Military Applications of Wind Characterization Models Relative to Army Sniper Operations

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ABSTRACT

Snipers have become an integral part of the modern battlefield and the effectiveness of a sniper team (shooter and spotter) is closely tied to their ability to successfully acquire and engage targets. This in turn is a function of numerous variables, many of which can be overcome by training, individual skill, experience, and/or advances in technology. One variable however, has proven very challenging and this is accurately calculating wind deflection of the bullet. This study focused on improving calculations for wind deflection by developing wind characterization models that may be applied by a sniper team in the field. This study used two test areas, one with little to no change in elevation (<5% change in elevation for point A (0 meters) to point B (1000 meters)) and subsequently little anticipated topographic effect on wind patterns. A second, hillier test area was used where measureable topographic effects were anticipated. Wind speed and direction were collected at each study site where wind velocity was, 1) ≤1m/s, 2) 1-2 m/s, and 3) ≥ 2 m/s. Wind velocity was measured using an array of nine Kestrel anemometers, which collect numerous weather variables along with wind speed and direction. Inverse Distance Weighted Spatial interpolation was used to produce wind velocity layers. Close examination of these data layers allowed for a greater understanding of wind patterns especially as it relates to interactions with terrain features. Resulting models may be combined with existing ballistics software to develop an application that could be deployed on a ruggedized field laptop, smart phone, PDA, or integrated into the rifle itself as part of an optical ranging system. Results of this study indicate that while wind velocity changes across distances of 1000 meters the effect of terrain features were difficult to quantify under the calm wind conditions of this study.

KEYWORDS: Ballistics, Inverse Distance Weighted, Hotspot Analysis, Prevailing Winds

INTRODUCTION

Wind is an ever-changing variable that helps mold the shape of the ground beneath it and likewise is itself affected by the earth's terrain (Campbell and Norman 1998). Because of natural variations in terrain, as well as man-made features like buildings, wind velocity can change whenever impacted by these obstacles. According to Campbell and Norman (1998), “We are aware of random temporal variations of the wind through fluttering of flags and leaves, variations in the force of wind on us and other common experiences.” Wind is a critical factor for military applications such as long-range sniper missions. According to Plaster (2006), “The military definition of a sniper is an individual highly trained in field-craft and marksmanship who delivers long range, precision fire at select targets from concealed positions.”

A difficulty associated with long-range fire is the cumulative effect of wind on the bullet’s path and the uncertainty associated with knowing precise distance to the target (i.e., range estimation). While a 4.5 m/s wind may not seem to be a problem, by the time a 168 grain, 7.62 mm bullet has traveled just over 350 m, crosswind has deflected the bullet 34.5 cm; enough so that if the sniper were aiming at center of mass of a human-sized target the bullet would drift completely off target (Plaster 2006). Besides needing to know wind speed, the direction of the wind is also absolutely critical.

This paper will discuss two main topics, 1) whether or not wind speed is constant over a distance of 1000 meters and 2) if topographical features such as hills, saddles, spurs and draws have any effect on the wind velocity. To address these questions, two field sites were used for data collected, a fallow agricultural field in Aberdeen, Idaho and the Gate City Shooting Range in Chubbuck, Idaho.

MATERIALS AND METHODS

Study area

Wind data were collected at two sites; the first was a 1000 m site with $\leq$ 1% change in elevation across a fallow potato field in Aberdeen, Idaho (Aberdeen site). The second was a 1000 m site with $\geq$ 5% change in elevation. These data were collected at the Gate City Shooting Range (Range site). The Range site exhibited numerous rolling hills, spurs, draws, and a valley.

To determine the percent change in elevation at each site and thereby characterize each as either flat or hilly, the National Elevation Dataset (NED) was used. The NED is a 10m high-resolution digital elevation dataset that seamlessly covers Idaho. A polygonal feature class was created using the spatial extent of the wind fields at each site (i.e., Aberdeen and Range). Zonal statistics were generated to describe the elevation data within each study site polygon. Resulting statistics included minimum, maximum, range, standard deviation, mean, and median elevation.

Data collection

To model wind, relative to military sniper applications, data was collected using a nine anemometer sensor array across a distance of 1000 m (fig. 1). Wind data were collected using the Kestrel 4500 and 4000 Pocket Weather Trackers with a precision of 0.10 m/s. Due to logistical constraints; the wind field was measured in two separate segments. Wind measurements were collected first using nine sensors placed at 0-500 m. Six of these sensors were then moved from their 250 m and 500 m locations to 750 and 1000 m locations (fig 1).

Two sampling sessions were completed and during each session, data were collected every five seconds over two time periods (morning and afternoon) of 30 minutes each. To more accurately locate the position of each sensor, a Trimble GeoXH GPS receiver was used to record the latitude and longitude of the point where each anemometer was placed. Geographic positions were averaged for two minutes and recorded points were later post-process differentially corrected using Trimble's H-star and delta phase processing tools.

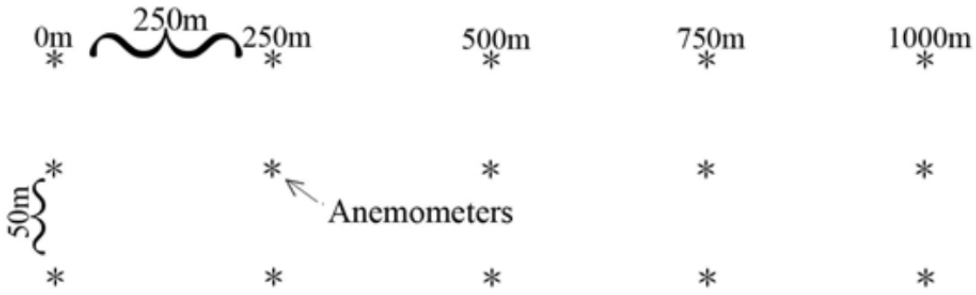

Figure 1. Anemometer spacing and general placement used at both the Aberdeen and Range sites.

Data processing and analysis

Following each data collection, wind data were downloaded to a PC workstation and converted into stand-alone tables within a geodatabase. Point data describing the location and unique identifier of each sensor were similarly imported into the geodatabase as point feature classes. Using data from sensor two (the virtual sniper's location) from each morning collection session, 10 temporally specific instances of wind events were randomly selected. Temporally corresponding data from the remaining sensors (0-500 m) were also selected. To complete the 1000 m wind field, the wind velocity for sensor two at each of the 10 previously selected instances was noted. Ten corresponding wind velocities were then identified from sensor two's afternoon session and the precise time of these observations noted. Data from the remaining sensors (750-1000 m) recorded at the same 10 instances in time were also selected. The selected records were then assembled into 10 distinct instances of wind events and saved as stand-alone tables within the geodatabase. This process was completed for both the Aberdeen and Range sites. A relationship class was developed to associate each wind event instance table with the sensor point feature class. These data were then used for spatial interpolation of wind velocity across each site.

Inverse Distance Weighted (IDW) spatial interpolation was selected for this study because it is a quick and exact deterministic interpolator. With IDW, the value of the point at a predicted location is calculated by summing the weighted contributions from neighboring sample points. In IDW the closer the neighboring points are to a prediction point, the greater the weight given relative to those points father away. This is done so the weight is inversely proportional to the p^{th} power of the distance between the location of the prediction and the sampling points. IDW is an exact interpolator because it predicts a value identical to the measured value at a sampled location. If the prediction coincides with one of the sampling points, then the prediction is replaced with the measured value at that location (Krivoruchko 2011).

Ten IDW models were developed for the Aberdeen site and 10 for the Range site. A regression model was run every time IDW was used to test the goodness of fit using root mean square error (RMSE). A prevailing winds model was also calculated using IDW and mean wind velocity observed across all wind event instances (*n* = 10 from each site).

Following this, 300 random sample points were generated across each study site polygon. Using these random sample points, Hot Spot Analysis (HSA) was performed. Hot Spot Analysis calculates the Getis-Ord Gi* Statistic in which each point feature of the dataset was used. The outputs were z-scores and p-values that describe values that are statistically higher or lower than the mean and if they are considered spatially clustered or dispersed. A given feature that has a high value is interesting but may not be a statistically significant hot spot. In order to be considered a statistically significant hot spot, other points with a high value must surround the feature as well. The local sum for that point and its neighbors are compared proportionally to the sum of all the points and when the sum is very different from the expected local sum (the difference is too large to be attributed to random chance), the result is a statistically significant z-score and thus is considered a hot spot (ESRI ArcGIS 2012)

HSA was used to determine if there existed consistent hot or cold spots at each site, or in other words, if a specific geographic feature caused either elevated wind velocity (a hot spot) or depressed wind velocity (a cold spot). Ten HSA tests were run using randomly sampled Aberdeen IDW models as well as 10 HSA tests using randomly sampled Range IDW models.

RESULTS AND DISCUSSION

One anemometer failed to record data (sensor one) and was not used in the analysis. All remaining sensors functioned properly and were used throughout the remainder of the study. Resulting wind speeds at both the Aberdeen and range sites were comparable (table 1). This study made the simple assumption that the sniper would be located at the same location as sensor two. The summary statistics of wind speed observed at sensor two were a mean of 0.7 m/s (SE = 0.3) (Aberdeen site) and a mean of 0.8 m/s (SE = 0.3) (Range site)

Table 1 - Descriptive Statistics for Aberdeen and Range site wind speed

	Wind speed (m/s)	
	Aberdeen	**Range**
Mean	0.7	0.7
Maximum	2.8	3.2
Minimum	0.0	0.0
Standard deviation	0.5	0.5

Zonal statistics analysis of terrain at the test sites indicate the difference in elevation at the Aberdeen site was <1% (minimum elevation = 1341 m; maximum elevation = 1342 m; 0.1% difference in elevation) and 5% at the Range site (minimum elevation = 1476 m; maximum elevation = 1548 m; 5.0% difference in elevation).

Regression analyses illustrate only a weak correlation between elevation and wind speed ($R^2 = 0.1$). The average RMSE for cross validation regression analysis at the Aberdeen site was 0.96 m/s and 0.90 m/s for the Range site. IDW wind field models for discrete wind events (fig. 2) and prevailing wind analyses (fig. 3) suggest inherent variability in wind velocity over a distance of 1000 meters, which is only exacerbated in more hilly terrain (i.e., the Range site). A change in wind velocity was also noted across flat terrain however (i.e., Aberdeen) and sample variances across both wind fields were very similar (0.6 m/s and 0.7 m/s at the Aberdeen and Range sites respectively). This result alone demonstrates the variability in wind speed across a 1000 m wind fields but does not support the conclusion that more variability exists at hillier sites. Prevailing wind models illustrate that wind velocity changes over distance, even on flat ground and thus, the conclusion was formed that wind speed changes over distance, even with no topographical features to influence it.

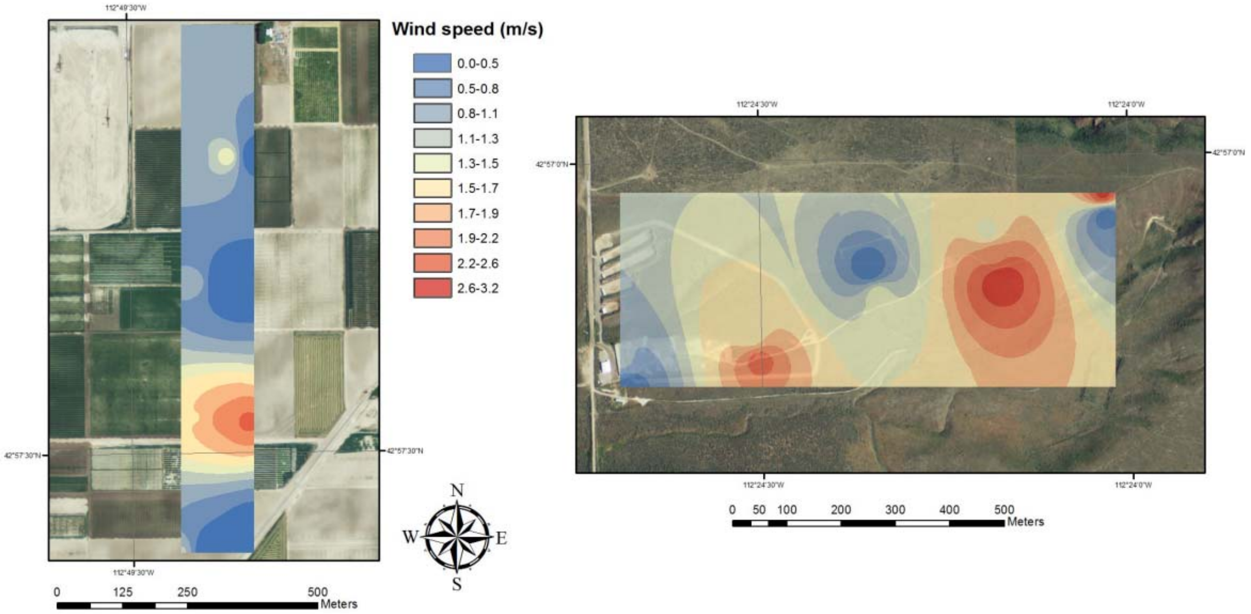

Figure 2. Result of Inverse Distance Weighted (IDW) spatial interpolation of a single wind event on November 11th, 2011 at the Aberdeen test site (left) and Range test site on November 28th, 2011

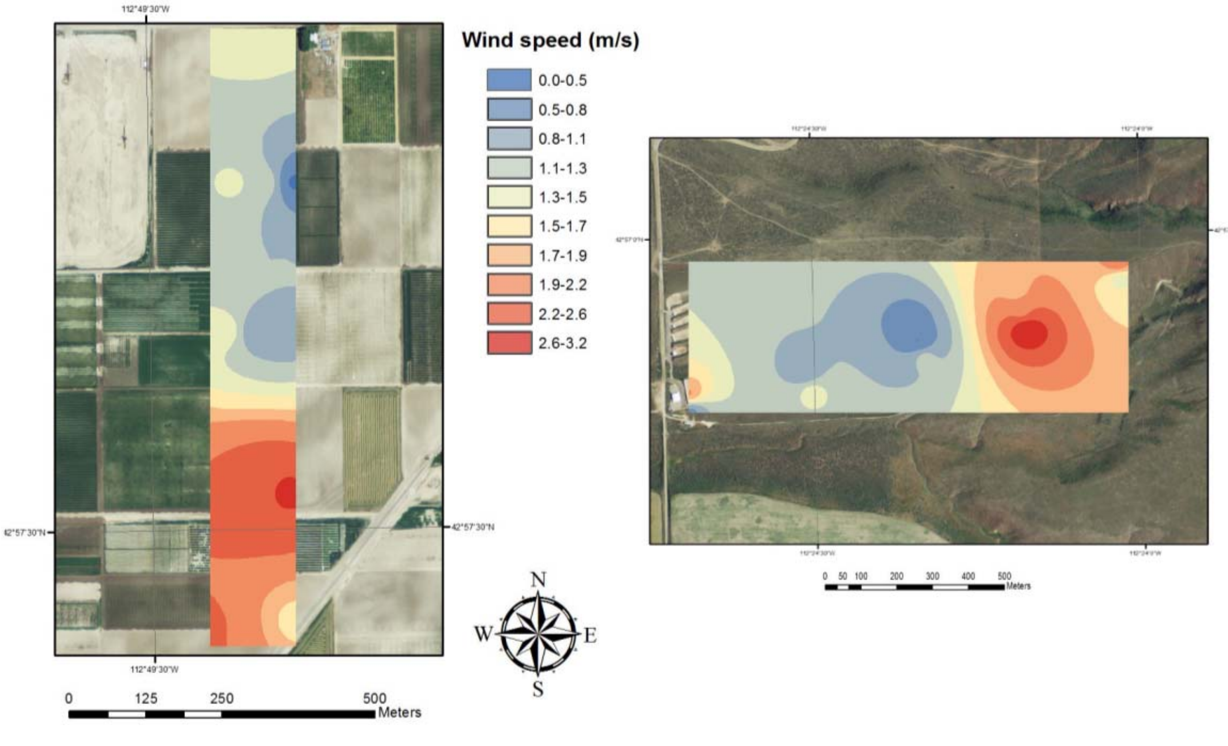

Figure 3. Result of Inverse Distance Weighted (IDW) spatial interpolation of prevailing winds on November 11th, 2011 at the Aberdeen test site (left) and Range test site on November 28th, 2011.

The results of HSA shows some consistent hot spot (n = 48; 16% of sample points) and cold spot (n = 12; 4% of sample points) areas at the Aberdeen site as well as a consistent hot spot (n = 14; 5% of sample points) at the Range site. The latter appears to be coincident with the crest of the largest hill at the Range site but no topographic feature exists to associate the hot and cold spots observed at the Aberdeen site save for the consistency of wind events on that day. HSA does not support the hypothesis that terrain effects wind variability.

CONCLUSIONS

In conclusion, this study illustrates that wind flows at different speeds across distances of 1000 meters even in areas with little topographic relief. The most likely cause for the similarity in results at both flat and hilly test sites is that recorded wind events were effectively calm on both days and perhaps insufficient to demonstrate terrain effects. Also, improvements in the experimental design of this study may improve the ability to detect terrain-based wind variability. Specifically, a full complement of 15 anemometers would allow for easier setup and more lengthy measurement sessions. In addition, using calibrated cross-wind velocities instead of wind speed might further improve the ability to detect terrain-based variability. Lastly, capturing wind events on days where wind speed exceeded 5-10 m/s might also make terrain effects more apparent.

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