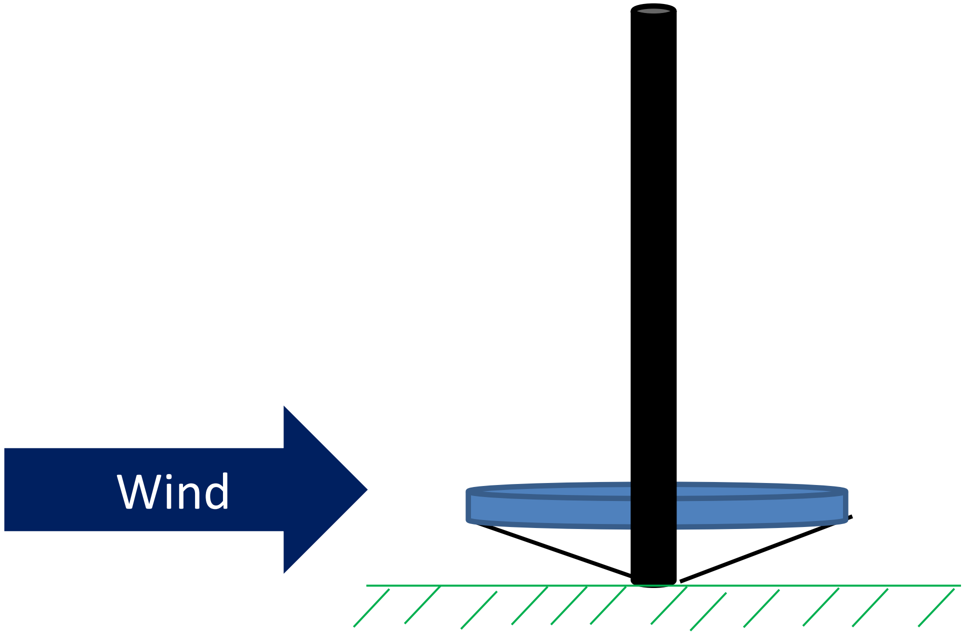


Side View

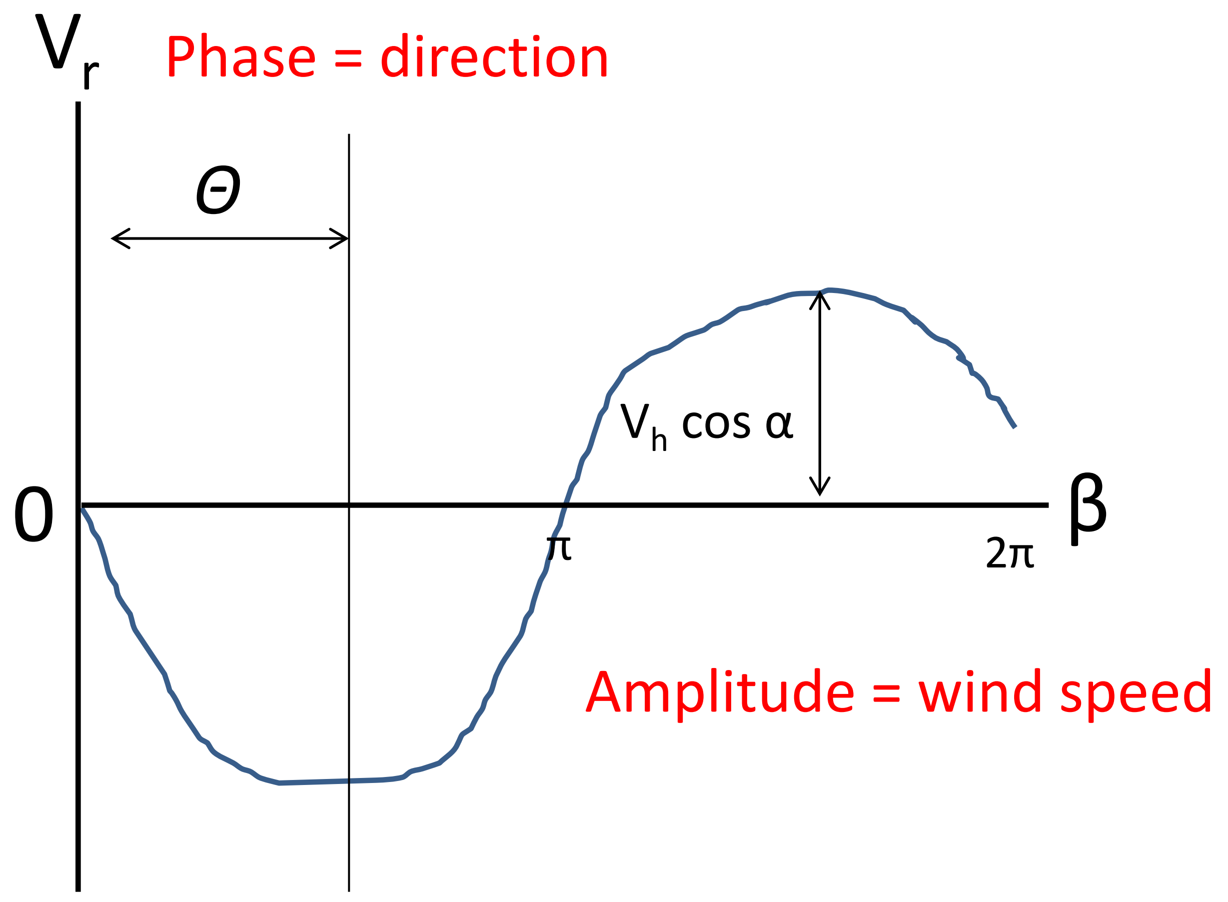


# Method: VAD Technique

- Velocity-Azimuth Display
  - Scan radar beam about a fixed elevation angle
    - As the beam rotates, radar provides an output of radial velocity vs. azimuth (VAD)
    - Mean radial velocity is a sine function of azimuth angle

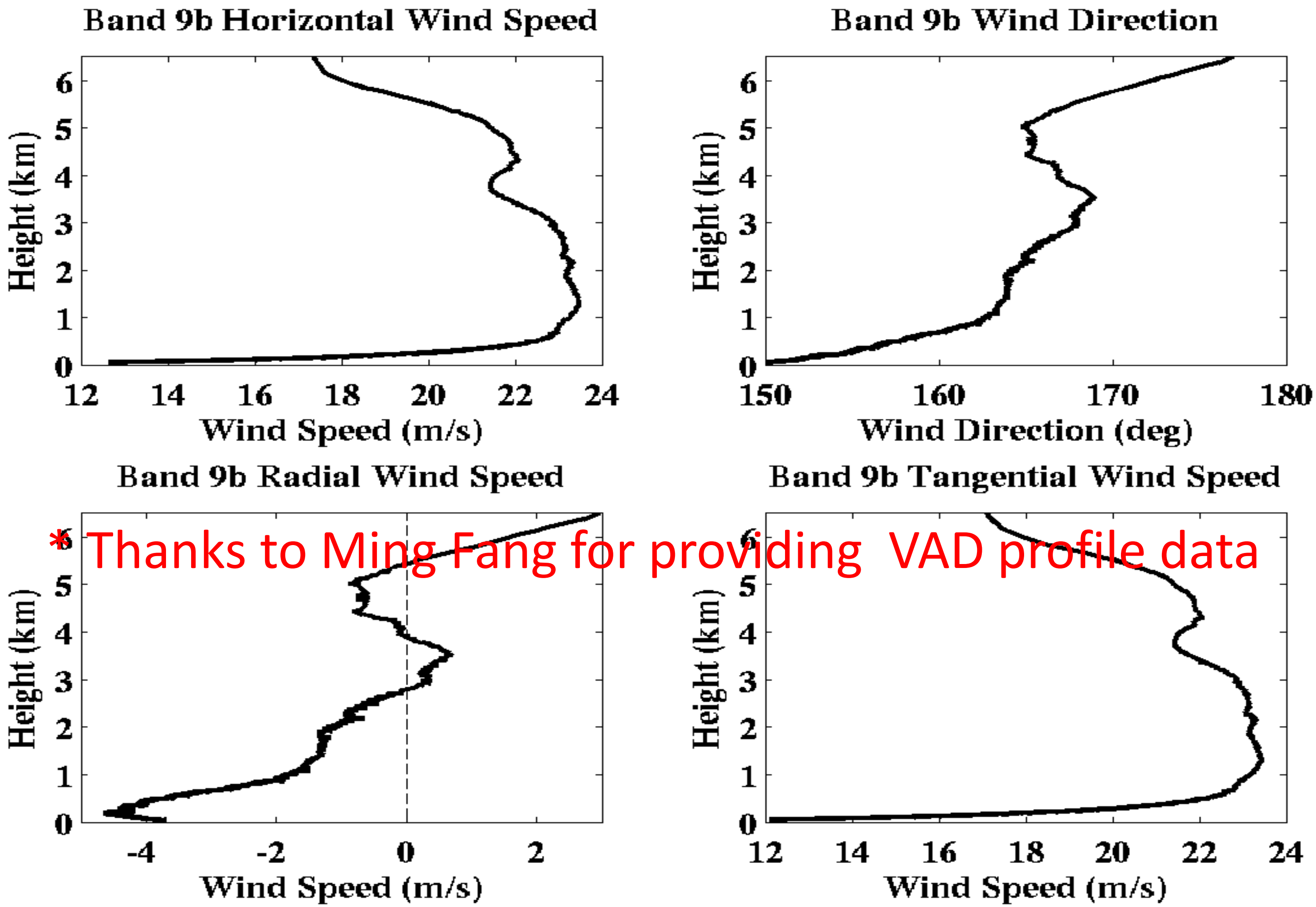


# VAD Technique



# VAD Wind Extraction

Resolution
2 m @ 65 m
85 m @ 6.5 km
Mean~7 m

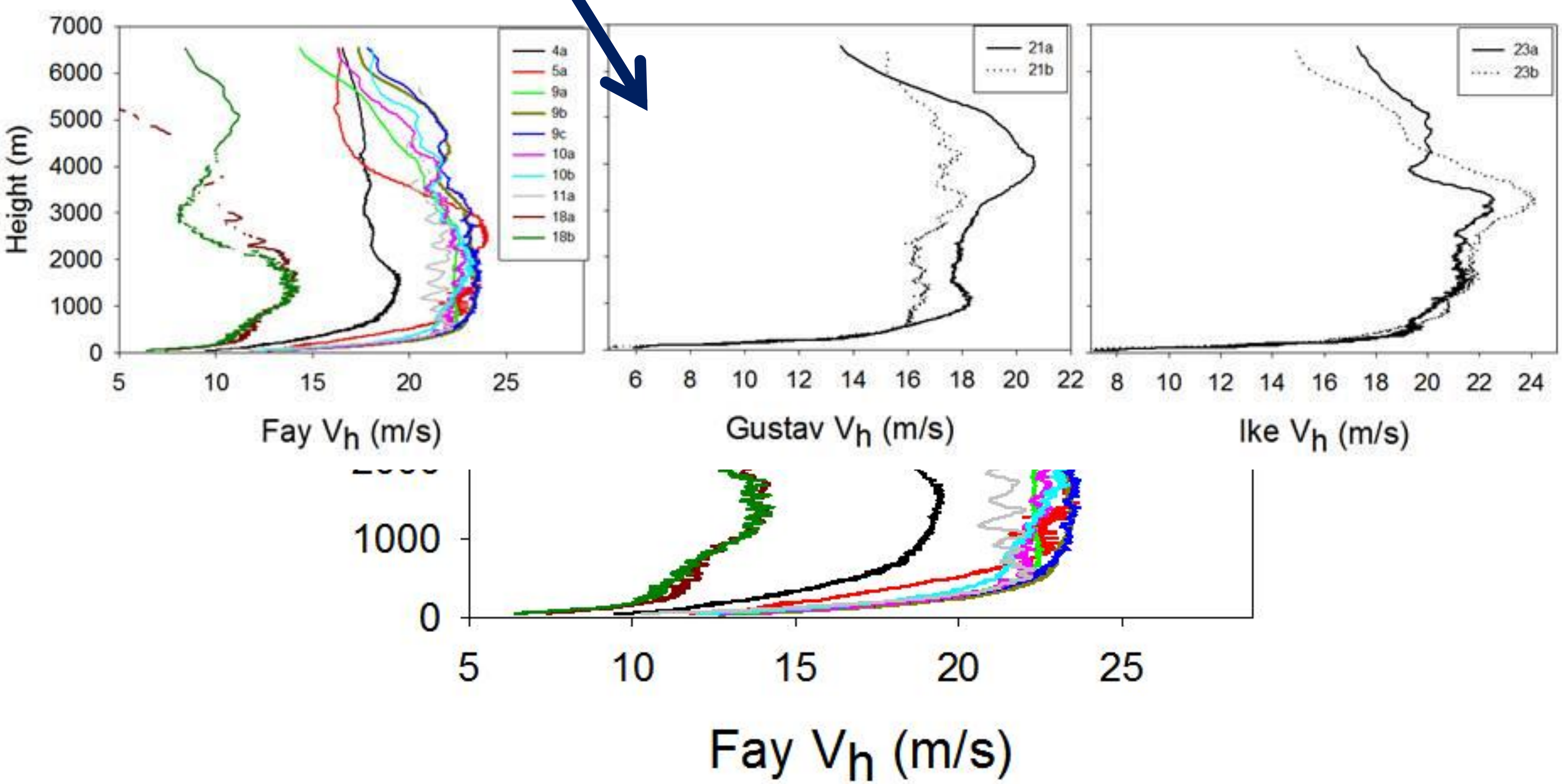



* Thanks to Ming Fang for providing VAD profile data

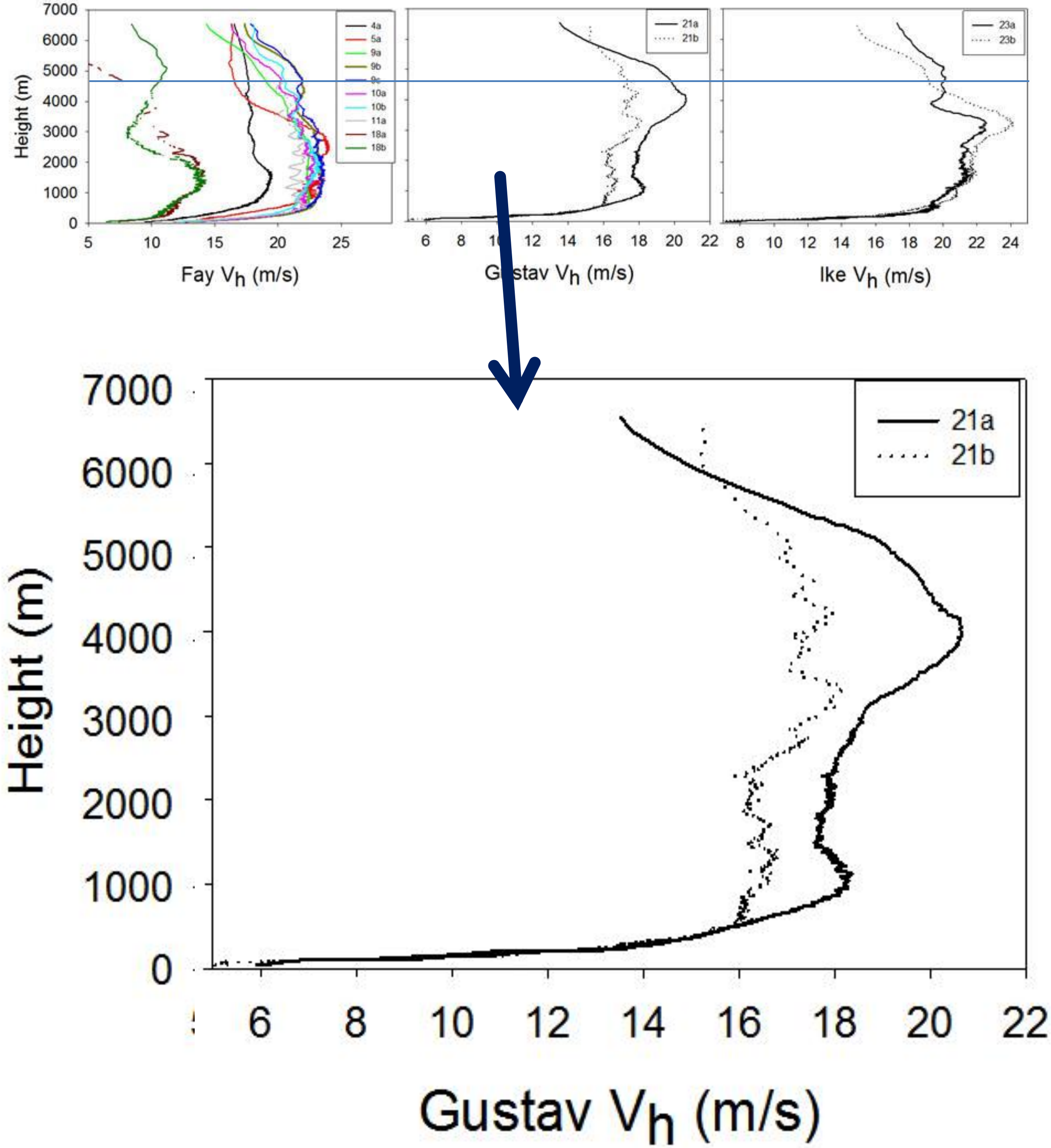
# Stratiform Profiles

# MEAN WIND COMPONENTS

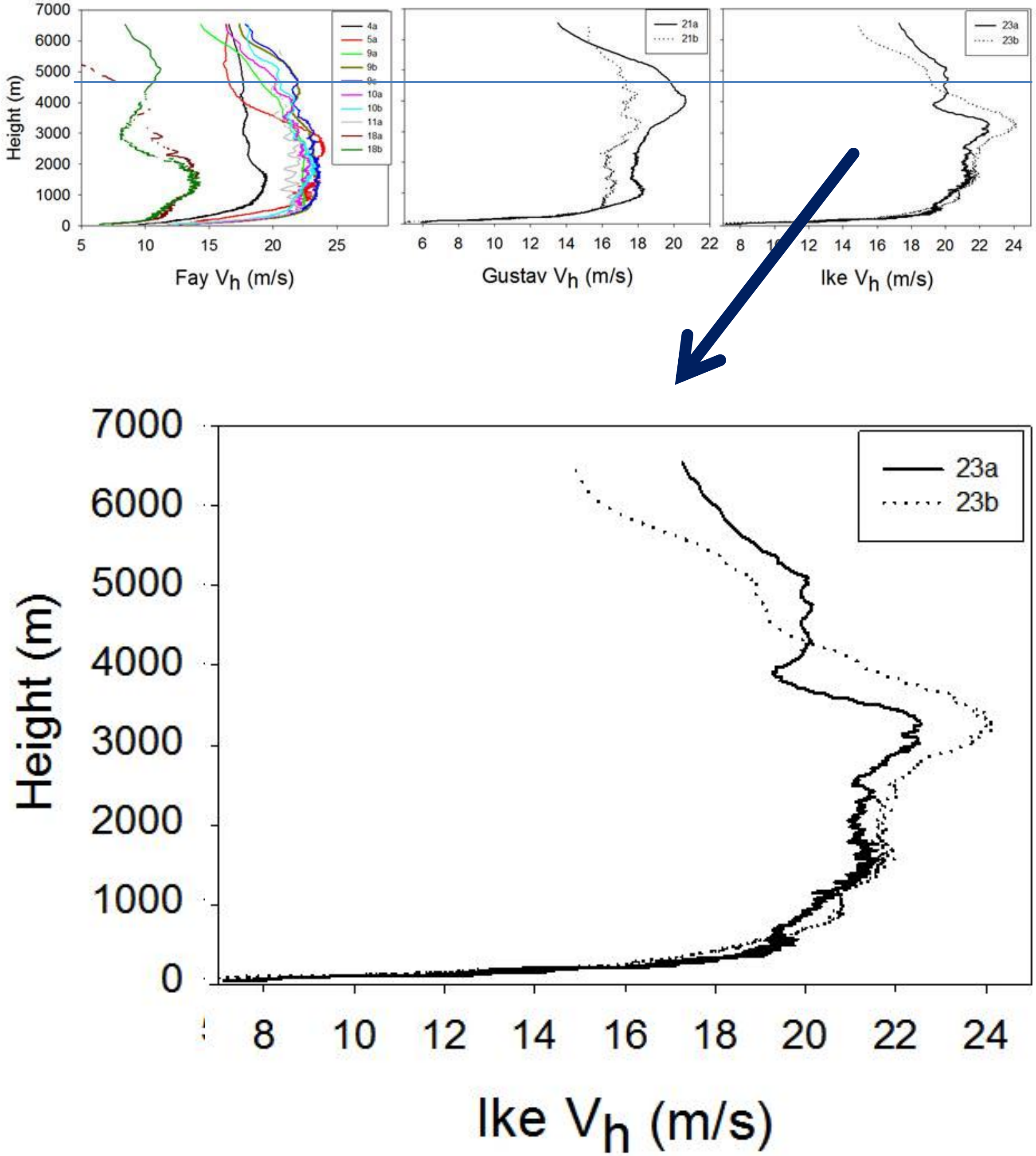
## Mean Wind Speed Profiles by Storm



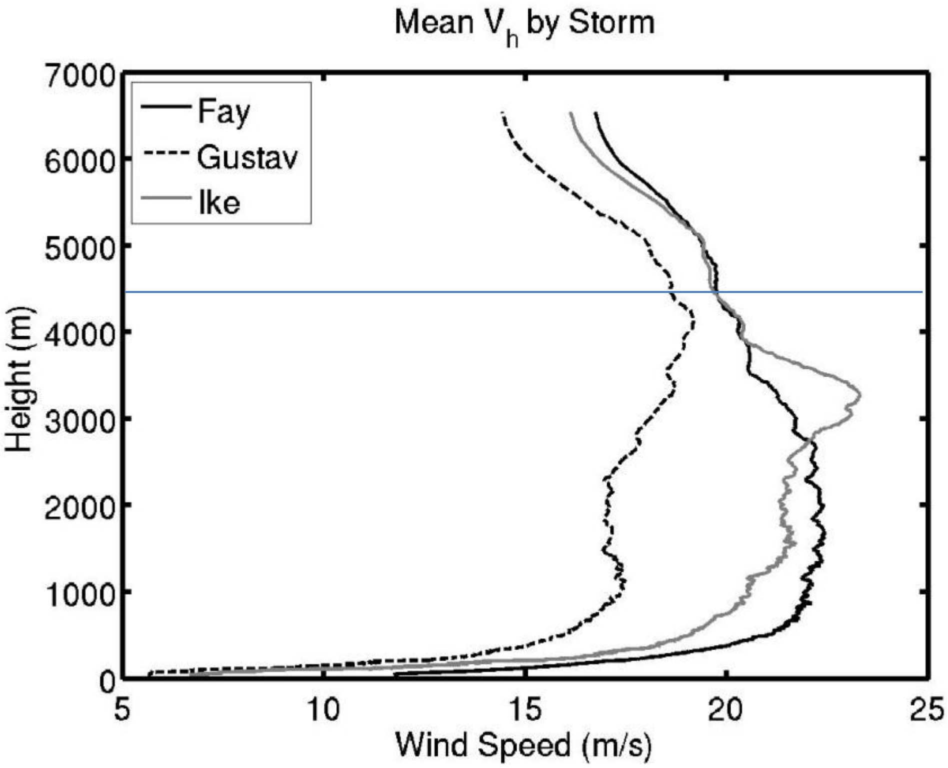
# Mean Wind Speed Profiles by Storm

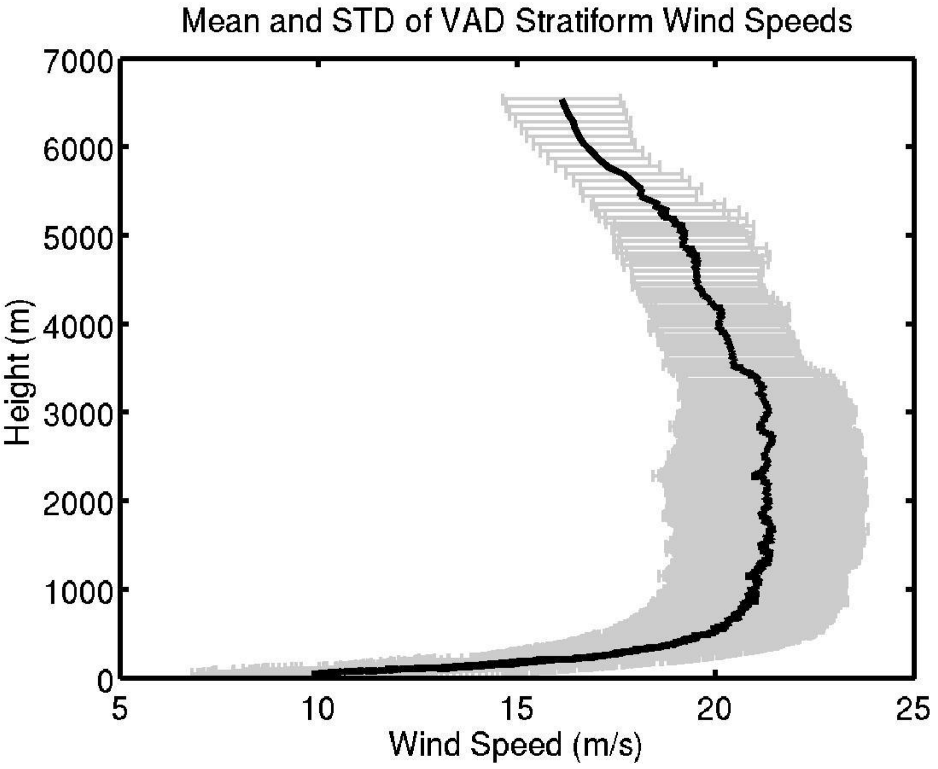


Mean Wind Speed Profiles by Storm



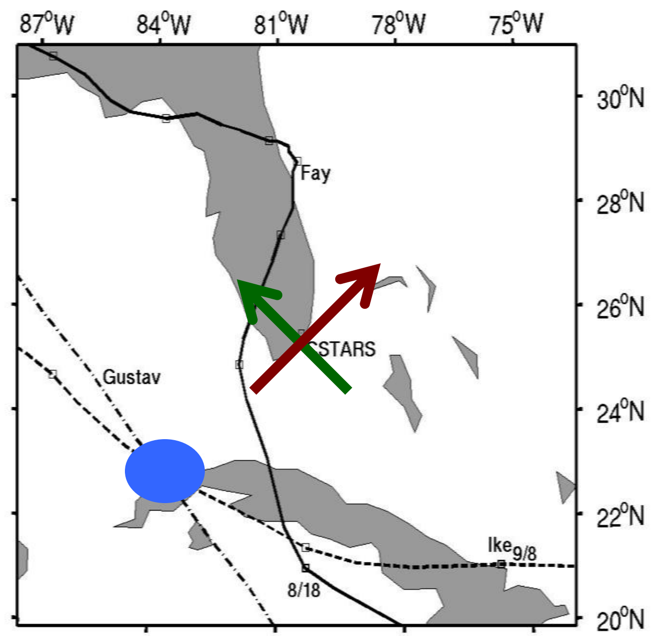
# Mean VAD Horizontal Wind



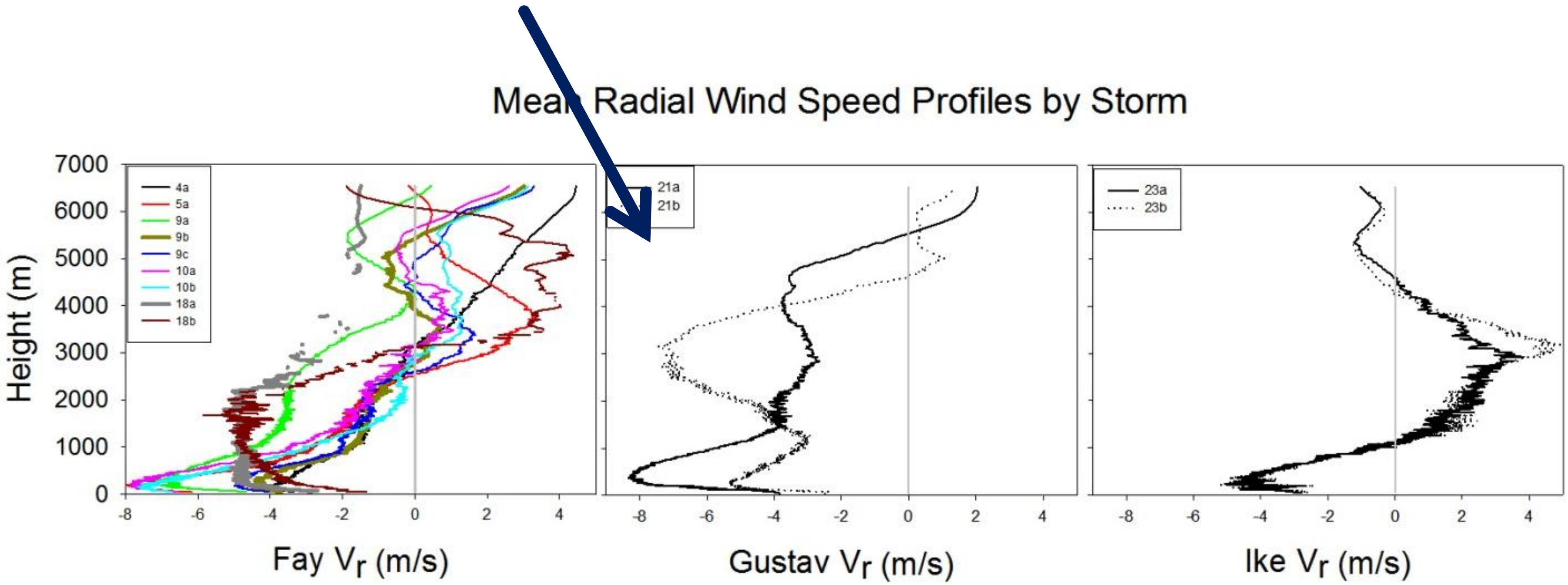



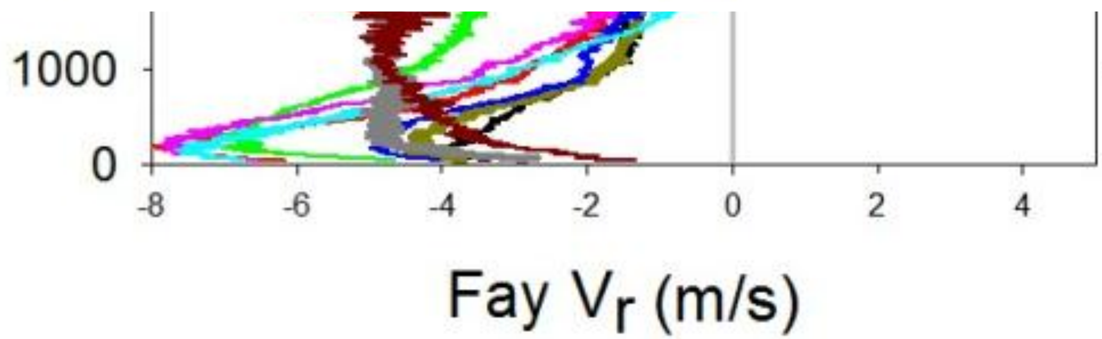
# Radial and Tangential Winds

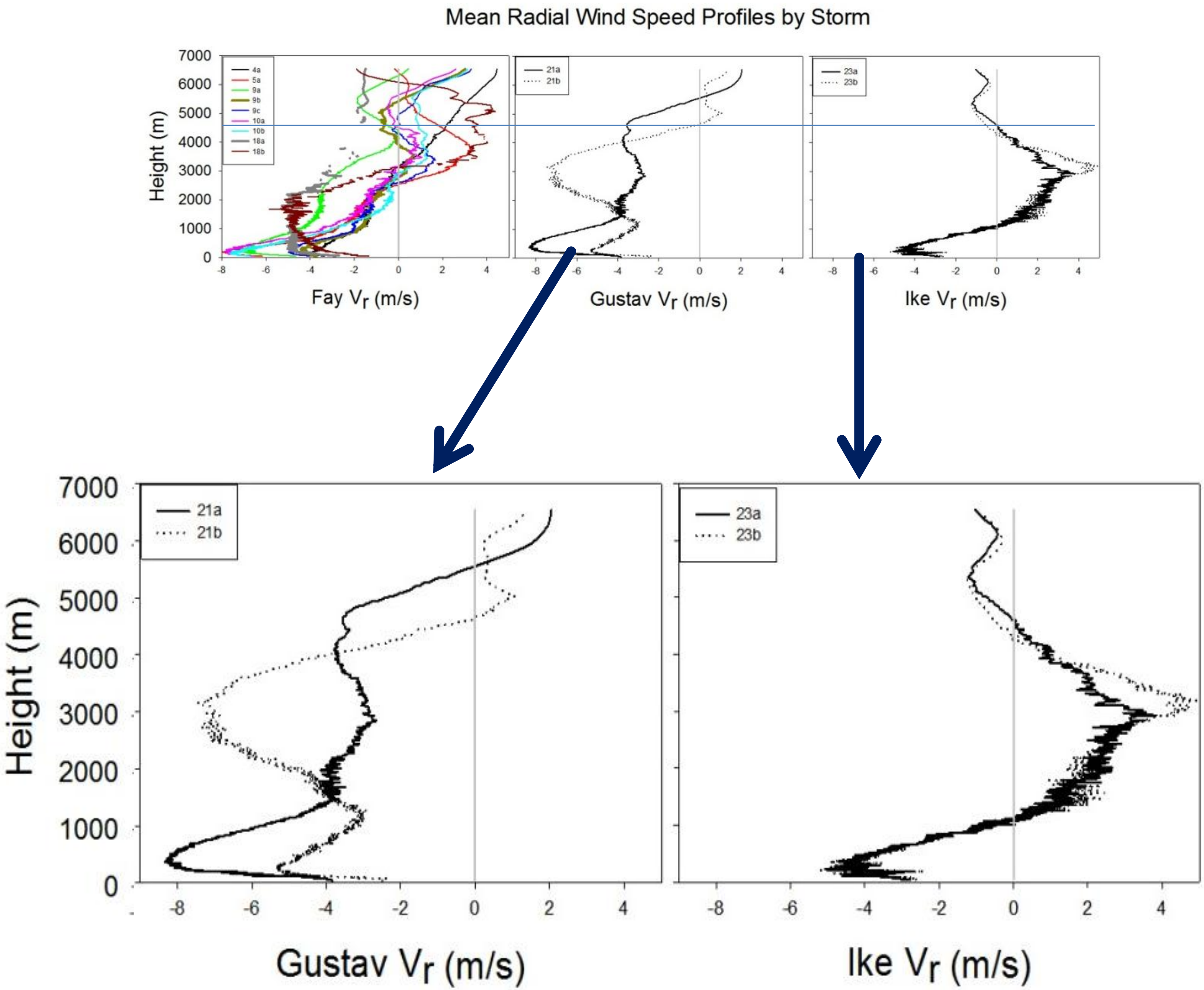
- Radial: Towards (negative) and away from (positive) the center of the storm
- Tangential: Perpendicular to storm (cyclonic=positive)



# Mean Radial Wind Speed Profiles by Storm

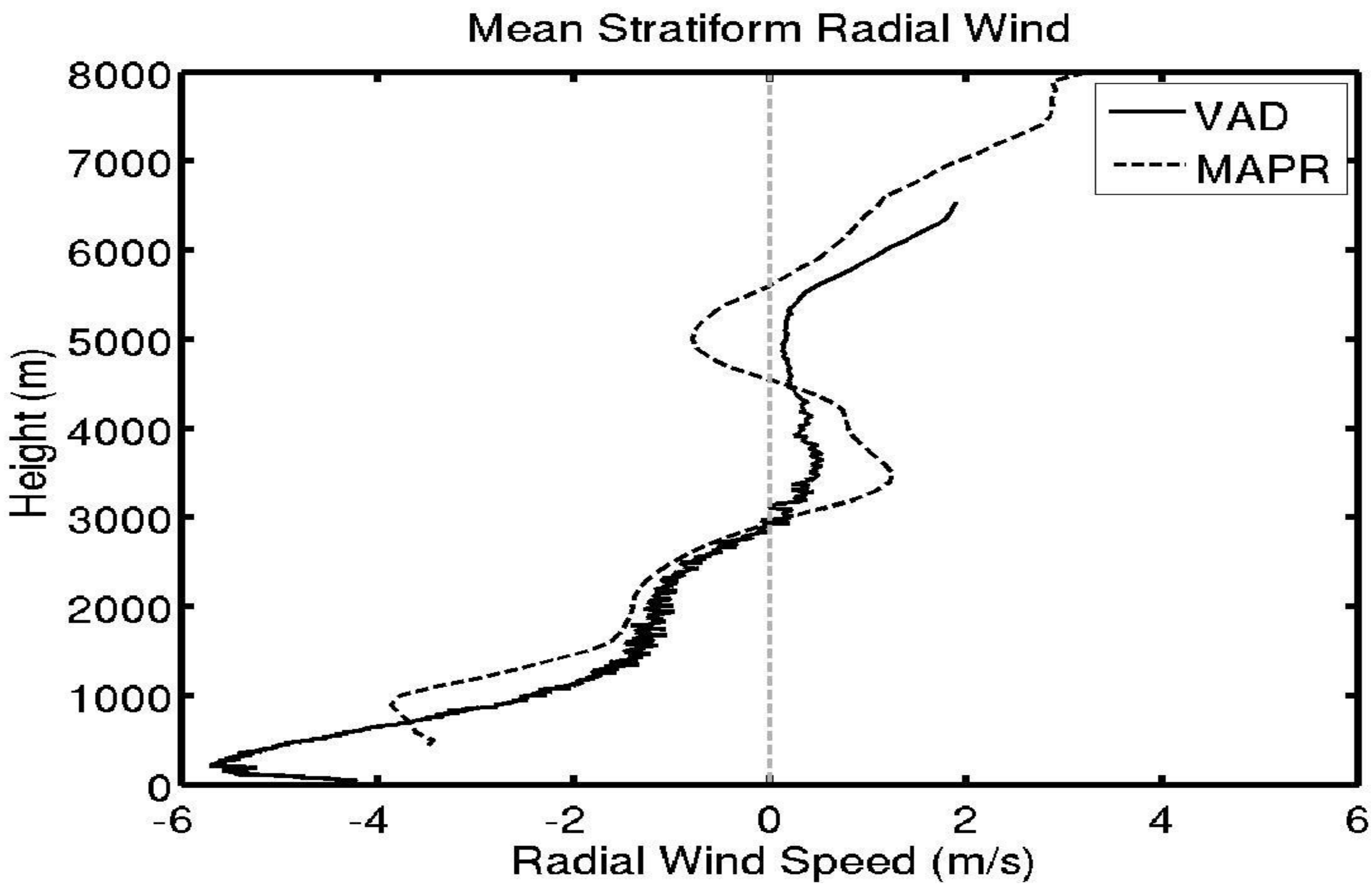


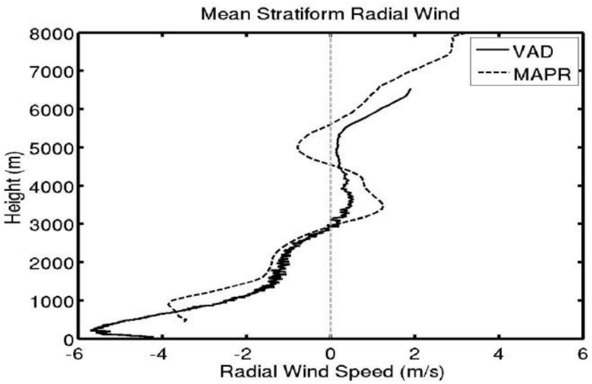



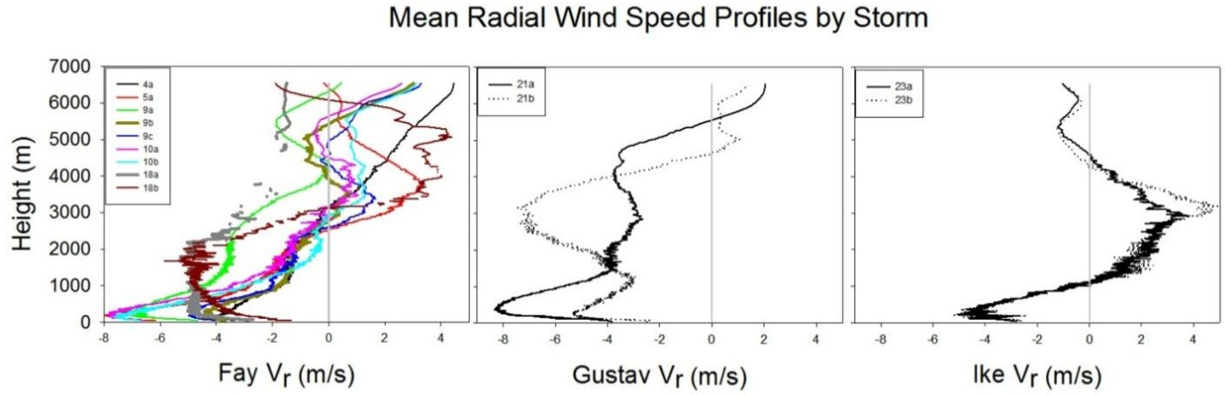


Mean Radial Wind Speed Profiles by Storm
Height (m)
4a
5a
9a
9b
9c
10a
10b
18a
18b
Fay Vr (m/s)
21a
21b
Gustav Vr (m/s)
23a
23b
Ike Vr (m/s)

# Mean Radial Winds

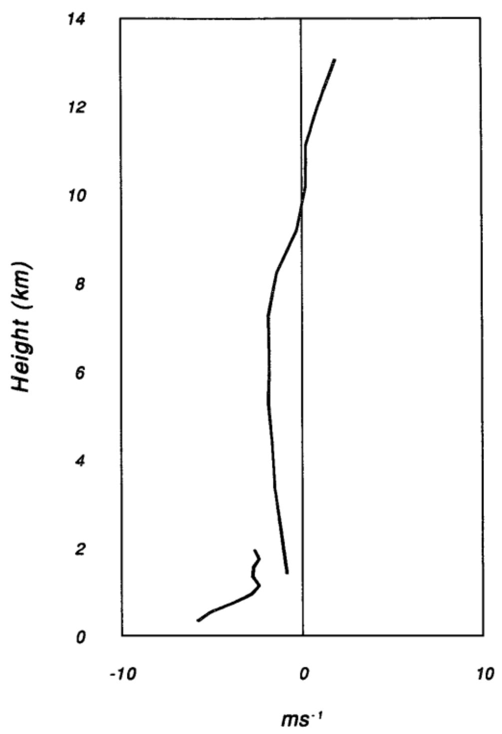


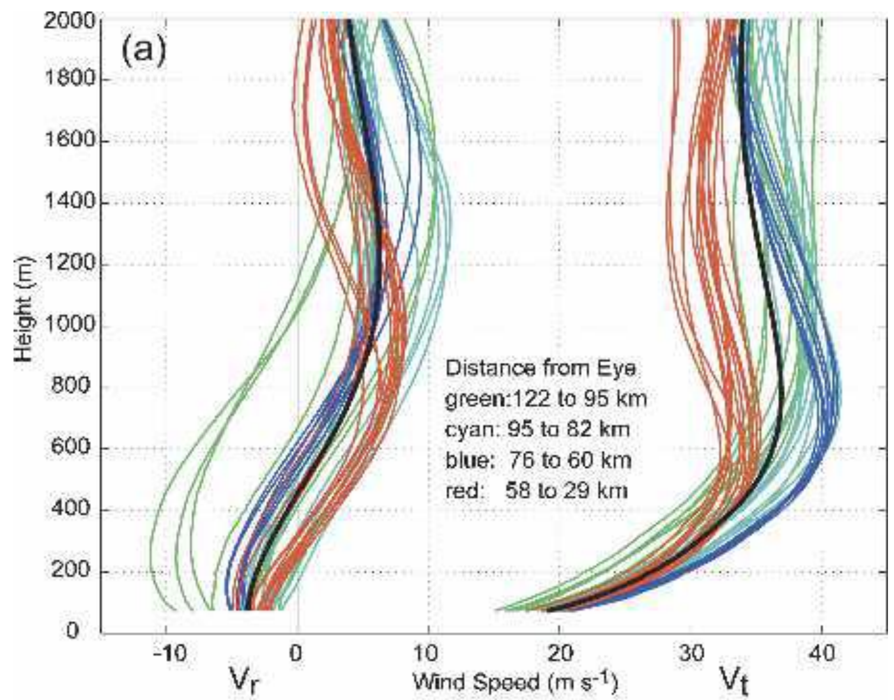


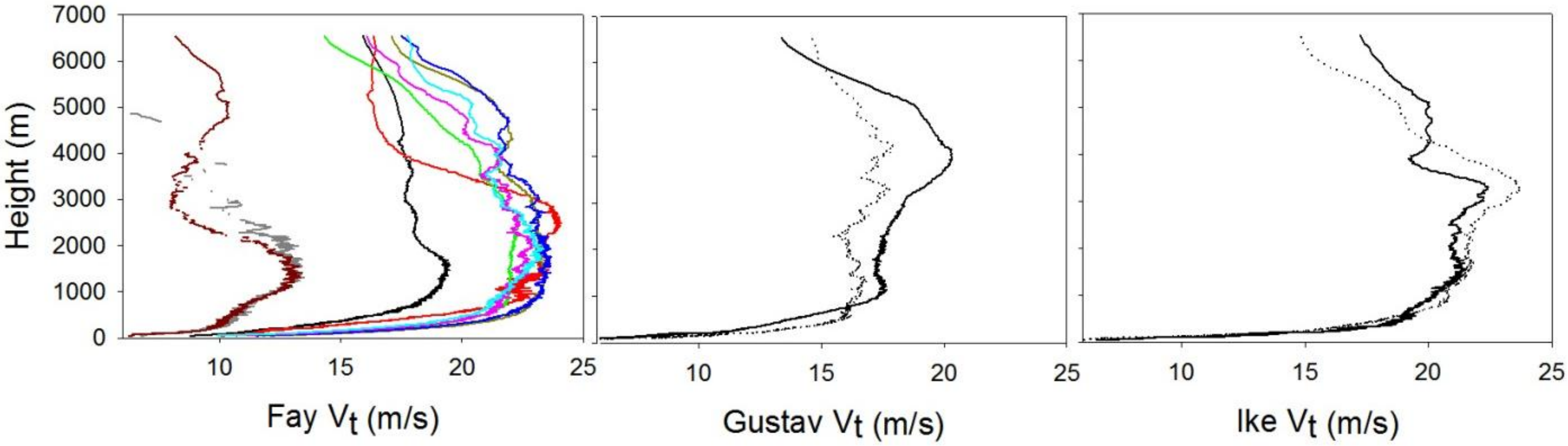

May et al. 1994

Morrison et al. 2005



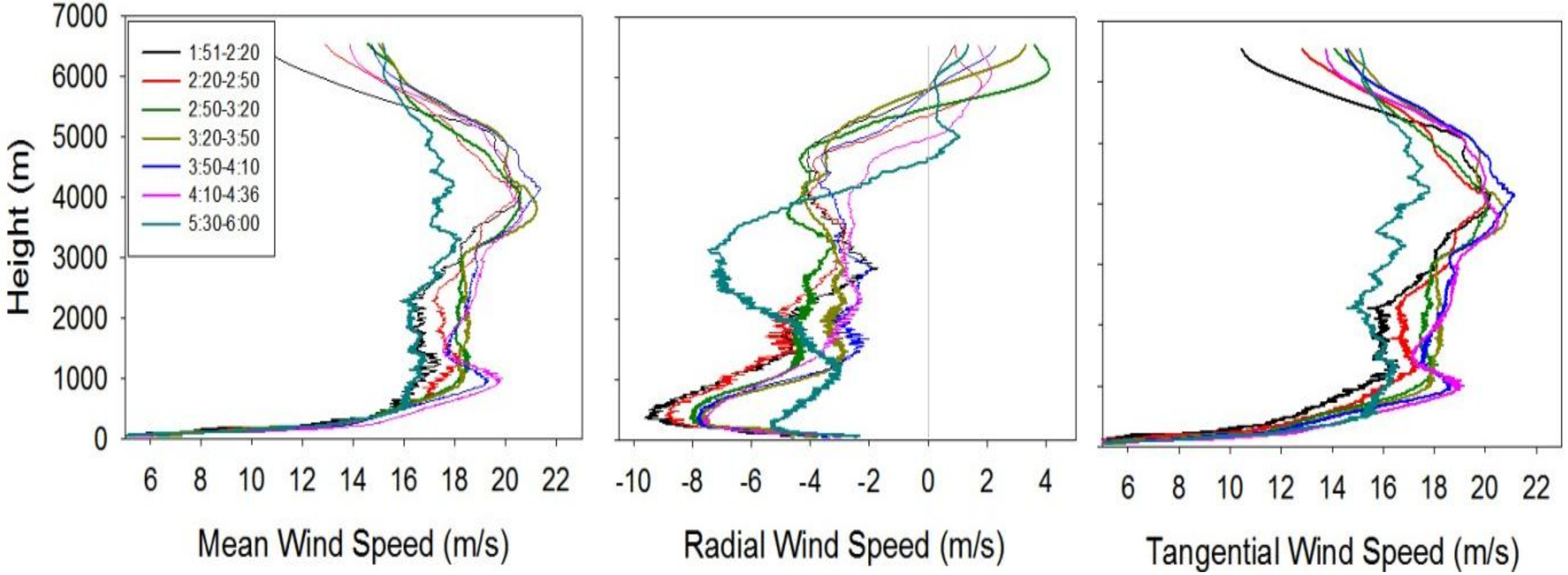



# Mean Tangential Wind Speed Profiles by Storm

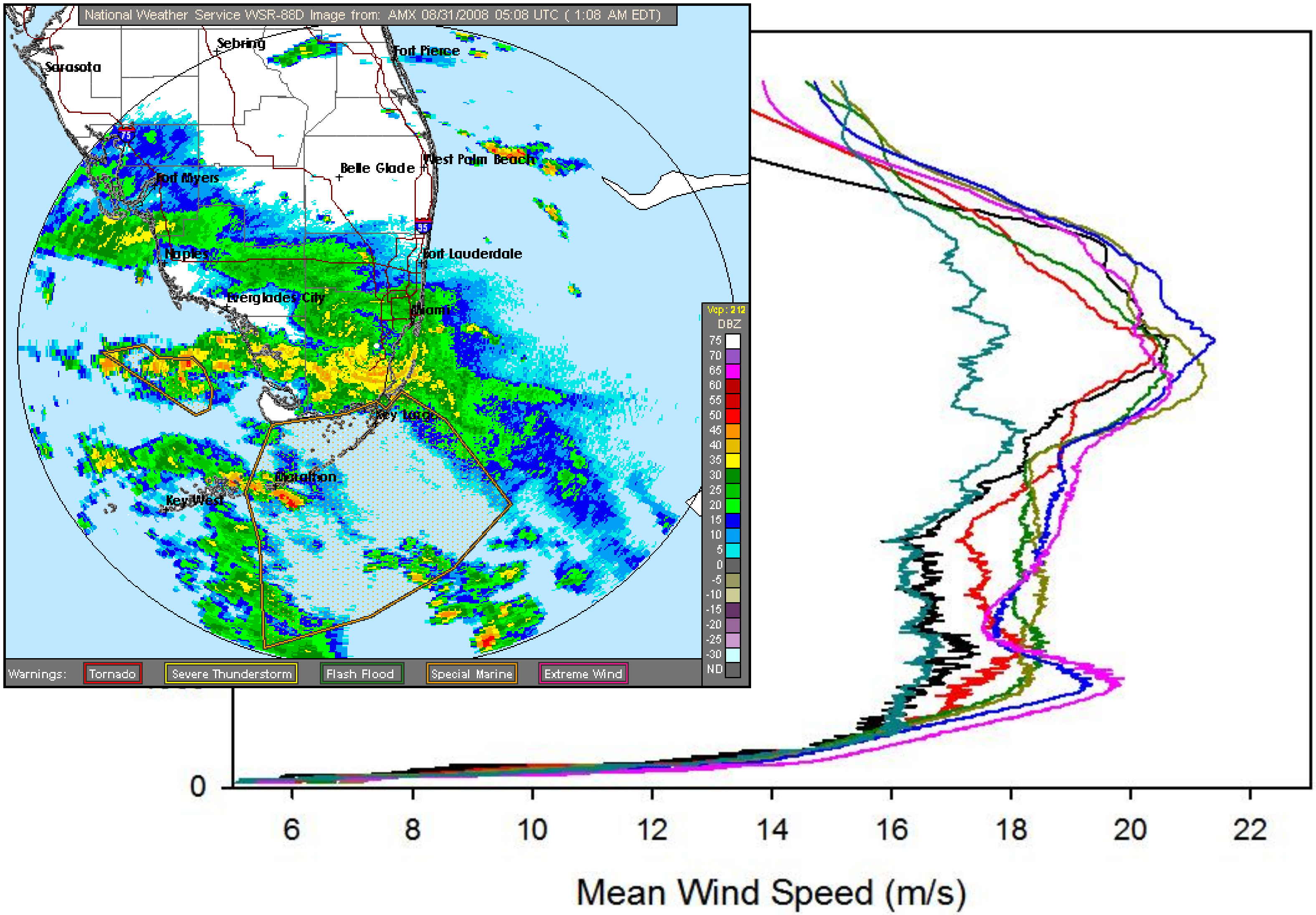


# TIME VARIABILITY IN PROFILES

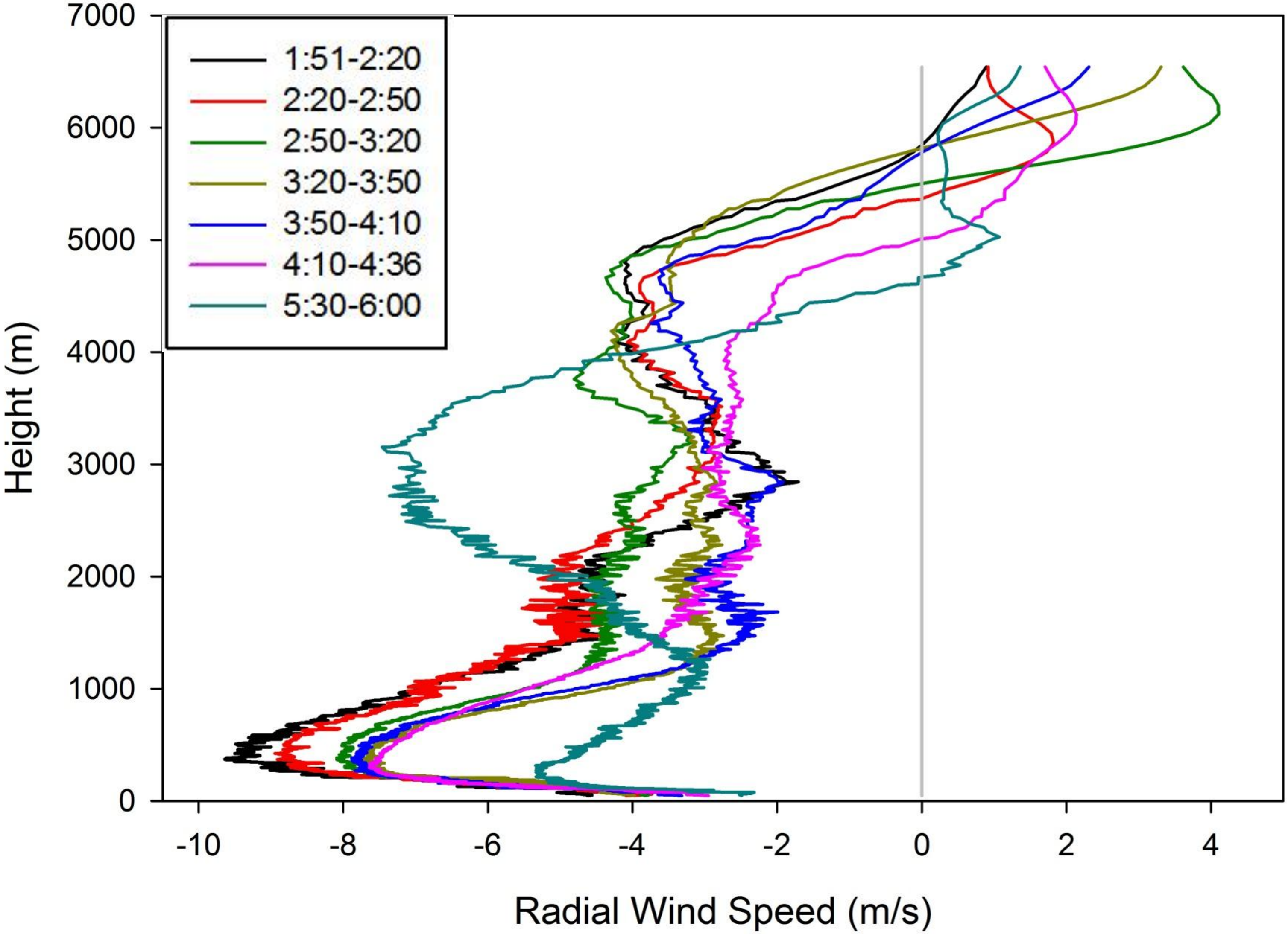
# Time Series During Band 21



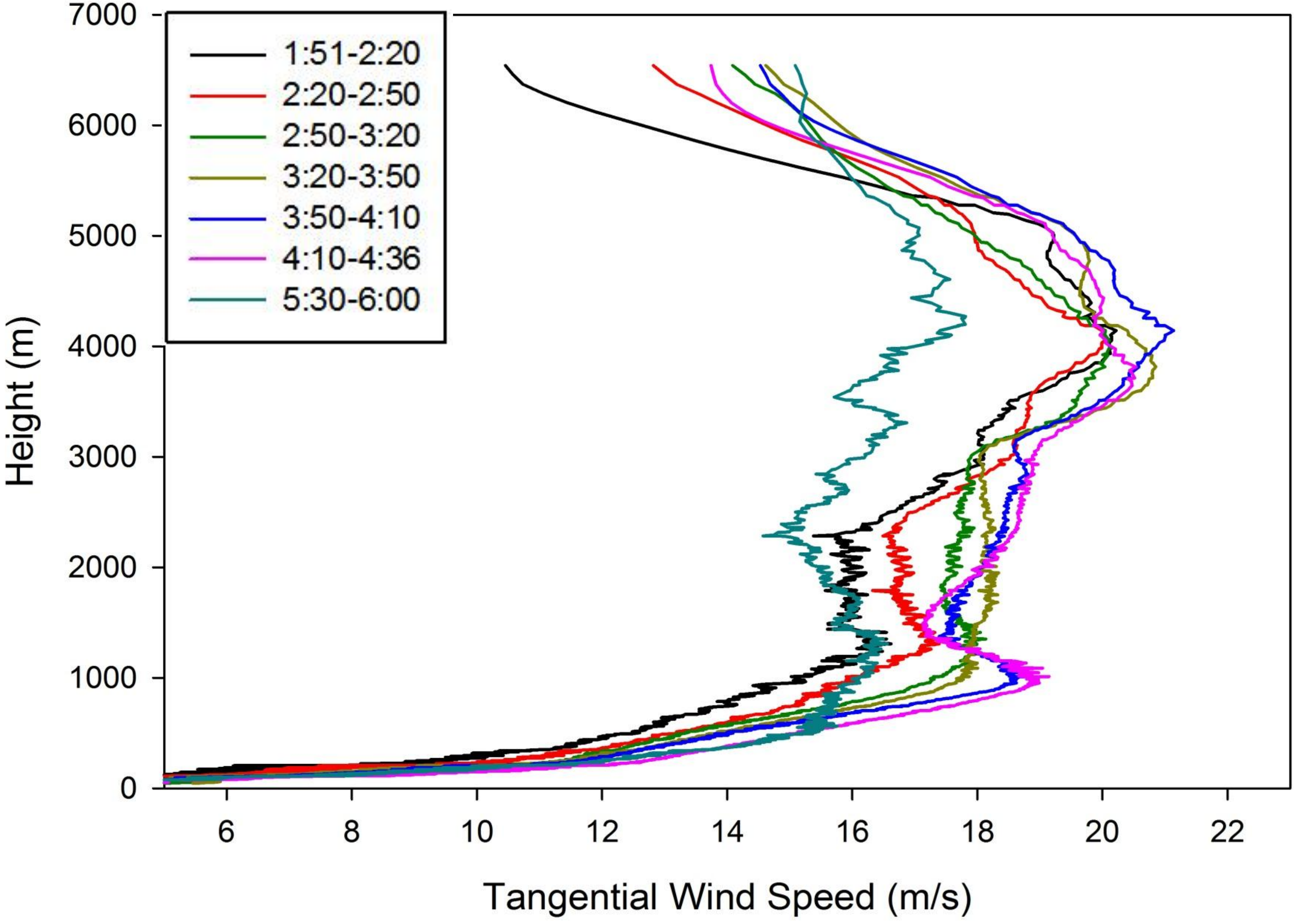
# Time Series: Wind Speed



# Time Series: Radial Wind

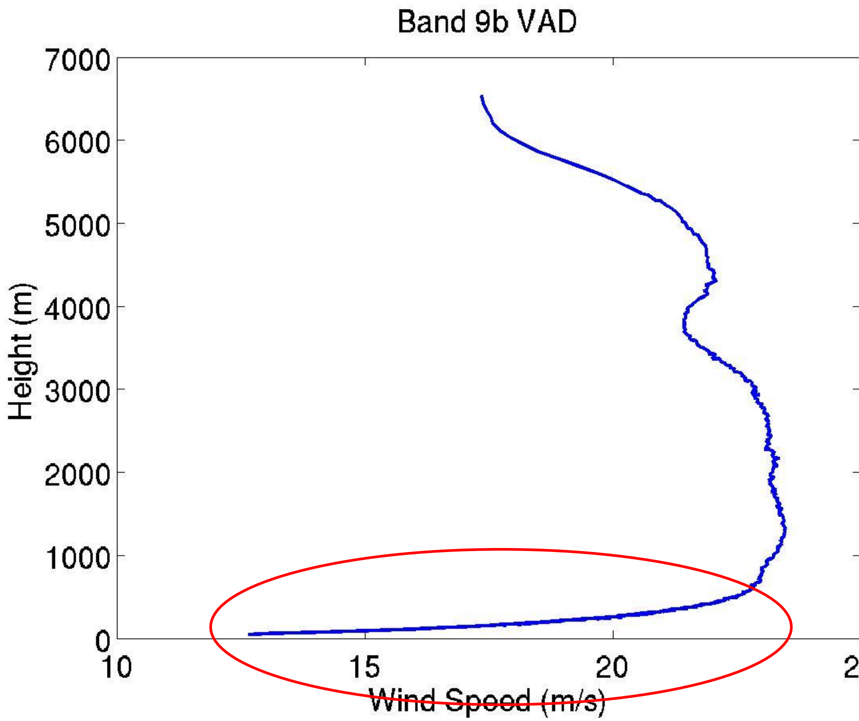


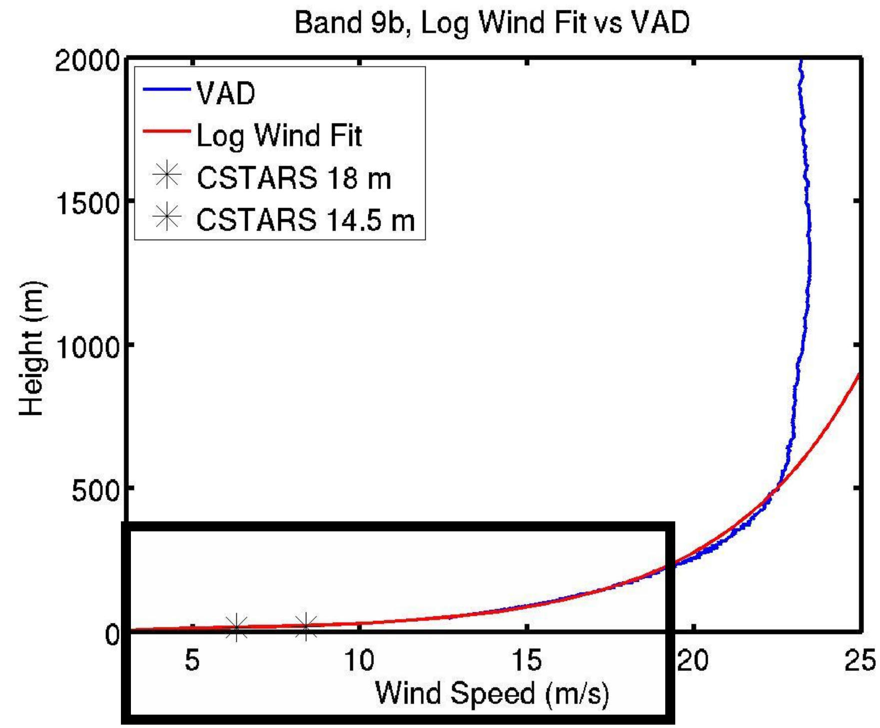
# Time Series: Tangential Wind



# LOW-LEVEL WINDS

# Log-Wind Layer




$$\overline{U} = \left(\frac{u_*}{k}\right) \ln\left(\frac{(z-d)}{z_0}\right)$$

$u_*$: friction velocity

k: von Karman constant (0.35)

d: displacement distance (6 m)

$z_o$: aerodynamic roughness length

Stull 1988

# Method: Log Wind Fit

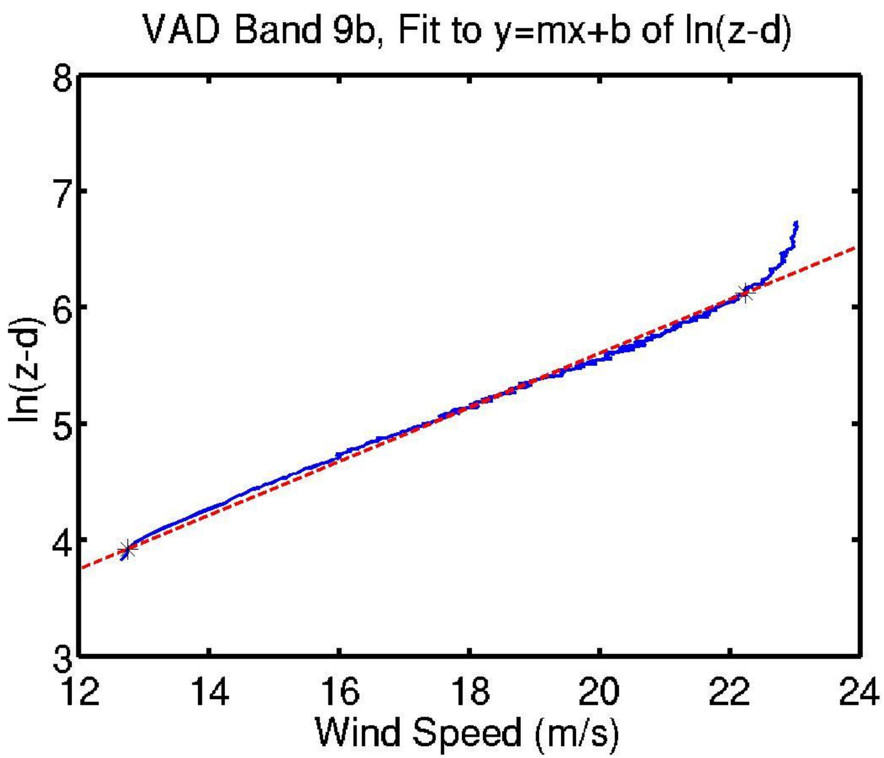
$u_*$: friction velocity

k: von Karman constant (0.35)

d: displacement distance (6 m)

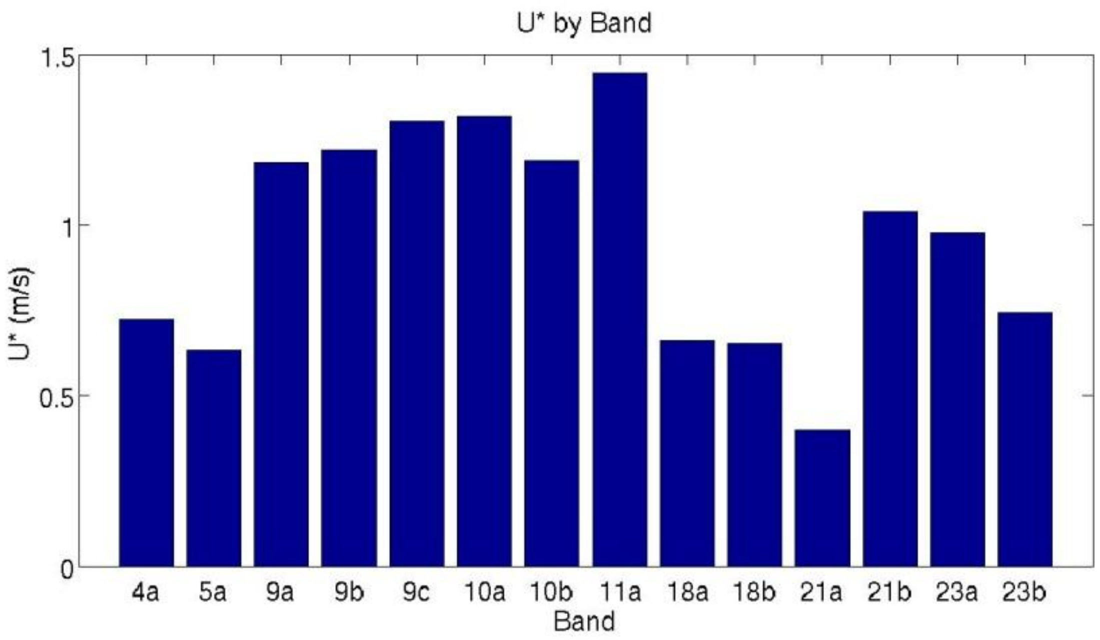
$z_o$: aerodynamic roughness length

$$\ln(z - d) = \left(\frac{k}{u_*}\right)U + \left(\frac{u_*}{k}\right)\ln(z_0)$$



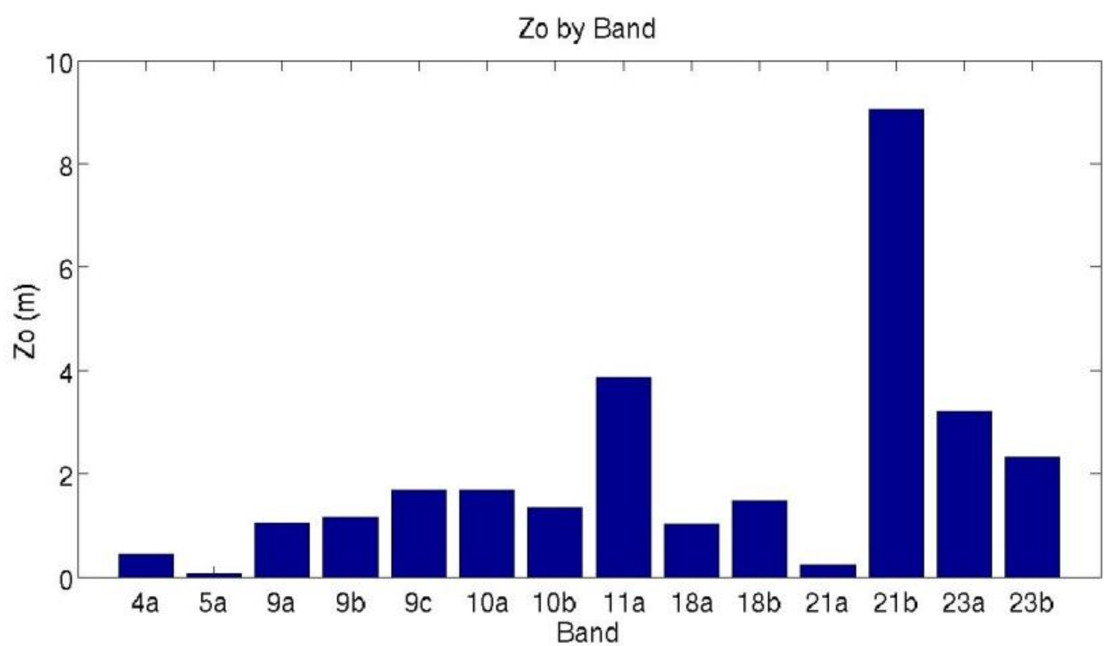

<u>Goodness of fit (r)</u>

0.891-0.997




$u_*$: friction velocity

$z_o$: aerodynamic roughness length



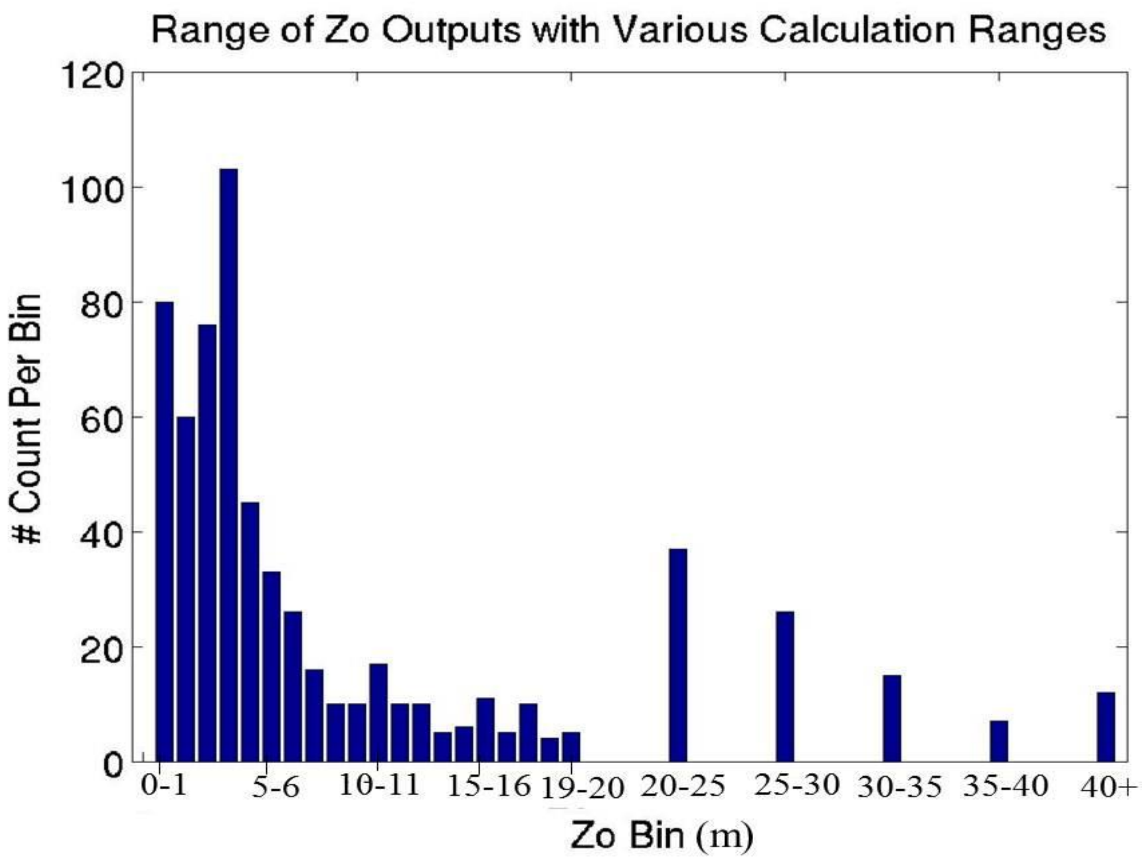

$z_o$ ~0.8-1.4 m in centers of large towns

$z_o$ ~1.5-2.5 m in centers of cities with tall buildings

$z_o$ ~10 m in Appalachian Mnts

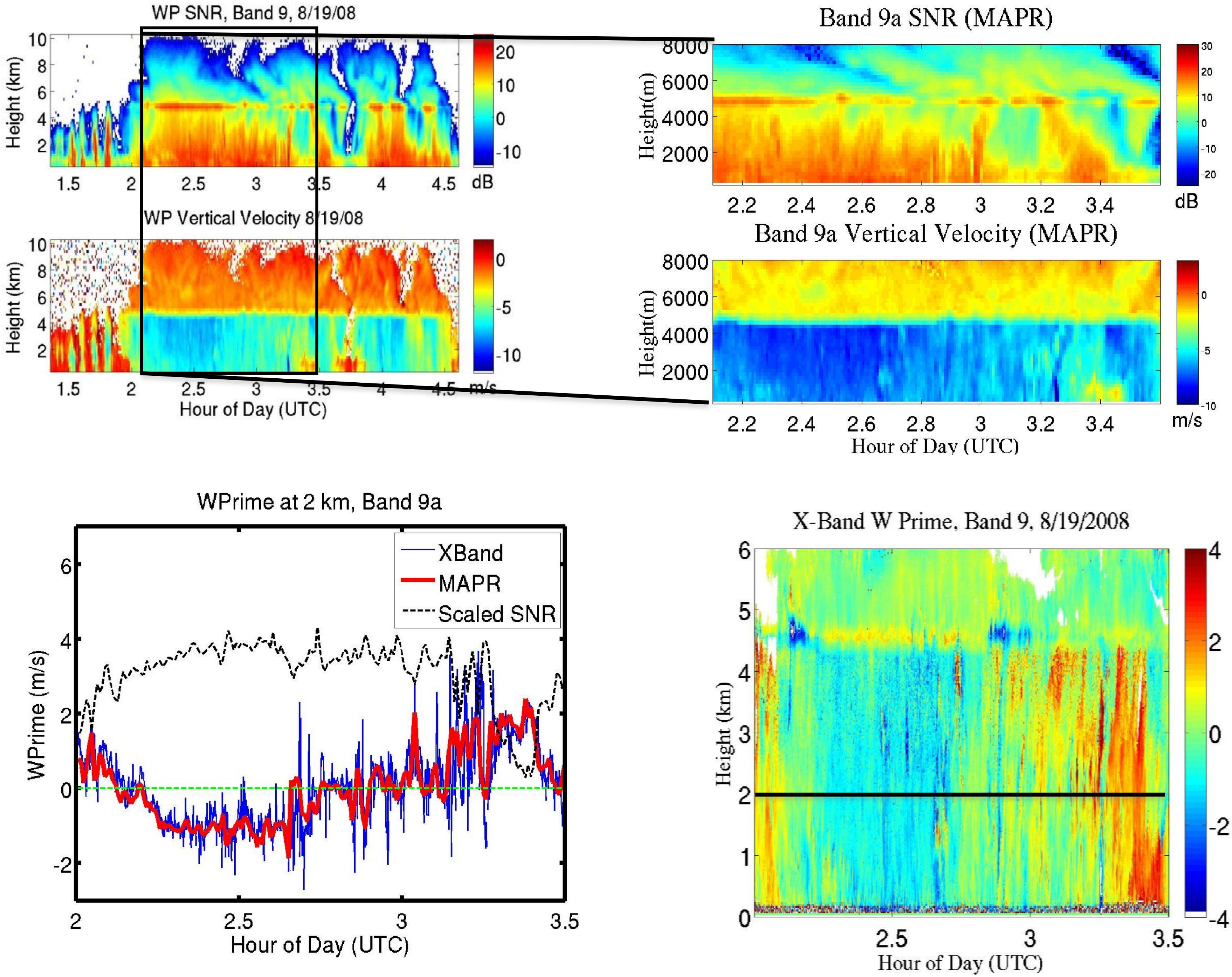
*Mean* $z_o$ = 1.5 m

# Sensitivity of $z_0$

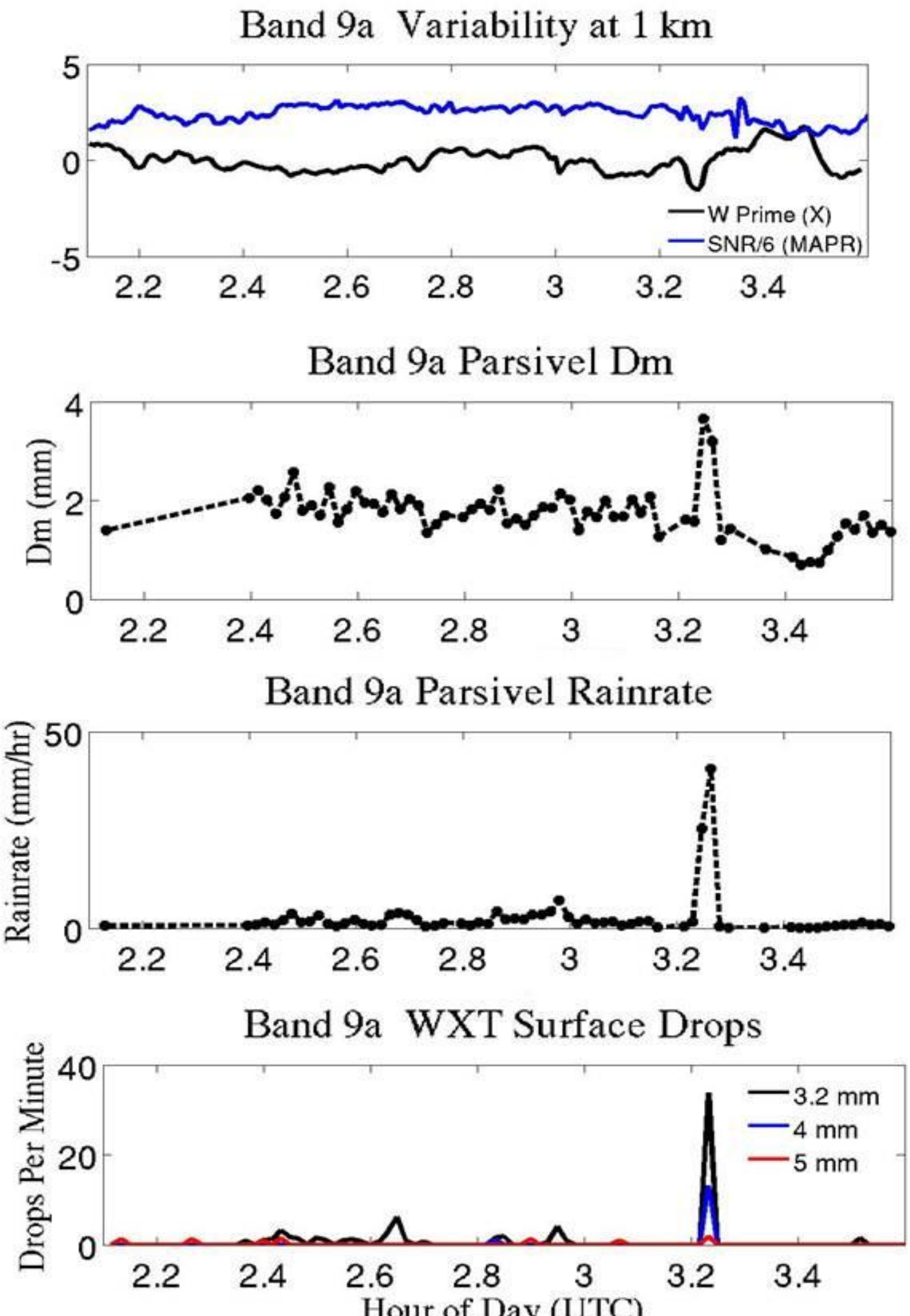


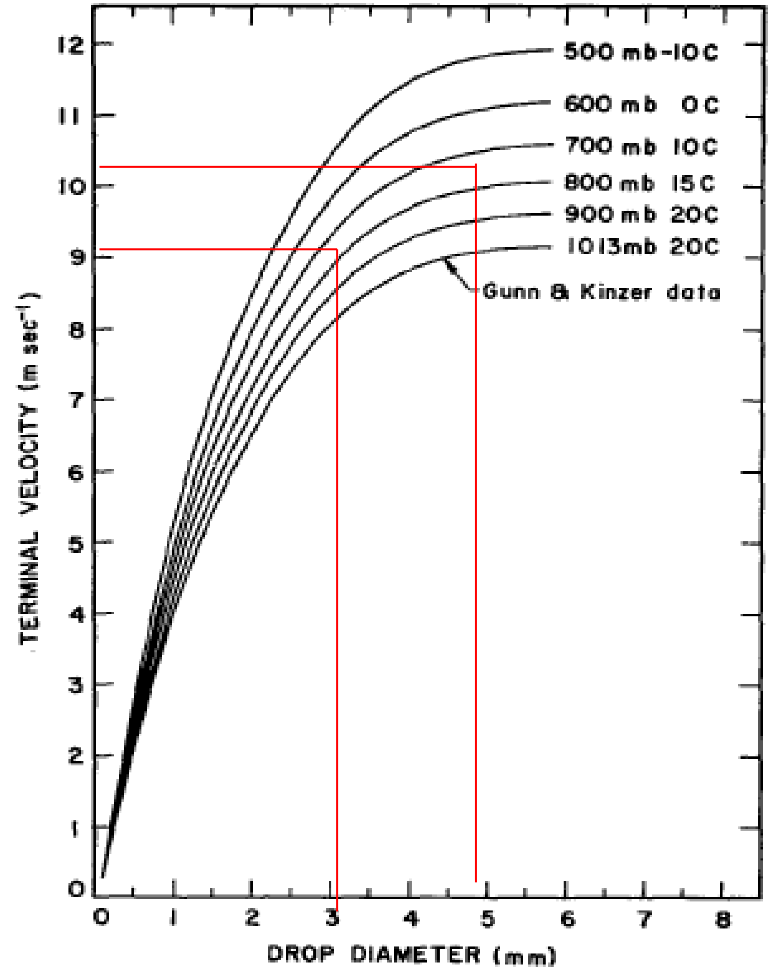

- Total of 630 calculations of $z_0$ from all stratiform bands
- Height ranges varying by 50 meters up to a height of 500 meters

# Variability



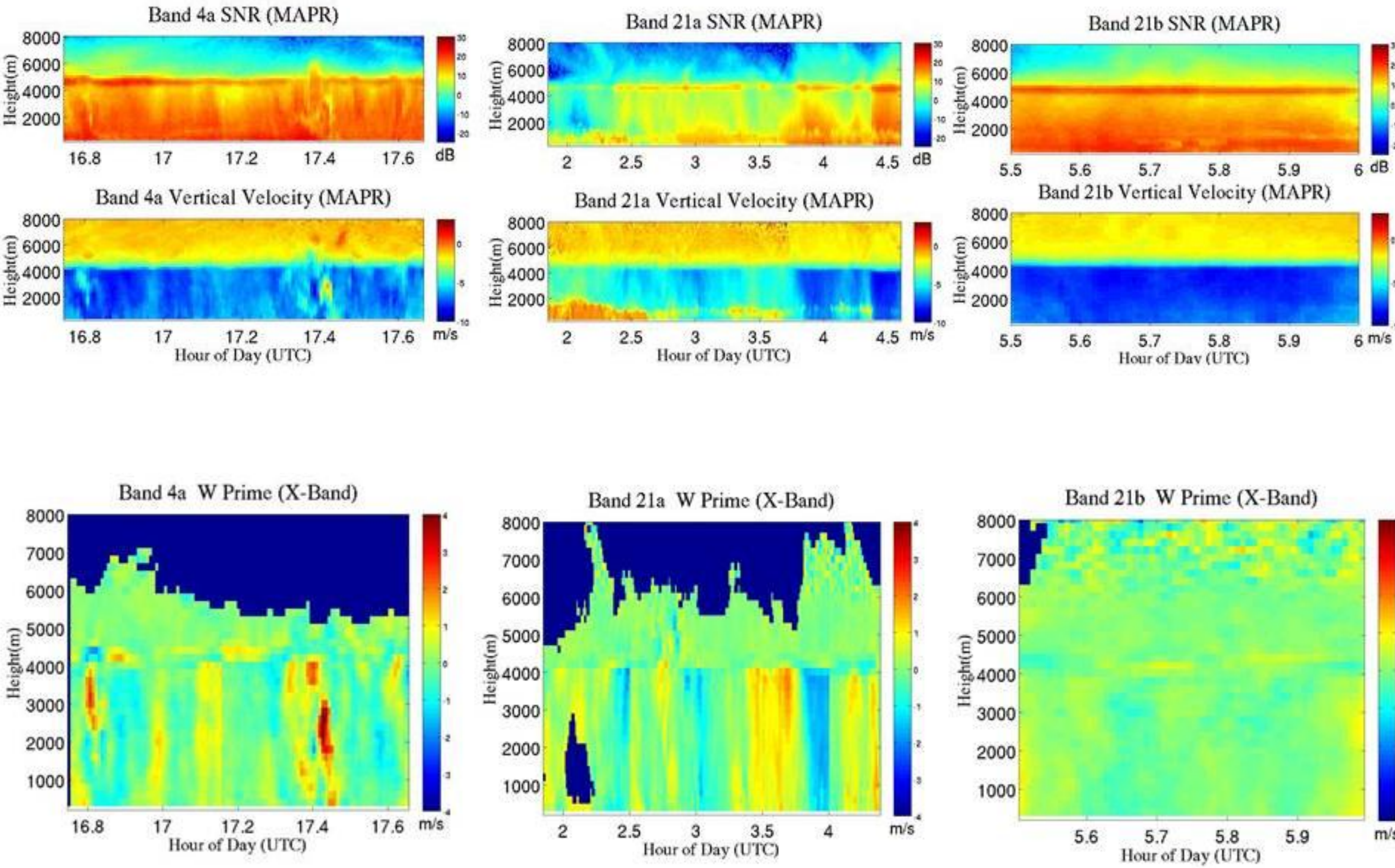
WP SNR, Band 9, 8/19/08
Height (km)
dB
WP Vertical Velocity 8/19/08
m/s
Hour of Day (UTC)
Band 9a SNR (MAPR)
Height(m)
Band 9a Vertical Velocity (MAPR)
WPrime at 2 km, Band 9a
XBand
MAPR
Scaled SNR
WPrime (m/s)
X-Band W Prime, Band 9, 8/19/2008



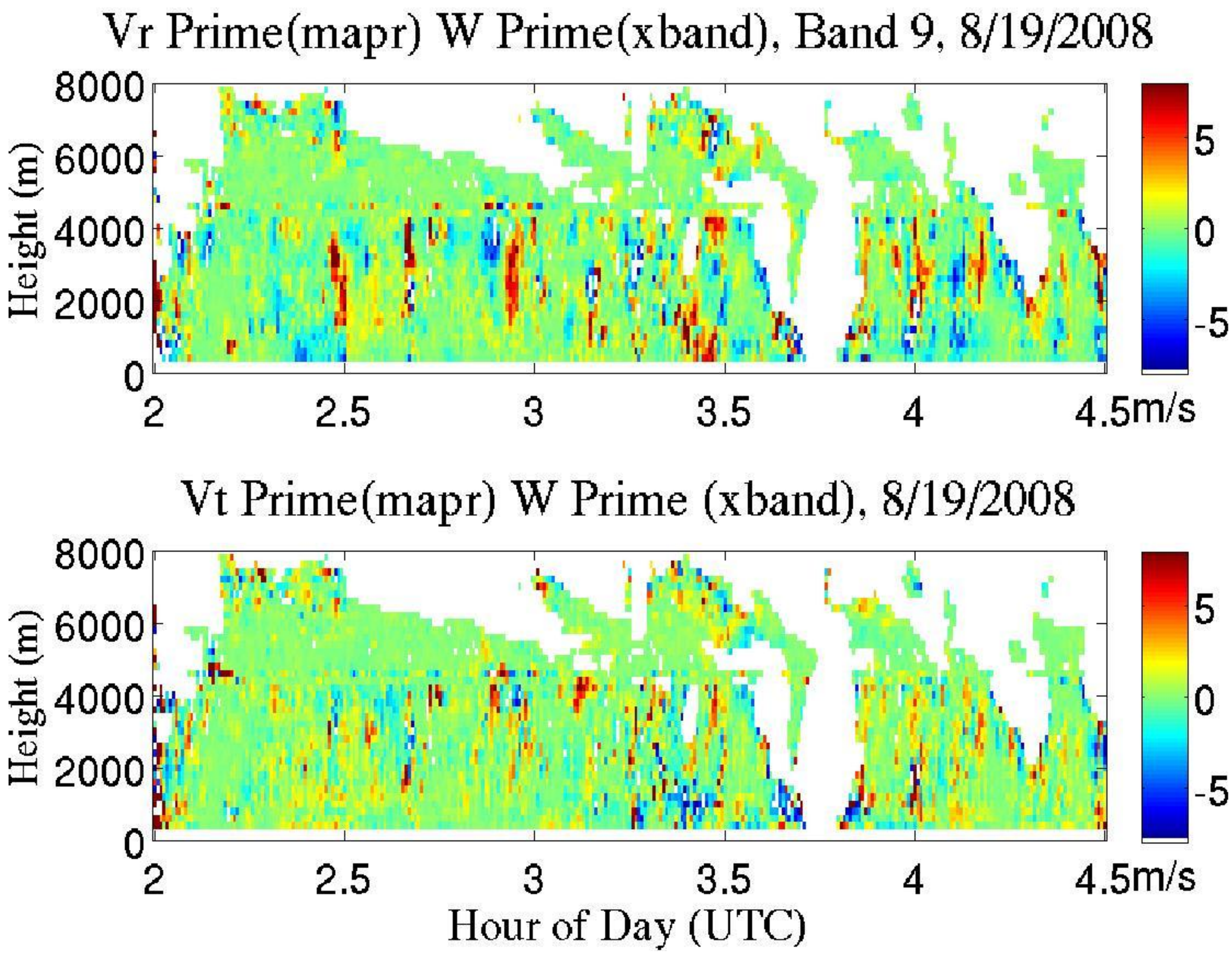




Foote and DuToit 1969

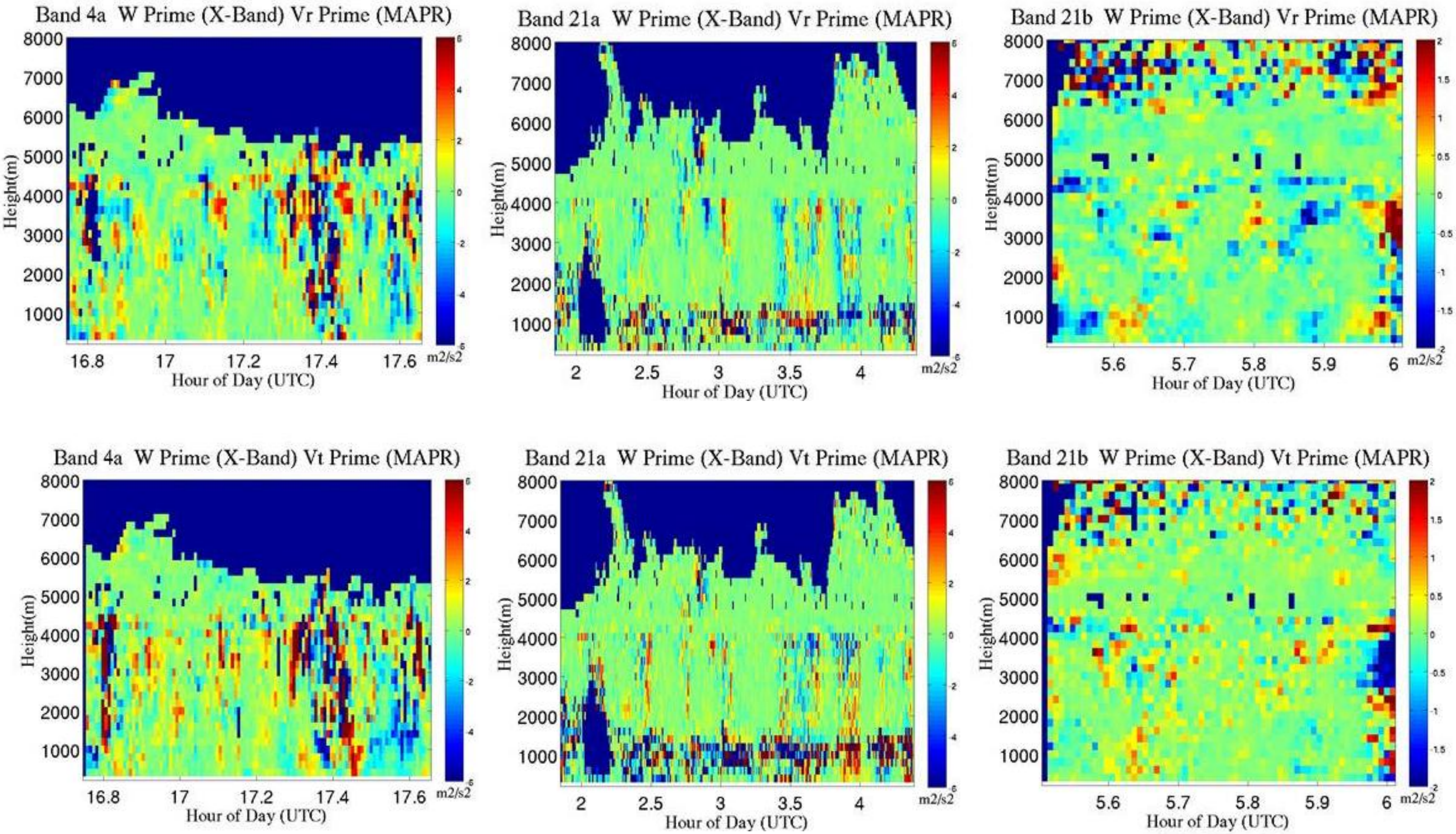
$w' \sim w'_{air}$ and $w'_{drops}$


Band 4a SNR (MAPR)
Band 21a SNR (MAPR)
Band 21b SNR (MAPR)
Band 4a Vertical Velocity (MAPR)
Band 21a Vertical Velocity (MAPR)
Band 21b Vertical Velocity (MAPR)
Band 4a W Prime (X-Band)
Band 21a W Prime (X-Band)
Band 21b W Prime (X-Band)
Height(m)
Hour of Day (UTC)
dB
m/s

# Fluxes: $\overline{w'V_r'}$ and $\overline{w'V_t'}$




λ~ 5.3 km

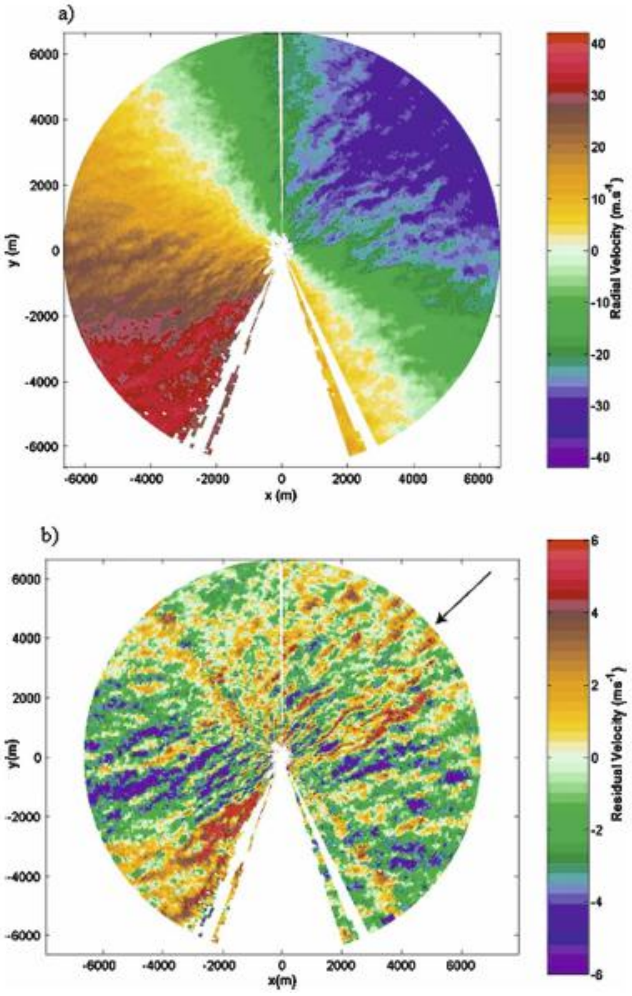



λ~ 3.6 km

λ~ 3.6 km

No discernible features

# Forcing Mechanisms: BL Rolls

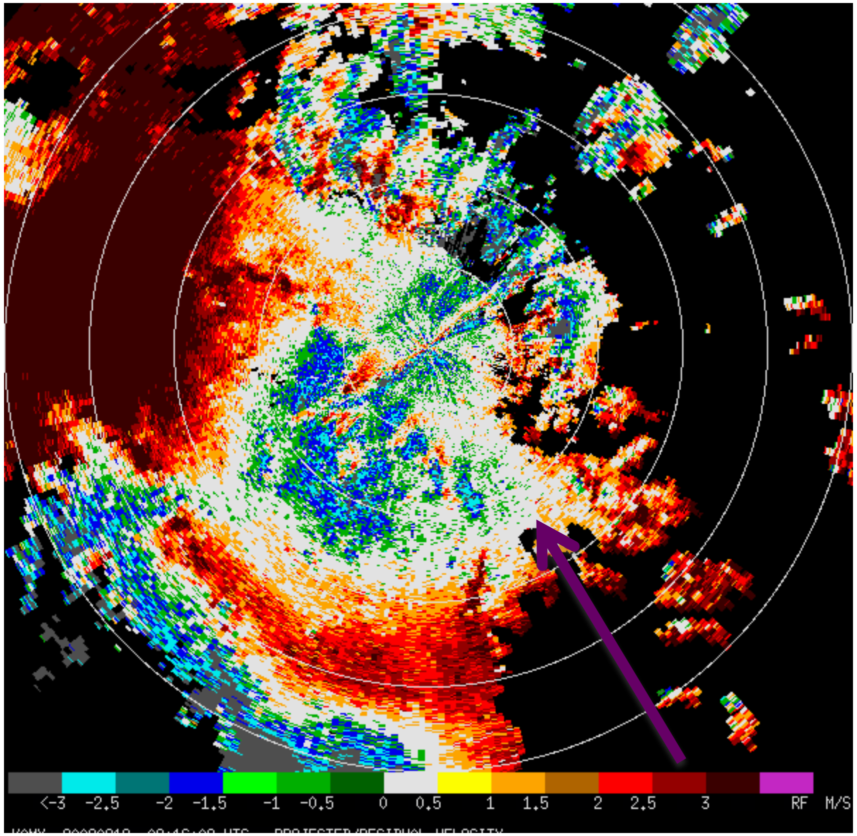



Lorsolo et al. 2008

- "Small scale features as linear structures"
- 500 m wavelength
- Below 1000-1500 m
- Aligned with the mean wind
- More defined in Frances than Isabel, but always present
- Can transport momentum upward

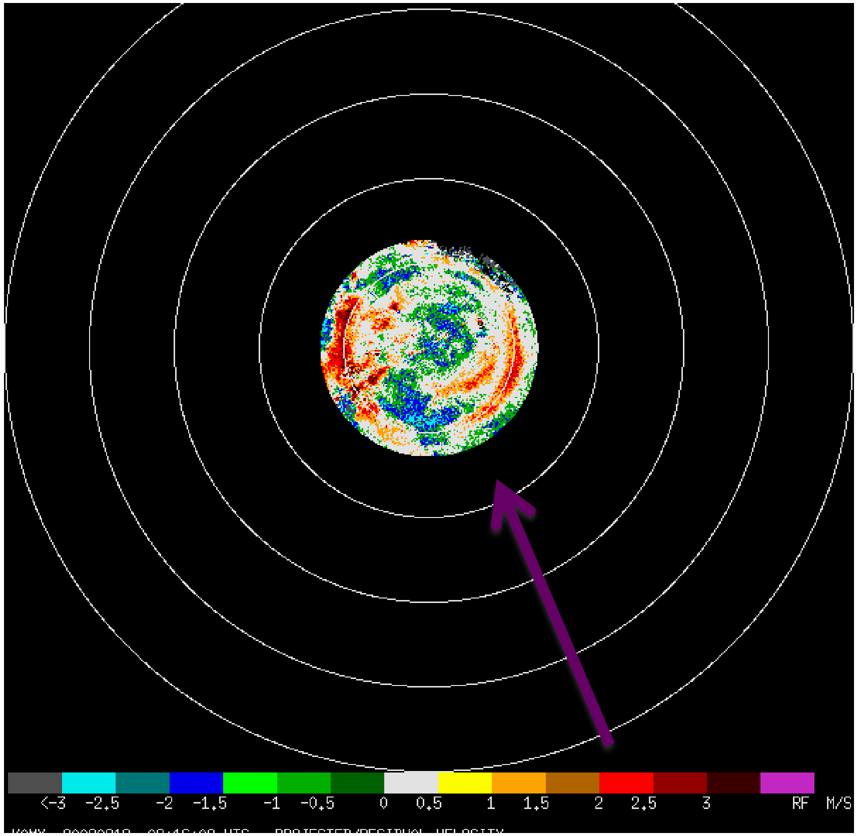
# Residual Radial Velocity

**3.1º Elevation Angle**



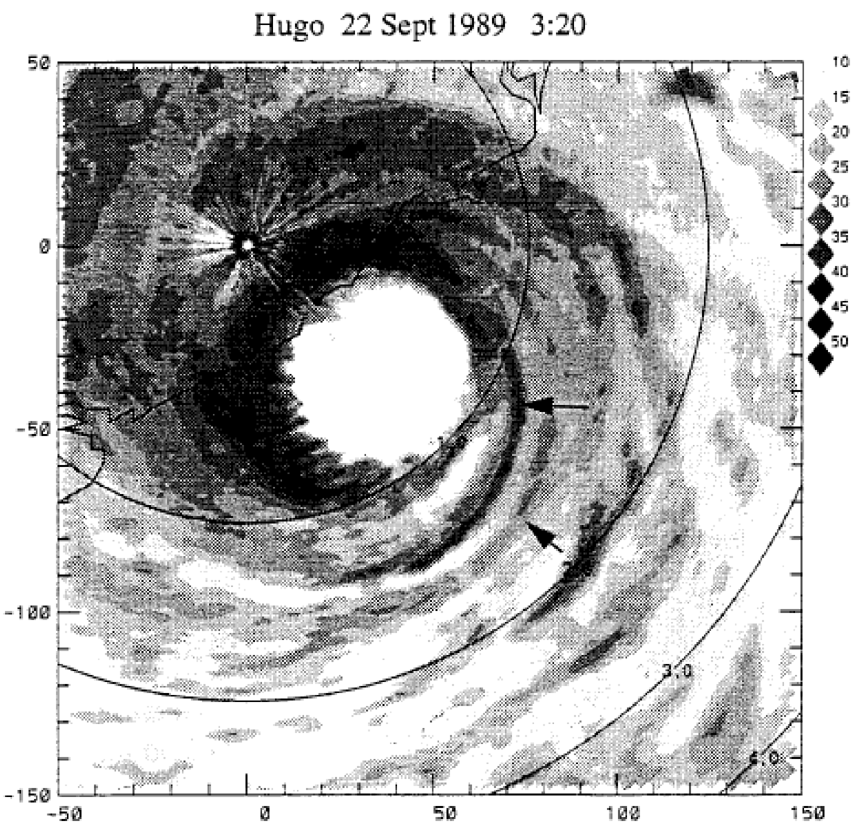

1.5 km wavelength

**15.6º Elevation Angle**




* Thanks to Ming Fang for providing these figures

# Finescale Bands



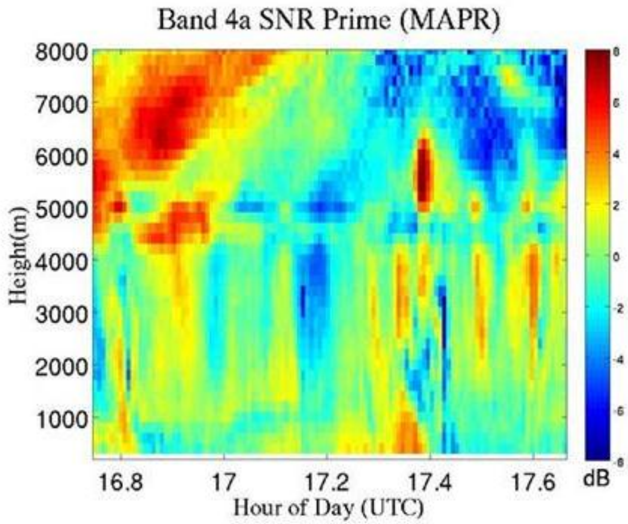

Gall et al. 1998

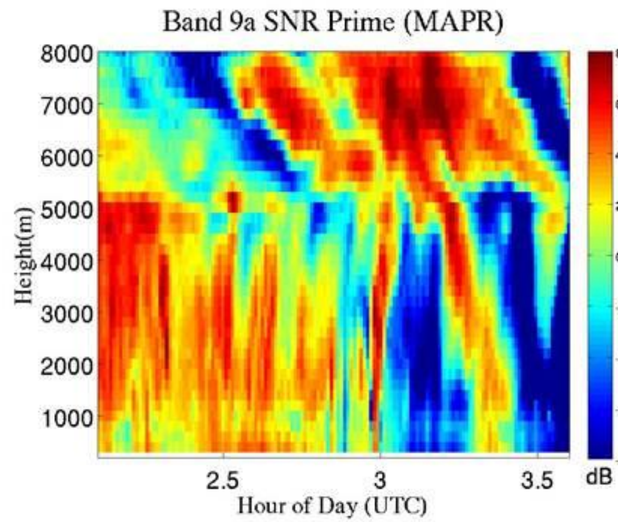
Regions of enhanced updrafts
$w' \sim 8$ m/s
$\lambda$ : 4-10 km
z: 6 km
Move with $V_t$

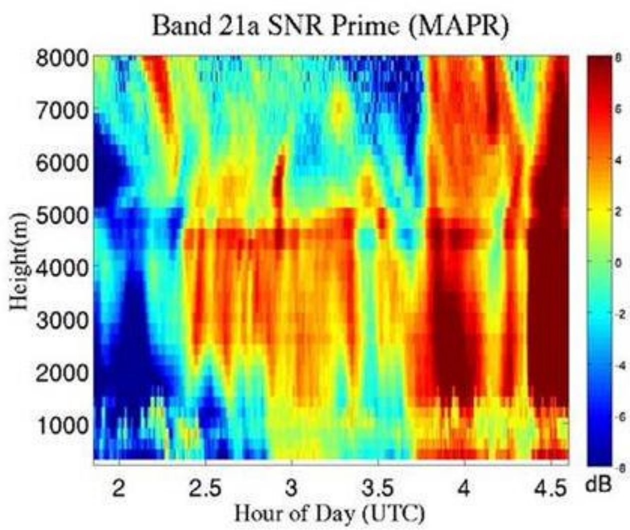
Triggered by strong (Cat 2) storms approaching land

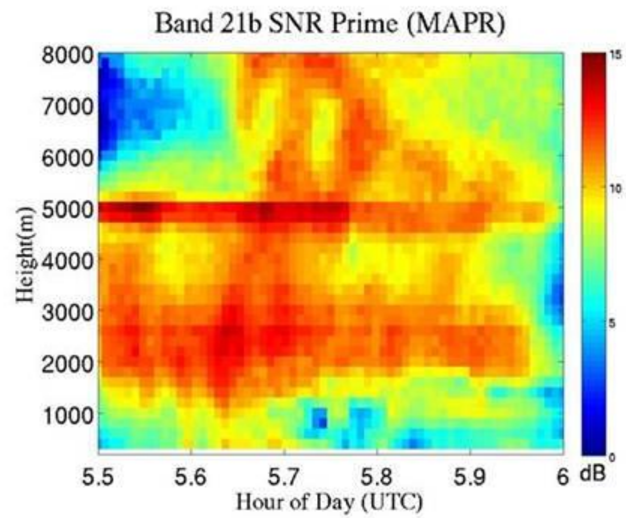
BL shear and K-H instability

# Forcing Mechanism: ML Processes



# Summary

# Rainband Summary

- VAD technique captures small-scale features in profile
- Main features (maxima, friction, inflow/outflow) present in all bands, but vary widely
- Time variation shows robustness of VAD features and evolution with time
- Logarithmic profile exists for each case, but does not give a universal $z_0$
- Vertical variability is a combination of $w'_{air}$ and $w'_{drops}$
- BL rolls and ML processes could be acting in combination to trigger perturbations

# Educational Applications

## An Assessment of Traditional vs. Inquiry-Based Lab Approaches for Undergraduate Meteorological Instruction

# Scientific Inquiry

The *National Science Education Standards* define scientific inquiry as "the activities through which students develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world."

- Inquiry is often used in the college classroom through forecasting (i.e. Yarger et al. 2000; Grundstein et al. 2011) or hands-on data collection (Cohn et al. 2006)

- *What is the best way to use non-real-time data in the classroom?*
  - *Can content learning and NOS learning be accomplished at the same time?*

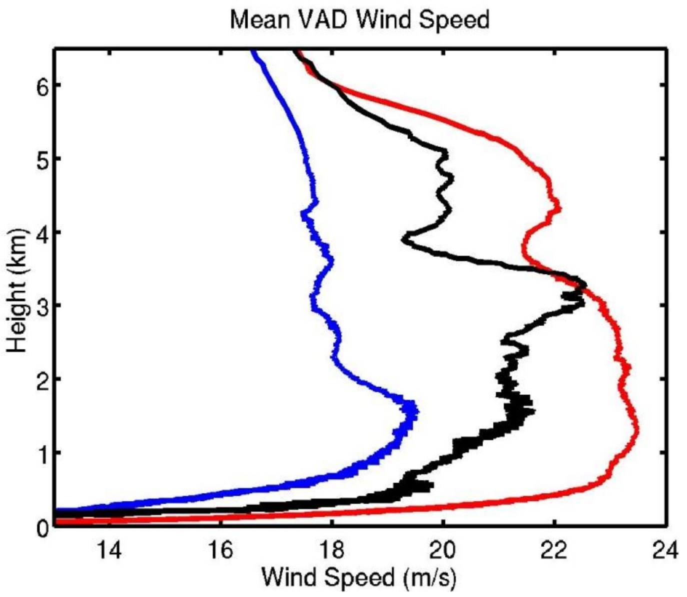
# Research Questions

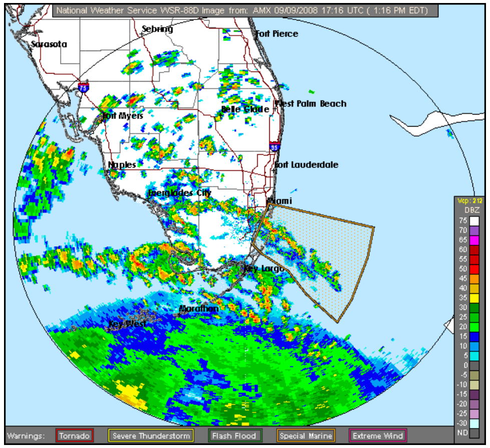
- Does inquiry with real-world data effectively convey content knowledge in an undergraduate meteorology classroom?
- Does this approach enhance students' understanding about the nature of science or improve their attitude towards science?
- Is this approach more or less effective than a traditional approach?
- What are the challenges associated with an inquiry approach and a traditional approach and how can they be overcome?

Study Group: METR4424

# Scientific Data

- 3 case studies (4a,9b,23a)
  - Radar
    - Mean wind speed
    - Radial and tangential wind
  - Soundings
    - Mean wind speed and direction
    - Temp, dwpt, RH
  - Supplemental
    - Surface, radar loops, storm information



# Methodology

**Day 1: Pretest and lecture**

- 51 students randomly drew numbers

-Pretest

-Lecture: experiment, instrumentation, and background info (radar operations, VAD technique, basics of tropical cyclones, and radial/tangential winds)

**Day 2: Inquiry** (27 students)

**Day 3: Traditional** (24 students)

**Day 4: Post-test and discussion**

-Post-test

-Whole-class discussion

**One month later: Content Retention Test**

# 2 Approaches

## Inquiry (guided)

- Whole class

  Each student on own laptop
- *Study all three wind components*

  *Look at change with band passage*
- Discussion of what data to use, came to consensus on results
- Answered their own ?'s

  I explained topics as needed

## Traditional

- Worked independently
- *Plot the VAD mean horizontal wind vs. height for each case.*

  *1a. Where is the wind maximum located in each case?*
- I helped with data/plotting issues
- Took 1.5 hours for most to finish

# Test Questions + Scoring

- Attitude
  - *Likert scale (1-5)*

  *Inquiry +*
  - *I enjoy learning how scientists work with data sets*

  *Traditional +*
  - *I prefer to follow lab instructions in a step-by-step approach*

5= Strongly Agree
4= Agree
3= Neutral
2= Disagree
1= Strongly Disagree

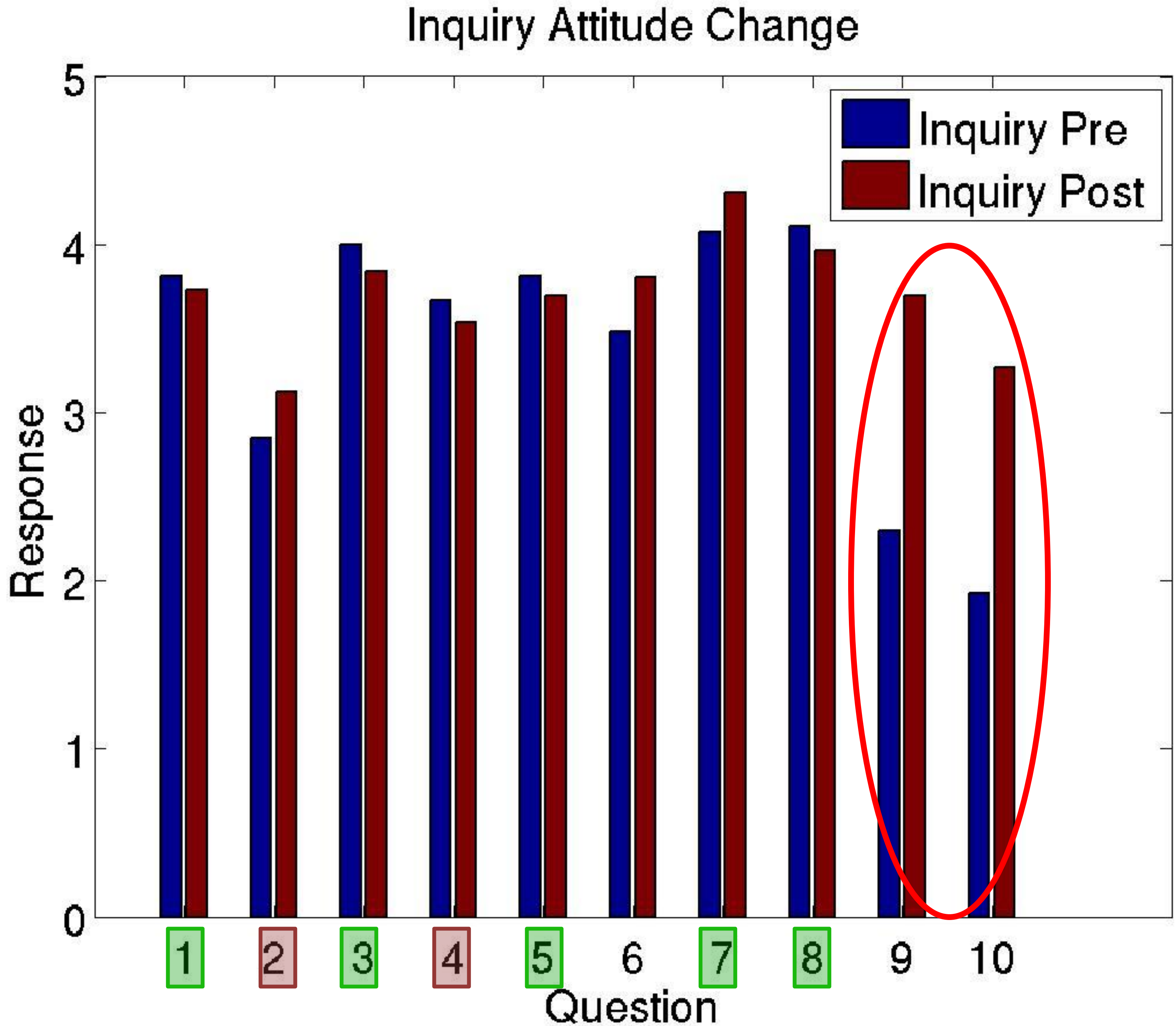
- Content
  - 10 Short Answer
    - *4 Point Rubric*
    - *Explain what radial and tangential winds are relative to a TC*
  - 1 Multiple Choice
    - *Which of the above profiles is most likely to be a mean wind profile in a TC rainband? Explain your reasoning.*

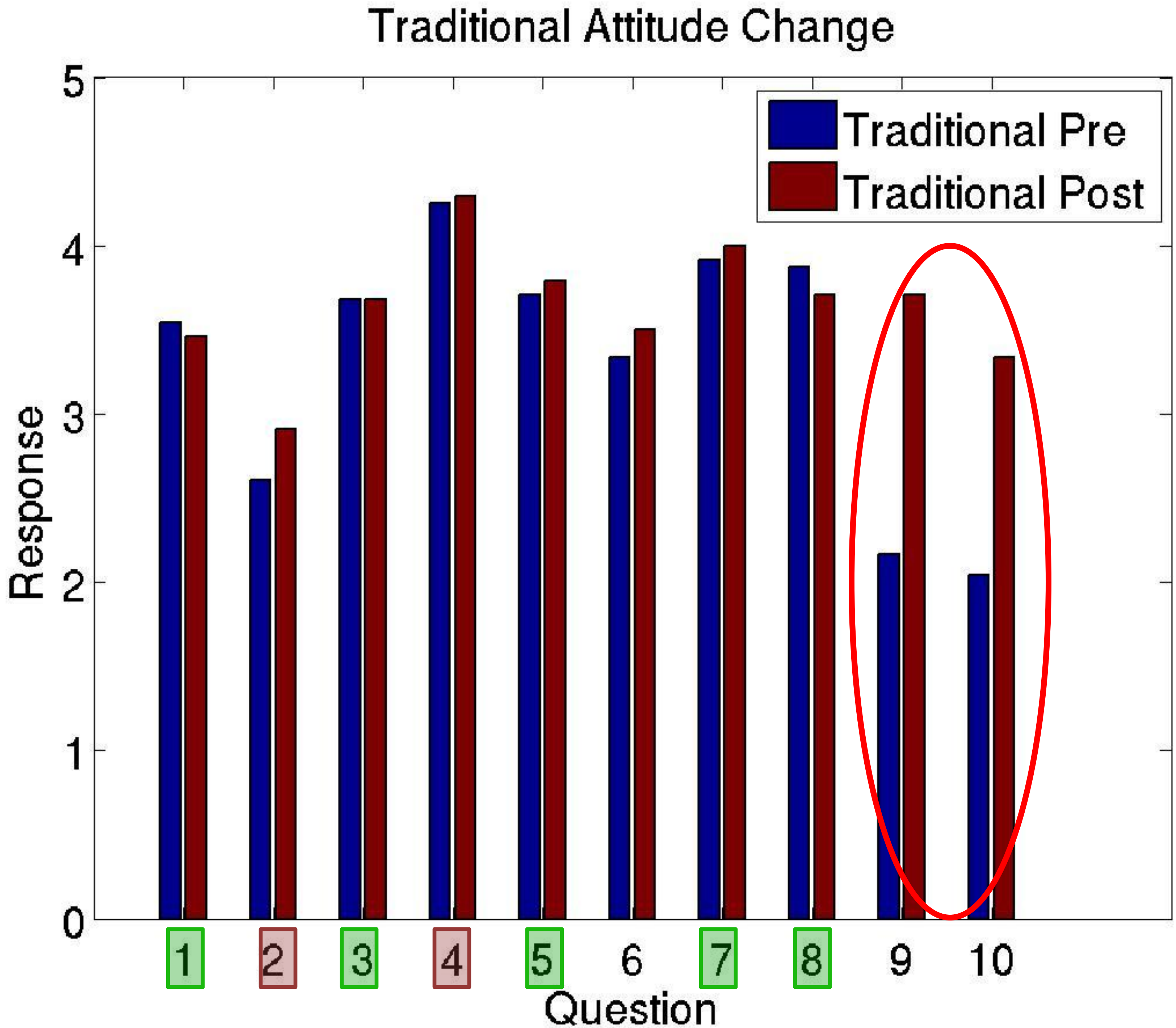
3= full correct answer
2= partial correct answer
1= incorrect answer
0= Blank / "Don't know" / "Don't remember"

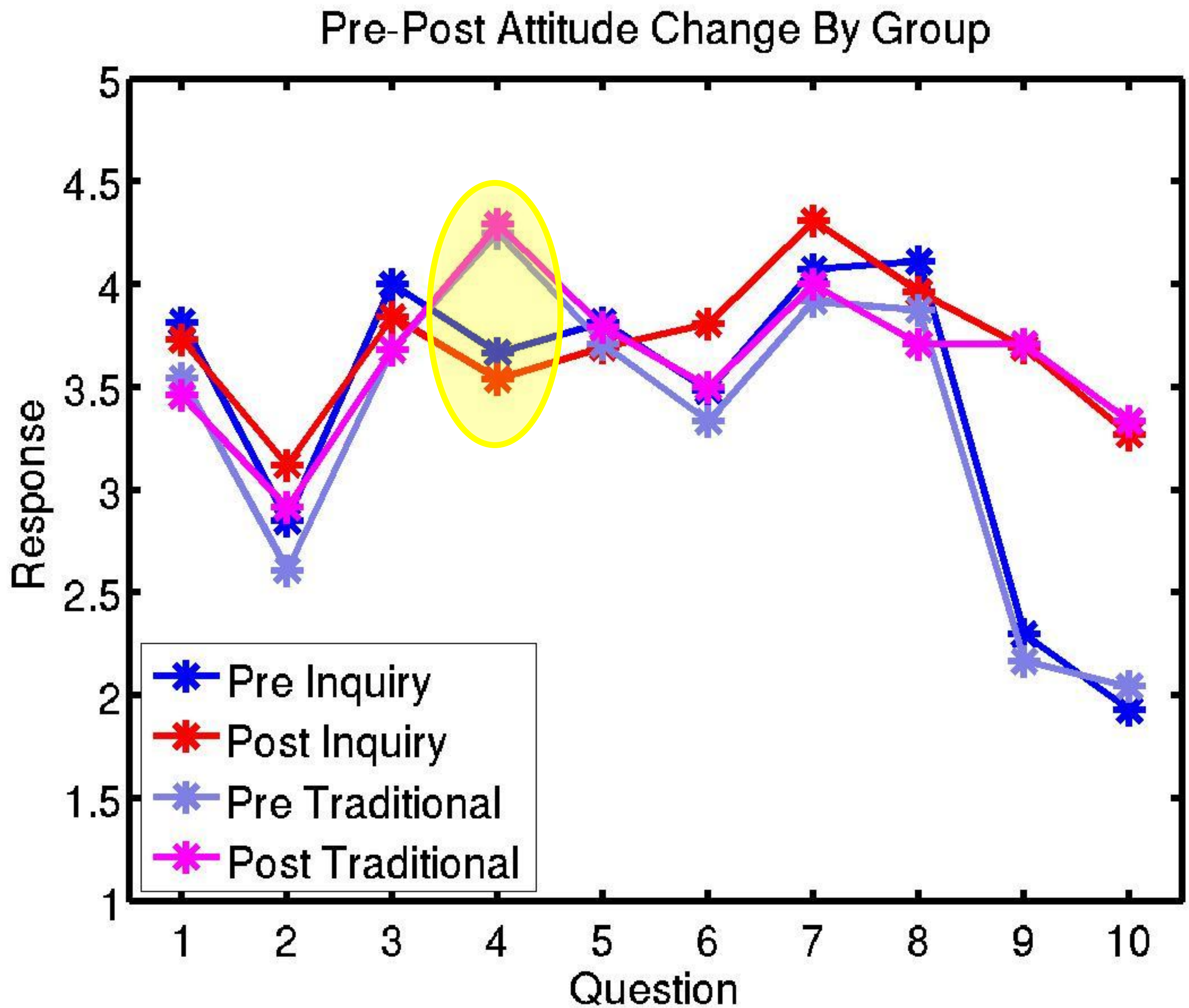
# RESULTS

Used one-way analysis of variance (ANOVA)

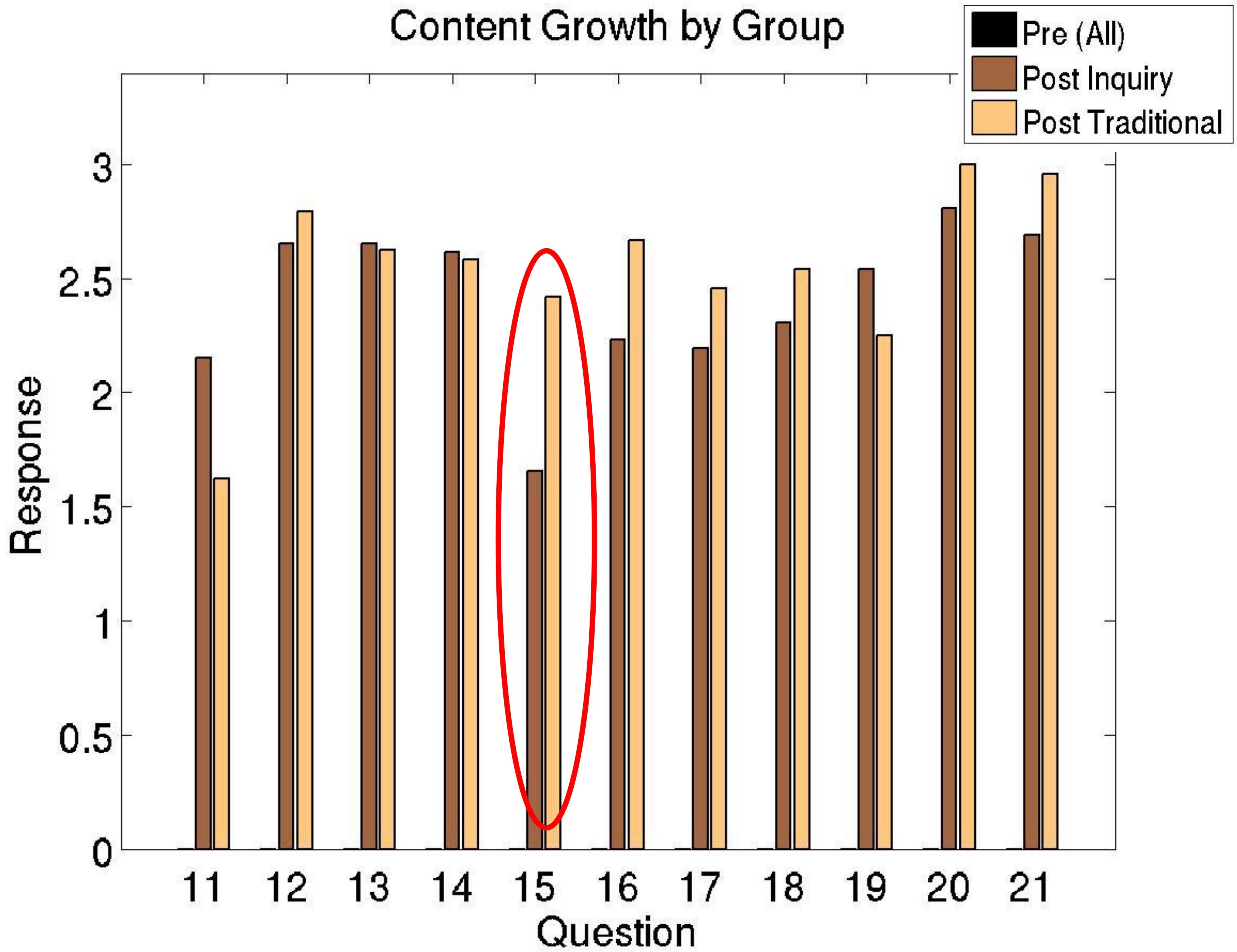
Changes in Attitude by Group
Changes in Content Knowledge by Group
Content Retention by Group


Inquiry Attitude Change
Inquiry Pre
Inquiry Post
Response
Question
0
1
2
3
4
5
1
2
3
4
5
6
7
8
9
10

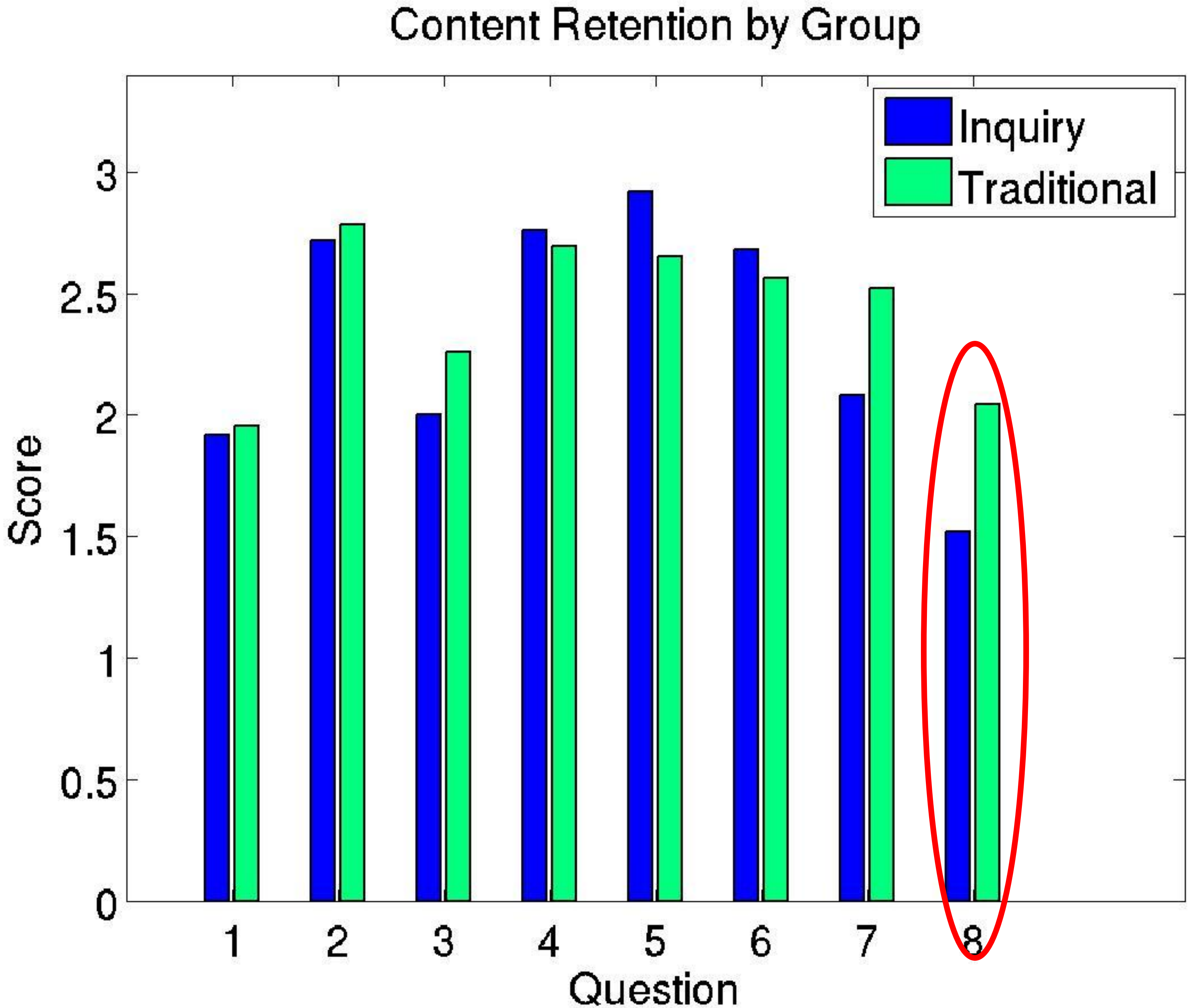

Traditional Attitude Change
Traditional Pre
Traditional Post
Response
Question
0
1
2
3
4
5
1
2
3
4
5
6
7
8
9
10



Pre-Post Attitude Change By Group
Response
Question
5
4.5
4
3.5
3
2.5
2
1.5
1
1
2
3
4
5
6
7
8
9
10
Pre Inquiry
Post Inquiry
Pre Traditional
Post Traditional



Content Growth by Group
Pre (All)
Post Inquiry
Post Traditional
Response
Question
0
0.5
1
1.5
2
2.5
3
11
12
13
14
15
16
17
18
19
20
21


Content Retention by Group
Inquiry
Traditional
Score
0
0.5
1
1.5
2
2.5
3
1
2
3
4
5
6
7
8
Question

# Conclusions

- Both groups had no statistically significant attitude changes about science labs

- Both had significant content growth

- Only minor significant differences in content growth or retention by group
  - Favors traditional

**Inquiry-based learning approach using real-world data was effective at conveying content knowledge.**

# Discussion

- Preference for other group
- Technology had largest influence on attitude
- Both had challenges
  - Traditional
    - Wanted more feedback during lab
    - Couldn't discuss how to plot
    - Found it boring and repetitive
  - Inquiry
    - Struggled to keep pace with group
    - Too much focus on plotting, not enough on learning

These challenges can be overcome by providing students with more opportunity to become familiar with the technology and providing teacher scaffolding as they build their inquiry skills.

# Acknowledgements


<u>Committee</u>
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359


Thank You!