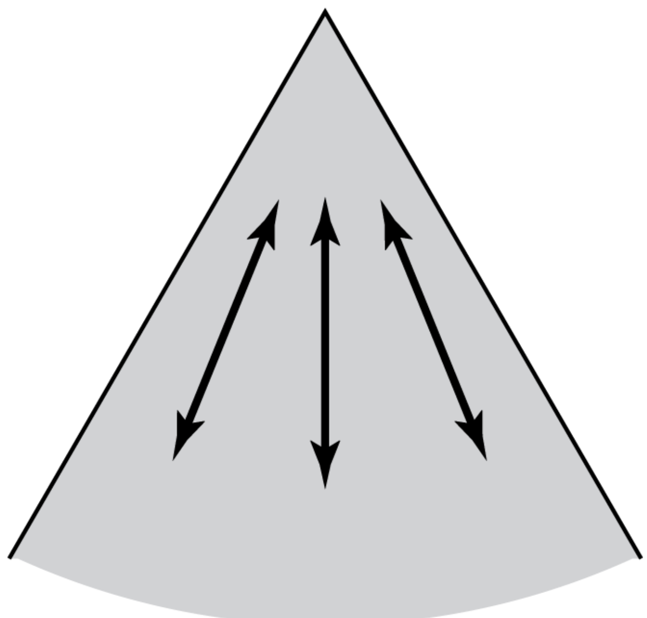
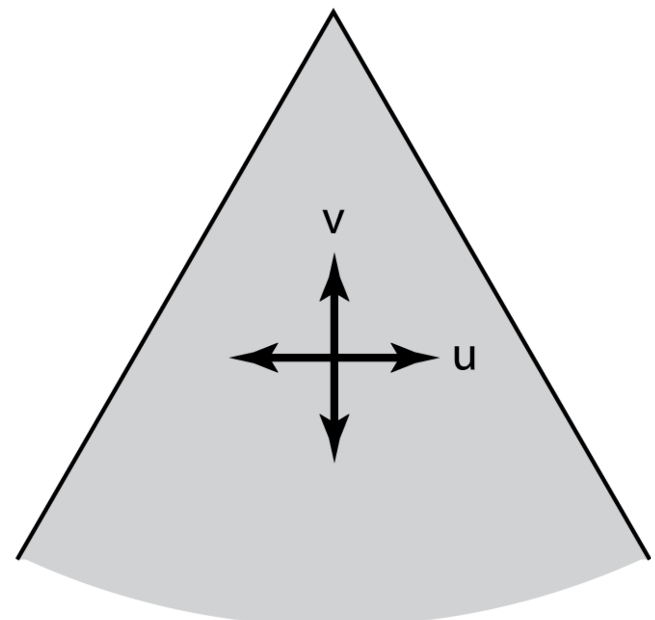
Two-component horizontal motion vectors from scanning eye-safe aerosol lidar and the correlation method

Shane D. Mayor
Department of Physics
California State University Chico

Radial component only
(toward or away)



2-components
(i.e. east-west and north-south)



Previous work on cross-correlation method applied to aerosol lidar data:

Eloranta, E. W., J. M. King, and J. A. Weinman, 1975: The determination of wind speeds in the boundary layer by monostatic lidar. *J. Appl. Meteor.*, **14**, 1485–1489.

Kunkel, K. E., E. W. Eloranta, and J. A. Weinman, 1980: Remote determination of winds, turbulence spectra and energy dissipation rates in the boundary layer from lidar measurements. *J. Atmos. Sci.*, **37**, 978-985.

Sroga, J. T., E. W. Eloranta, and T. Barber, 1980: Lidar measurements of wind velocity profiles in the boundary layer. *J. Appl. Meteor.*, **19**, 598–605.

Hooper, W. P. and E. W. Eloranta, 1986: Lidar measurements of wind in the planetary boundary layer: the method, accuracy and results from joint measurements with radiosonde and kytoon. *J. Clim. Appl. Meteor.*, **25**, 990–1001.

Sasano, Y., H. Hirohara, T. Yamasaki, H. Shimizu, N. Takeuchi, and T. Kawamura, 1982: Horizontal wind vector determination from the displacement of aerosol distribution patterns observed by a scanning lidar. *J. Appl. Meteor.*, **21**, 1516–1523.

Kolev, I., O. Parvanov, and B. Kaprielov, 1988: Lidar determination of winds by aerosol inhomogeneities: motion velocity in the planetary boundary layer, *Appl. Opt.*, **27**, 2524-2531.

Schols, J. L. and E. W. Eloranta, 1992: The calculation of area-averaged vertical profiles of the horizontal wind velocity from volume-imaging lidar data. *J. Geophys. Res.*, **97**, 18 395–18 407.

Piironen, A. K. and E. W. Eloranta, 1995: Accuracy analysis of wind profiles calculated from volume imaging lidar, *J. Geophys. Res.*, **100**, 25,559-25,567.

Mayor, S. D. and E. W. Eloranta, 2001: Two-dimensional vector wind fields from volume imaging lidar data. *J. Appl. Meteor.*, **40**, 1331–1346.

Objective: Evaluate the accuracy and reliability of an aerosol lidar and the cross-correlation method to derive 2-component horizontal vector wind fields in the surface layer.

New in this work:

- Eye-safety by operating at 1.5 microns wavelength.
- Scanning for 3-months and through an instrumented tower.
- Vectors from pairs of scans only. (No CCF averaging.)

Outline

- Instrument: REAL
- Experiment: CHATS
- Algorithm: Cross-correlation
- Time-series examples
- Preliminary data analysis results
- Conclusions
- Related concurrent work

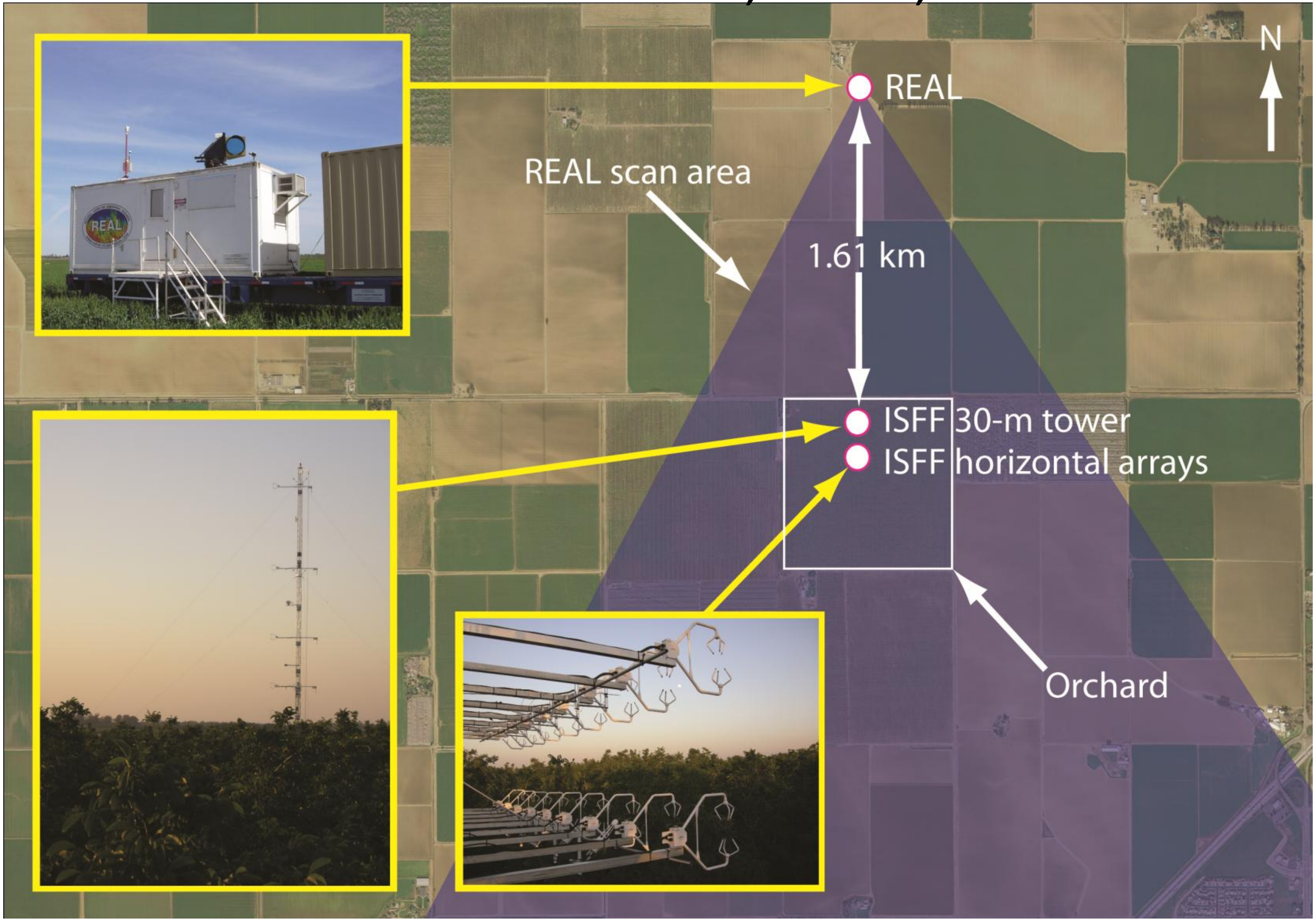
Raman-shifted Eye-safe Aerosol Lidar (REAL)

Wavelength: 1.543 microns
Pulse energy: 170 mJ
Pulse rate: 10 Hz
Pulse duration: 6 ns
Beam diameter ($1/e^2$ pts) :
- At 0.0 km range: 66 mm
- At 1.6 km range: 0.5 m
- At 6.0 km range: 1.5 m

Beam divergence: 0.24 mrad (full)
Receiver field-of-view: 0.54 mrad (full)
Telescope diameter: 40 cm
Detector type: InGaAs APD (200 microns)
A to D converter sampling rate: 100 MHz
A to D converter resolution : 14 bits

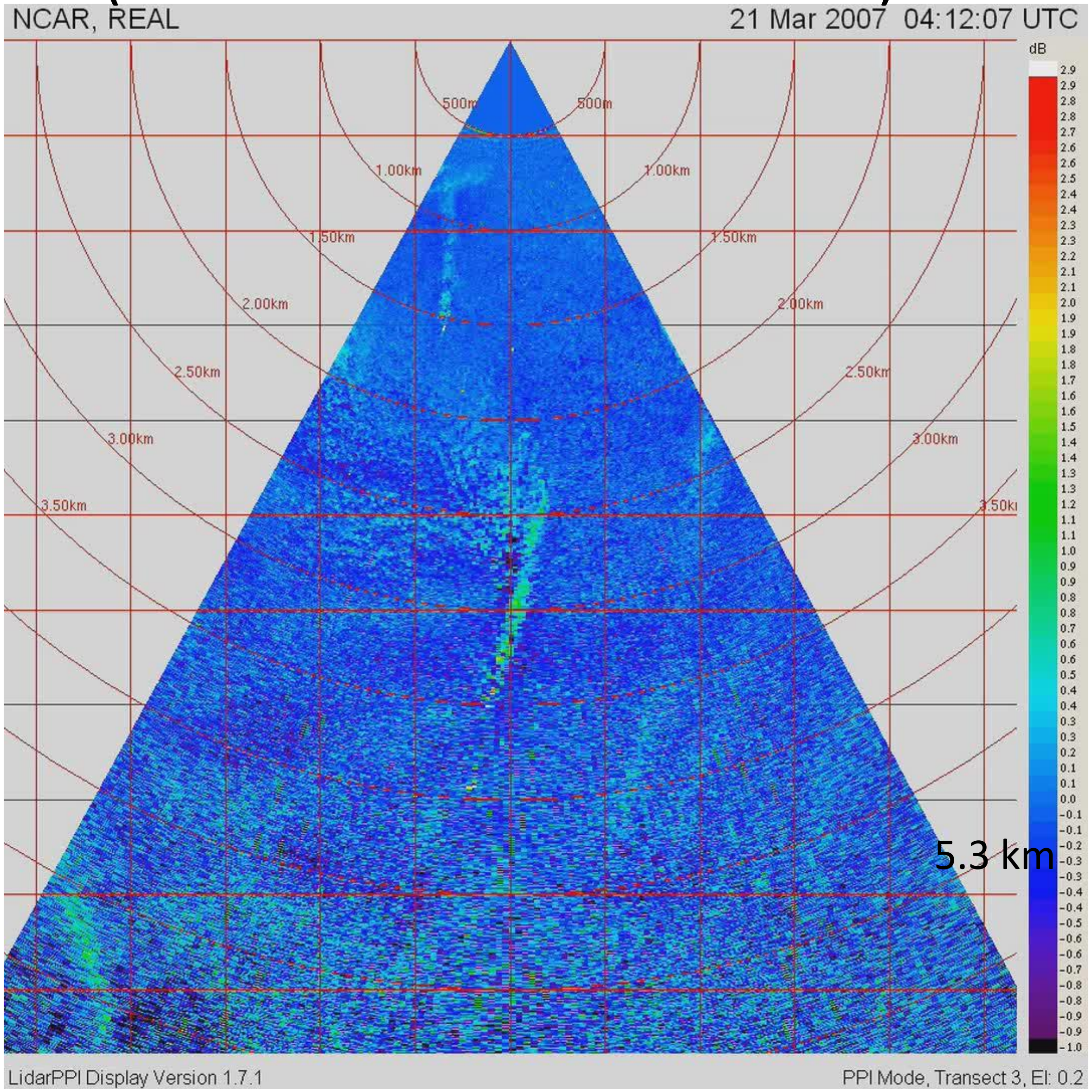
Mayor, S. D., S. M. Spuler, B. M. Morley, E. Loew, 2007: Polarization lidar at 1.54-microns and observations of plumes from aerosol generators. *Opt. Eng.*, **46**, 096201.

Canopy Horizontal Array Turbulence Study (CHATS)
15 March – 11 June 2007, Dixon, California

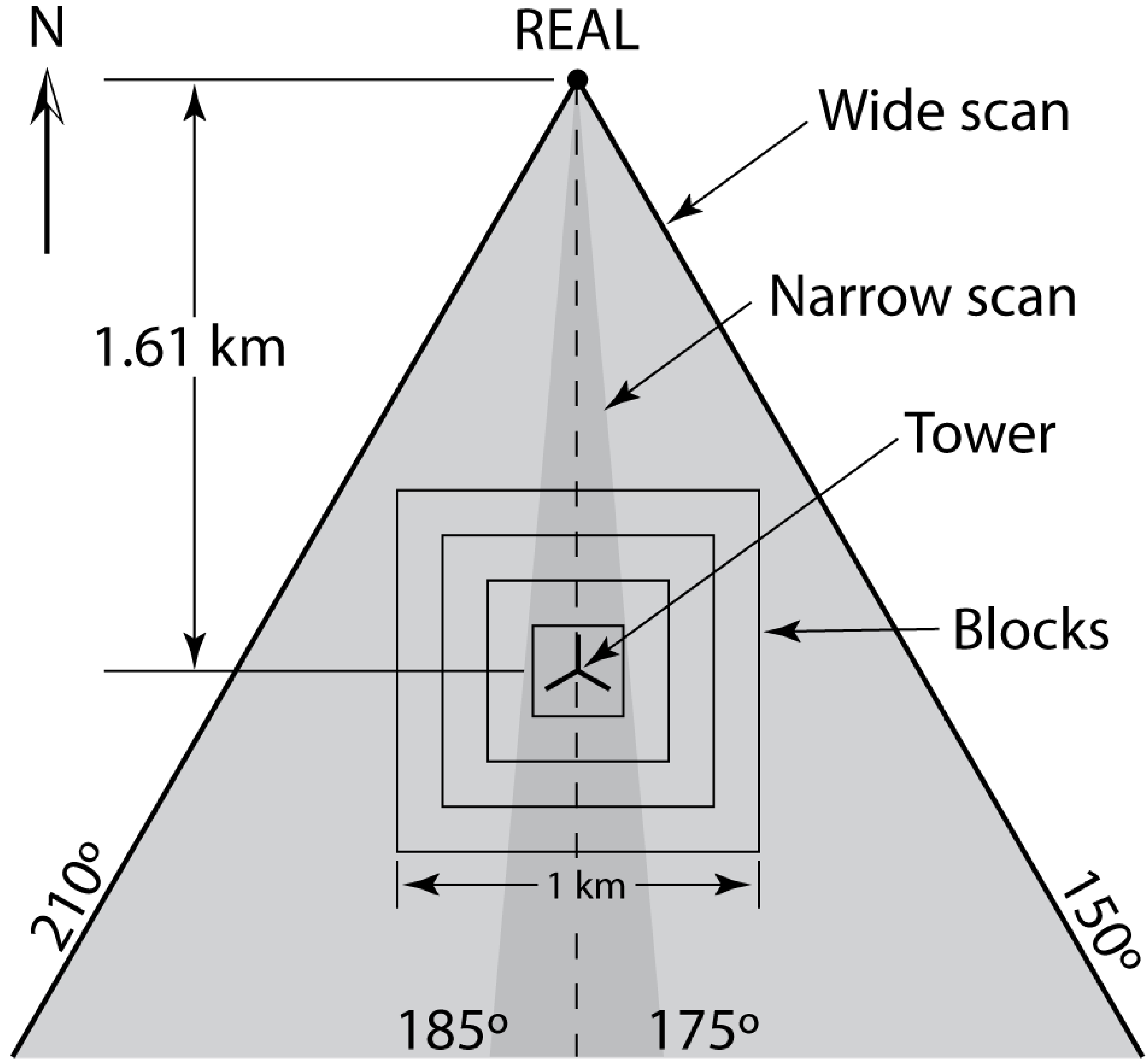


Patton, E. G., et al., 2011: The Canopy Horizontal Array Turbulence Study (CHATS), *Bull. Amer. Meteorol. Soc.,* In Press.

21 March 2007: 04:12 – 6:35 UTC
(7:12 PM to 11:35 PM PDT)

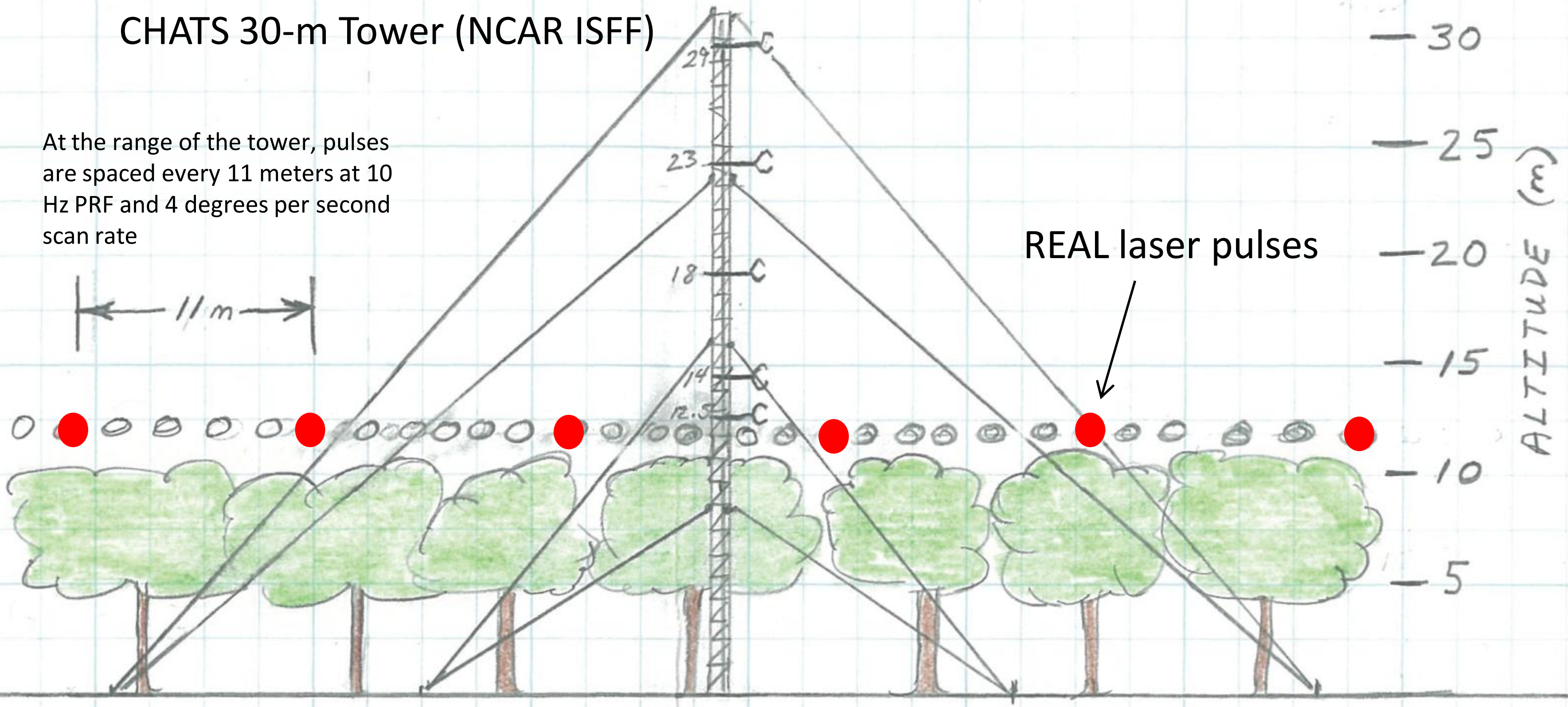


2 hours 23 minutes duration

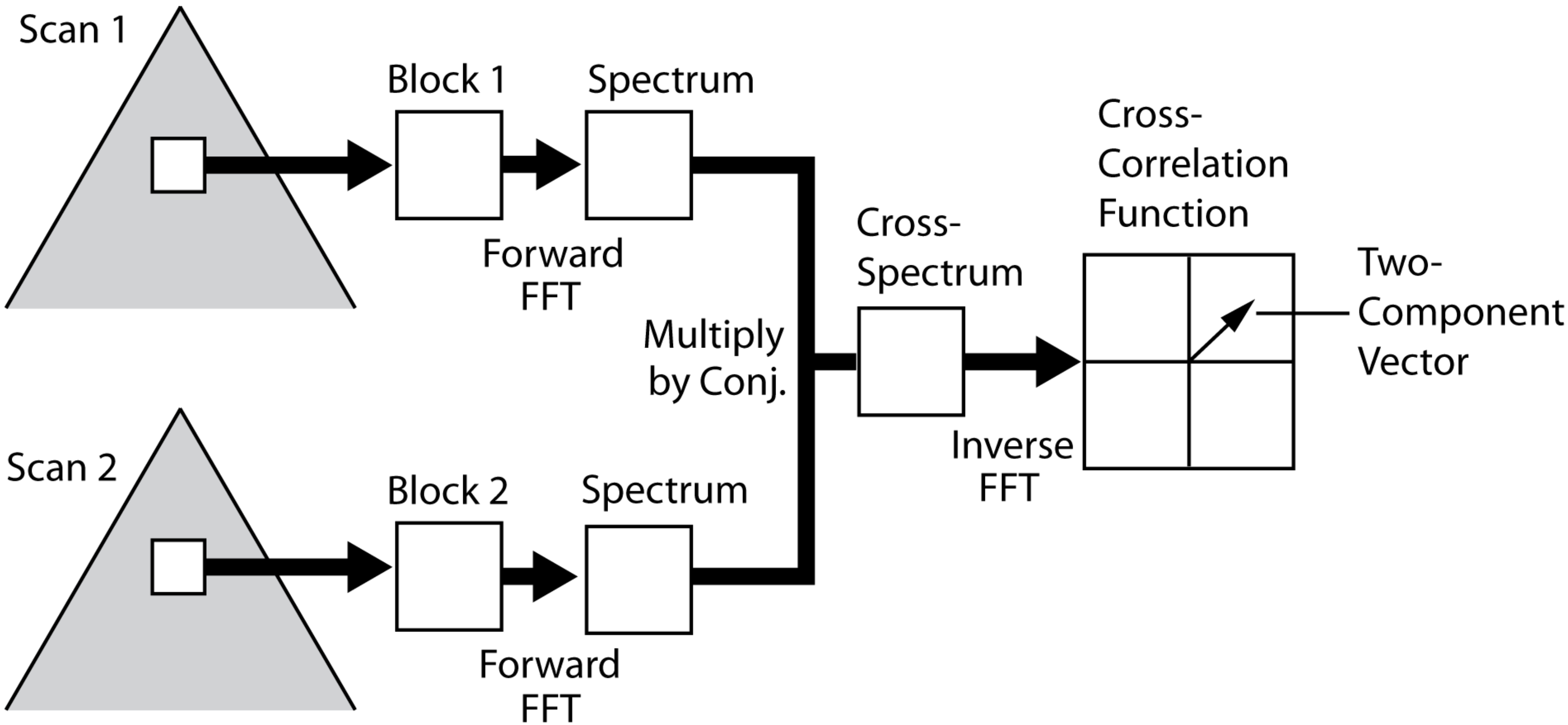

N
REAL
Wide scan
Narrow scan
Tower
Blocks
1.61 km
1 km
210°
150°
185°
175°

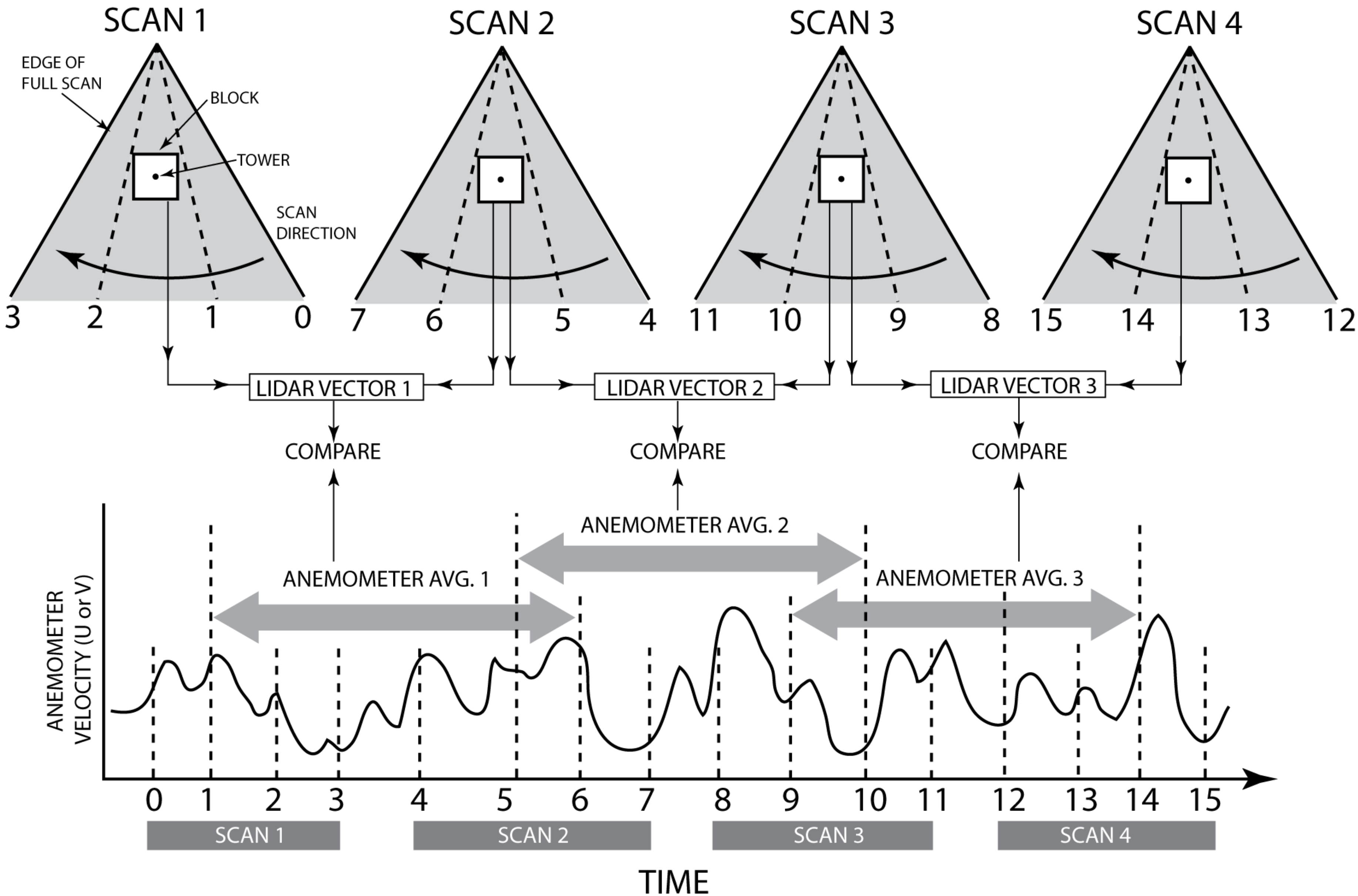
CHATS 30-m Tower (NCAR ISFF)

At the range of the tower, pulses are spaced every 11 meters at 10 Hz PRF and 4 degrees per second scan rate



Cross-correlation algorithm




SCAN 1
SCAN 2
SCAN 3
SCAN 4
EDGE OF FULL SCAN
BLOCK
TOWER
SCAN DIRECTION
3 2 1 0
7 6 5 4
11 10 9 8
15 14 13 12
LIDAR VECTOR 1
LIDAR VECTOR 2
LIDAR VECTOR 3
COMPARE
COMPARE
COMPARE
ANEMOMETER AVG. 1
ANEMOMETER AVG. 2
ANEMOMETER AVG. 3
ANEMOMETER VELOCITY (U or V)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
SCAN 1
SCAN 2
SCAN 3
SCAN 4
TIME

Date/ Time	LIDAR Box Size	LIDAR Δt	LIDAR – SONIC Δu	LIDAR – SONIC Δv	SONIC TKE	SONIC Ri	LIDAR CCF Peak Max	LIDAR Raw SNR	LIDAR Image SNR
20070326/20:12:30	250	17	0.21	-0.11	0.23	0.15	0.22	132	5.2
20070326/20:12:30	500	17	-0.16	0.83	0.23	0.15	0.24	128	4.8
20070326/20:12:30	700	17	0.34	-0.52	0.23	0.15	0.32	130	5.1
20070326/20:12:30	1000	17	0.45	0.01	0.23	0.15	0.41	113	4.9
20070326/20:12:47	250	30	-0.12	-0.06	0.12	0.23	0.23	125	4.5
20070326/20:12:47	500	30	0.32	-0.28	0.12	0.23	0.28	140	5.3
20070326/20:12:47	700	30	-0.15	0.19	0.12	0.23	0.35	136	5.2
20070326/20:12:47	1000	30	0.03	-0.23	0.12	0.23	0.42	127	4.8
20070326/20:13:04	250	30	-0.42	0.36	0.15	0.13	0.17	130	5.1

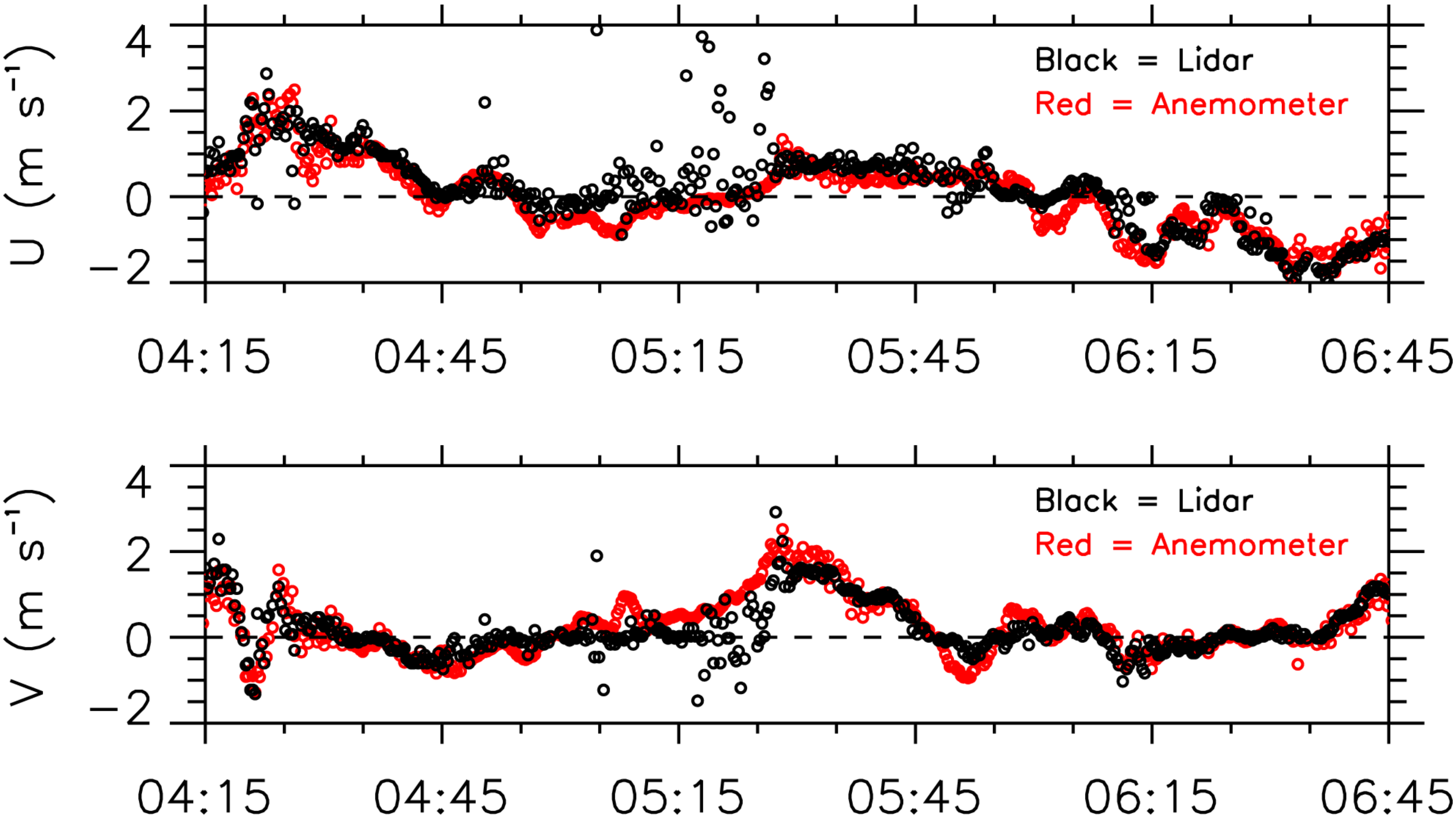
800,000 two-component vectors from approximately 275,000 PPI scans

		Block size			
		250 m	500 m	750 m	1000 m
Time Between Scans	10 s	69483	47392	0	0
	17 s	97567	103142	103148	103150
	30 s	61720	69667	69825	69827

Hypothesis

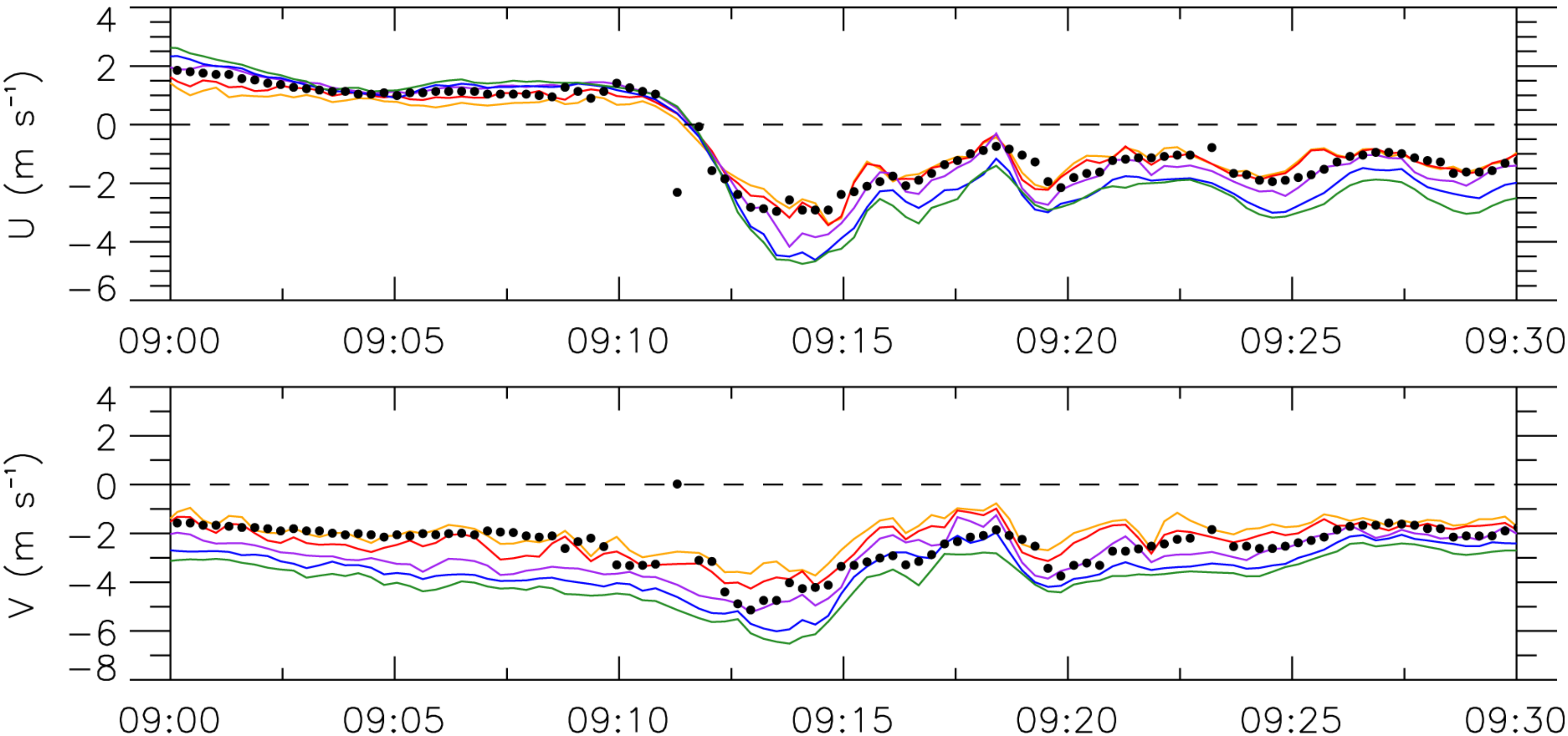
- Lidar-vectors will agree with sonic anemometer vectors better during the day because turbulence creates coherent aerosol features that move with the wind.
- Lidar-vectors may not agree with sonic anemometer vectors during the night because stability promotes gravity waves which may propagate differently from the local wind.

21 March 2007: 04:15 – 6:45 UTC
(7:15 PM to 11:45 PM PDT)



Dt = 17 s, Box size = 250 m x 250 m

21 March 2007: Night-time wind shift (1:00 – 1:30 PST)

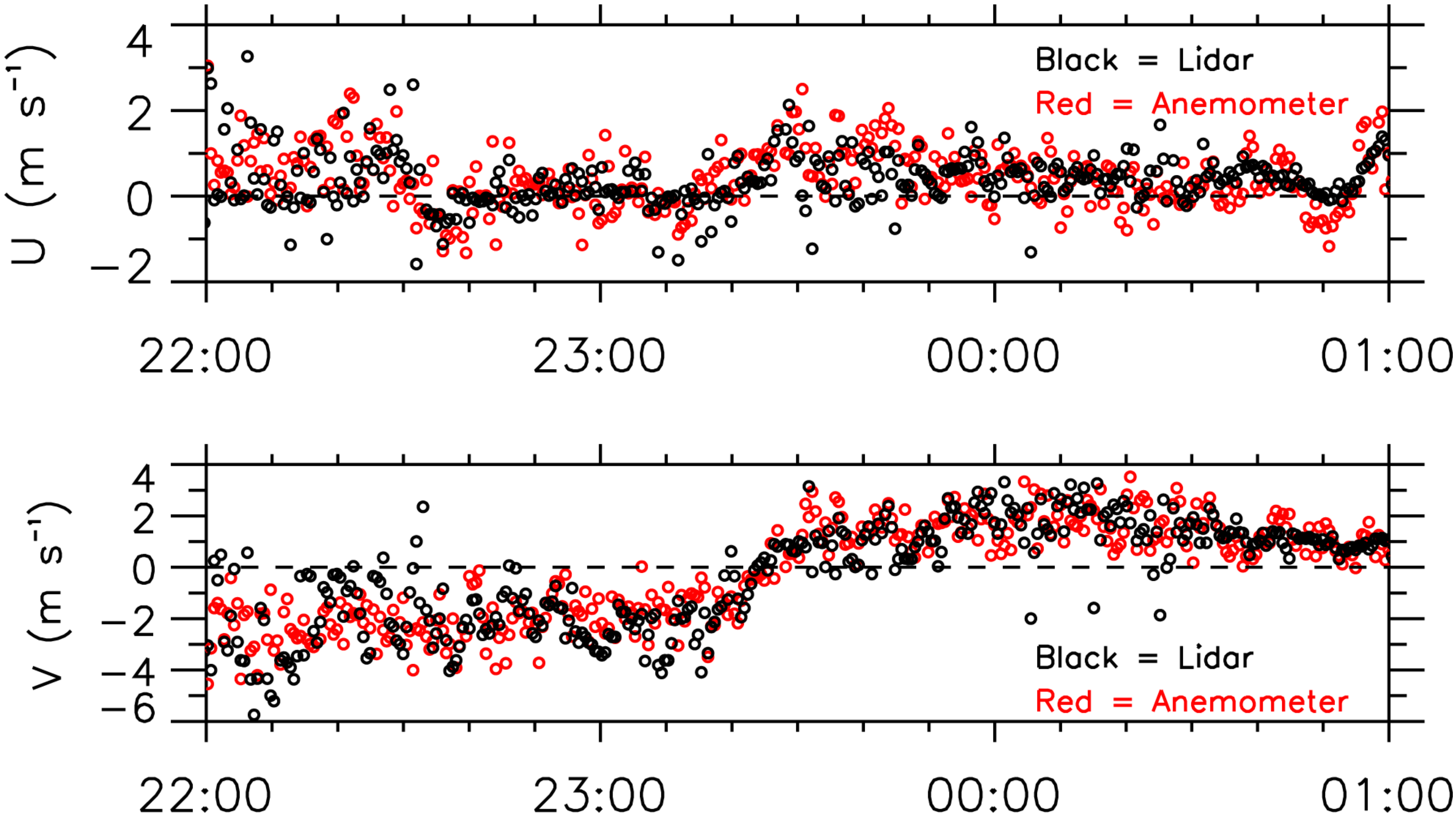


Black dots from Lidar
Dt = 17 s
Box size =Dx = Dy = 500 m

Colored lines from Sonics

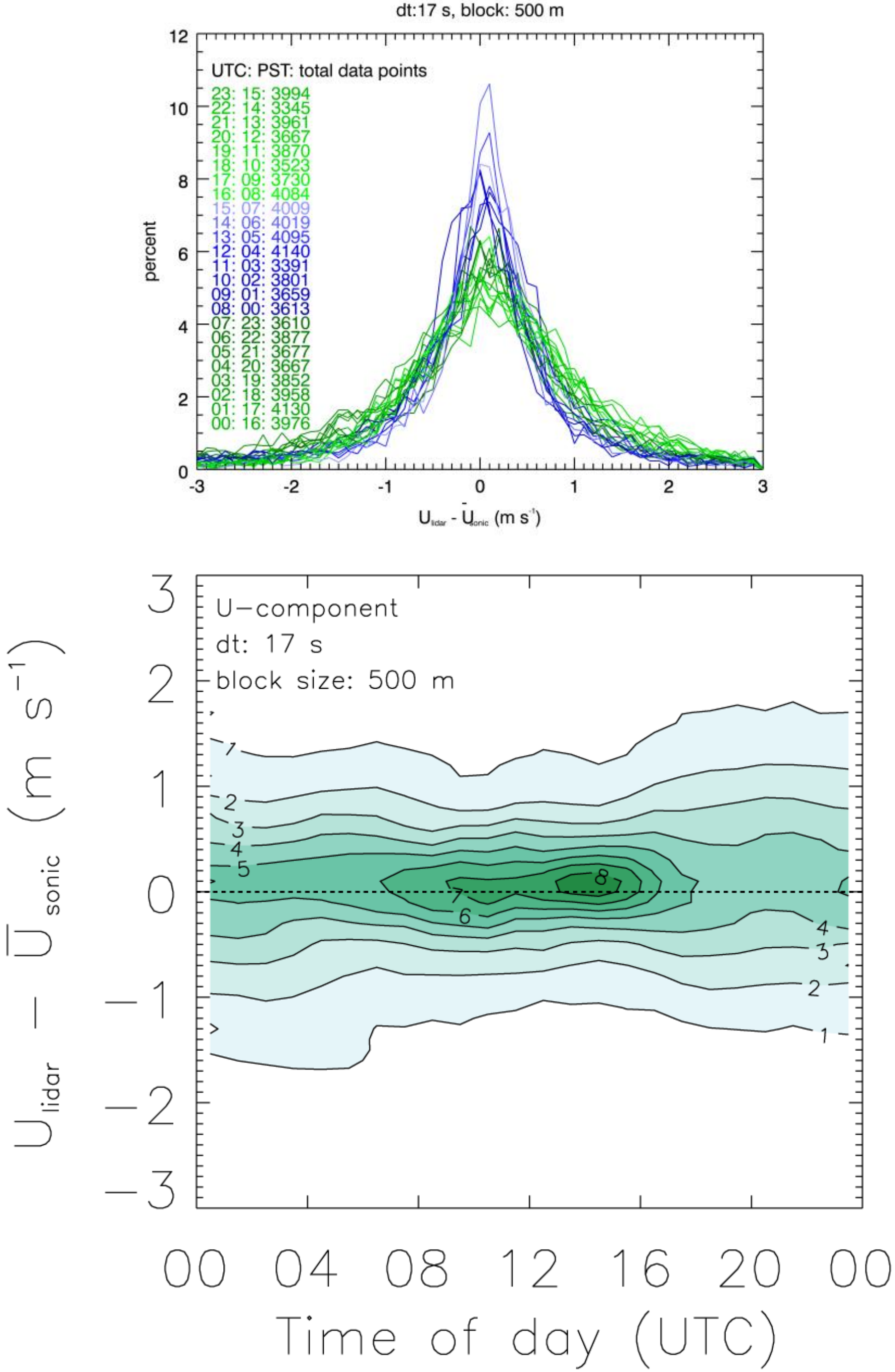
Orange	12.5 m
Red	14 m
Purple	18 m
Blue	23 m
Green	29 m

26 April 2007: 22:00 – 01:00 UTC (next day)
(14:00 PST to 17:00 PST)

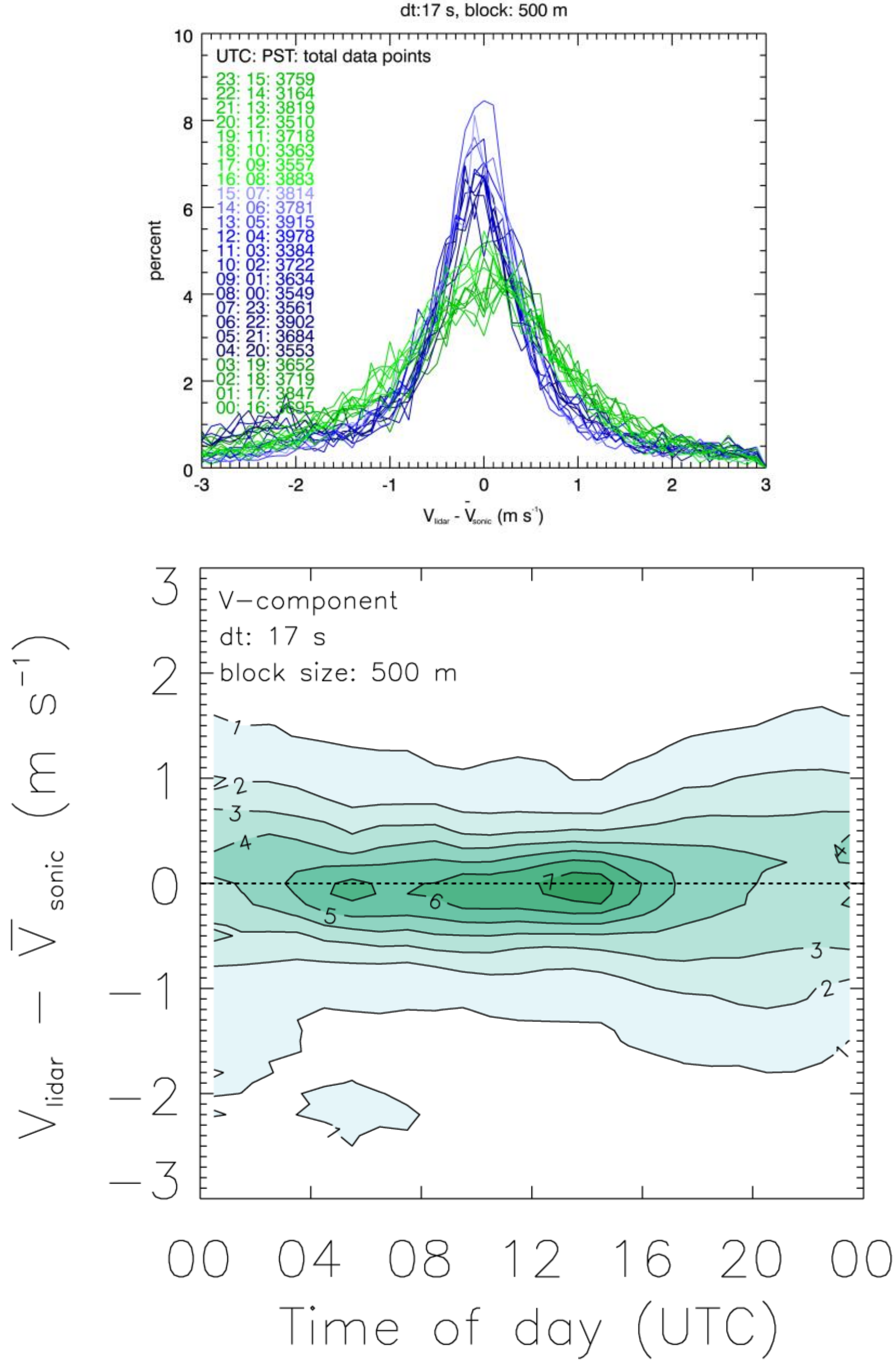


Dt = 30 s, Box size = 500 m x 500 m

U-COMPONENT

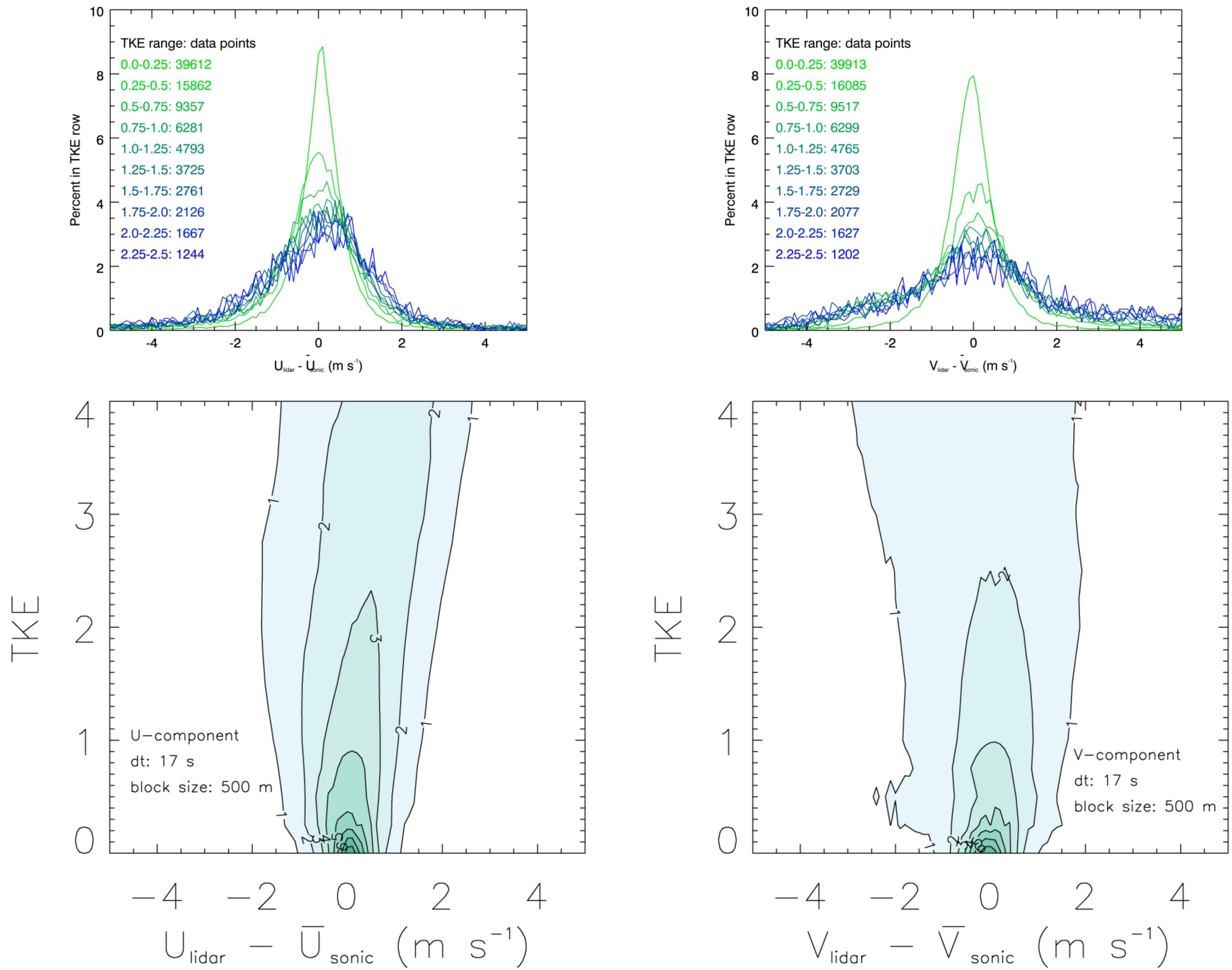


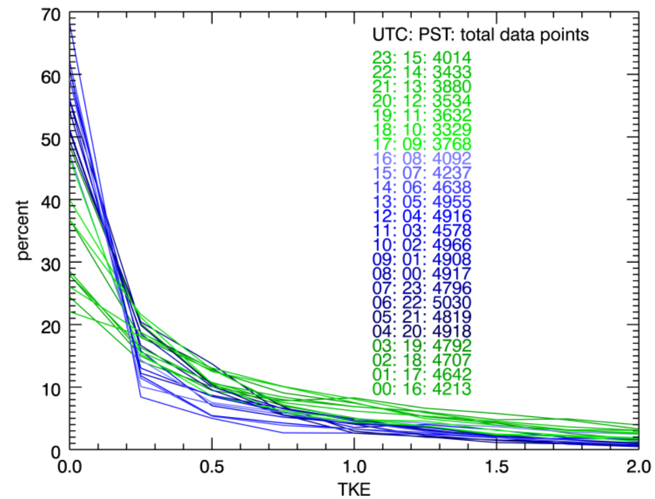
V-COMPONENT

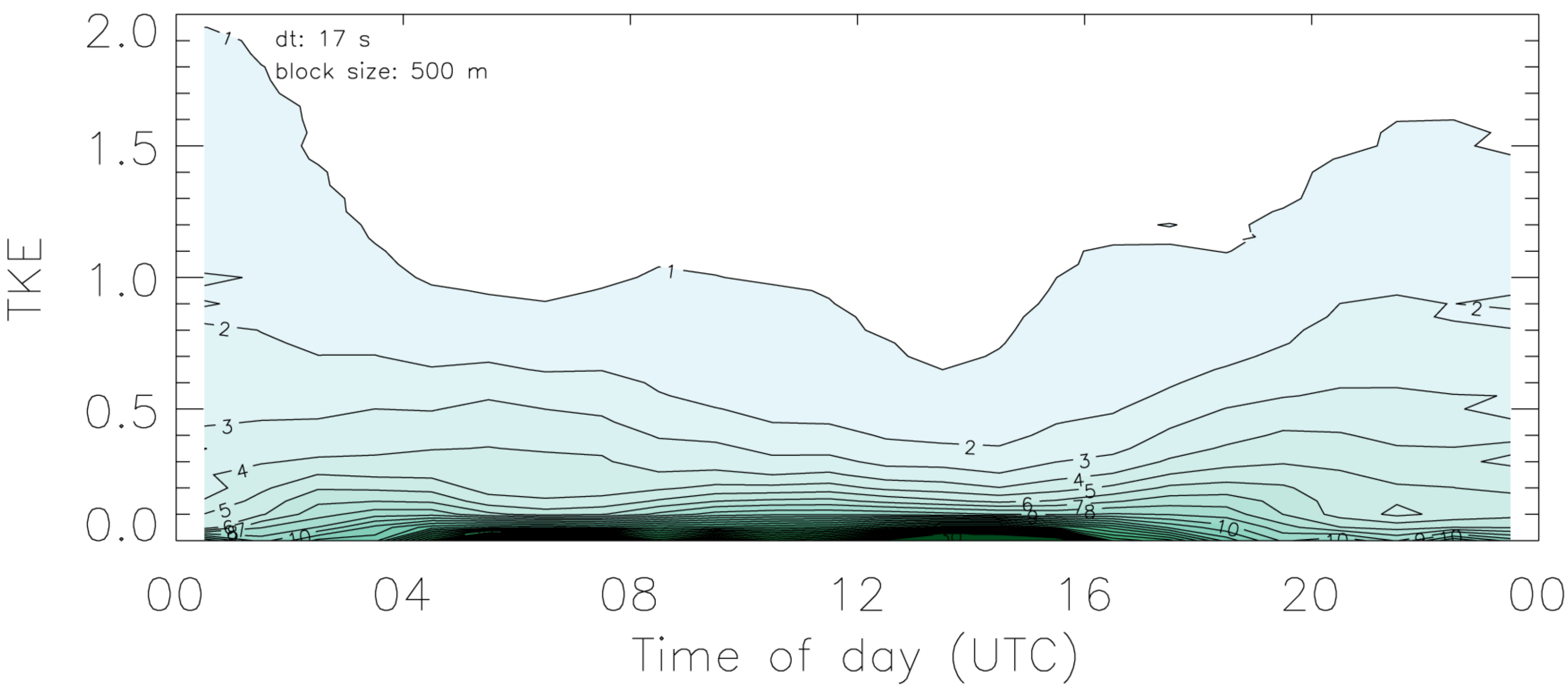


U-COMPONENT

V-COMPONENT

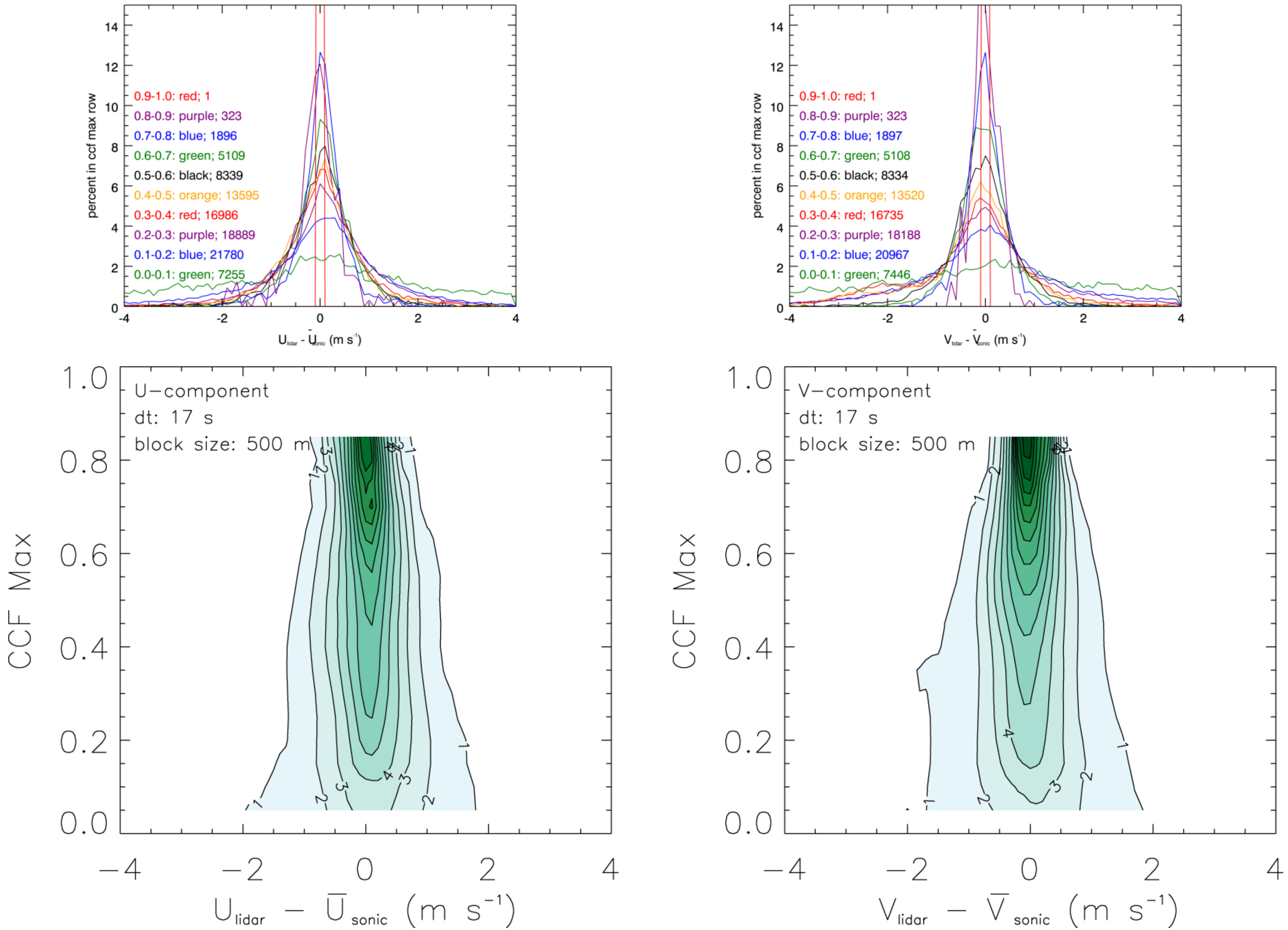


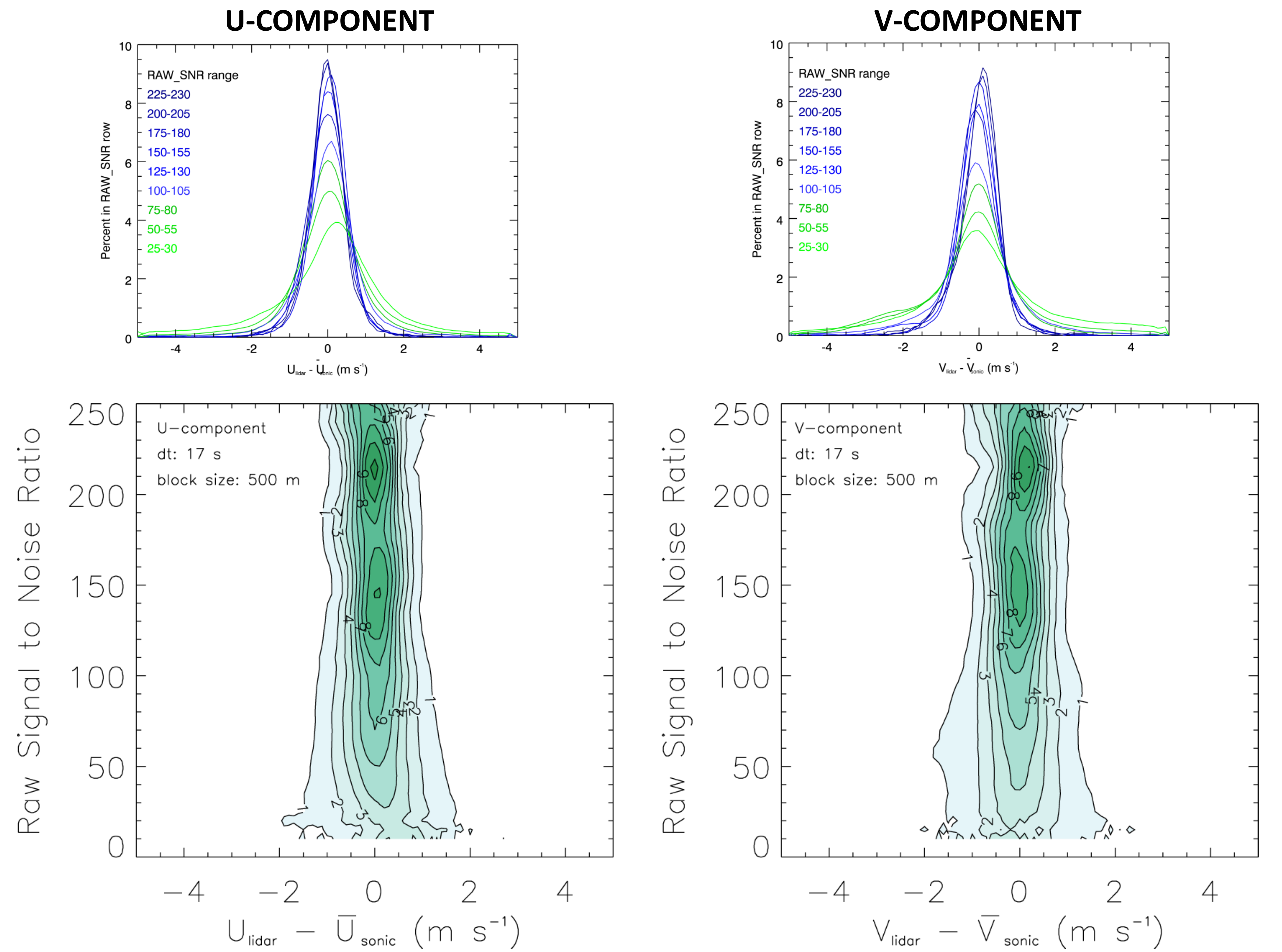

UTC: PST: total data points
23: 15: 4014
22: 14: 3433
21: 13: 3880
20: 12: 3534
19: 11: 3632
18: 10: 3329
17: 09: 3768
16: 08: 4092
15: 07: 4237
14: 06: 4638
13: 05: 4955
12: 04: 4916
11: 03: 4578
10: 02: 4966
09: 01: 4908
08: 00: 4917
07: 23: 4796
06: 22: 5030
05: 21: 4819
04: 20: 4918
03: 19: 4792
02: 18: 4707
01: 17: 4642
00: 16: 4213
percent
TKE


dt: 17 s
block size: 500 m
TKE
Time of day (UTC)

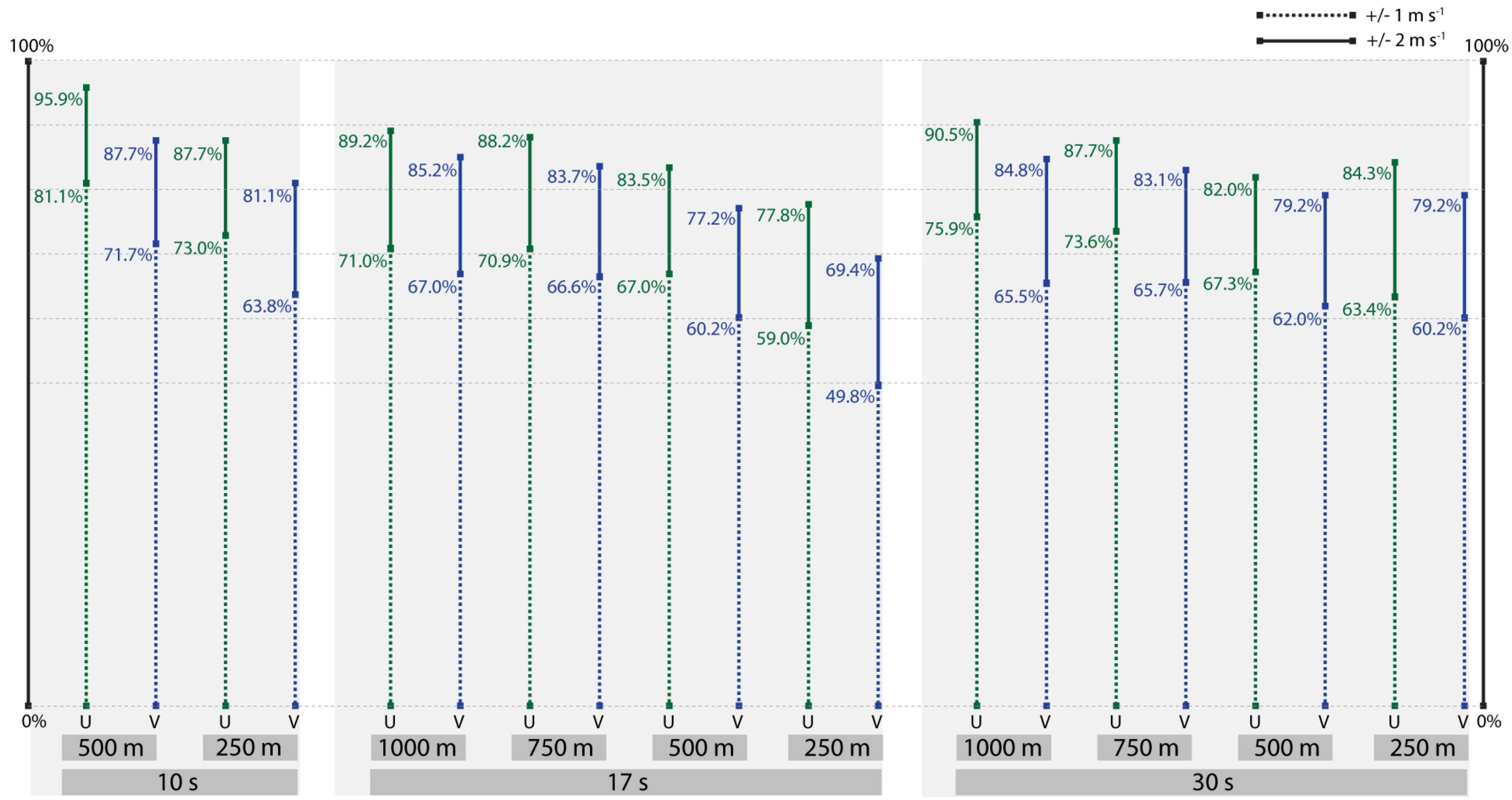
U-COMPONENT

V-COMPONENT





U-COMPONENT
V-COMPONENT
RAW_SNR range
225-230
200-205
175-180
150-155
125-130
100-105
75-80
50-55
25-30
Percent in RAW_SNR row
U_lidar - Ū_sonic (m s⁻¹)
V_lidar - V̄_sonic (m s⁻¹)
U-component
V-component
dt: 17 s
block size: 500 m
Raw Signal to Noise Ratio



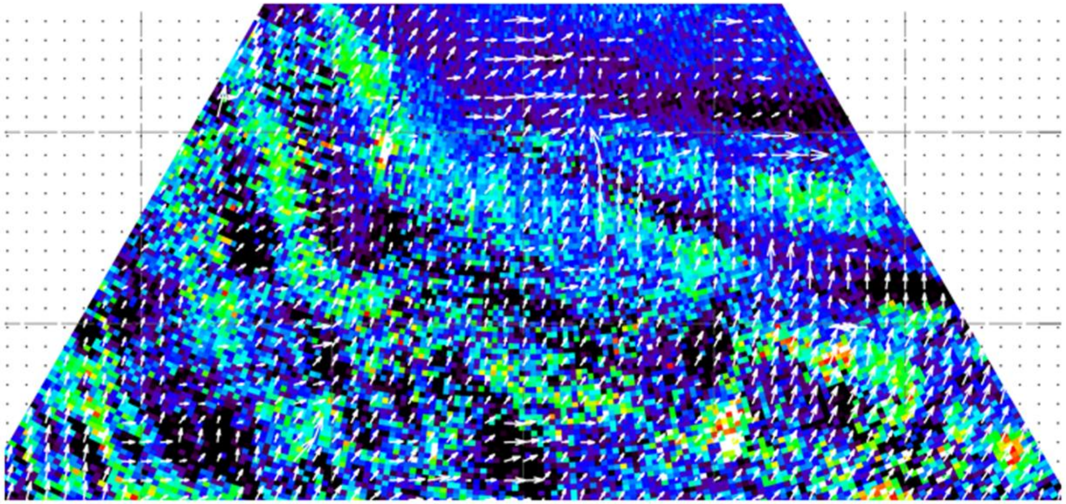
+/- 1 m s^{-1}
+/- 2 m s^{-1}
100%
0%
95.9%
81.1%
87.7%
71.7%
87.7%
73.0%
81.1%
63.8%
89.2%
71.0%
85.2%
67.0%
88.2%
70.9%
83.7%
66.6%
83.5%
67.0%
77.2%
60.2%
77.8%
59.0%
69.4%
49.8%
90.5%
75.9%
84.8%
65.5%
87.7%
73.6%
83.1%
65.7%
82.0%
67.3%
79.2%
62.0%
84.3%
63.4%
79.2%
60.2%
U V U V
500 m 250 m
10 s
U V U V U V U V
1000 m 750 m 500 m 250 m
17 s
U V U V U V U V
1000 m 750 m 500 m 250 m
30 s

Related concurrent work

Atmospheric Lidar Research Group

REAL

Department of Physics
California State University Chico



The REAL is a scanning, infrared, elastic backscatter lidar. It is used to visualize the structure and movement of the clear lower atmosphere via aerosol scattering. The instrument excels at observing the dispersion of aerosol plumes, detecting density current fronts, and monitoring the atmospheric boundary layer height. The REAL was developed at NCAR, is property of the NSF, is maintained at California State University Chico, and is available for use.

EVENTS

January 25, 2011

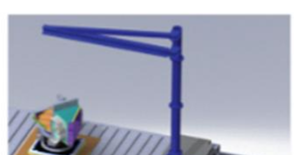
Dr. Mayor presents at the 91st AMS Annual Meeting this week:

5th Symposium on Lidar Atmospheric Applications
22-27 January 2011, Seattle, WA.

- Abstract

December 10, 2010

Capstone Design of the Jib-crane for the Lidar Beam Steering Unit is complete.



NEWS

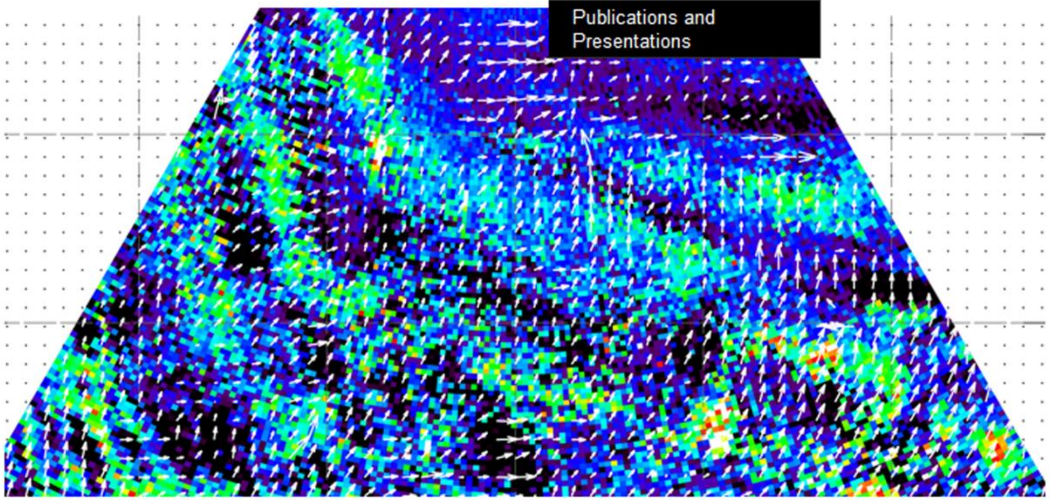
Looking for a post-doc position in Atmospheric Science? Come work with us! Research opportunities are abundant at Chico State in the areas of atmospheric lidar, boundary layer meteorology, and image processing. NSF AGS is accepting applications for Post-docs until April 11, 2011.

Contact Dr. Mayor as a sponsoring scientist for your proposal to NSF AGS.

Atmospheric Lidar Research Group

REAL

Department of Physics
California State University Chico



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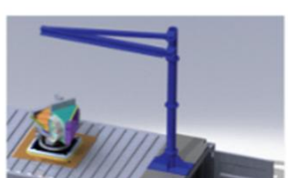

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To access animations and images from REAL at CHATS, click on any of the following dates that are listed as Available

14 March 2007 Available
15 March 2007 Available
16 March 2007 Available
17 March 2007 Available
18 March 2007 Available
19 March 2007 Available
20 March 2007 Available
21 March 2007 Available
22 March 2007 Available
23 March 2007 Available
24 March 2007 Available
25 March 2007 Available
26 March 2007 Available
27 March 2007 Available
28 March 2007 Available
29 March 2007 Available
30 March 2007 Available
31 March 2007 Available

1 April 2007 Available
2 April 2007 Available
3 April 2007 Available
4 April 2007 Available
5 April 2007 Available
6 April 2007 Available
7 April 2007 Available
8 April 2007 Available
9 April 2007 Available
10 April 2007 Available
11 April 2007 Available
12 April 2007 Available
13 April 2007 Available
14 April 2007 Available
15 April 2007 Available
16 April 2007 Available
17 April 2007 No data
18 April 2007 Available
19 April 2007 Available
20 April 2007 Available
21 April 2007 Available
22 April 2007 Available
23 April 2007 Available
24 April 2007 Available
25 April 2007 Available
26 April 2007 Available
27 April 2007 Available
28 April 2007 Available
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1 May 2007 Available
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14 May 2007 Available
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16 May 2007 Available
17 May 2007 No data
18 May 2007 No data
19 May 2007 Available
20 May 2007 Available
21 May 2007 Available
22 May 2007 Available
23 May 2007 Available
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28 May 2007 Available
29 May 2007 Available
30 May 2007 Available
31 May 2007 Available

1 June 2007 Available
2 June 2007 Available
3 June 2007 Available
4 June 2007 Available
5 June 2007 Available
6 June 2007 Available
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8 June 2007 Available
9 June 2007 Available
10 June 2007 Available
11 June 2007 Available

Atmospheric Lidar Research Group

Department of Physics
California State University Chico

26 March 2007, Dixon, CA. Sunset: 0225 UTC (1825 PST). Sunrise: 1402 UTC (0602 PST).

UTC: 00 - 03 | 04 - 07 | 08 - 11 | 12 - 15 | 16 - 19 | 20 - 23
PST: 16 - 19 | 20 - 23 | 00 - 03 | 04 - 07 | 08 - 11 | 12 - 15

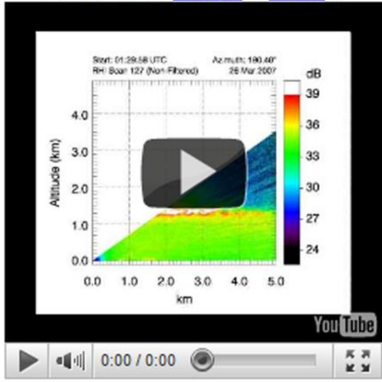
List of all days
<-- | Previous Day | | Next Day | -->

Vertical (RHI)

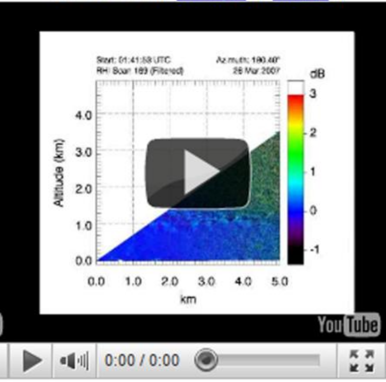
Horizontal (PPI)

Unfiltered | Filtered | Unfiltered | Filtered

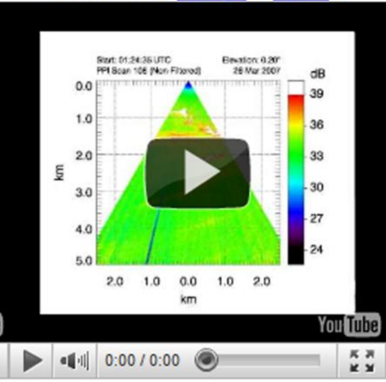
00-03 UTC | Images | Movie |



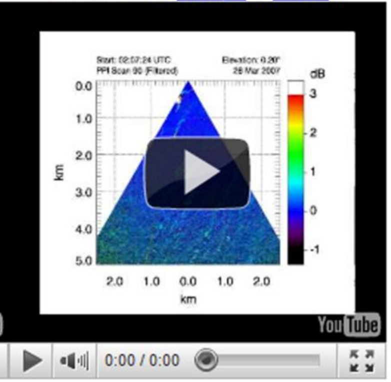
00-03 UTC | Images | Movie |



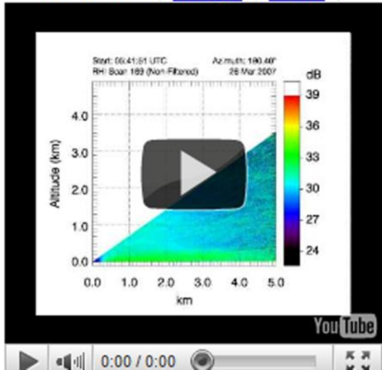
00-03 UTC | Images | Movie |



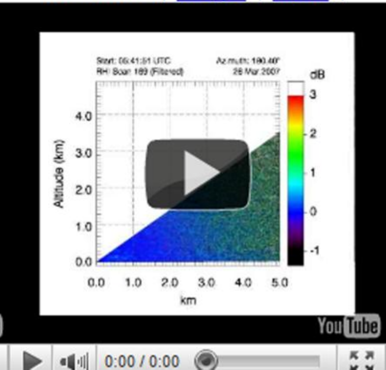
00-03 UTC | Images | Movie |



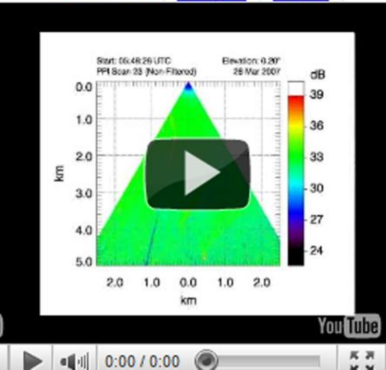
04-07 UTC | Images | Movie |



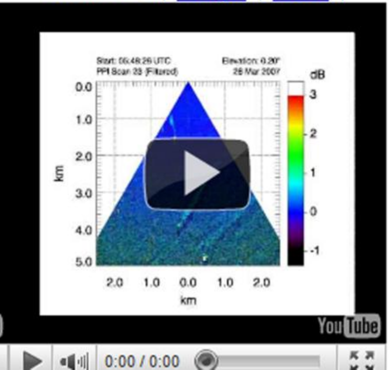
04-07 UTC | Images | Movie |



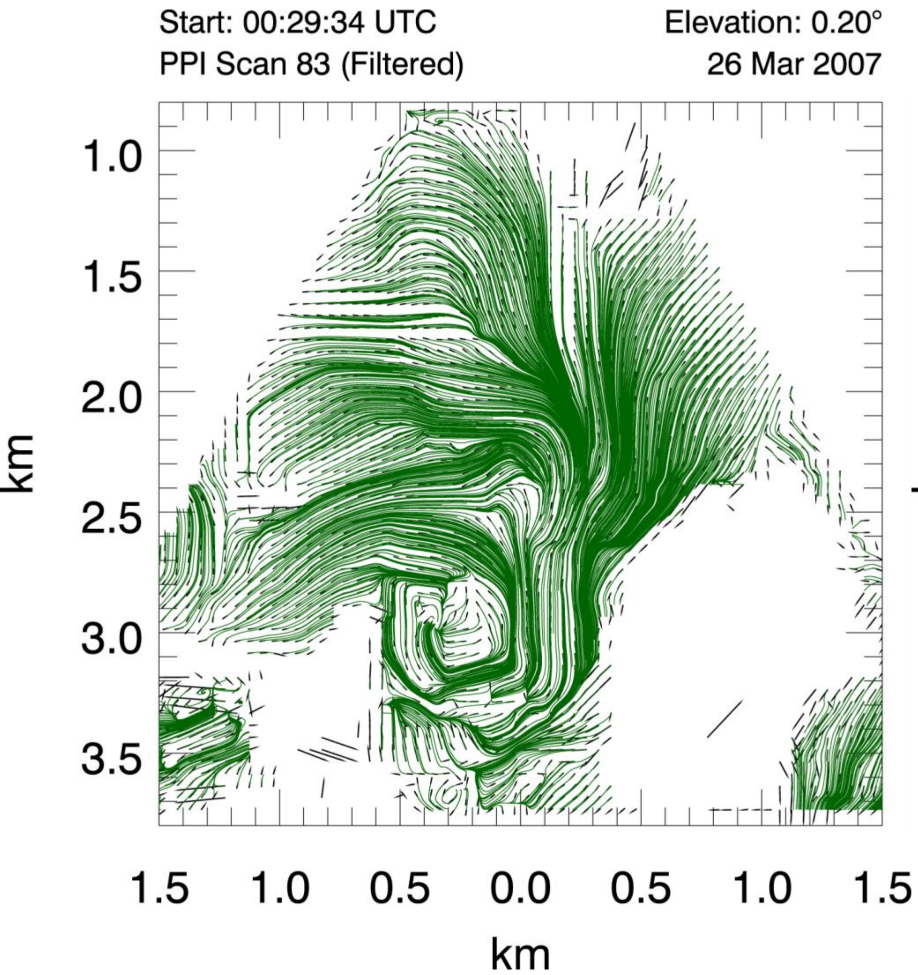
04-07 UTC | Images | Movie |

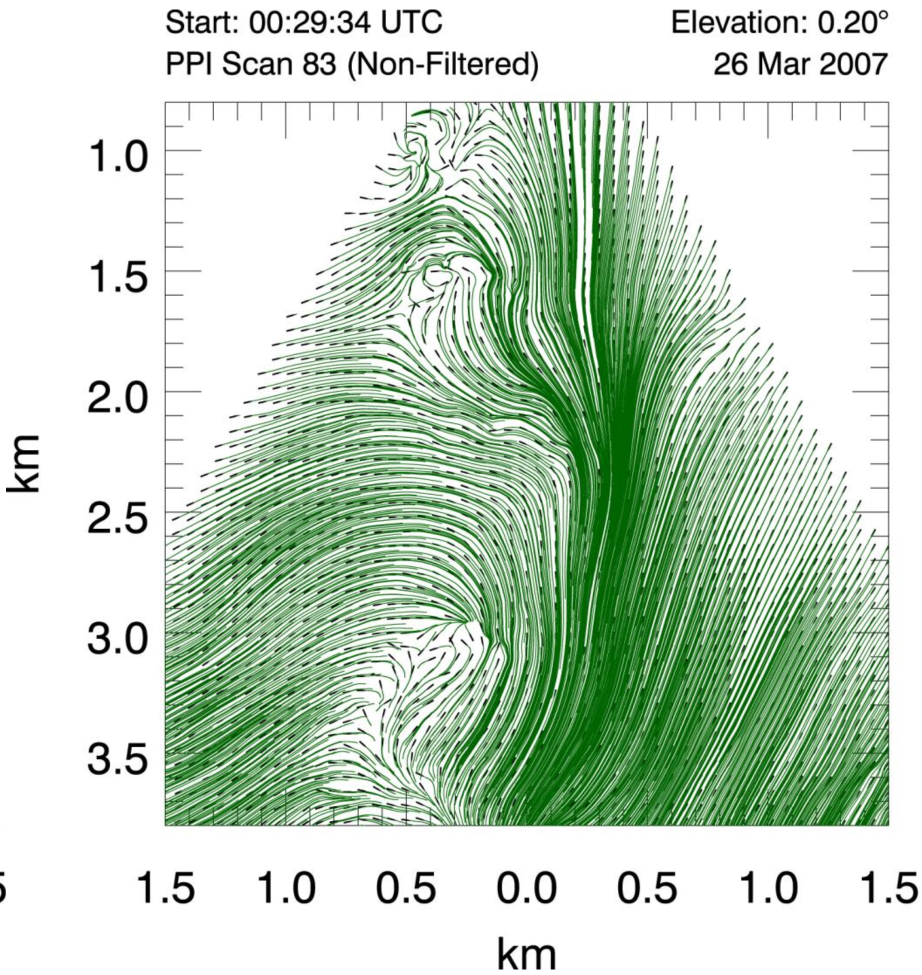


04-07 UTC | Images | Movie |



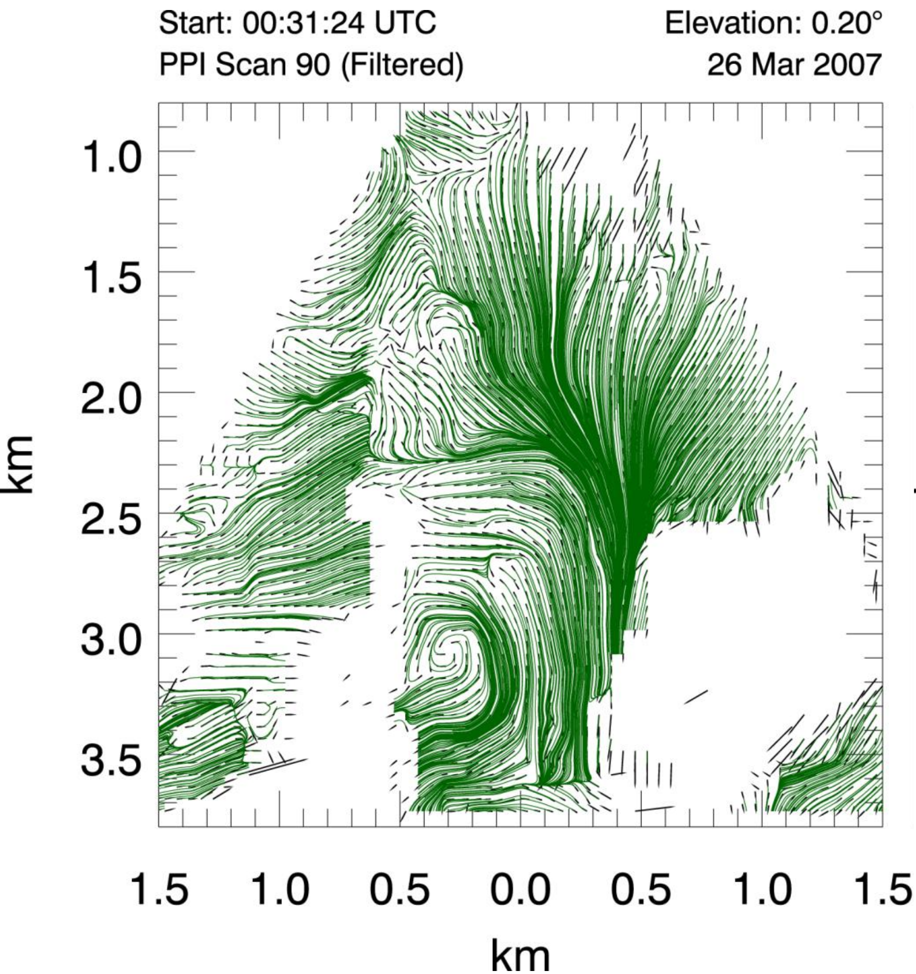
Cross-correlation Optical Flow



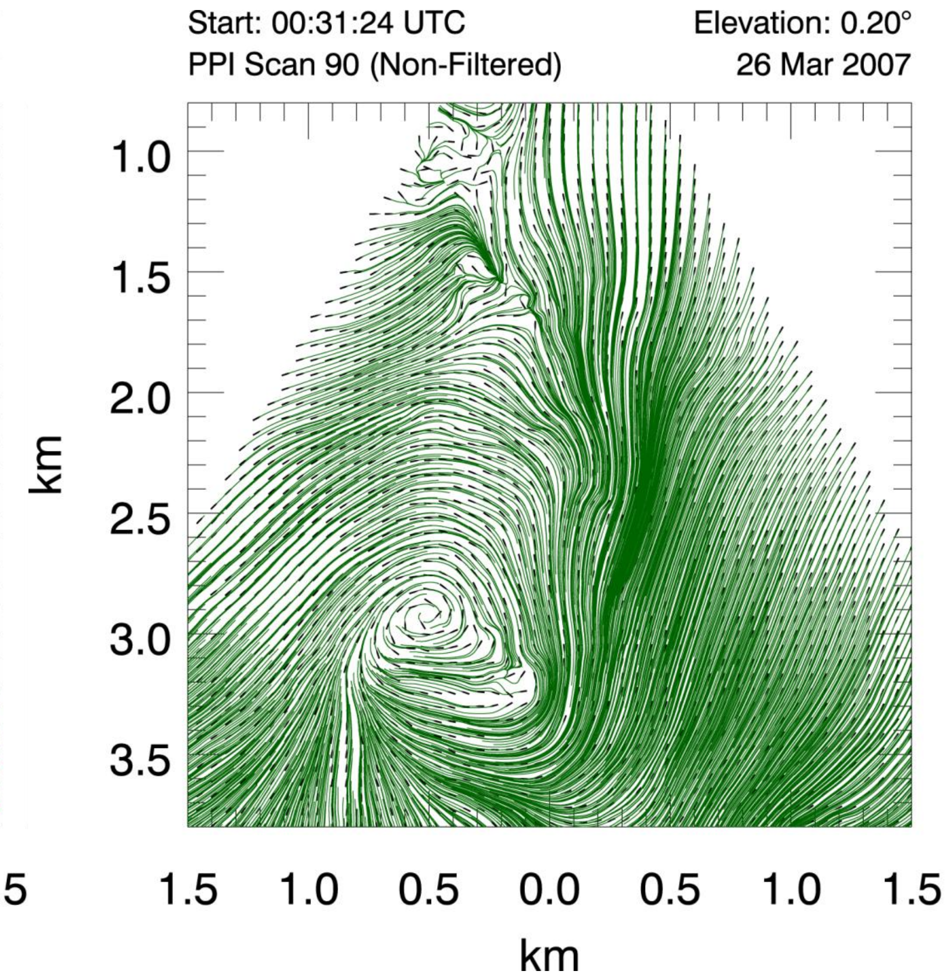


Derian, P., P. Heas, E. Memin, and S. D. Mayor, 2010: Dense motion estimation from eye-safe aerosol lidar data. 25th International Laser Radar Conference, St. Petersburg, RU, 5-9 July.

Cross-correlation



Optical Flow



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Parallel Processing using Graphical Processing Units (GPUs)

Conclusions

- Better agreement at night when TKE is low.
- Gravity waves do not appear to present a significant problem.
- Better agreement with higher CCF maximums.
- Code is not perfect. (v-components show less agreement than u-components.)
- Faster scanning will improve measurements.
- Optical Flow has strong promise to “fill the gaps” but needs tuning.

New questions:

- How much averaging of the sonic anemometer data for the fairest comparison?
- Does the technique work at higher altitudes?

Thanks to:

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