

Dual-Doppler lidar measurements during multi-month field campaign

Adam Medina^{*a,c}, Tyler W. Pfeifer^a, Zackary Mitchell^a, Narasimha Prasad^a, Kyle Renshaw^c, Grady Koch^b

^aNASA Langley Research Center, Hampton, Virginia 23681

^bApex Photonics, Huntsville Alabama, 35802, United States

^cUniversity of Central Florida, The College of Optics and Photonics (CREOL), Knight Vision Lab, Orlando, FL 32186, United States

ABSTRACT

A coordinated wind lidar system was utilized during a multi-month campaign to characterize wind conditions in the Planetary Boundary Layer. Understanding wind conditions in this dynamic layer of the atmosphere is critical to ensure safe and reliable aircraft operations that include Uncrewed Aircraft Systems (UAS). The dual-Doppler lidar technique was first demonstrated by NASA for Advanced Air Mobility (AAM) applications. Using this technique, continuous resolved wind vectors at low altitudes were successfully measured. Unexpectedly, a hurricane formed off the coast of California and its remnants made landfall and passed through the test site. The coordinated dual-Doppler lidars ran continuously through an extreme weather event and successfully measured wind dynamics caused by the storm. This work will focus on the deployment of a multi-lidar setup and analyzing the wind dynamics caused by the storm.

Keywords: Lidar, Wind, Dual-Doppler, Remote Sensing, Severe Weather

1. INTRODUCTION

A multi-month field campaign named AEROcAST (Advanced Exploration of Reliable Operation at low Altitudes: meteorology, Simulation, and Technology) was planned to measure wind conditions in the lower atmosphere during the summer of 2023 at NASA, Armstrong Flight Research Center (AFRC), Edwards Air Force Base, California. The primary objective of the campaign was to characterize wind flow at lower altitudes near a structure to better understand how winds around structures could impact aircraft operations. This has been a potential barrier for Advanced Air Mobility (AAM) which foresees many light aircraft flying in the lower atmosphere and near urban environments.^[1-5] Two commercially available ruggedized Doppler Wind lidars, which are used to measure wind vectors, were placed at a test site which consisted of a large, isolated structure when an unexpected severe weather event occurred. A Category 4 Hurricane named Hilary, formed off the West Coast of the United States and impacted southern California and Mexico. The hurricane reached a maximum sustained wind speed of 220 km/h off of the West Coast of the United States but weakened to a strong tropical storm as it made landfall and passed over the test site^[6]. The two Doppler wind lidars were synchronized and programmed to run continuously and coordinated throughout the multi-month duration of the field campaign. The coordinated lidars performed dual-Doppler virtual (meteorological) tower scans. Similar to meteorological towers which have wind sensing instruments at various altitudes, virtual tower lidar scans yield resolved wind vectors at various altitudes by intersecting lidar beams at selected altitudes. These virtual towers are spatially agile and provide higher altitudes than those achieved using mobile meteorological towers. For this campaign, the two Doppler wind lidars were operationally synchronized to create virtual towers. The number of virtual towers that can be created depend on the lidar scanning angles and their intersecting field of view. Throughout the severe weather event, the virtual towers measured wind dynamics at the test site.

2. METHODOLOGY

Two coordinated Doppler wind lidars were strategically positioned near a large shuttle hangar (25.3 m height) to measure wind dynamics throughout the duration of the test campaign. Figure 1 shows the hangar at the test site and Figure 2 is an image of one of the two Doppler wind lidars used.

^{*}adam.a.medina@nasa.gov, 757-864-5313, <https://www.nasa.gov>



Figure 1. Shuttle Hangar at AFRC test site



Figure 2. One of two, Doppler wind lidars near the hangar at AFRC

Doppler wind lidars measure wind speed by emitting a laser pulse with a known frequency through the atmosphere. This pulse backscatters off aerosols in the atmosphere and returns some of the emitted light to the lidar. This returned light has a Doppler shifted frequency due to the aerosols moving with the wind. This Doppler shifted frequency is proportional to the wind speed along the lidars Line-of-Sight (LOS). Scanning Doppler wind lidars can measure the different components of the wind through various means.^[7,8] The dual-Doppler approach involves intersecting two Doppler wind lidar beams at a specific location and time to measure the horizontal wind vector. The virtual tower created by the dual-Doppler lidars consists of discrete altitudes where both lidar beams intersect providing wind measurements at various altitudes throughout. To implement this dual-Doppler virtual tower approach, each lidar was programmed with specific elevation and azimuthal angles. Figure 1 displays two scanning lidar units that intersect at various elevation and azimuthal angles to create four virtual towers.

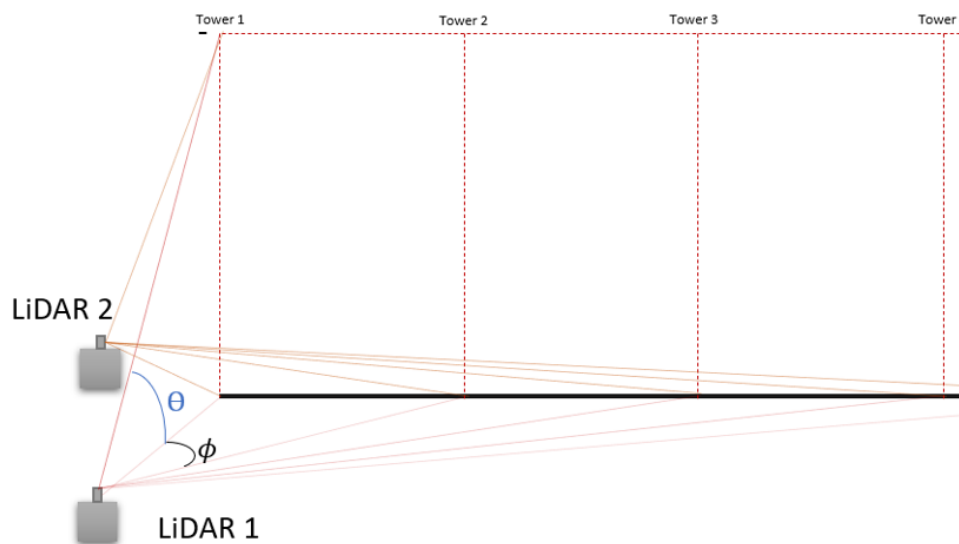


Figure 3. Virtual Towers created by intersecting lidar beams from two Doppler lidar wind lidar units

The positions of the virtual towers, as well as the lidar intersection altitudes were determined by site parameters and objectives of the campaign. For this campaign, the virtual tower altitudes chosen were 0.9 m, 3.048 m, 6.096 m, 9.144 m, 12.192 m, 15.240 m, 18.288 m, 21.336 m, 24.384 m, 27.432 m, 30.480 m, 36.576 m, 45.720 m, 60.960 m, 76.200 m, and 152.40 m Above Ground Level (AGL). The corresponding elevation and azimuthal angles for dual-Doppler intersections at each virtual tower were calculated and programmed into the lidars. The intersection was verified at the base of each virtual tower with infrared viewers. To complete the four scans, the lidars would begin by intersecting at tower 1, cycling through the various altitudes and then continuing to the following tower. Once the lidars completed scanning virtual tower 4, the lidars would return to tower 1 and repeat. Scanning through the four virtual towers would take less than two minutes. By analyzing the data^[2], we can plot the wind direction and speed measurements for each of the four virtual towers.

3. RESULTS

Tropical storm Hilary made landfall and reached the AFRC test site on August 20th 2023. The dual-Doppler lidars successfully measured the wind dynamics for approximately 38 hours. To plot the wind dynamics, the wind direction and speed were plotted in side-by-side plots. Each plot displays altitude vs. time with the measured wind direction and wind speed plotted respectively in color code. Figure 2 displays the 24-hour wind measurements recorded via the dual-Doppler lidar technique.

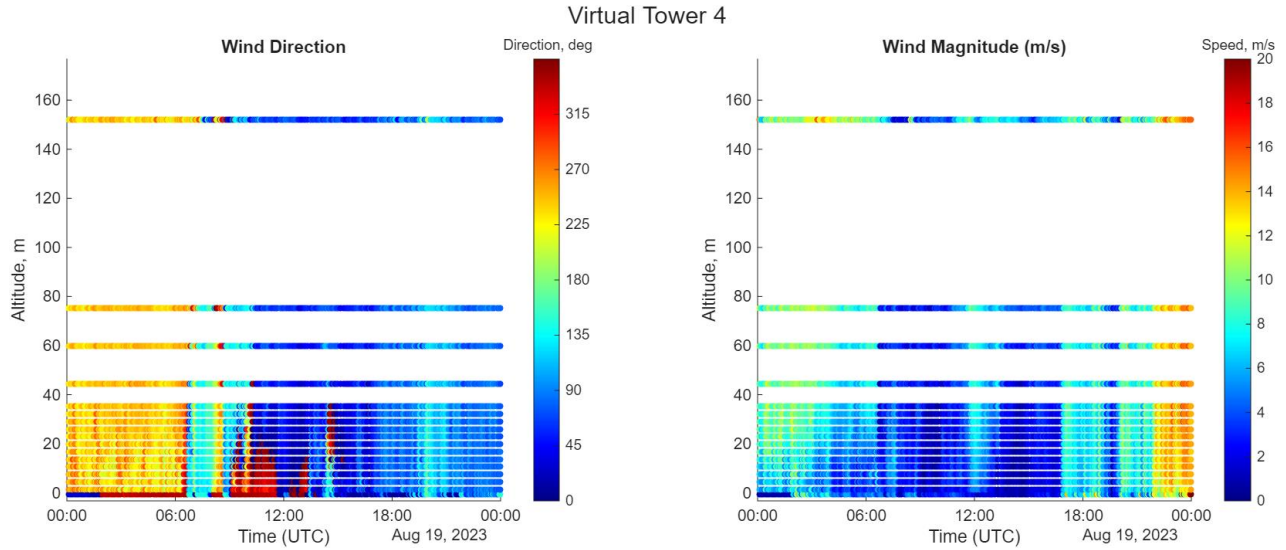


Figure 4. 24-hours of a single virtual tower measurement for 8/20/23

The discrete altitudes of lidar intersection can be observed. The higher density of measurements at lower altitudes was chosen to better sample the wind conditions of a simulated vertiport near a structure as well as still measure the wind flow above. Throughout the 24-hour period changes in wind direction and speed can be observed throughout the measured altitudes. This 24-hour perspective allows for an understanding of the wind dynamics at the virtual tower location throughout the day. To plot the dynamics measured by the four virtual towers during the tropical storm, the four virtual towers are plotted in Figures 2-5.

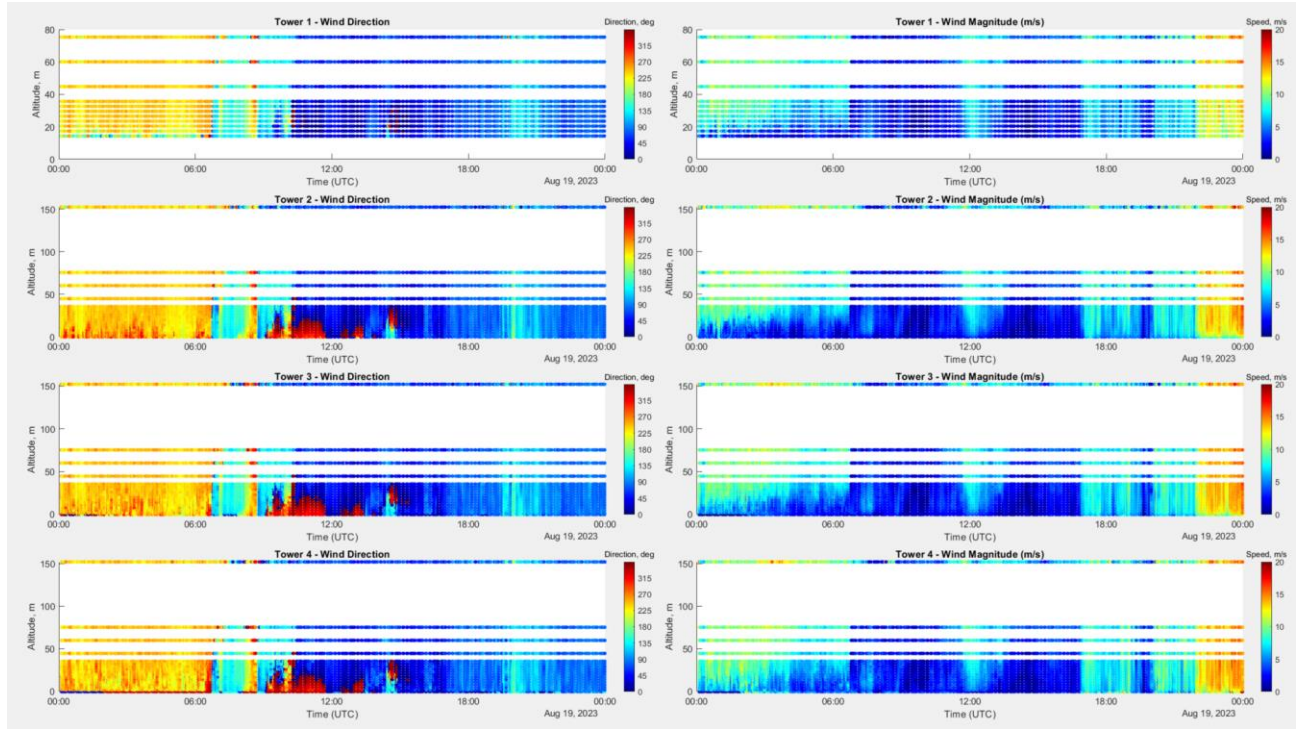


Figure 5. 24-hours of virtual tower measurements on 8/19/23. Tropical Storm Hilary impacts the test site in late afternoon.

On August 19th, 2023 from 00:00 UTC to approximately 20:00 UTC a low wind speed less than 10 m/s and at times less than 5 m/s is recorded and displayed in Figure 2. As the tropical storm approaches the site at 20:00 UTC, an abrupt increase in windspeeds is recorded by all four virtual towers. As tropical storm Hilary reached the test site, the wind speed increased to 15 m/s and at higher altitudes approaches 20 m/s. These higher windspeeds would persist throughout the following day as the tropical storm was overhead the test site. The following day on August 20th 2023, windspeeds of 15 m/s – 20 m/s from a consistent wind direction is measured for all four of the virtual towers.

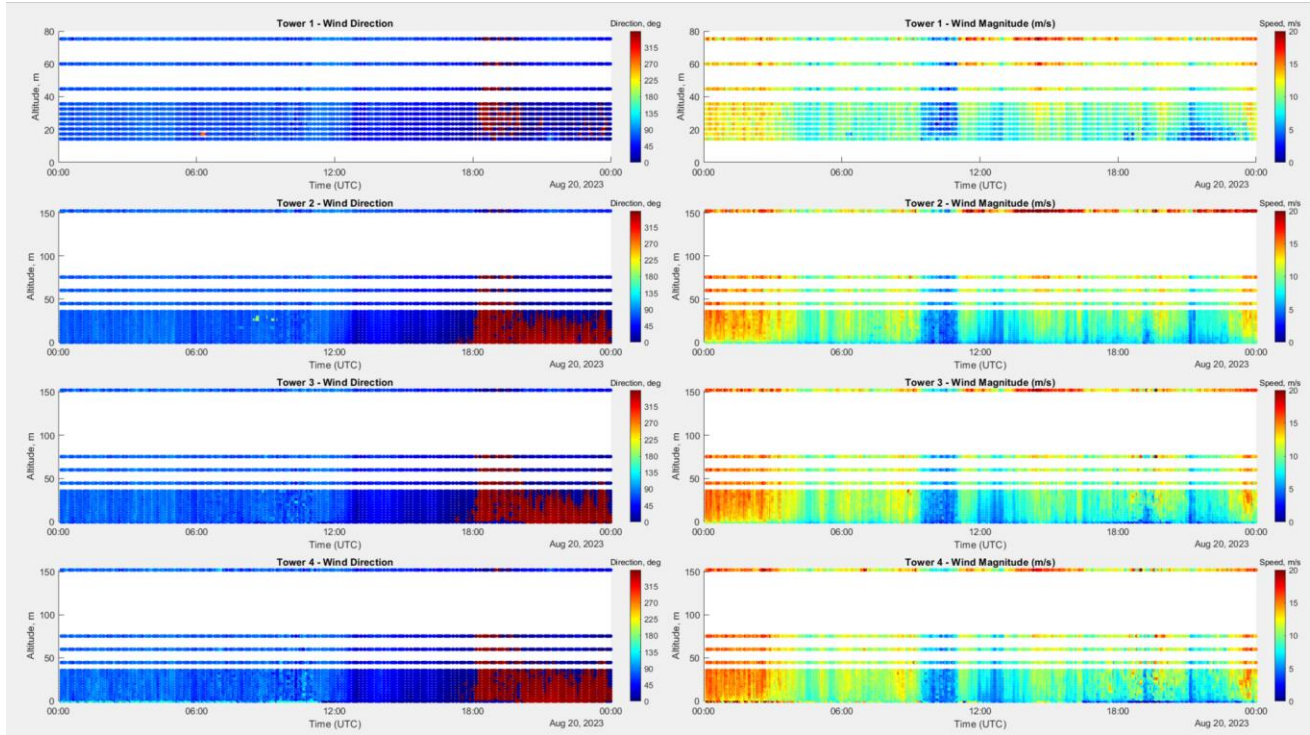


Figure 6. 24-hours of virtual tower measurements on 8/20/23. Tropical Storm Hilary impacts the test site with higher recorded windspeeds.

In Figure 3 the wind speeds measured at higher altitudes tend to be faster. This is the case throughout the 24-hour period plotted in Figure 3. This could be due to the more freely flowing air that is unobstructed by structures at the test site. As the day progresses initially the windspeed drops slightly, particularly at the lower altitudes, and then there are periods of faster wind speeds later in the day.

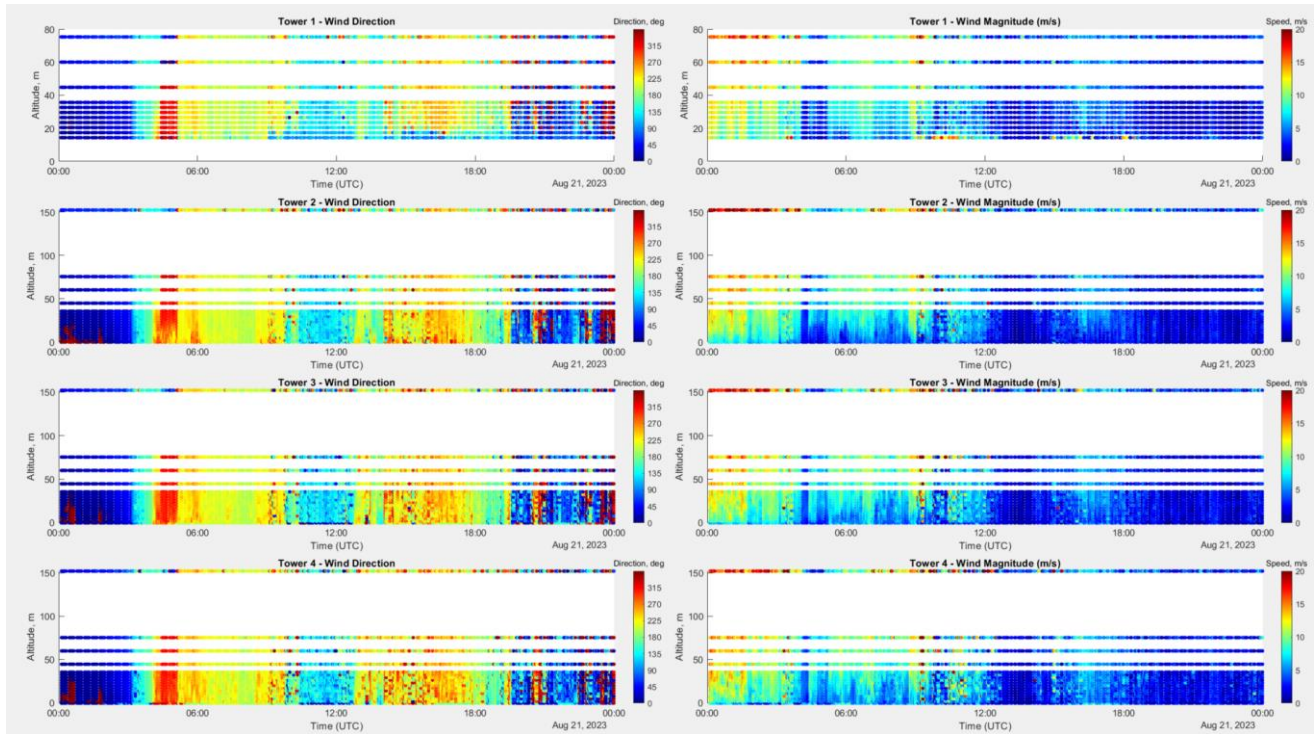


Figure 7. 24-hours of virtual tower measurements on 8/21/23 as Tropical Storm Hilary impacts the test site and windspeeds dissipate around 12:00 UTC.

In Figure 4, from 00:00 UTC to 12:00 UTC the lidars measured winds caused by tropical storm Hilary. Similar to Figure 3, the windspeed at higher altitudes was faster than those at lower altitudes. The difference, however, is in the variation of wind direction. The wind direction measured by the four virtual towers is changing throughout the 24-hour period. Beginning at 12:00 UTC and lasting throughout the rest of the day, the wind speed dropped to less than 5 m/s. This coincides with the path of the tropical storm. This low windspeed continued throughout August 22nd and is displayed in Figure 5.

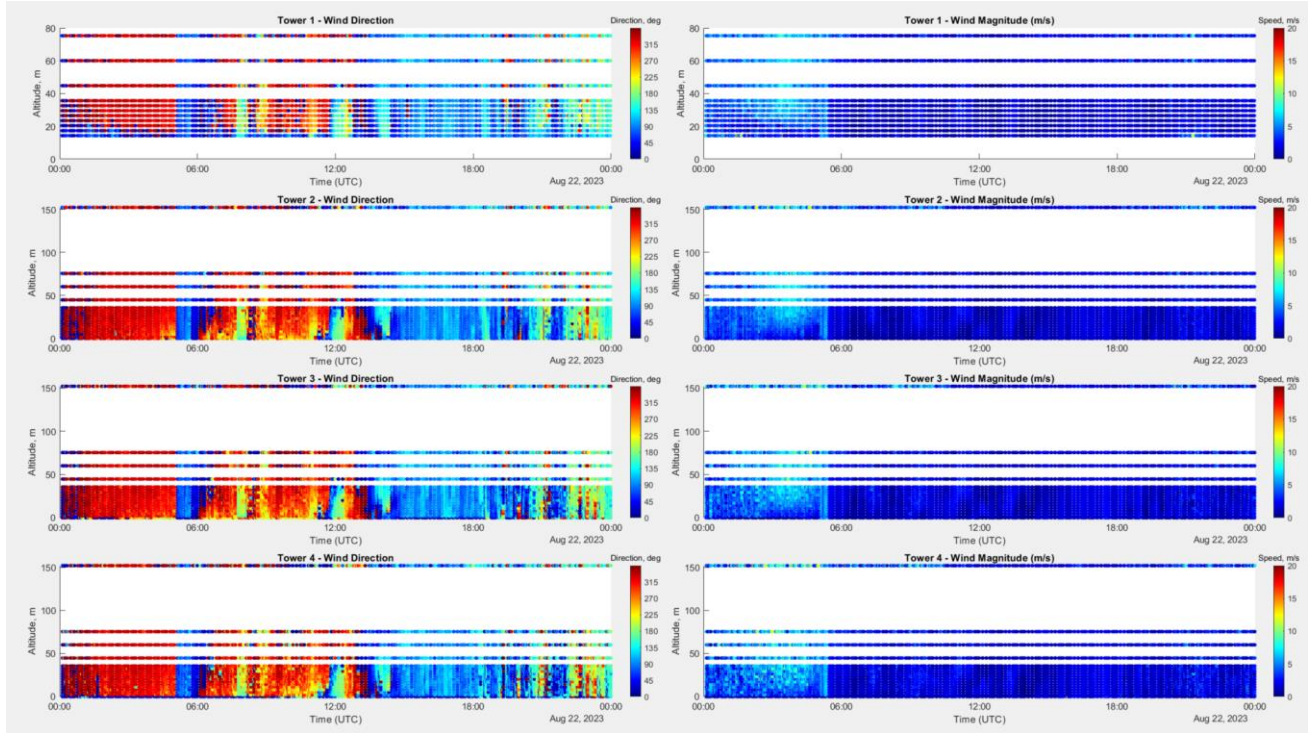


Figure 8. 24-hours of virtual tower measurements on 8/22/23 after tropical storm Hilary passed. Low windspeeds were measured following the storm.

After tropical storm Hilary passed through the test site, the wind speed was much lower. This low windspeed is consistent throughout the four virtual towers and all the measured altitudes.

4. CONCLUSION

Virtual towers provide wind measurements over long ranges (several kilometers) and thus provide significant advantages over fixed or mobile meteorological towers. In this paper, wind dynamics from tropical storm Hilary were successfully captured using the dual-Doppler based virtual tower technique. The lidars operated continuously throughout the tropical storm passing through the test site at Edwards Air Force base. The dual-Doppler lidar virtual tower technique uniquely provides the capability to measure winds at higher altitudes and longer ranges.

ACKNOWLEDGEMENTS

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