## 10.1 Intercomparison of wind measurements at adjacent test grid locations

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### 1.INTRODUCTION

U.S. Army Dugway Proving Ground (DPG) is the nation's leading facility for outdoor chemical and biological simulant testing. Planned infrastructure upgrades may require the relocation of testing from a certain test grid location to a new location approximately 1 km northwest. The current location has been in use for 20 years and was selected based, in part, on the prevailing meteorological conditions at the site. To compare the two locations, two identical sets of meteorological instrumentation were deployed. Wind speed, wind direction, temperature, and relative humidity (RH) were compared by subtracting the measurements recorded at the old location from the new location measurements. Over the period of measurement, differences between the two test grid locations were found to be comparable in magnitude with instrumental error.

### 2. INSTRUMENTATION

#### 2.1 *LOCATION*

Two identical sets of instrumentation were deployed at the original test grid and the proposed new test grid. The two regions being compared are somewhat overlapping 1-km$^2$ grids. The instrumentation on each 1-km$^2$ region consisted of a 32-m tower with wind, temperature, and RH sensors at 2, 4, 8, 16, and 32 m above ground level located in the center of the grid and four Portable Weather Information Display Systems (PWIDS), one on each corner measuring wind, temperature, and RH at a 2-m height. Four additional PWIDS were also deployed on or near the two grids. Instrumentation locations are depicted in Figure 1.

#### 2.2 *TYPES OF INSTRUMENTATION*

Two types of sensors were used to make the measurements for comparison. Temperature and humidity were measured using Campbell Scientific HMP-45C probes, with an accuracy of ±4$^{o}$C over the range of temperatures measured during this comparison. The humidity accuracy of the HMP-45C is ±2% for RH values between 0 and 90% and ±3% for RH values between 90 and 100%. Wind measurements were made using R.M. Young Model 05103 Wind Monitor units, a propeller-type wind sensor with an accuracy of ±0.3 m/sec for wind speed and ±3 degrees for wind direction. The propeller starting threshold of this instrument is 1 m/s.

Data collection at 1 Hz began for all stations on or before 9 December 2008. The last day used in this analysis was 3 September 2009.

**Figure 1. Map of instrumentation showing location of existing test grid (red square), proposed new test grid (yellow square), towers (yellow icons), and PWIDS (blue icons).**

### 3. ANALYSIS

In order to eliminate sub-grid scale turbulence in the measurements, 5-min averages were calculated for each of the instruments. Additionally, quality control parameters were applied to eliminate data outside the ranges listed in Table 1. Wind direction and wind speed were calculated from the eastward and northward vector components after quality control and averaging.

**Table 1. Quality control restrictions applied to the dataset.**

| | |
|---|---|
| Temperature | ± 40ºC |
| Relative Humidity | 0 to 100% |
| Vector Wind speed | ±40 m/sec |

Differences in the measurements of the two grids were found by subtracting the value recorded at the old grid from the corresponding value at the same grid relative location for the new grid for the same 5-min time period. Positive difference values indicate the new location is greater in magnitude than the old for wind speed, RH, and temperature. Positive values of wind direction difference indicated that the new location is more clockwise than the old, while negative values indicate the difference is in an anti-clockwise direction. For example, when the old location has westerly winds, a difference of +15 degrees would indicate that the new location has north-northwesterly winds.

The alignment of each 2-m wind vane at all stations was verified in order to ensure accuracy of the wind direction. There were some minor alignment discrepancies that were corrected before analysis. Table 2 shows the measured alignment of each of the wind sensors which was used to correct the difference in measurements between the two grids. The convention of ‘northwest corner’ is used to describe the grid points as if the centerline was north-south, even though the centerline is actually skewed toward southeast-northwest.

Four statistics were computed for each variable: mean, standard deviation (std), linear correlation coefficient (corr), and accuracy-restricted error $E_A$, which is the percentage of error explained by the instruments’ accuracy limit (N.B. Due to the subtraction of two sensors, the value used to compute $E_A$ is twice that listed by the manufacturer’s specifications).

## 4. RESULTS

### *4.1 Towers*

Tables 3 and 4 list the statistics for the comparison of the two towers at grid center sorted by level. As expected by the temporal and spatial scales of atmospheric boundary layer turbulence, the temperature and RH exhibit the smallest differences, while the wind direction exhibits the largest. The mean difference between towers is, in almost all cases, less than the instrument accuracy for both temperature and RH, with over 85% of the differences between towers accounted for by the sensor accuracy limit. Thus we conclude there is not a significant difference between the tower locations for temperature and RH measurements.

Wind speed measurements also exhibit small differences between the locations, with $E_A$ greater than 60%, indicating no significant change between locations. Wind direction presents more of a challenge. The mean differences for 2-, 4-, 8-, and 16-m levels appear to be close to sensor accuracy, but larger differences are seen in an anti-clockwise direction at 32 m. Due to the height of the sensors, it was not possible to check the alignment of the wind sensors above 2 m. It is possible that sensor orientation error can account for much of direction difference at 32 m.

The frequency of wind direction for the two tower locations can be compared by examining Figures 2 and 3. The distribution of wind directions is very similar between the two sites with the majority of the wind coming from the southeast (approximately 150 degrees) during the measurement period. Figure 4 presents the frequency of occurrence for each semi-octant for both the old and the new locations. This figure shows a slight shift from south-southeast in the original location . to southeast at the new location.

**Table 2. Alignment (with magnetic declination correction of 12.7 ºE ) of Wind Monitor Units on PWIDS.**

| Original grid square | | | Proposed new grid square | | |
|---|---|---|---|---|---|
| Unit number | Location | Alignment | Unit Number | Location | Alignment |
| 21 | Northwest | 79.7º | 33 | Northwest | 92.7º |
| 27 | Northeast | 86.7º | 7 | Northeast | 88.7º |
| 32 | Southwest | 92.7º | 43 | Southwest | 89.7º |
| 63 | Southeast | 87.7º | 5 | Southeast | 91.7º |

At the new location, most other directions had a frequency of occurrence within 2% of that seen at the original location.

Overall, due to the similar frequency of occurrence of wind direction, combined with the mean difference in wind direction which is within instrumental error in 85% of the cases, it is concluded that the mean wind directions at the two grid locations are not substantially different.

**Table 3. Wind error statistics for towers (N.B. 2 m heights have been corrected for alignment).**

| | Wind Speed | | | | Wind Direction | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std | Corr | $E_A$ | Mean | Std | Corr | $E_A$ |
| 2m | -0.1139 | 0.5559 | 0.9563 | 0.7821 | 3.8647 | 34.7428 | 0.5335 | 0.3772 |
| 4m | -0.0155 | 0.6450 | 0.9542 | 0.7349 | 0.4158 | 32.5639 | 0.7120 | 0.4431 |
| 8m | 0.1721 | 0.7101 | 0.9555 | 0.6708 | -2.8608 | 33.7719 | 0.7206 | 0.3809 |
| 16m | 0.2199 | 0.8530 | 0.9480 | 0.6307 | 8.5328 | 34.3498 | 0.7441 | 0.3134 |
| 32m | 0.0771 | 0.7926 | 0.9652 | 0.6610 | -8.4026 | 28.5744 | 0.6848 | 0.2027 |

**Table 4. Temperature and relative humidity error statistics for towers.**

| | Temperature | | | | RH | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std | Corr | $E_A$ | Mean | Std | Corr | $E_A$ |
| 2m | 0.0775 | 0.4490 | 0.9994 | 0.8501 | n/a | n/a | n/a | n/a |
| 4m | -0.0739 | 0.4564 | 0.9993 | 0.8764 | -0.5382 | 1.7737 | 0.9979 | 0.9587 |
| 8m | -0.1712 | 0.4508 | 0.9993 | 0.8577 | 1.2222 | 1.8852 | 0.9982 | 0.9305 |
| 16m | 0.0448 | 0.4398 | 0.9993 | 0.8901 | -0.9101 | 1.7290 | 0.9977 | 0.9575 |
| 32m | 0.1908 | 0.4192 | 0.9994 | 0.8823 | -0.3167 | 1.6514 | 0.9979 | 0.9672 |

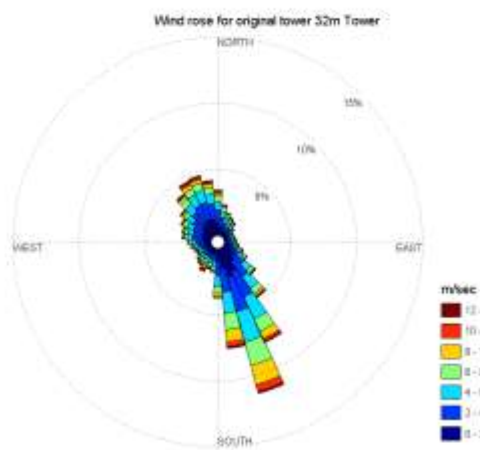


**Figure 2. Frequency of wind direction for all tower levels at the original grid center location. The angular coordinate is the direction the wind is coming from (**degrees**) and the radial coordinate is frequency of occurrence (%).**

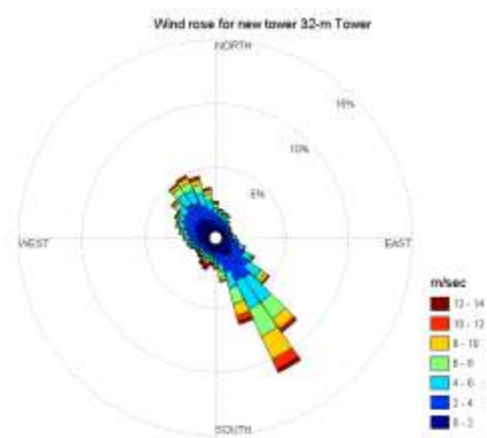


**Figure 3. Frequency of wind direction for all tower levels at the new grid center location (see Figure 2 for plot description).**

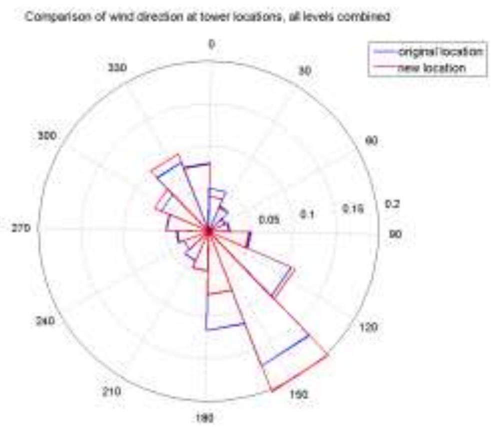


**Figure 4. Wind roses for the original location (blue line) and new location (red line) show substantial overlap.**

***4.2 PWIDS***

Data from PWIDS stations located at the corners of each grid were compared, and the results of the statistical analysis are presented in Tables 5 and 6. The PWIDS data show similar results to the tower with high correlation and $E_A$ values for temperature, RH, and wind speed and lower values for wind direction.

The northwest corner exhibits a higher mean and lower $E_A$ value than the other locations. However, the temperature differences are still less than instrument accuracies.

**Table 5. Wind speed and direction differences for PWIDS at grid corners.**

| | Wind Speed | | | | Wind Direction | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std | Corr | EA | Mean | Std | Corr | EA |
| NW | -0.0368 | 0.5637 | 0.9567 | 0.7852 | 6.5200 | 34.3253 | 0.6369 | 0.3166 |
| NE | 0.0620 | 0.5284 | 0.9529 | 0.7897 | -0.9993 | 35.0815 | 0.6972 | 0.4158 |
| SE | 0.0453 | 0.5627 | 0.9568 | 0.7858 | 2.2055 | 33.5884 | 0.7254 | 0.4185 |
| SW | -0.1219 | 0.6564 | 0.9519 | 0.6924 | -3.0074 | 37.2882 | 0.7120 | 0.3636 |

**Table 6: Temperature and RH differences statistics for PWIDS at grid corners.**

| | Temperature | | | | Relative Humidity | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std | Corr | $E_A$ | Mean | Std | Corr | $E_A$ |
| NW | -0.5899 | 0.4157 | 0.9994 | 0.5368 | 0.3773 | 1.6597 | 0.9983 | 0.9677 |
| NE | 0.0380 | 0.3837 | 0.9995 | 0.9079 | -0.2723 | 1.5667 | 0.9985 | 0.9743 |
| SE | 0.0484 | 0.4140 | 0.9994 | 0.9000 | 0.0349 | 1.4313 | 0.9986 | 0.9768 |
| SW | -0.1495 | 0.5161 | 0.9991 | 0.8773 | -0.1049 | 1.5673 | 0.9983 | 0.9732 |

As a final measure of the wind direction similarity of the two grid locations, the percentage of time the 2-m wind fell between 120 and160° or between 300 and 340°, was calculated and is shown in Table 7.

**Table 7. Wind direction frequency by test grid.**

| | 120 to 160° | 300 to340° |
|---|---|---|
| Original Grid | 26.77% | 13.97% |
| New Grid | 26.84% | 15.79% |

The frequencies of occurrence were found to be nearly identical indicating that the differences in wind direction between the two grids are not substantial.

**4.3 Seasonal Variability**

An examination was made of the seasonal dependence of the results. First the data were split into spring (March, April, May), summer (June, July, August), fall (September, October, November), and winter (December, January, February); then the mean wind direction difference was computed for each season. The seasonal variability in the wind direction and wind speed difference between the two sets of PWIDS are presented below. There is very little seasonal dependence in the variability between the two grids yielding confidence that the yearly results are representative of the spring and summer testing seasons.

Table 8. Seasonal dependence of mean difference between grid locations.

| Mean Difference of / Season | PWIDS | | TOWER (all levels) | |
|---|---|---|---|---|
| | Wind Direction | Wind Speed | Wind Direction | Wind Speed |
| Spring | -2.44 | -0.01 | -1.5538 | 0.1161 |
| Summer | -2.75 | -0.01 | -1.7696 | 0.0702 |
| Fall | -4.04 | 0.01 | -5.8047 | -0.0655 |
| Winter | -3.42 | 0.05 | -5.2623 | 0.0181 |

## 5. CONCLUSION

The analysis presented here demonstrates that the proposed new test grid location should experience conditions very similar to that of the original location. In particular, temperature and RH variability between locations was found to vary within instrument accuracy over 90% of the time. Wind speed variability was within instrument accuracy more than 60% of the time, with similar distributions of wind speeds by direction seen on the tower measurements. Wind direction frequency of occurrence varied less than 2% over the range of directions typically used in testing scenarios.

Based on the analysis completed here, the two locations are found to vary within instrumental error for temperature, RH and wind speed. Wind direction shows larger variability consistent with the turbulence of boundary layer flow; however, when considering the range of acceptable wind directions for operations, the variability is reduced to less than 1% (Table 8). Thus the relocation of the test grid is not found to have a significant impact on the expected meteorological conditions based on the 10-month period of measurement.