Analysis of Low Level Winds Measured by a Ship-Mounted, High Resolution Doppler Lidar during the Dynamics of the Madden Julian Oscillation (DYANMO) Experiment

Wm. Alan Brewer
NOAA R/E/CSD3
325 Broadway
Boulder, CO 80305
phone: (303) 497-7859 fax: (303) 497-5318 email: alan.brewer@noaa.gov

Award Number: N0001412IP20126
http://www.esrl.noaa.gov/csd/groups/csd3/measurements/dynamo/

LONG-TERM GOALS

The goal of this research is to contribute to the understanding of atmospheric predictability on intraseasonal and longer time scales. This involves understanding the nature and source of the predictability in the oceans and the physical processes by which that predictable signal is ultimately realized and coupled into the atmosphere. A better understanding of air-sea interactions is critical to this goal because most of the modes of variability (the diurnal cycle, Madden-Julian Oscillations - MJO, Monsoons, ENSO, upwelling) are fundamentally dependent on air-sea interaction processes.

OBJECTIVES

- Characterize the vertical turbulence profiles in the clear air and overlying cloud layer (when present) and cloud microphysical parameters and relate these quanties to subsurface and air/sea fluxes, cloud formation, upper tropospheric moistening and precipitation.
- Measure the horizontal wind, its variations, and mesoscale and sub-mesoscale organized features in the horizontal wind field and relate these meaurements to ocean turbulence, the change in air/sea fluxes, and the transport of thermodynamic energy through the Marine Atmospheric Boundary Layer (MABL).
- Study the evolution of convection in the Marine Atmospheric Boundary Layer in order to understand its role in transporting moisture into the upper troposphere and effect on the initiation and propagation phases of the Madden Julian Oscillation (MJO).

APPROACH

The instrumentation suite on the RV Roger Revelle was designed to provide coverage of dynamic processes below the ocean surface (OSU ocean profiling), at the air-sea interface (NOAA Air-Sea Flux and surface met) and through the Troposphere and lower portion of the Stratosphere (NCAR Sondes and 915 Wind Profiler, NOAA W-Band and Doppler Lidar, CSU/NASA C-Band Radar). The NOAA High Resolution Doppler Lidar (HRDL) was mounted on the O3 deck of the RV Roger Revelle and provided continuous coverage of clear air dynamics from within a few meters of the ocean surface

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2012**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Analysis of Low Level Winds Measured by a Ship-Mounted, High Resolution Doppler Lidar during the Dynamics of the Madden Julian Oscillation (DYANMO) Experiment**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **NOAA R/E/CSD3 325 Broadway Boulder, CO 80305**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**10**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

through the top of the MABL. The ship-based Doppler lidar measurements are being analyzed and combined with other measurements of atmospheric and oceanic properties made during legs 2 and 3 of the Dynamics of the Madden Julien Oscillation (DYNAMO) experiment to address the objectives outlined in the previous section.

The research focus for the past year has been:

1) Acquire data during the field phase (legs 2, 3) and make real time results available on the web
2) Archive and quality control the data
3) Analyze the data to calculate continuous profiles of horizontal wind, turbulence, and aerosol distribution.
4) Combine and compare HRDL Horizontal Wind measurements with other measurements from the RV Revelle.
5) Form statistics of the winds and turbulence profiles.
6) Attend science meeting and scientific conferences

WORK COMPLETED

(1) Acquire data during the field phase (legs 2, 3) and make real time results available on the web

HRDL operated continuously during Legs 1, 2, and 3 and performed a repeating 20-minute sequence of scans. These scans, shown in Figure 1 were designed to measure vertical profiles of the horizontal wind speed and direction, moments of the vertical wind speed, and horizontal wind variance, and spatial distribution of aerosol. In addition, the scanning data can be used to visualize spatial variations and their temporal evolution in the horizontal wind field out to a range of 6-8 km and, in that mode, are useful in studying phenomena such as precipitation driven outflows. During a portion of the cruise, additional long range vertical stares were added to characterize cirrus cloud levels.

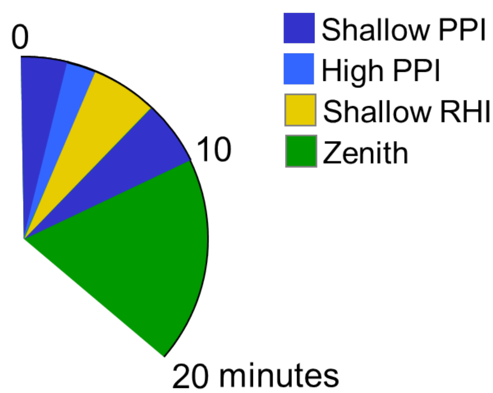

Figure 1 Twenty minute scan sequence used during DYNAMO

The scan sequence shown in Figure 1 has two low-elevation-angle (1 degree) azimuthal scanning (PPI) sweeps designated as Shallow PPI. These scans have 1 degree azimuth resolution for each beam and take approximately 2 minutes to perform. They are positioned in the sequence at the beginning and middle to provide as close to a regular spacing as possible. The parameters of the azimuthal scans designated as High PPI depended on conditions and the depth of the aerosol layer. Typically we operated with elevation angles of 8 and 45 degrees, but would often lower these elevation angles to fill in gaps in the vertical profiles as needed. The shallow RHI scans are elevations scans (0-30 degrees) performed at two fixed azimuth angles, typically separated by 90 degrees, one plane forward the other off the starboard side. The two-sweep pattern would be repeated 3 times giving a total of 6 sweeps, 3 in each azimuth plane. The remainder of the time (approximately 10 minutes) was spent staring vertically. For a period of three days, the first part of the vertical stare was set to our longest range setting in order to characterize cirrus clouds when present. A summary of the scans and the data products derived from them are shown in Table 1.

Table 1 Scans and associated data products

Scan	Data Product
Shallow PPI	Horizontal wind profiles, Divergence profiles, Spatial feature tracking
High PPI	Horizontal Wind Profiles, Divergence profiles
Shallow RHI	Horizontal Wind Profiles, Horizontal wind variance, Spatial feature tracking
Zenith	Moments of the vertical velocity, Cloud statistics

At the end of every twenty minute scan sequence, basic data products (profiles of horizontal wind speed and direction, vertical velocity variance, aerosol backscatter signal intensity and surface wind vectors) were automatically generated and posted to a ship-based web page for on board usage. When the satellite internet connection was available, these products were also posted to a NOAA web page and were uploaded to the NCAR field catalog. When the connection was available, but limited, the results were uploaded every 4 hours. Figure 2 shows typical images of these products for a 12-hour period: Horizontal wind speed and direction, vertical velocity variance, aerosol backscatter signal strength, and surface wind vectors (for a different 6 hour period). The NOAA web page can be found at: http://esrl.noaa.gov/csd/lidar/dynamo.

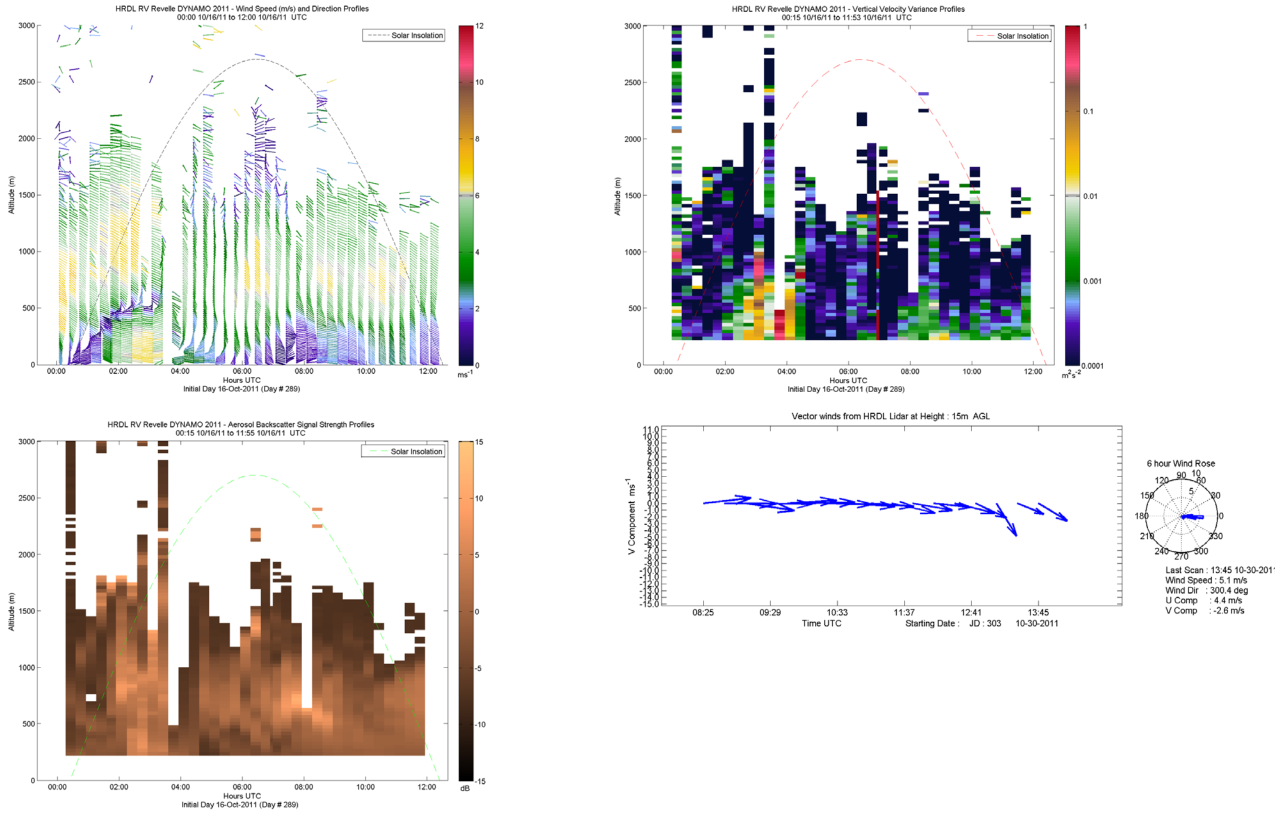

Figure 2 HRDL Lidar results posted to the web every twenty minutes during continuous operation: Vertical profiles of horizontal wind speed and direction, vertical velocity variance, aerosol backscatter signal strength for a 12 hour period and 6 hour vector surface winds.

HRDL operated continuously during legs 2&3 of the DYNAMO experiment with no major outages Table 2 and Figure 3 show the statistics and temporal coverage of the two operational periods for HRDL during the study. The table indicates over 1300 hours of operation during Legs 2&3. The number of files (and hence scans) are shown in the second part of the table, broken out for each type of scan with a total of 11,001 scans for the period of interest.

Table 2 Running Statistics for Legs 1, 2, and 3.

	Number of hours					Number of scans				
Leg	Total	zenith	RHI	VAD	% data collection time	zenith	RHI	1ppi	VAD	Total
2	690.1	328.2	103.9	258.0	96.5%	2162	2146	4320	2146	10774
3	656.8	310.0	95.4	251.5	95.9%	2112	2046	4123	2046	10327

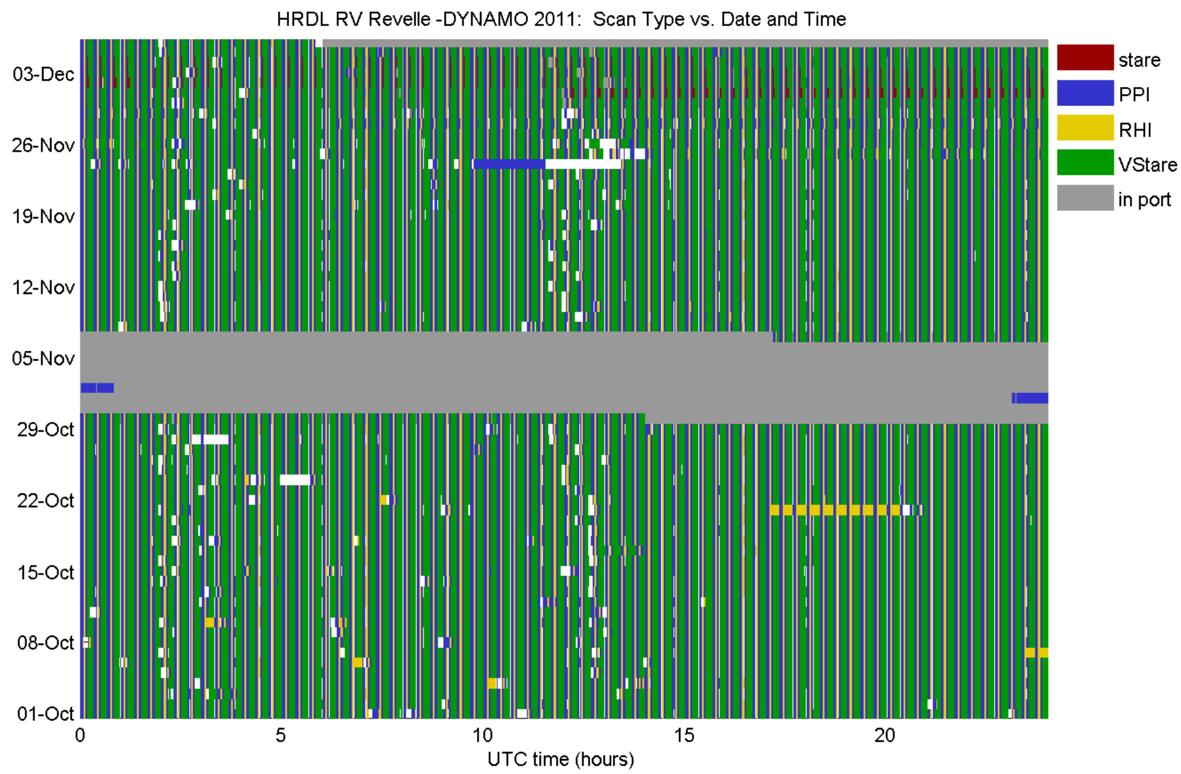

Figure 3 Scan chart for Leg 3 of DYNAMO. Colors represent the different scan types

(2/3) Archive and quality control the data Analyze the data to calculate continuous profiles of horizontal wind, turbulence, and aerosol distribution.

The raw and processed data were archived and multiple backup copies of the data have been generated. The data have been quality controlled and analyzed to form level-two profiles of wind speed and direction, and vertical velocity variance profiles. There results will be made available to the community through the NCAR data site.

(4-6) These will be discussed in the results section

(7) Attend science meeting and scientific conferences

Oral Presentation:
Preliminary Results from a Motion-Stabilized, Scanning, Doppler Lidar, Operated from the RV Revelle During DYNAMO. Wm. Alan Brewer, R. J. Alvarez II, A. Weickmann, S. Sandberg, and M. Hardesty AMS 3 1)
Combine and compare HRDL Horizontal Wind measurements with other measurements from the RV Revelle.0th Conference on Hurricanes and Tropical Meteorology
15-20 April 2012, Ponte Vedra Beach, Florida

Oral Presentation
Measurements of Marine Atmospheric Boundary Layer Dynamics using a Ship-based, Motion-stabilized, Doppler Lidar during the Dynamics of the Madden Julian Oscillation

(DYNAMO) Experiment. Wm. Alan Brewer, R. J. Alvarez II, A. Weickmann, S. Sandberg, and M. Hardesty
16th International Symposium for the Advancement of Boundary-Layer Remote Sensing
5-8 June 2012, in Boulder, Colorado, USA.

Oral Presentation
Statistics of Atmospheric Boundary Layer Winds and Turbulence from Ship Based Doppler Lidar Measurements made during DYNAMO. Wm. Alan Brewer, Simon de Szoeke, and Chris Fairall
18th Conference on Air-Sea Interaction
9-12 July 2012, Westin Copley Place, Boston, MA

Attended ONR DYNAMO Data Meeting: 12-13 July 2012, Boston, MA

RESULTS

(4) Combine and compare HRDL Horizontal Wind measurements with other measurements from the RV Revelle.

As discussed in the previous section, HRDL generated profiles of horizontal wind speed and direction from within a few meters of the ocean surface through the MABL every twenty minutes. Figure 4 shows a time height display of these results for legs 2 & 3. The RV Revelle also had motion-compensated, high-temporal-resolution surface wind measurements from a NOAA sonic anemometer mounted at a height of 18m above the ocean surface on the jack staff, wind profile measurements every 30 minutes from the mechanically-stabilized NCAR 915 MHz wind profiler, and radio sonde launches every 3 hours during intensive measurement periods.

The ship was typically oriented into the prevailing direction of the wind to maintain ideal observational conditions for flux measurements made from the bow. Comparing with only those observations where the wind direction was within ±90 degrees of the bow and averaging results in time to a common 20 minute resolution, Figure 5 shows a scatter plot of wind speed and direction as measured by the NOAA Sonic and HRDL at a similar height for all of Legs 2&3. Results from a least squares analysis are shown in Table 3. These show a very strong correlation (0.99) between the measurements with very little bias (less than 6 cm/s in speed and 3.5 degrees in direction). These results are being used to evaluate the active stabilization and line-of-site velocity correction algorithms used by HRDL.

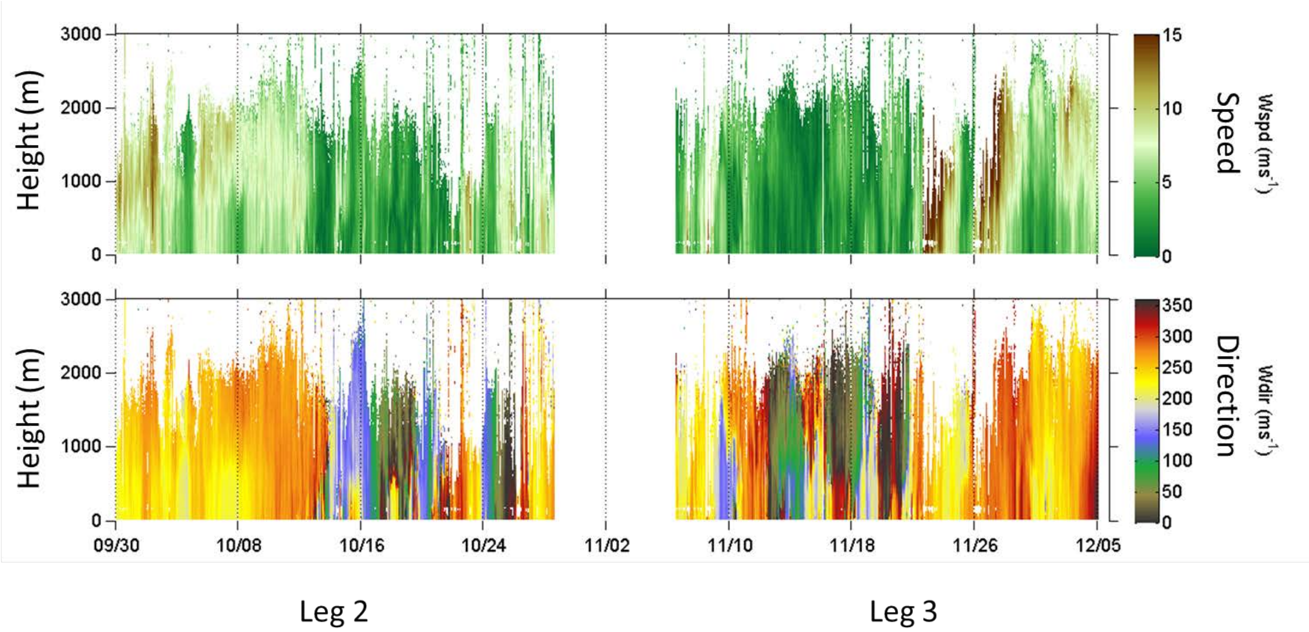

Figure 4 Horizontal wind speed (top) and direction (bottom) for legs two and three of DYNAMO

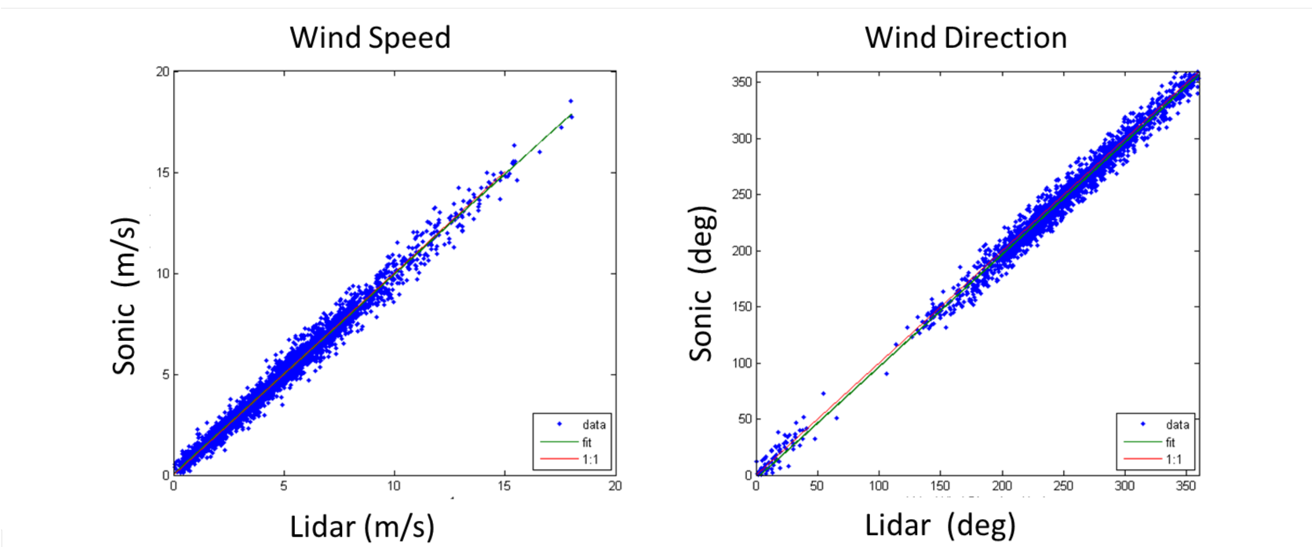

Figure 5 A comparison of wind speed (left) and direction (right) as measured by the bow mounted NOAA Sonic and HRDL wind profile results at a similar height. The sonic data were averaged to the same time resolution as the lida profiles: 20 minutes.

Table 3 Least squares analysis results from the comparison of the NOAA Sonic measurements and HRDL Lidar wind profiles

	Speed (m/s)	Direction (deg)
Slope	0.99	1.0
Offset	0.06	-3.49
Corr Coef	0.99	0.99

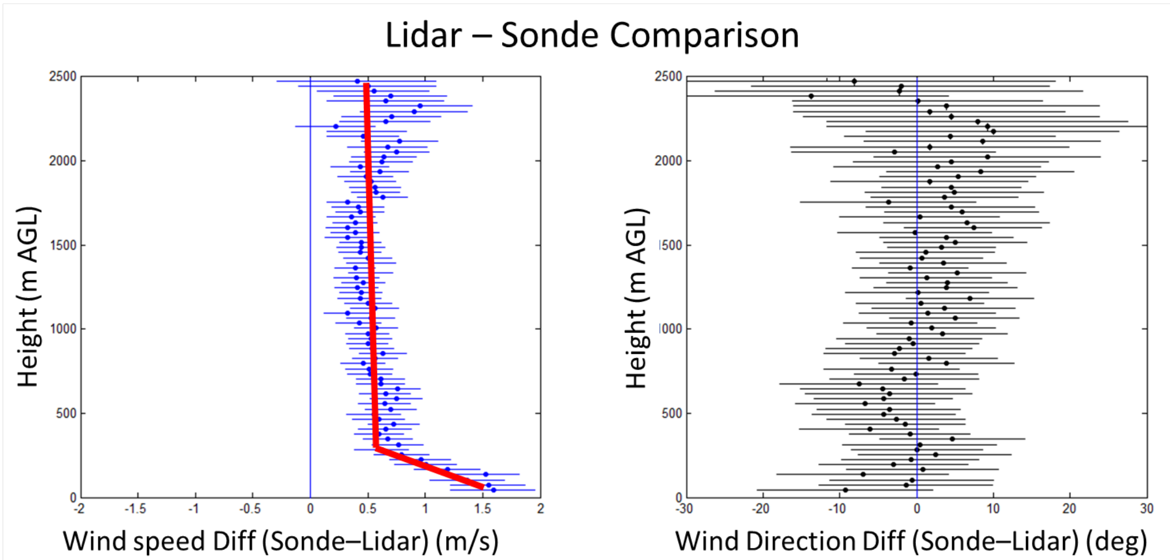

Figure 6 Comparison of wind speed and direction profiles as measured by radio sondes launched every 3 hours and the nearest HRDL observations in time for all sonde launches in legs 2 & 3

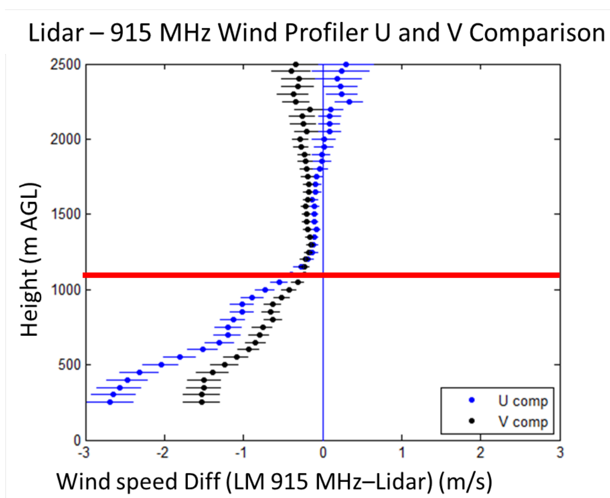

Figure 7 Comparison of horizontal wind components U and V as measured by HRDL and the NCAR 915 MHz wind profiler

The wind profiles were also compared to those measured by radio sondes launched every three hours from the ship (Figure 6) and 30 minute wind profiles measured by the mechanically stabilized 915MHz wind profiler (Figure 7). Both of these comparisons are being made with RAW data obtained on the ship during the cruise. An additional comparison will be performed with quality controlled results provided by investigators from NCAR who are currently updating the both the sonde and wind profiler data sets. The results in both figures show the mean difference between the time series of all measurements made during legs 2&3 at each height. The error bars represent ±3 sigma standard deviation of the mean. The difference in wind speed in the left plot of Figure 6 shows a static offset of 0.5 m/s for heights above 500m and a linearly increasing offset as a function decreasing height from 250m to the surface. These features are most likely a result of noisy sonde position data that are stronger near the surface due to pendulum effects common after launch. The difference in direction shown in the right hand plot does not show s statistically significant difference from zero.

The difference between the U and V components of the wind as measured by the wind profiler and the lidar as a function of height is shown in Figure 7. The significant structure below 1200m is most likely caused by spurious reflections off ocean waves otherwise known as seaclutter. Investigators at NCAR are applying post processing techniques to minimize this effect and the expectation is that the impact of seaclutter will be minimized for data above 500m. The comparison will be repeated in order to help evaluate these techniques.

(5) Form statistics of the winds and turbulence profiles.

Figure 8 contains normalized distributions of the legs 2&3 horizontal wind profiles shown in Figure 4. The left distribution shows that the wind speed probability peaked between 1 m/s and 7 m/s in the lower 500m of the MABL with some acceleration present above 1000m. There were peak winds over 20m/s, but the prevalence was low. The right hand distribution shows that the winds were generally out of the West turning towards the SW below 700m.

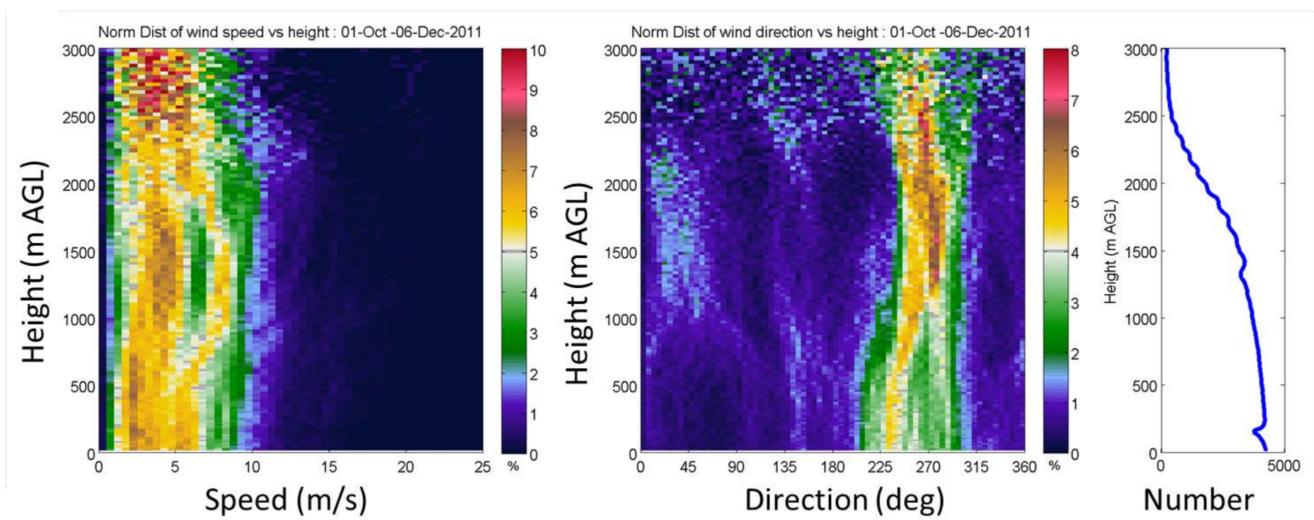

Figure 8 Normalized distributions of wind speed and direction

Estimates of vertical velocity variance and skewness are calculated for every 20 minute period. Figure 9 contains local solar time composite profiles of these quantities for all data taken during legs 2&3.

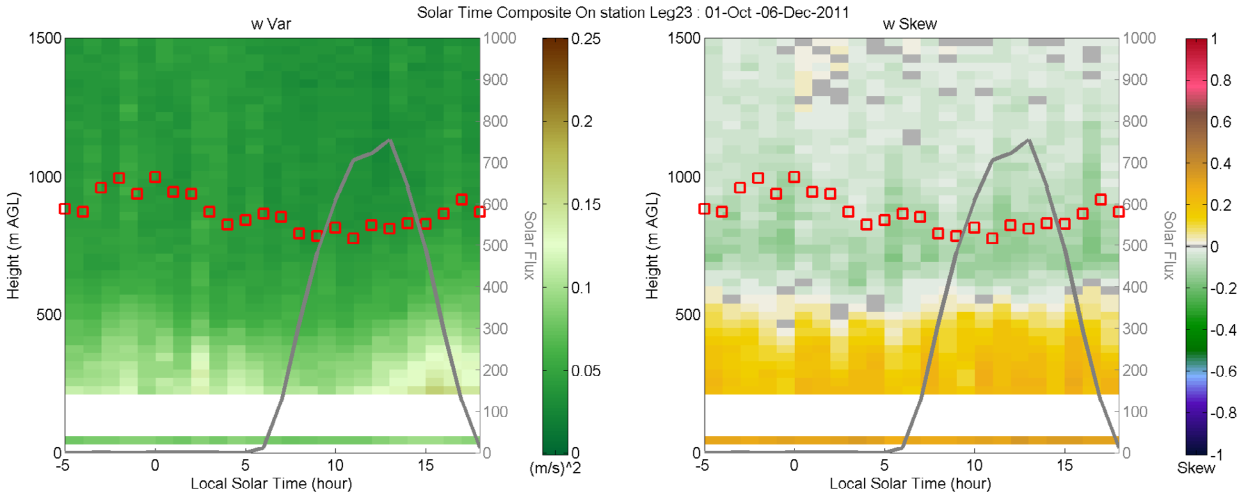

Figure 9 Local Solar Time composite profiles of vertical velocity variance and skewness for all data taken during Legs 2&3. The red squares are composited estimates of cloud base from ceilometer. The gray lines are composted insolation measurements to indicate day vs night conditions.

The red squares are composites of cloud base estimates from the ship mounted ceilometer. These results show a slight diurnal pattern of lower cloud base and lower amounts of vertical variance during the morning and mid afternoon. The strongest vertical variance occurs during the late afternoon into early evening. The skewness is generally positive below 500m and negative above that altitude with no strong diurnal pattern.

IMPACT/APPLICATIONS

Results from the lidar are being combined with other, similar measurements from the RV Revelle to evaluate data quality and aide in technique development. The collaboration with NCAR on the sonde generated wind profiles and development of techniques being applied the wind profiler data to minimize seaclutter contamination are two such examples. In the lower 200m height of the MABL, lidar provides unique high temporal and spatial resolution measurements that are being used to study turbulence in this portion of the atmosphere. Future work will focus on combining the lidar results with other instruments such as the vertically pointing W-band radar to provide estimates of turbulence that are continuous through the MABL to cloud top (when present).

Horizontally and vertically scanning data from the lidar are being used to provide contextual information for the hundreds outflows that passed over the ship while on station. The scanning strategy allows the outflows to be tracked in time and their spatial extent to be characterized. Work is being done to use these data to determine the vertical extent of each outflow. Ultimately, these results will be combined with measurements from the suite of instruments on the RV Revelle to form a catalog of outflow events for both legs 2&3.