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# INITIAL RESULTS FROM THE EXPERIMENTAL MEASUREMENT CAMPAIGN (XMC) FOR PLANETARY BOUNDARY LAYER (PBL) INSTRUMENT ASSESSMENT (XPIA) EXPERIMENT

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## ABSTRACT

The Experimental Measurement Campaign (XMC) for Planetary Boundary Layer (PBL) Instrument Assessment (XPIA) is a DOE funded study to develop and validate methods of making three dimensional measurements of wind fields. These techniques are of interest to study wind farm inflows and wake flows using remote sensing instrumentation. The portion of the experiment described in this presentation utilizes observations from multiple Doppler wind lidars, soundings, and an instrumented 300m tower, the Boulder Atmospheric Observatory (BAO) in Erie, Colorado.

## 1. INTRODUCTION

Knowledge of the time evolving, three dimensional wind field is essential in developing and evaluating large eddy simulation (LES) models, the study of turbine wake effects, and optimization of turbine layout for wind farms.

A network of scanning, pulsed, Doppler wind lidars can be used to measure the wind speed over a common volume or along a common vertical line (virtual towers (Calhoun, 2006)). These observations, projected onto multiple line-of-site (LOS) look angles, are combined to estimate the three dimensional wind field.

The goal of this study was to develop an understanding of the trade-off between:

(1) Synchronous vs asynchronous observations,

(2) The spatial resolution of the common observational points within the measurement volume vs the temporal update rate of entire volume

(3) To optimize the geometric layout of the observational network given maximum range of the lidars, the rate at which the measurements are made, the size of the measurement volume, and the need to have sufficiently large relative look angles to maintain precision in the 3-D wind retrieval.

Utilizing a network of commercially available, low-pulse-energy, high-pulse-repetition frequency (PRF), Doppler wind lidars, the Experimental Measurement Campaign (XMC) for Planetary Boundary Layer (PBL) Instrument Assessment (XPIA) Experiment was conducted at the Boulder Atmospheric Observatory (BAO) from March 3rd – May 1st 2015. It was funded by the Department of Energy (DOE) and was designed to develop and evaluate methods for making three dimensional measurements of the wind field using remote sensing techniques.

## 2. METHODOLOGY

The XPIA study was conducted at the NOAA BAO, the site of a 300m meteorological tower outfitted with a set of three-axis sonic anemometers positioned on the NW and SE sides of the tower, every 50m in height. The portion of the study described in this presentation consisted of eight Doppler wind lidars: five commercial scanning units (either Leosphere 200S or Halo

Photonics Streamline), one scanning research system (NOAA High Resolution Doppler Lidar - HRDL), and two vertically profiling systems (Leosphere V1).

The locations of the instruments are shown in Figure 1 and described in Table 1. The red rings in the figure have 500m and 1000m radii, centered on the BAO tower. The HALO lidar operated primarily in a vertically staring mode and was located at the super site, just south of the tower, along with two Leopshere V1 lidar wind profilers.

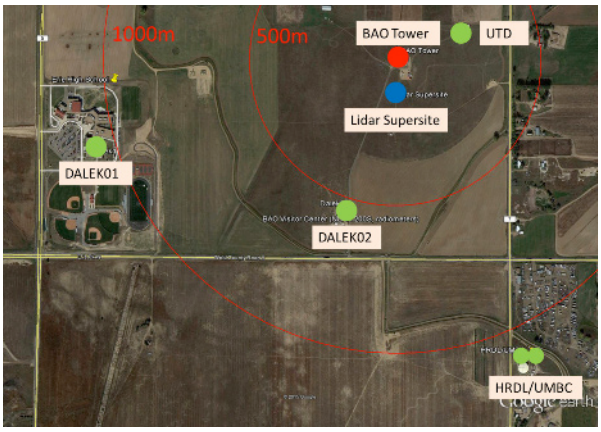


**Figure 1. Instrument locations during XPIA field campaign. The inner red circle is of radius 500 m centered on the tower while the outer circle is 1000 m radius centered on the BAO tower.**

| Designation | Model | Affiliation |
|---|---|---|
| DALEK01 (D1) | 200S | NOAA/ESRL |
| DALEK02 (D2) | 200S | NOAA/ESRL |
| UTD | 200S | U of Texas, Dallas |
| UMBC | 200S | U of Maryland, BC |
| HRDL | Research | NOAA/ESRL |
| At Super Site: | | |
| UCA | V1 | Univ of Colorado |
| UCB | V1 | Univ of Colorado |
| HALO | Streamline | DOE/PNNL |

**Table 1 The instrumentation deployed during the part of the XPIA experiment described in the presentation**

The location of the four scanning Leosphere 200s units were chosen to be within 1.1km of the tower (in order to provide measurement overlap in the case of moderately clean conditions) and positioned such that relative azimuths of the beams, when intersecting near the tower, would not degrade the precision of the 3-D wind retrieval due to geometry.

Projecting the D2 line of site to the tower through the tower and measuring the relative azimuth look angles to that projection, the relative angles of the [D1, D2(Proj), HRDL/UMBC] line of sites at the tower are [97,128,135] degrees (where 120 degrees would be equally spaced). The location of the UTD system is closer to the tower than the other units and, while its azimuthal line of site to the tower is nearly parallel with D1, it is closer and provides a steeper elevation angle than is possible from the other systems.

The co-located HRDL and UMBC 200S have nearly identical look angles. During the latter stages of the study, when the UMBC system was present, HRDL was operated in a survey mode to provide contextual information about the horizontal wind field over the entire measurement area while the four 200S units did synchronized scans.

The overlapping measurement volumes used in this study were typically either centered on the instrumented tower or over the lidar supersite (where continuous vertical velocity data from the HALO unit and continuous horizontal wind profiles from the V1 units could be used for evaluation purposes). Several measurement volumes and scanning approaches were evaluated: asynchronous scanning/horizontal plane, asynchronous scanning/vertical line (virtual tower), synchronous staring, small and large synchronous staring/horizontal plane array.

Initially, the lidars performed scans to determine the location of the booms holding the sonic anemometers on the tower and then performed synchronized stares at each level. This was done to determine the pointing angle offsets of each lidar, verify the alignment of the sonic anemometers, and evaluate the accuracy of software tools used to facilitate coordinated pointing of the multiple lidars.

The next step was to probe various measurement volumes with multiple lidars. Figure 2 shows the

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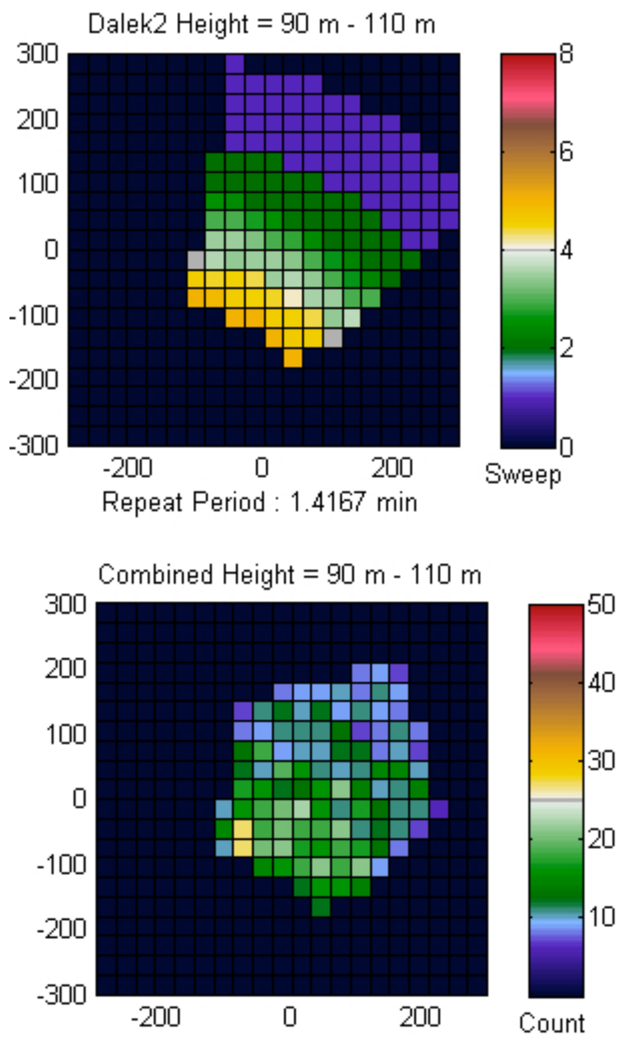


**Figure 2. Simulated scan geometry required to cover a horizontal plane centered at the tower extending +/- 100m horizontally at a height of 100m AGL. The top plot shows that it takes 5 sweeps to provide coverage from D2. The bottom plot shows the combined number of measurements from three systems (D1, D2, HRDL) in each 30mx30m grid cell between the heights of 90 and 110m AGL.**

simulated measurement density and scan geometry required to cover a plane extending +/- 100m horizontally around the tower at a height of 100m. The data are gridded into 30mx30m cells extending from 90m-110m vertically. The D2 unit, at a range of 600m, requires a 5 elevation plane azimuthal sector scan to completely fill the measurement volume (top plot). The lower plot shows the combined measurement count for three lidars (D1, D2, HRDL), asynchronously scanning, with a pattern repeat time of 1.4 minutes. Several versions of this pattern that were designed to either minimize the pattern repeat period or maximize the horizontal resolution were attempted. The lidars also performed a set of asynchronous elevation (RHI) scans that were designed to intersect (virtual towers) over the tower and the supersite. This pattern was repeated for several days through a range of atmospheric conditions.

Two sets of horizontal-plane, synchronized stares were designed to probe a 3x3 or 4x4 measurement grid at a height of 100m. The smaller 3x3 grid extended roughly 200m on a side and the larger 4x4 grid extended 1800m. The lidar scans were programmed to allow roughly 10 seconds dwell at each location and an attempt was made to keep the pattern repeat time shorter than 2 minutes.

In order to study the effect of the geometry of the look angles on the 3 dimensional fit (especially the vertical component). A series of 10 minute synchronous stares were programmed to have all four 200S units staring above the super site at a range of increasing altitudes (and elevation angles) over a period of several days. During these scans, the HRDL lidar performed a set of two plane azimuthal sector scans designed to provide contextual information on the horizontal wind field.

## 3. RESULTS

At the time of the submission of this abstract, the XPIA study is still underway. Significant effort has gone into developing tools to aid in multiple lidar coordinated scan design and implementation. Programing scans on different manufacturer's scanner control software (or different versions of the same software) so that they remain synchronous has proven to be challenging and techniques to do this have been developed. The pointing accuracy and stability of the commercial lidar systems have been evaluated. Preliminary results from the operations described in this abstract will be presented.

## ACKNOWLEDGEMENT

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