A discussion of WIND Profilers

- Lehmann et al. WMO/WIGOS workshop; 201: https://www.wmo.int/pages/prog/www/IMOP/meetings/SI/LangenWorkshop/Langen_Doc_Plan.html
- *I use heavily from Dan Wolfe and Steve Cohen [AMS Short Course on the Fundamentals of Boundary Layer Wind and Temperature Profiling using: Radar and Acoustic Techniques, 8-9 February 2003, Long Beach, California*
- https://psl.noaa.gov/data/obs/instruments/WindProfilerDescription.htmlhttps://psl.noaa.gov/data/obs/instruments/WindProfilerDescription.html

WIND how is it measured?

The WMO Integrated Global Observing System (WIGOS)

Vertical profiles of wind vector:

Ground based:

- *Radiosondes*
- *Pilot-Balloons*
- *Aircraft*
- *Wind profilers*
- *(Weather radars)*

Space based:

- *AMV's*
- *Indirect (through mass field)*

From WMO WIGOS-Flyer: http://www.wmo.int/pages/prog/www/wigos/index_en.html

We will discuss radars

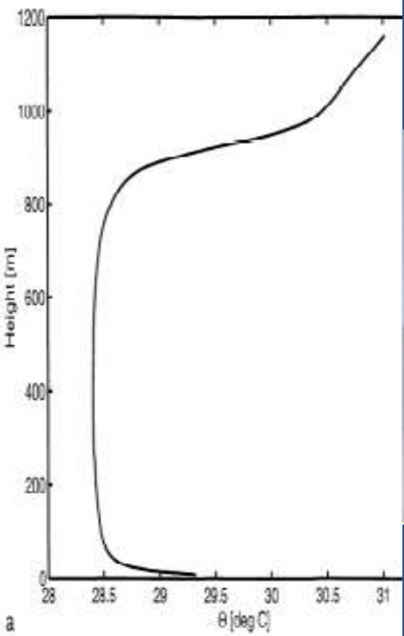
WIND Profilers: Basics (clear air)

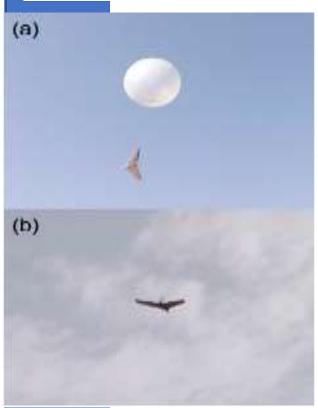
Refractive Index - n: $(n-1)_{Air} = \frac{k_1}{z_a}\frac{p}{T} + \frac{k_2}{z_w}\frac{e}{T} + \frac{k_3}{z_w}\frac{e}{T^2}$ or Using ➔ $N = (n-1)\cdot 10^6$

$$N = 77.6\frac{p}{T} + 71.6\frac{e}{T} + 3.7\cdot 10^5\frac{e}{T^2}$$

$$C_n^2 = \frac{\langle [n(r+\delta) - n(r)]^2 \rangle}{|\delta|^{2/3}}$$

https://angeo.copernicus.org/articles/34/767/2016/angeo-34-767-2016.pdf





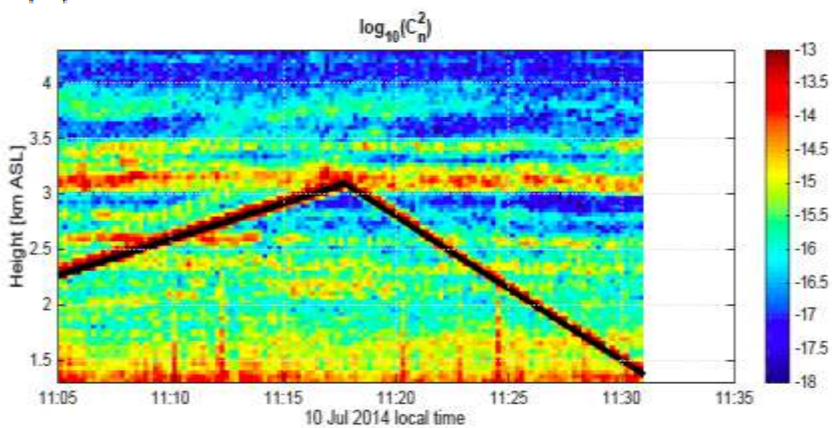
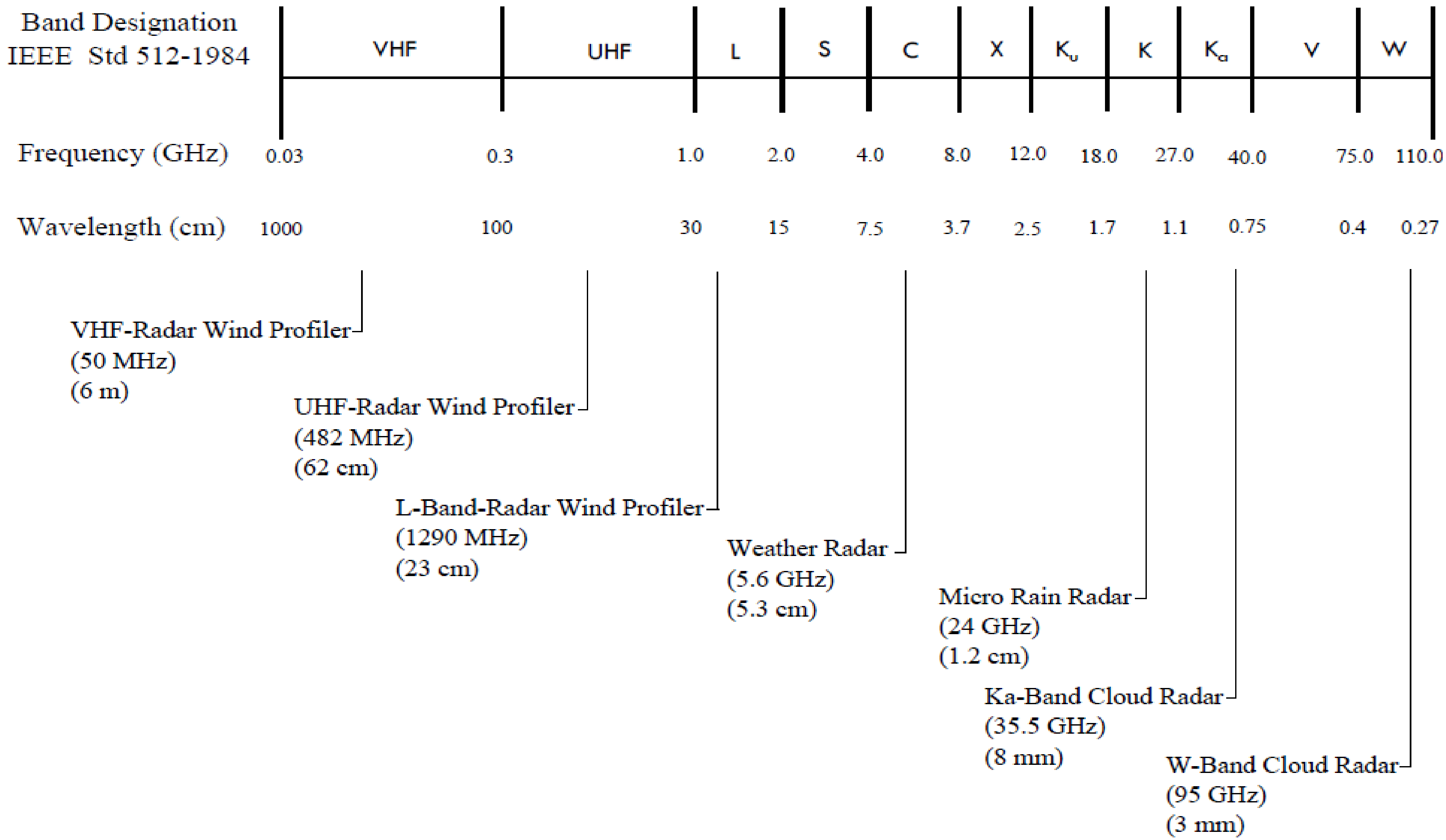


Figure 5. The black line represents the DataHawk altitude as a function of time plotted on top of the calibrated range-corrected received power for the morning flight (11:05–11:30). The DataHawk was dropped by a tethered balloon at an approximate altitude of 2.25 km. In this case, there is an ascent from its initial altitude to 3 km, followed by a descent over SOUSY down to 1.5 km.

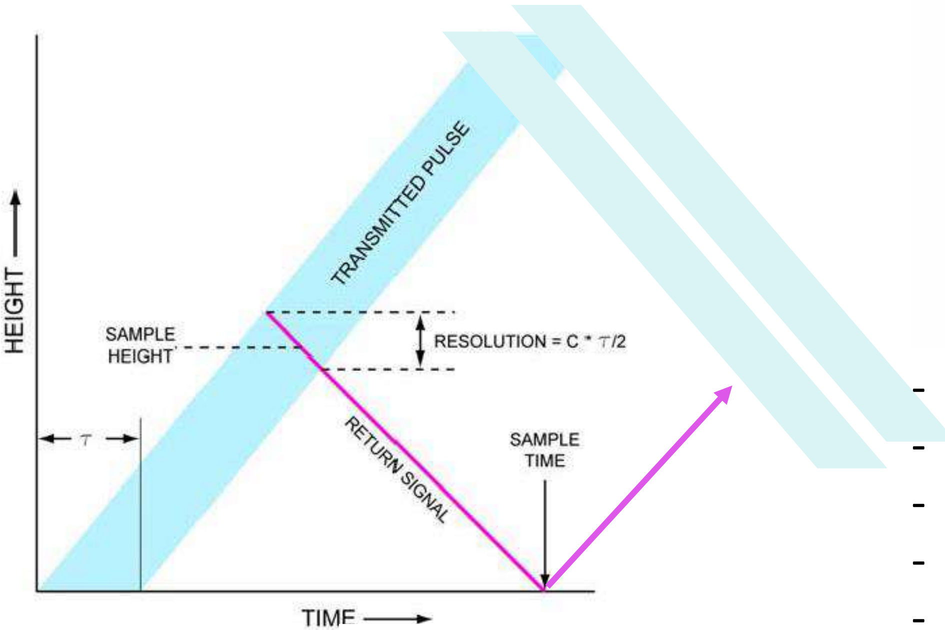
WIND Profilers: Frequencies

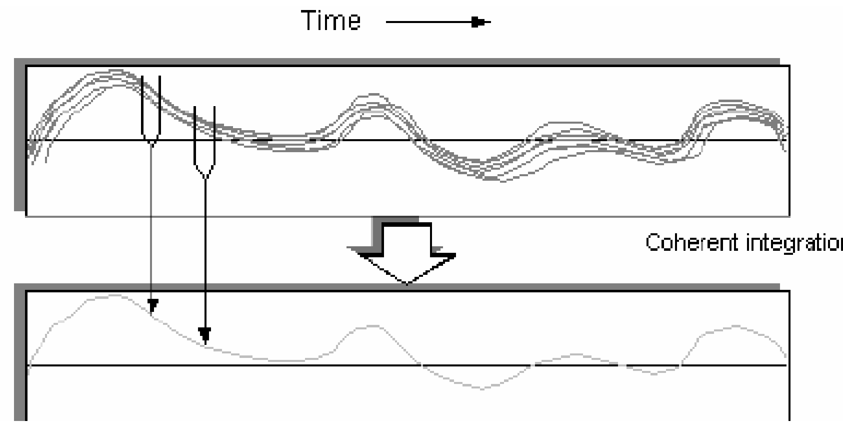
Radar frequencies used in Meteorology



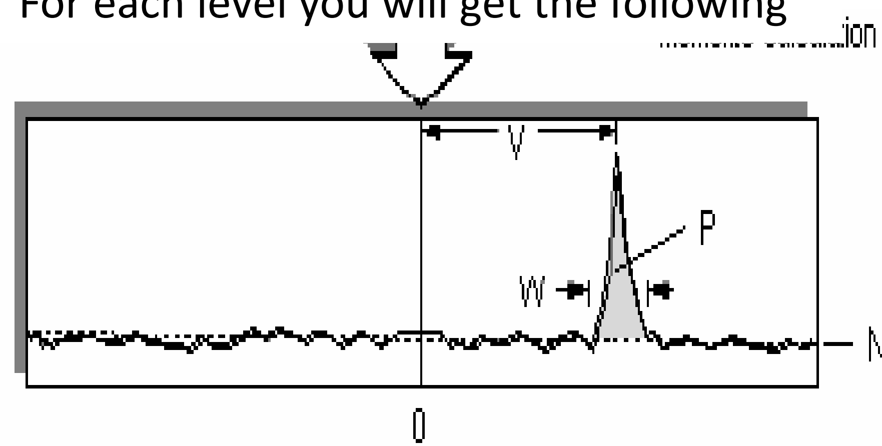
We will see the performance difference in a minute ...

WIND Profilers: Basics





- time to frequency domain conversion
- Spectral averaging, windowing,
- trend removal,
- Noise level detection
- For each level you will get the following



Doppler **Shift** ➔ $$\overline{f_D} = \sum_{i=f_1}^{f_2} f_i S(f_i) \Big/ \sum_{i=f_1}^{f_2} S(f_i)$$

Doppler width ➔ $$V_D = 2\sqrt{\sum_{i=f_1}^{f_2} ((f_i - \overline{f_D})^2 S(f_i)) \Big/ \sum_{i=f_1}^{f_2} S(f_i)}$$

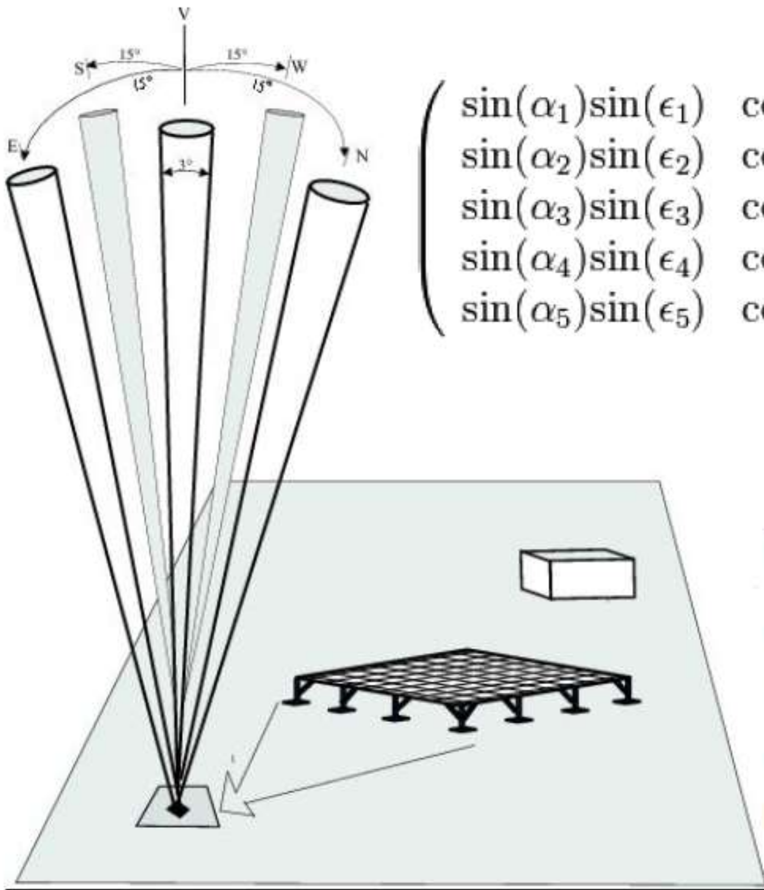
- Noise level: Calculated assuming gaussian noise
- Signal-to-Noise ratio: Ratio power/Noise

4- quantities: ***Backscattered power ; Noise level; Doppler shift; W: Spectral width***

- *Quantities calculated at each range gate, beam pointing direction, etc.;*
- *expressed in decibel (dB) - ratio between two values (e.g. signal-to-noise ratio)*

WIND Profilers: From line of site shift to full wind profiling by design

- Estimation of Doppler shift along 3-5 beams
- Calculation of u, v, w from radial velocities

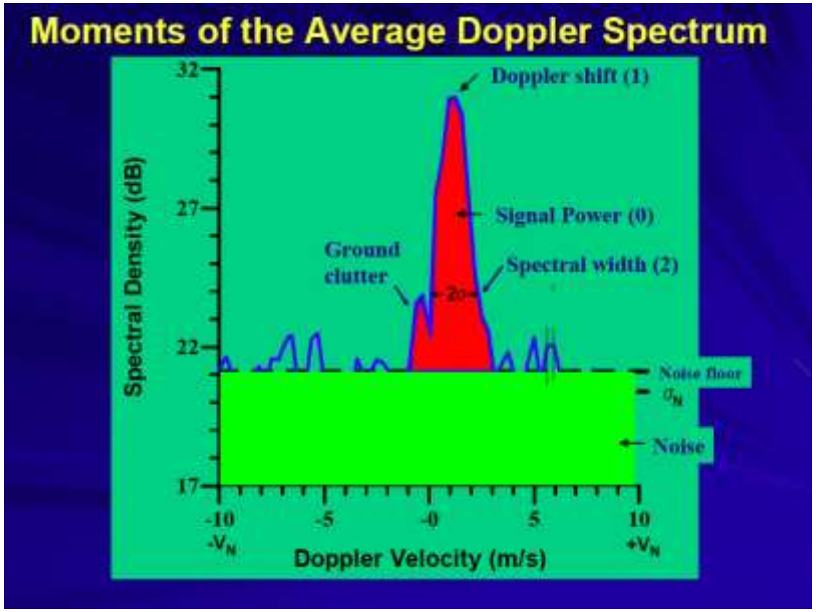


$$\begin{pmatrix} \sin(\alpha_1)\sin(\epsilon_1) & \cos(\alpha_1)\sin(\epsilon_1) & \cos(\epsilon_1) \\ \sin(\alpha_2)\sin(\epsilon_2) & \cos(\alpha_2)\sin(\epsilon_2) & \cos(\epsilon_2) \\ \sin(\alpha_3)\sin(\epsilon_3) & \cos(\alpha_3)\sin(\epsilon_3) & \cos(\epsilon_3) \\ \sin(\alpha_4)\sin(\epsilon_4) & \cos(\alpha_4)\sin(\epsilon_4) & \cos(\epsilon_4) \\ \sin(\alpha_5)\sin(\epsilon_5) & \cos(\alpha_5)\sin(\epsilon_5) & \cos(\epsilon_5) \end{pmatrix} \begin{pmatrix} u \\ v \\ w \end{pmatrix} = \begin{pmatrix} v_{r1} \\ v_{r2} \\ v_{r3} \\ v_{r4} \\ v_{r5} \end{pmatrix}$$

Assumptions:
- Uniform wind field across sampled volume (2.5 km @ z=5 km)
- Stationary wind field over measurement time (~ 30 min)

the system cycles through five beams (South, North, East, West, and vertical) at low power and high power (longer pulse length) setting. In ~ 5minutes.

WIND Profilers: What else?



Signal processing problem: How to find the signal and uncertainty when you have

- Low SNR
- Noise
- Ground clutter
- Moving clutter targets
- Radio-frequency interference (RFI)
- Aliasing

Assumptions:

- Moments input is of good quality
- Wind field is close to linear
- Vertical wind has no horizontal shear
- The wind field is stationary in time and space

Maximize your confidence (QC):

Consensus Time (e.g. 30 min; ARM ~ 1hr)

- Consensus Window (e.g. W=2 m/s)
- Consensus Threshold (e.g P=60%)

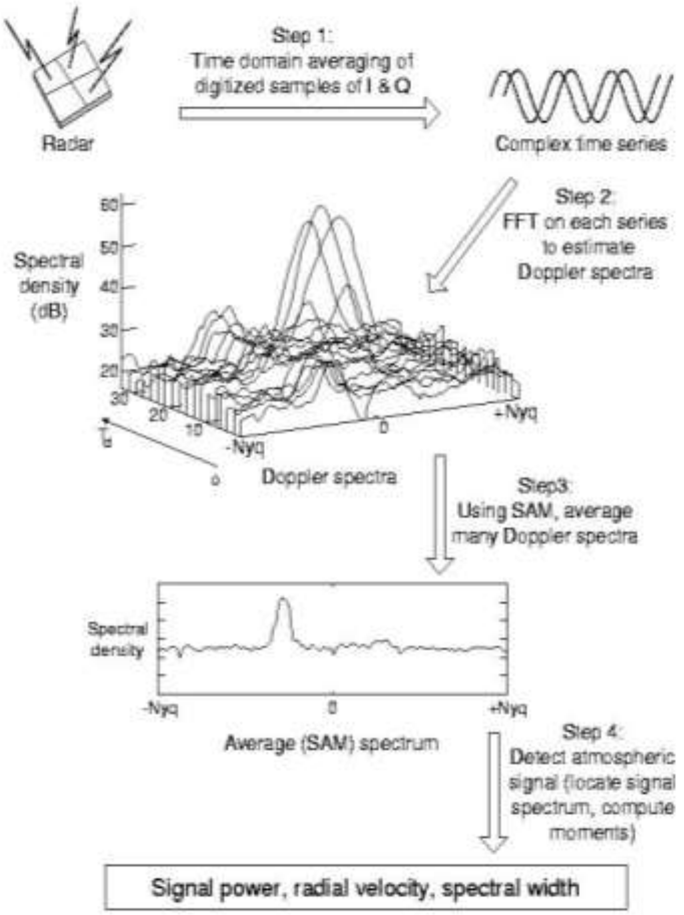
Question: Can we find a window of W m/s that contains at least P (%) of the measured velocities?

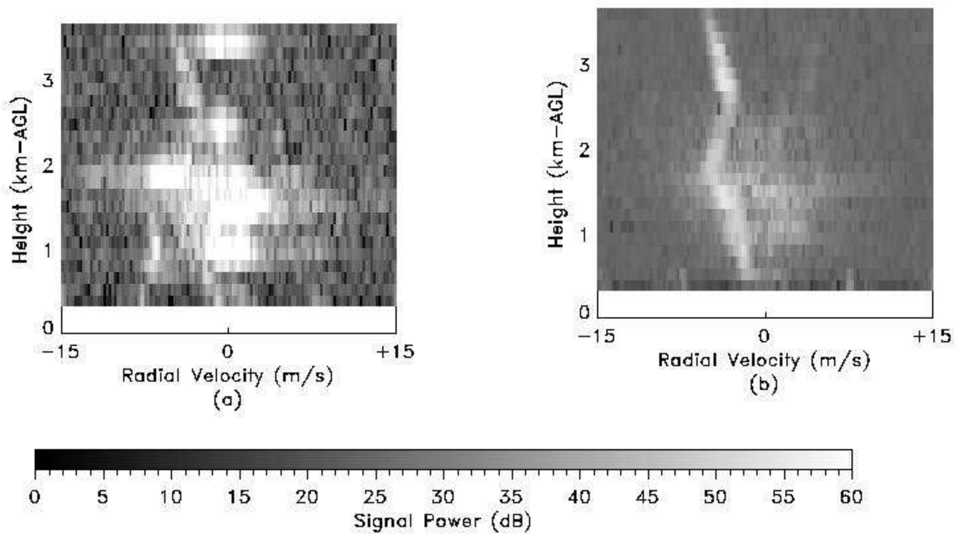
- No….no value reported
- Yes…value reported is the mean of the points within the defined window

Read more on QC: https://journals.ametsoc.org/jtech/article/20/11/1488/99567/Performance-of-Five-915-MHz-Wind-Profilers-and-an

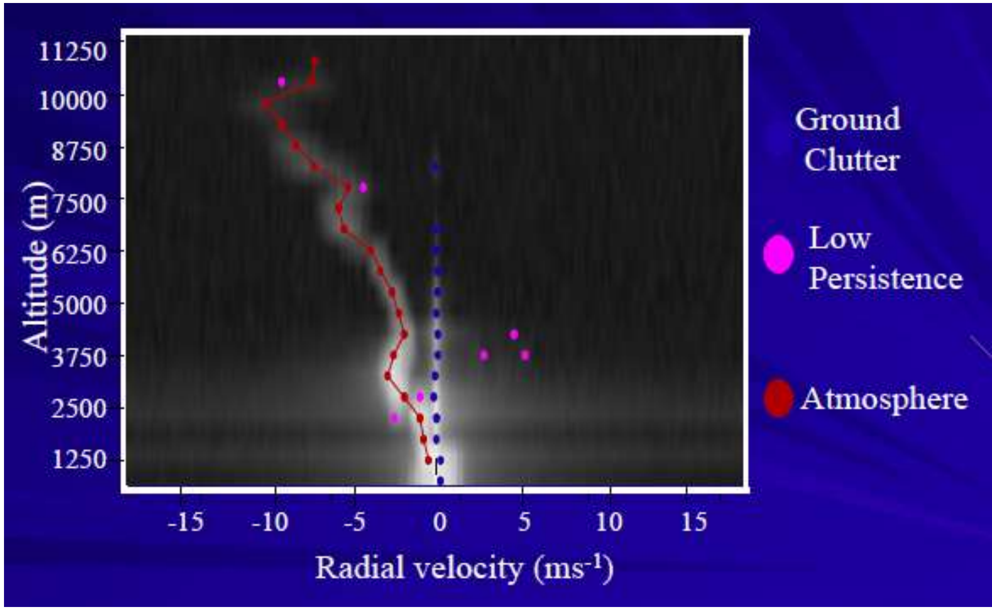
WIND Profilers: Processing – many methods

SATISTICAL AVERAGING METHOD (SAM)
Merritt D.A. 1995 JTech 12

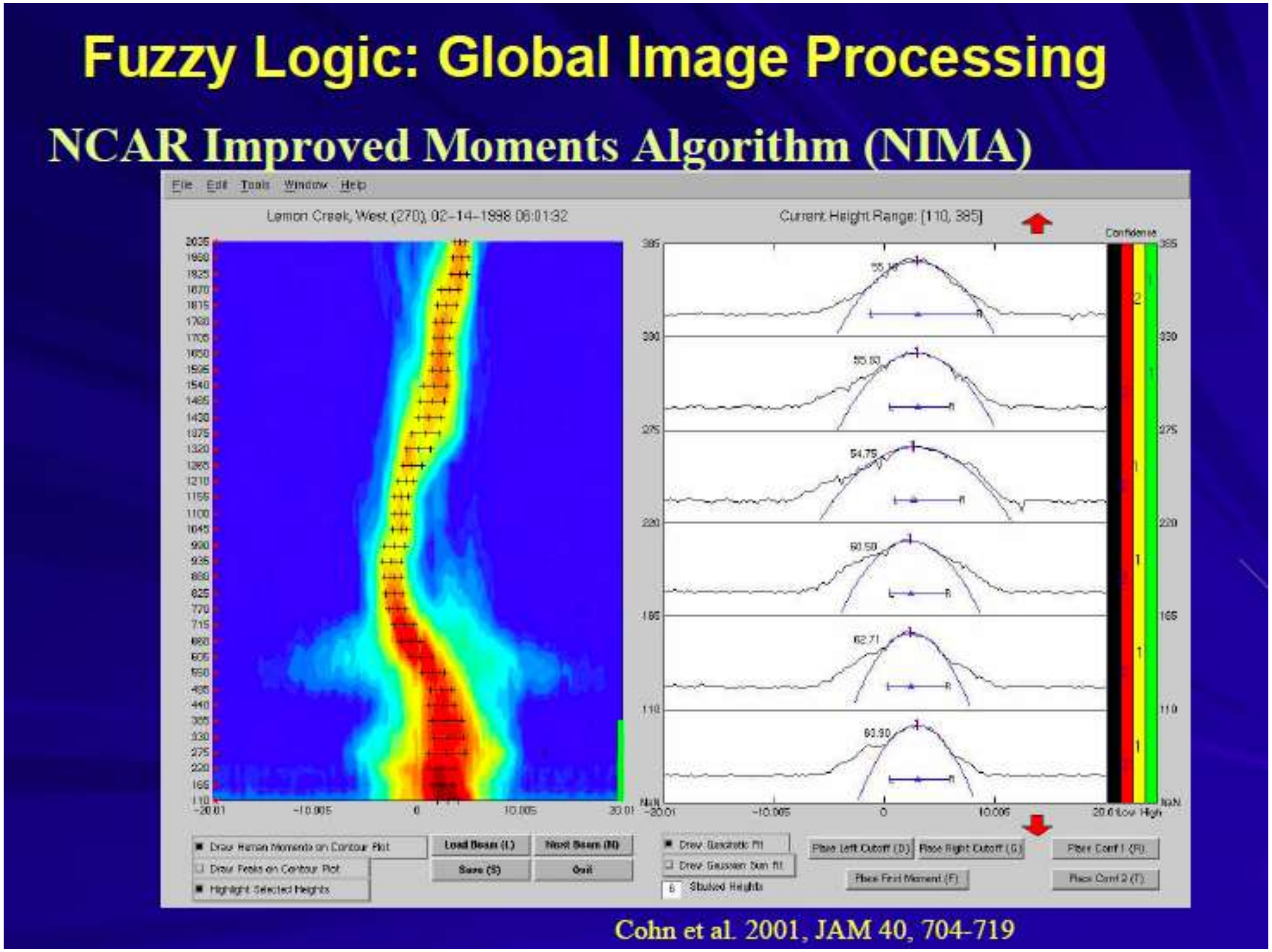




Clothiaux et al. JTech 11 (1994)

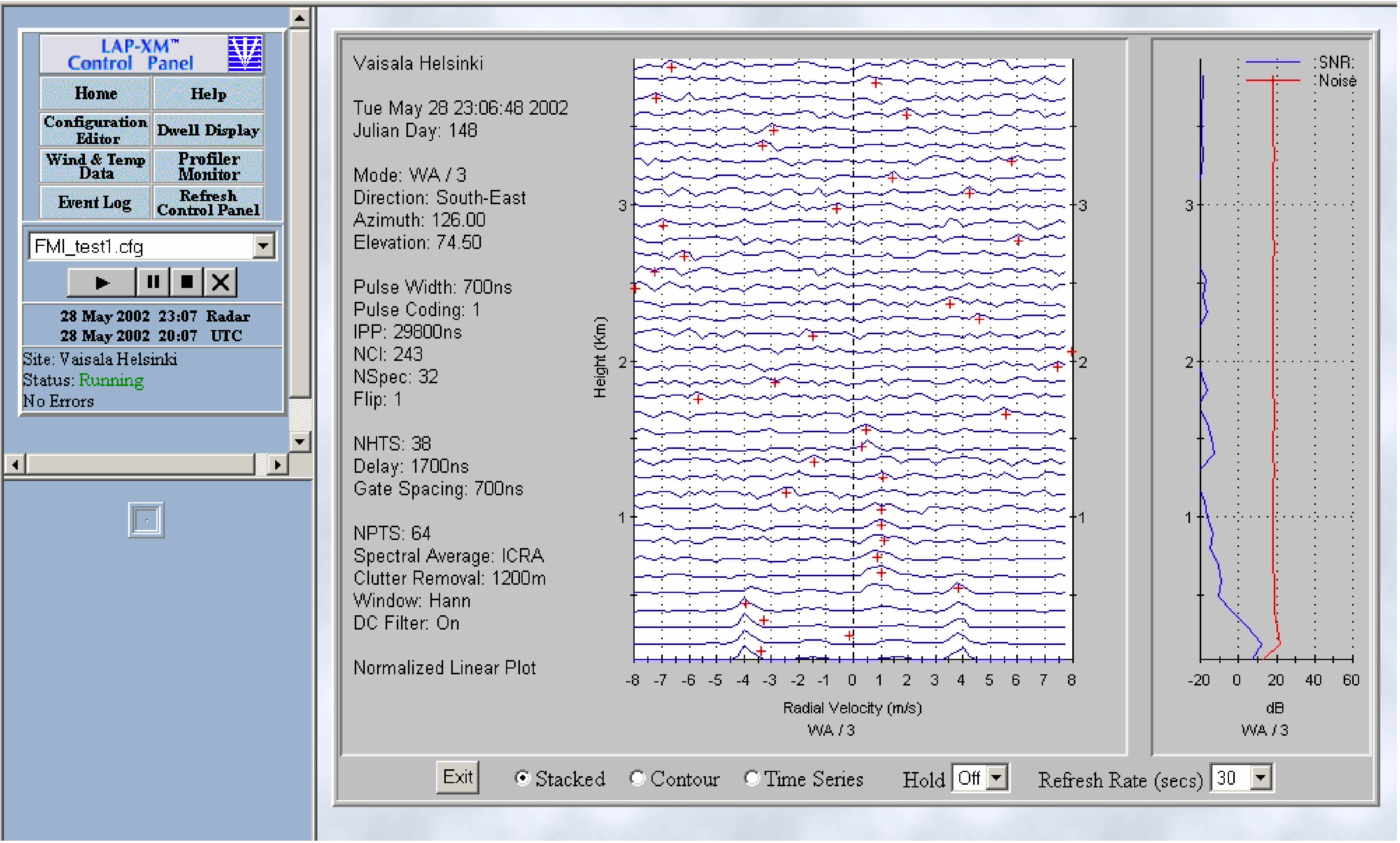


WIND Profilers: processing



Cohn et al. 2001, JAM 40, 704-719

WIND Profilers: Find the signal



If no COVID-19 you would see this at Beltsville

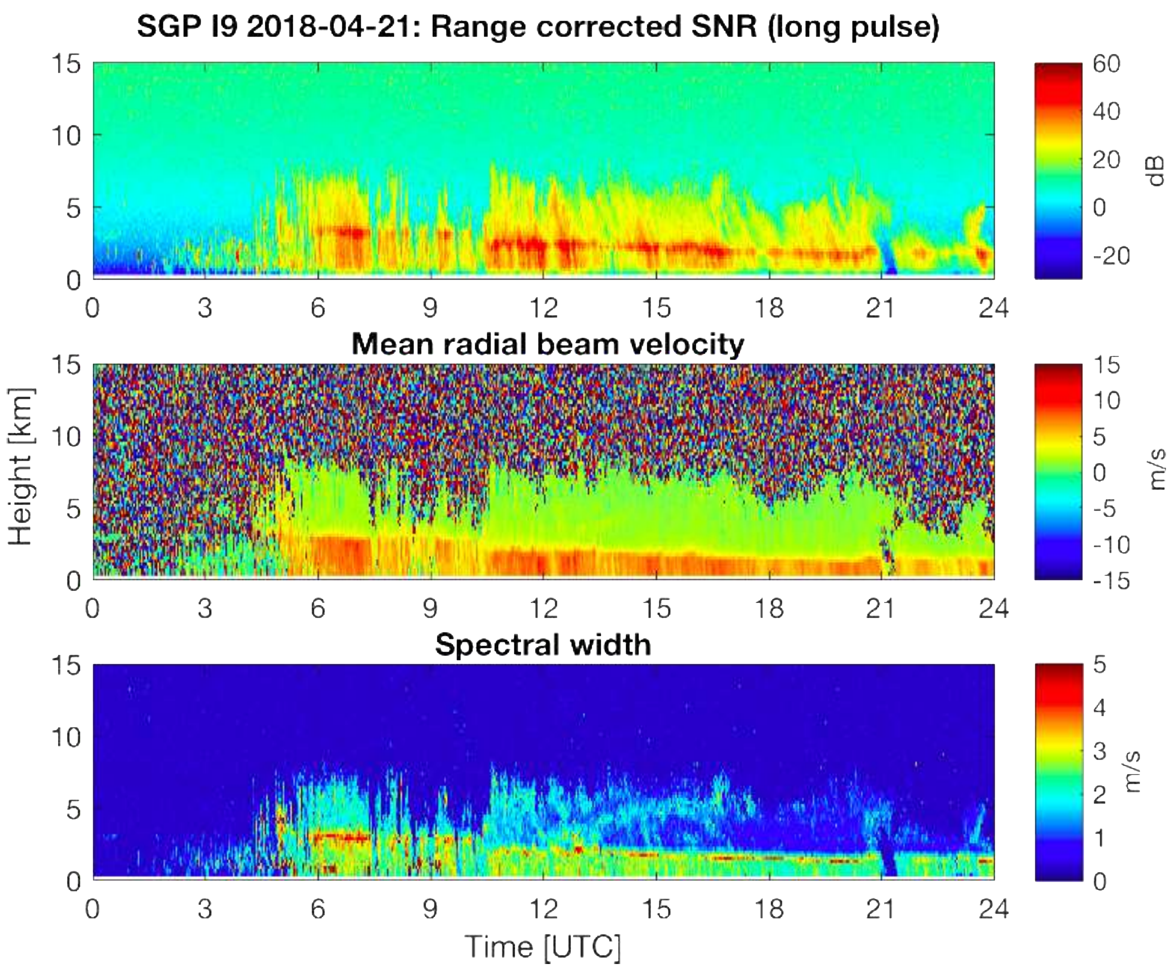
WIND Profilers: What data do we get?

5.2.1.1 Wind Profile Data

- Spectral Data
  - At each height, beam pointing direction, and power level:
    - Spectral amplitude (at each bin of FFT).
- Moments Data
  - At each beam pointing direction, and power level:
    - At each range gate:
      - Mean Doppler shift (in % of Nyquist frequency)
      - Spectral width (in % of Nyquist frequency)
      - SNR level (in dB)
      - Noise level (in dB)
- Average Data
  - At each power level:
    - At each range gate:
      - Wind speed (in m/s)
      - Wind direction (degrees relative to true north)
      - For each beam pointing direction:
        - Radial wind speed (positive = toward the antenna)
        - Number of moments that passed consensus criteria
        - Average SNR

This is basically what you need as a user ...

WIND Profilers: example



Calculated moments for the vertical beam at SGP I9, Billings, Oklahoma on 2018-04-21. [ARM 915 Handout]

Discuss:

"Note that the vertical velocity definition is such that positive is downward, towards the antenna. In this example, the vertical velocities, the SNR, and the spectral width are all affected by rainfall (large downward motion associated with energy scattered from falling rainfall rather than atmospheric structure) at about 0500 UTC until the end of the day. "

WIND Profilers: What to watch for

Wind measurement uncertainty considerations

Total uncertainty	=	Instrument uncertainty	+	Retrieval uncertainty	+	Representativity

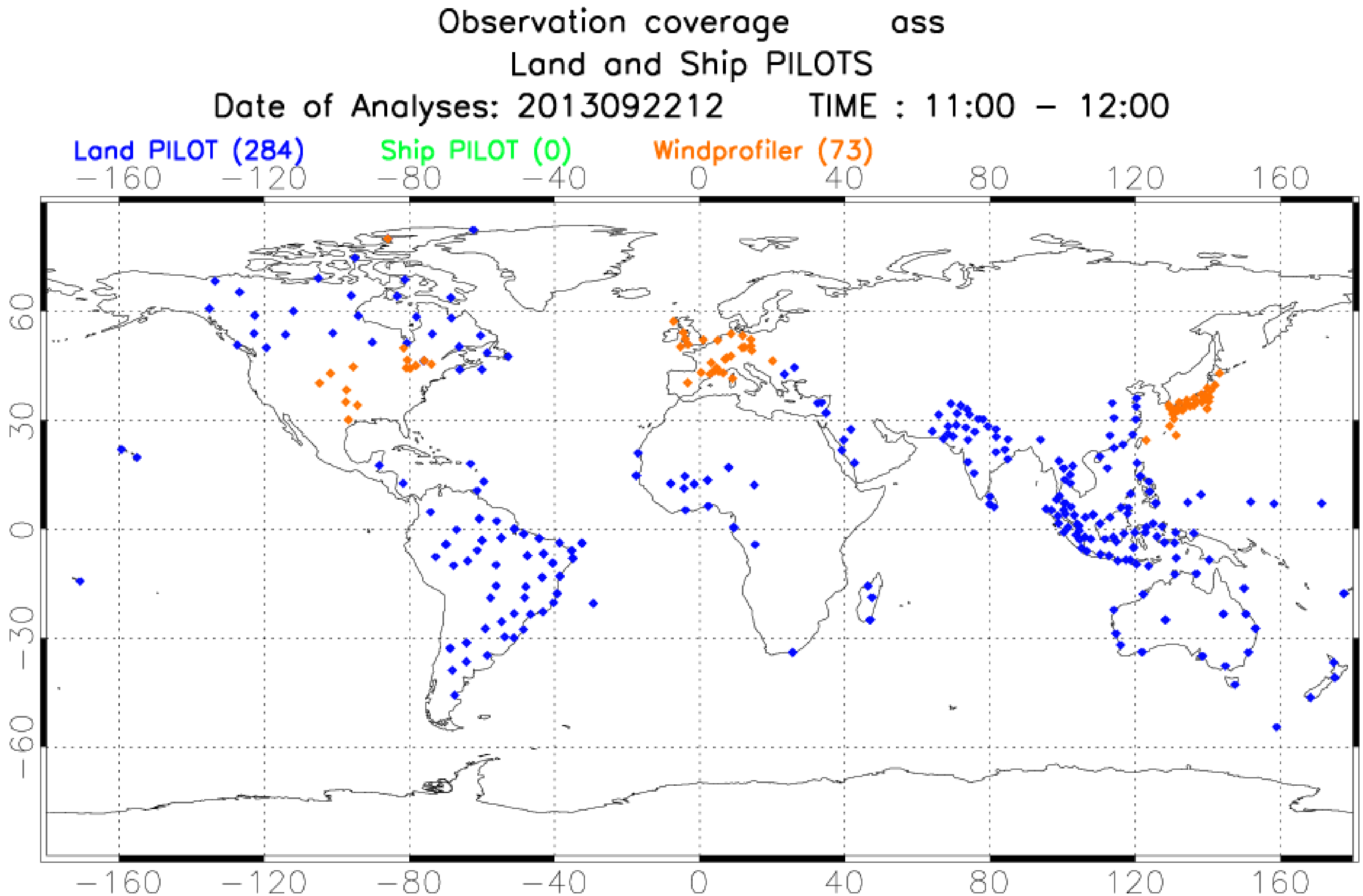
Pulse and beam forming, temporal sampling/ranging
Estimation of Doppler shift over large dynamic range (SNR)
Removal of clutter (ground & bird echoes) and radio frequency interference

Wind vector retrieval from radial velocities:
- Spatial sampling aspects: # of beams, elevation(s) & azimuths
- Horizontal homogeneity and stationarity of wind field required - averaging

Atmospheric variability & mismatch between observation and model scale
Partly accounted for by temporal integration

From Lehmann

WIND Profilers: Where are they located



Check out Japan

WIND Profilers: many types

radiometrics
Ahead of the Weather®

Radiometrics, Corp.
4909 Nautilus Court North, Suite 110
Boulder, CO 80301 USA
T (303) 449-9192 www.radiometrics.com

RAPTOR™ Radar Wind Profiler Models

Radiometrics, Corp. designs and manufactures a full line of radar wind profilers (RWPs). The different models are designed for various applications to allow the customer to choose the best system for their specific requirements. Most RAPTOR systems can be customized for user requirements. Please consult the Radiometrics factory or your representative for further information.

Table 1: RAPTOR Radar Wind Profiler Models by Atmospheric Height

RAPTOR Model	Atmosphere Level	Typical Height[1]	Frequency Band	Description
DBS-BL	Boundary Layer	3-4 km	900 – 1400 MHz	Upgrade for LAP®-3000[2]
FMC-BL		1-3 km	900 – 1400 MHz	Designed for shipboard installation
XBS-BL		3-4 km	900 – 1400 MHz	Lower cost; designed for trailer or static mount
VAD-BL		3-6 km	900 – 1400 MHz	High-performance stationary system
XBS-T	Troposphere	5-8 km	400 – 500 MHz	Lower cost; designed for trailer or static mount
FBS-T		5-8 km	400 – 500 MHz	Scalable antenna and transmitter
FBS-ST	Troposphere/Stratosphere	16 km	400 – 500 MHz	Scalable antenna and transmitter
FBS-ST-EX		18 km	200 MHz	Scalable antenna and transmitter
FBS-MST		20 km	50 MHz	Scalable antenna and transmitter

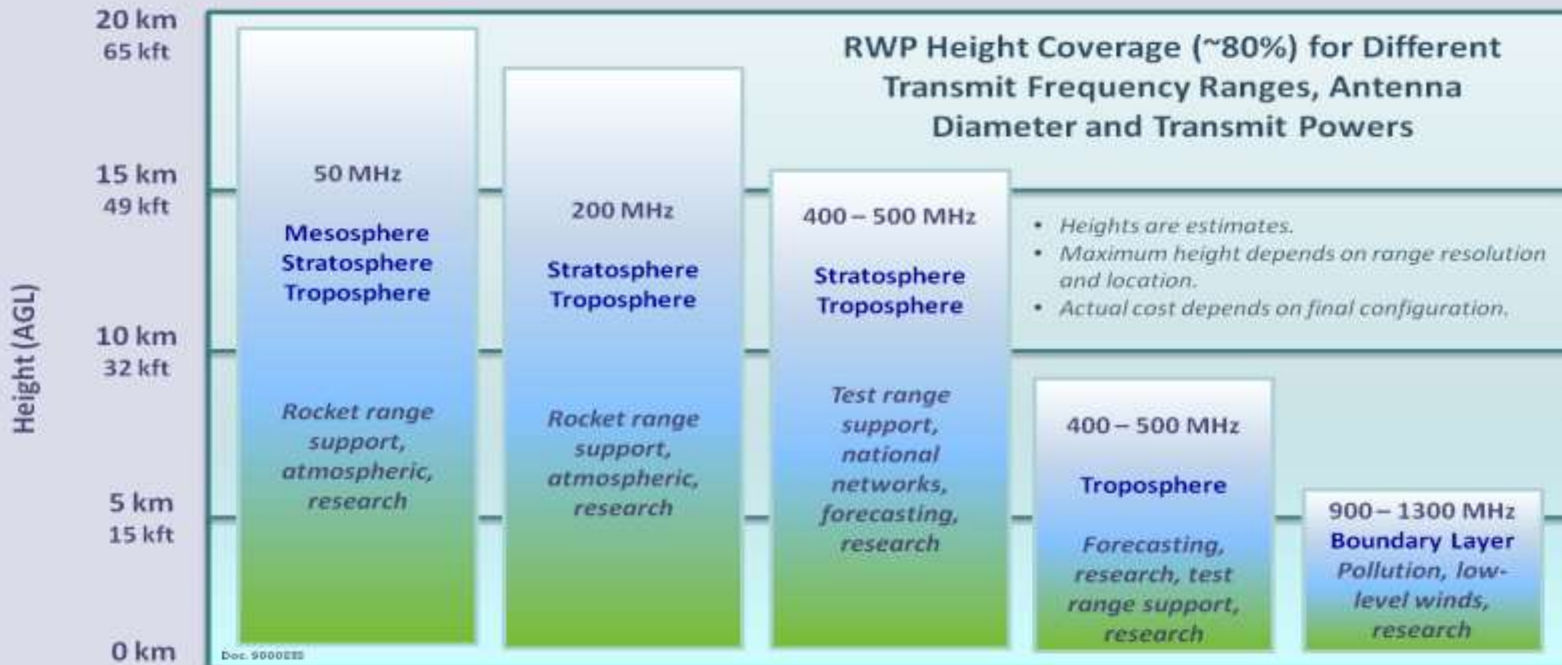
Acronyms: DBS – Doppler Beam Swinging, FMC – Full Motion Control, XBS – Hexagonal Beam Steering, VAD – Velocity Azimuth Display, FBS – Full Beam Steering, BL – Boundary Layer, T – Troposphere, S – Stratosphere, M – Mesosphere, EX – Extended.

A Radio Acoustic Sounding System (RASS) is available for all models or can be integrated with a Radiometrics radiometer system. Radiometrics also builds S- and X- band vertical hydro-meteorological radars and can customize all models.

[1] Maximum height is listed for clear-air and is highly dependent on geographical latitude and local climatology. Please check with the factory for maximum height estimate for your specific location. For boundary layer systems, rain improves maximum height.
[2] LAP is a registered trademark of Scintec Corp. These systems were formerly manufactured by Vaisala, Radian, and NOAA.

See in altitude and frequency?

WIND Profilers: Frequencies



Models:	FBS-MST	FBS-ST-EX	FBS-ST	FBS-T, XBS-T	VAD-, XBS-, FMC-BL
Antenna Size:	125 m	24 m	12 m	6 m	2 m
Peak Power:	125 – 250 kW	24 kW	8 – 12 kW	2 – 4 kW	800 – 2000 W

You can do wind in any frequency – just be careful of errors

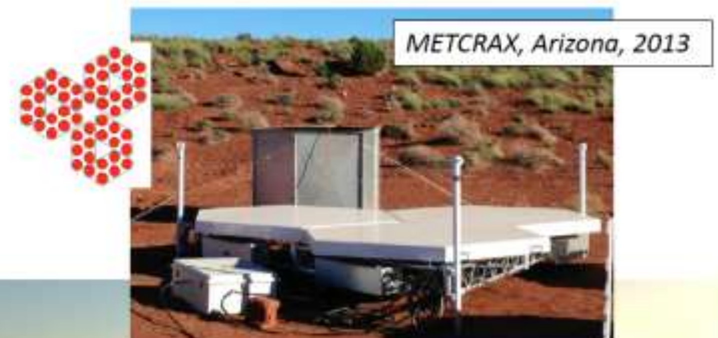
WIND Profilers: come in different sizes

MDE profiler @ BV

WIND Profilers: come in different sizes

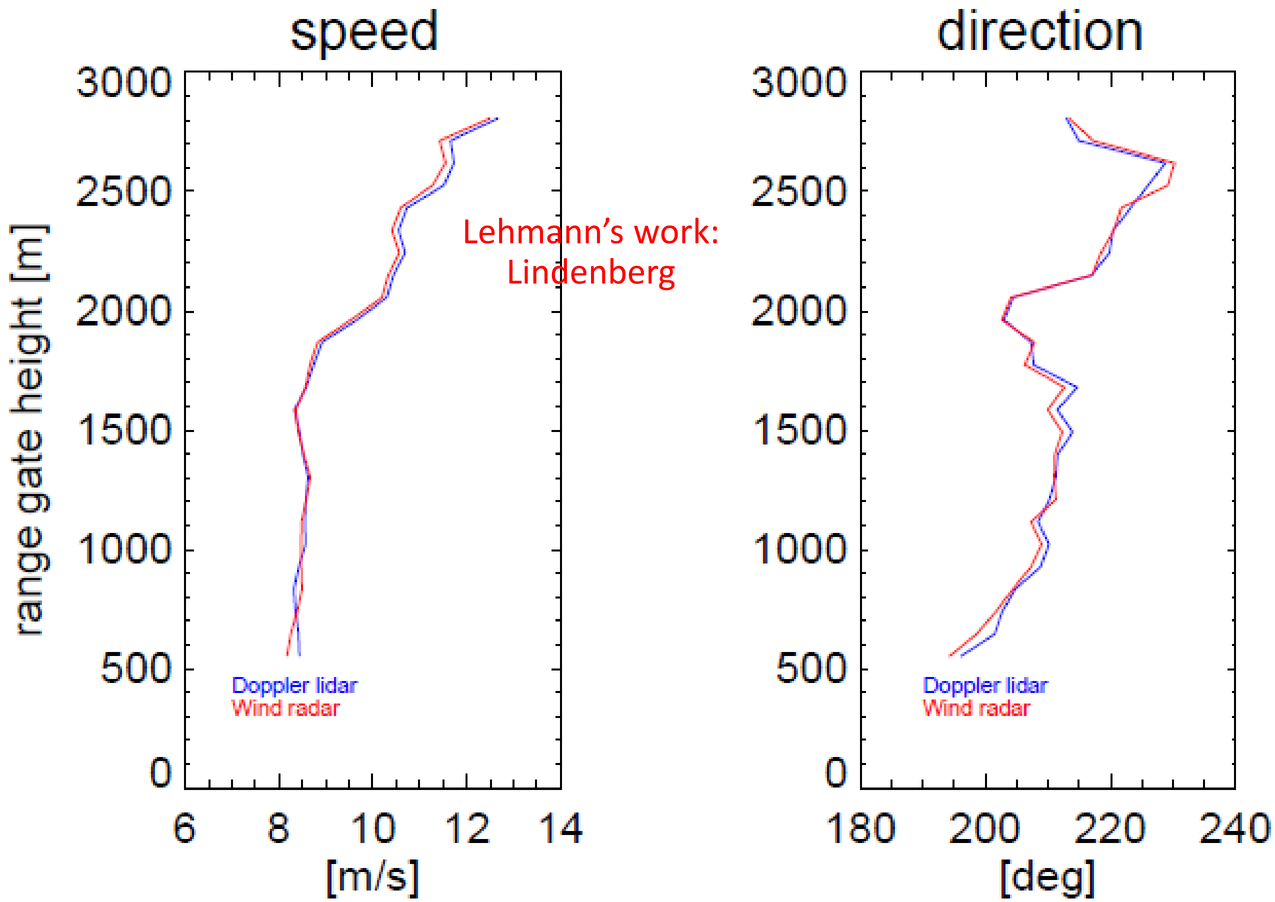
SA 449 MHz RWP

Courtesy:
Bill Brown



NCAR's modular design: Steve Cohen's work

WIND Profilers: How good?

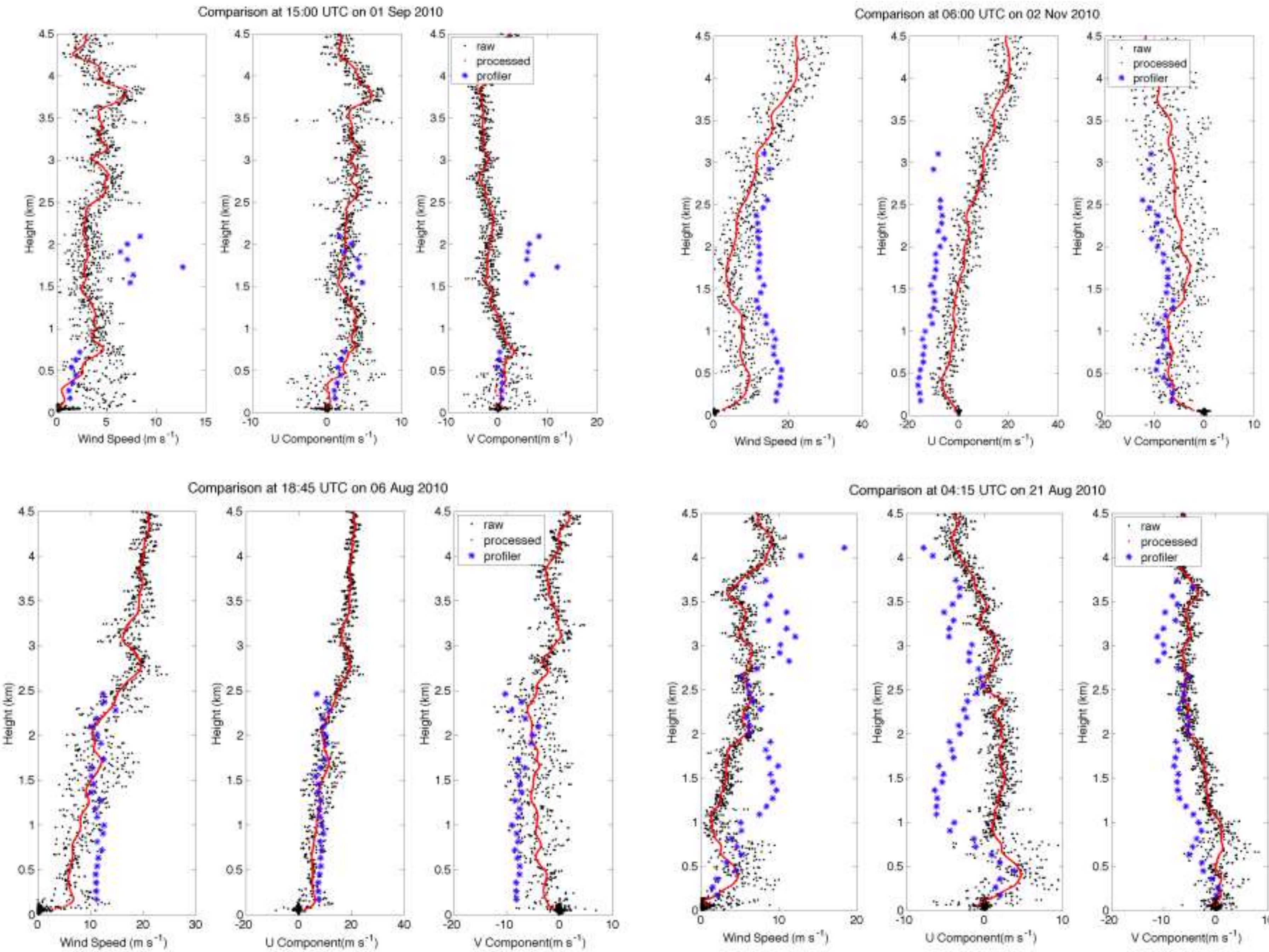


Discuss:

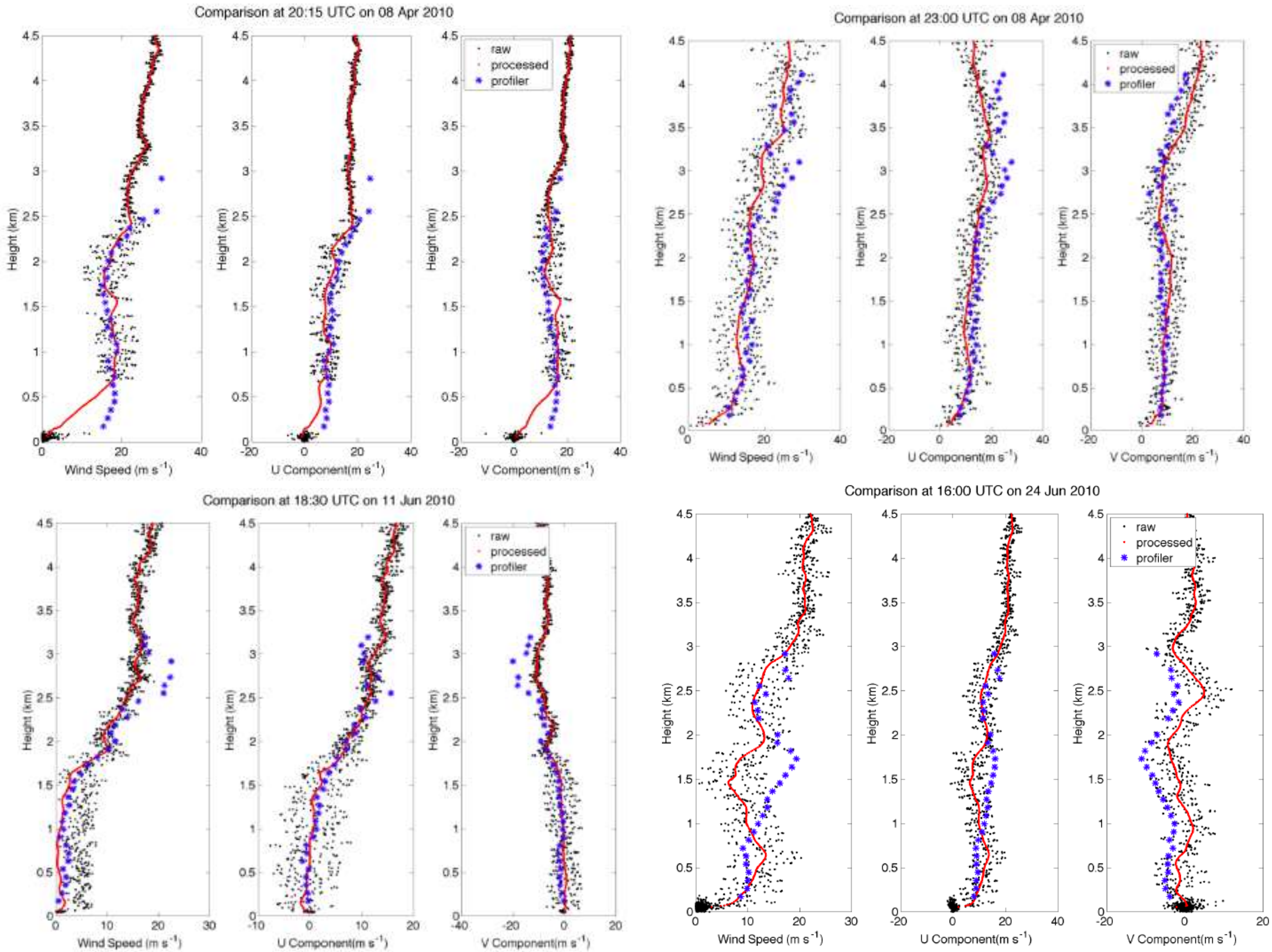
- *Kevin's work*
- *Henry's work – Task for hands-on*

WIND Profilers Vs Sonde
(Intern: Marry Morris)*

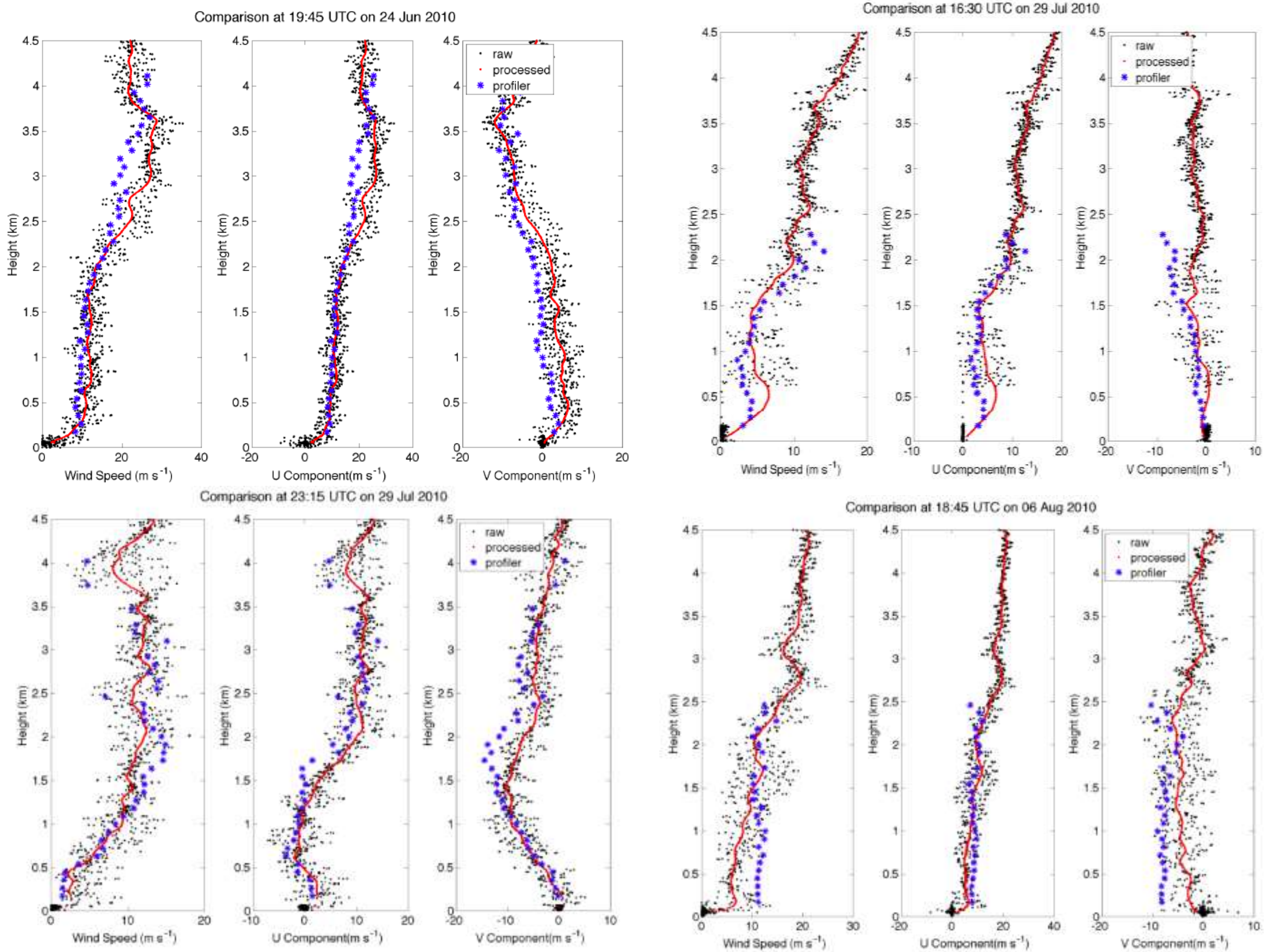
**Now at JPL; PhD in Michigan,*



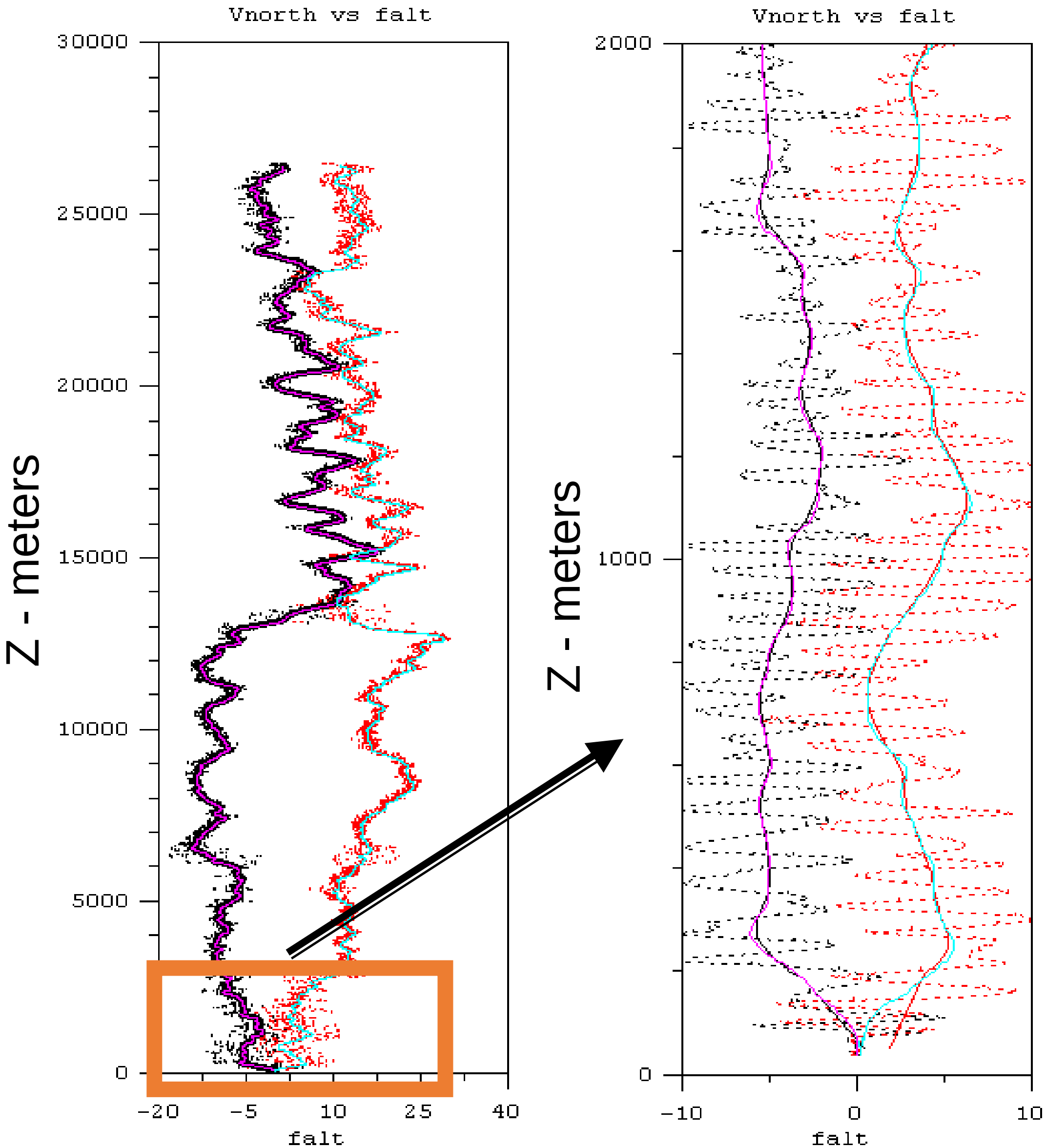
Comparison at 15:00 UTC on 01 Sep 2010
Comparison at 06:00 UTC on 02 Nov 2010
Comparison at 18:45 UTC on 06 Aug 2010
Comparison at 04:15 UTC on 21 Aug 2010
raw
processed
profiler
Height (km)
Wind Speed (m s⁻¹)
U Component(m s⁻¹)
V Component(m s⁻¹)



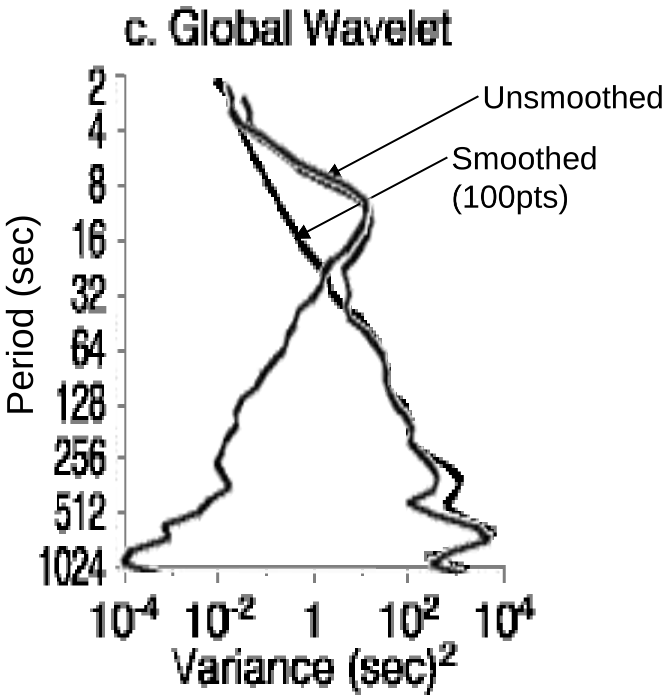
Comparison at 20:15 UTC on 08 Apr 2010
Comparison at 23:00 UTC on 08 Apr 2010
Comparison at 18:30 UTC on 11 Jun 2010
Comparison at 16:00 UTC on 24 Jun 2010
raw
processed
profiler
Height (km)
Wind Speed (m s-1)
U Component(m s-1)
V Component(m s-1)


Comparison at 19:45 UTC on 24 Jun 2010
Comparison at 16:30 UTC on 29 Jul 2010
Comparison at 23:15 UTC on 29 Jul 2010
Comparison at 18:45 UTC on 06 Aug 2010
raw
processed
profiler
Height (km)
Wind Speed (m s-1)
U Component(m s-1)
V Component(m s-1)

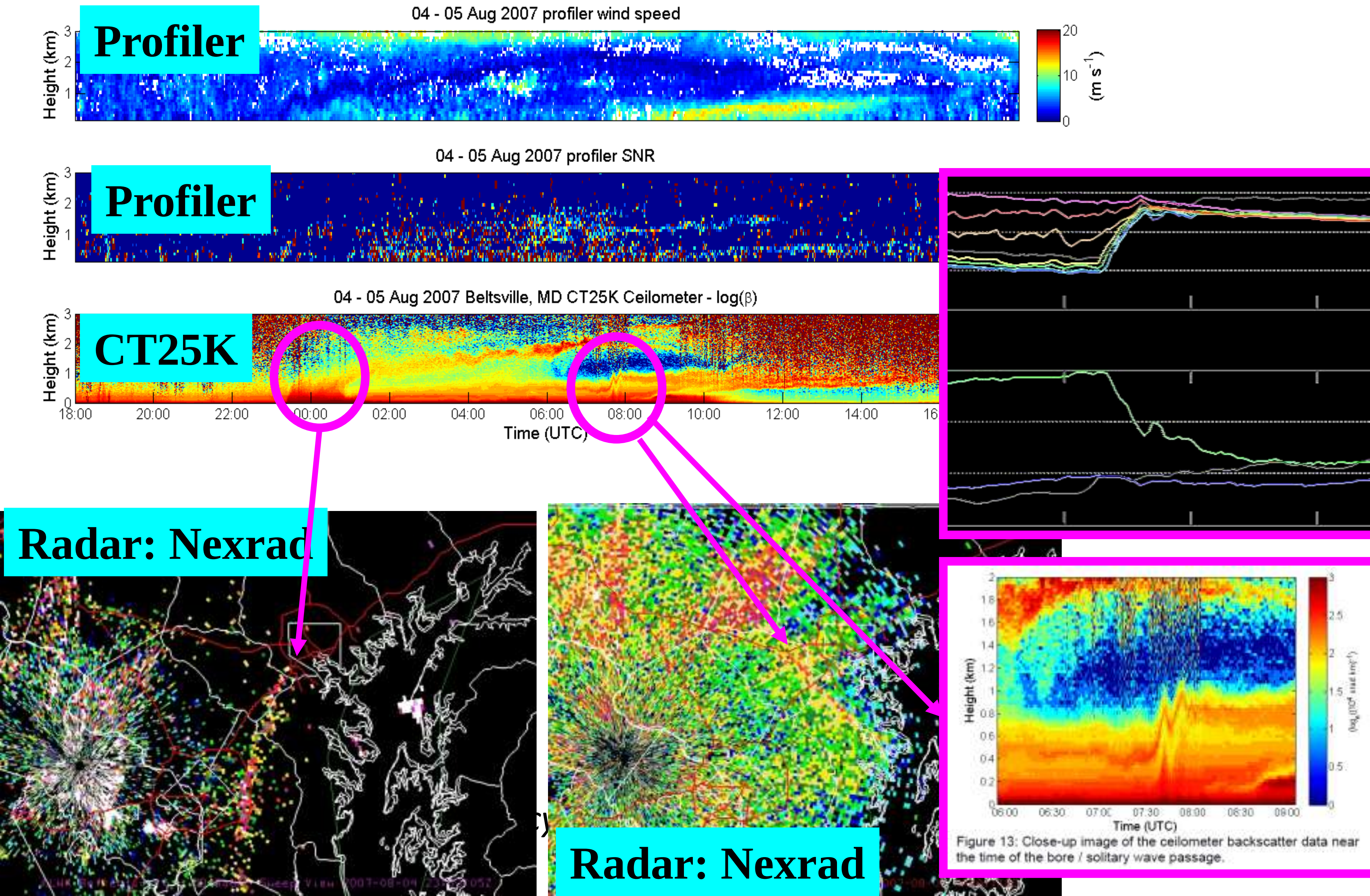
Caution: *Wind from sondes*



- Highly variable < 2km region
- 100pts smooth may be overkill
- Implications to lidar winds?



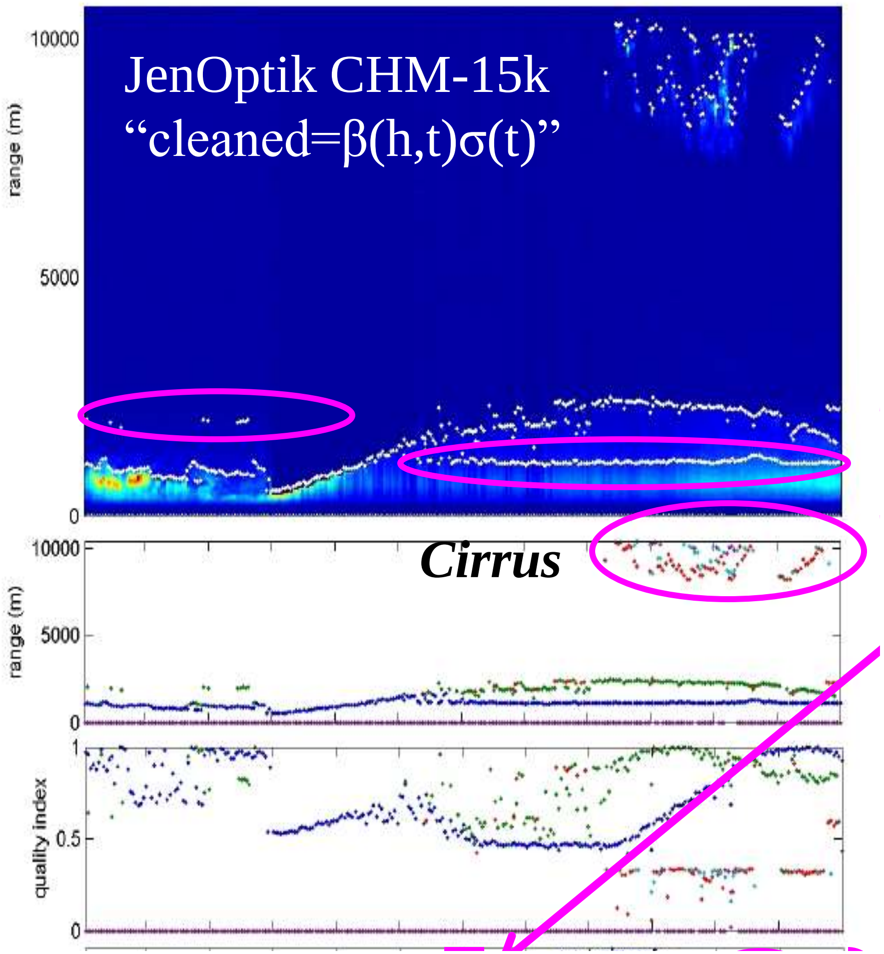
WIND Profilers: Applications

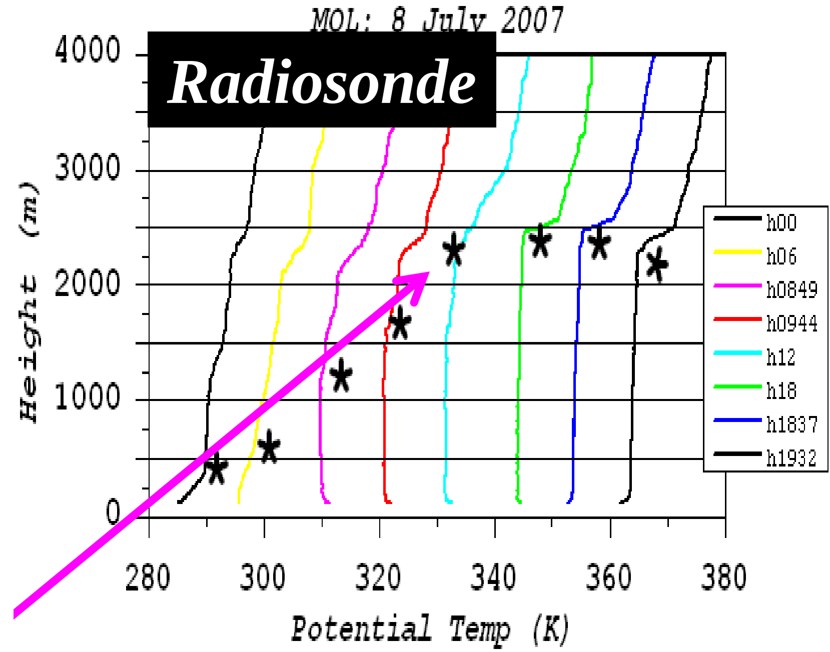


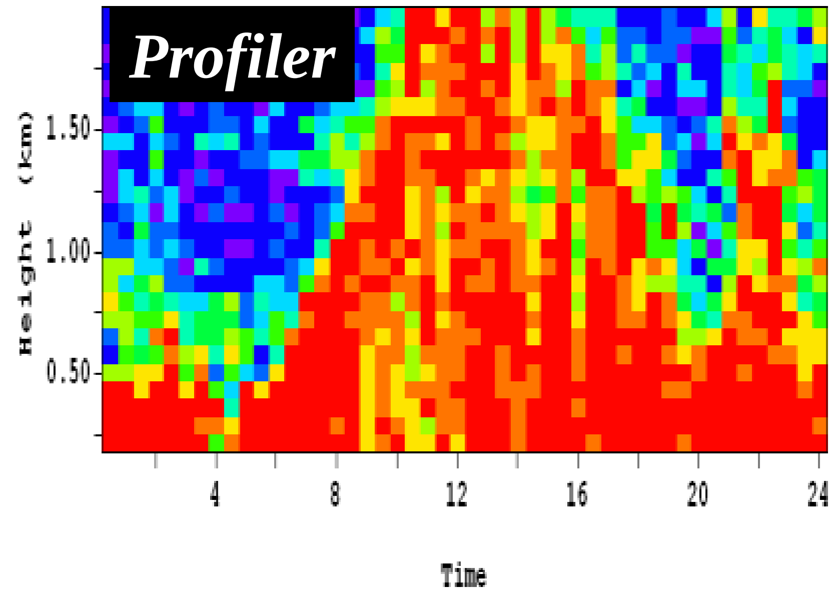
WIND Profilers: Use for PBLH:

Remember Ruben's ceilometer presentation?

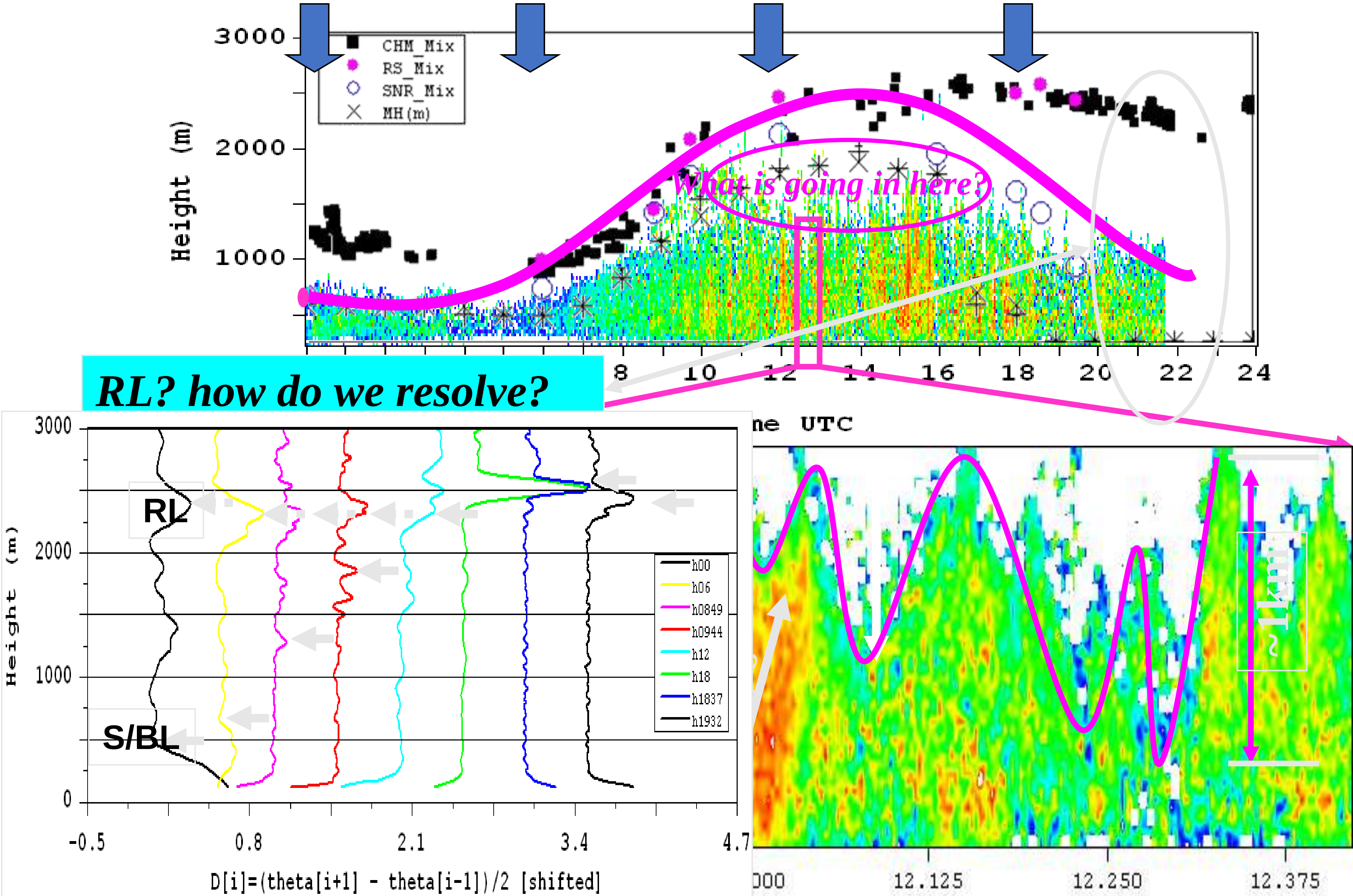
MOL: Ancillary BL data



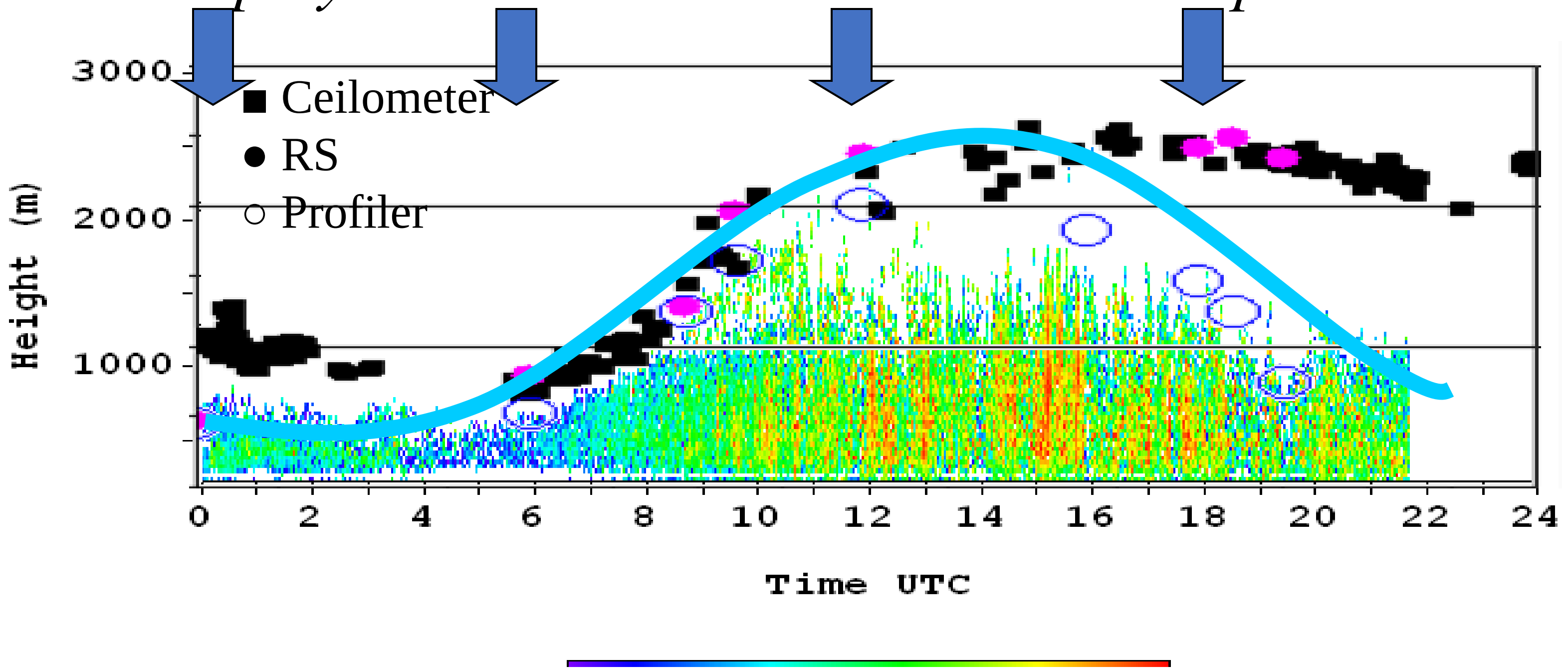




Composite: Radar Reflectivity, Sonde, Profiler



Profilers a role to play in PBLH discussion: Jamie Compton's work



Best way to detect PBLH is to consider a "quality factor/ weight" to each instrument and

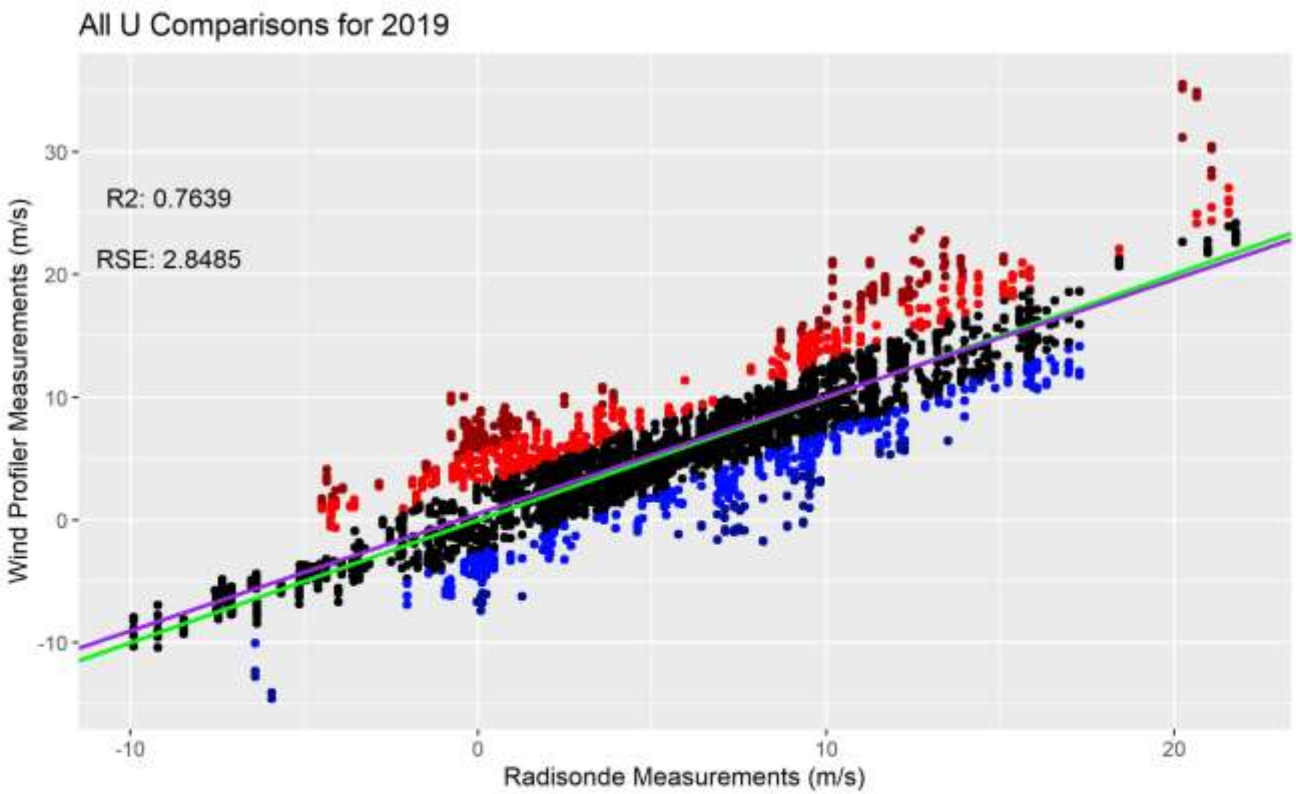
- ***physics of detection; time of day; error characteristics***
- ***BL physics (variability);***

Radars have more to offer that is not yet fully exploited.

WIND Profilers: Suggested work

Thanks Ricardo for the help

WIND Profilers Vs Sonde *(Intern: Henry Budris 2019*)*

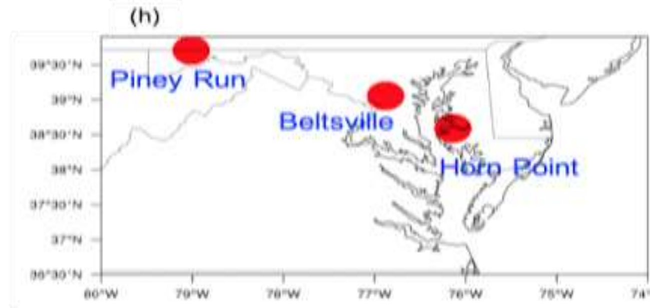


I have the data

- *Redo the analysis*
- *Compare single profiles with SNR etc*

WIND Profilers: Frequencies

Jun 9-12, 2015 case Plot SNR and compare with lidar data (Ozone, CL51)



Data in googledocs: can you plot the ceilometer and wind (speed/SNR) on single plot and discuss