4.2 AN INITIAL ANALYSIS OF RELATIONSHIPS BETWEEN 2- AND 10-MINUTE AVERAGED WINDS AT 10, 6, AND 1.8 METERS: IMPLICATIONS FOR FIRE BEHAVIOR AND DANGER APPLICATIONS.

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1. INTRODUCTION[?]

Recently there has been discussion in the National Wildland Fire Coordination Group (NWCG) fire danger and fire weather working teams about the impact of observations from different anemometer heights and, more importantly, averaging times, on inputs to fire management systems such as National Fire Danger Rating System (Deeming and others 1977) and the Fire Behavior Prediction System (Andrews 1986, Andrews et. al. 2003). The observation standard for the NFDRS is an anemometer 6 meters (20 feet) above vegetation, averaged for 10 minutes. The National Weather Service ASOS standard is a 2-minute average at 10-meters (33 feet). The portable 'Fire RAWS' that support incidents have masts about 1.8 meters (6 feet) above the ground. Their averaging time is generally 2-minutes; however some report both 2- and 10- minute averages. This paper reports on an initial analysis of wind speeds from data collected from 3 anemometers located at 1.8, 6, and 10 meters above the ground on the same mast. Characteristics of the wind speed probability distributions and correlations between the sampling heights and averaging times are presented.

2. DATA AND METHODS

A portable tower was designed and constructed to hold three anemometers at heights of 1.8, 6, and 10 meters. The anemometers were RM Young Ultrasonic (Model 81000) 3-dimensional, sampling at 10 Hz, accurate to 0.05 m/s up to 30 m/s. We used a Campbell Scientific CR-5000 data system, also sampling at 10Hz to compute and store one-second average u, v, and w components of the wind (m/s), plus temperature (ºC). Since a single data logger was used, we are certain that the timestamps from each anemometer observation were synchronized. Because the anemometers were mounted on the tower prior to raising the tower, our confidence in the direction component of the wind is not high enough to report directional relationships of these data.

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The tower was placed in three locations for 8-10 days at locations proximate to the Missoula Fire Sciences Laboratory during July and August, 2003. All locations were free from obstructions. Two sites had short grass (less than 0.2 m) and one was barren. The tower locations, dates and observation totals are shown in table 1. Figure 1 shows the tower at the Butler Creek site.

Table 1. Sampling locations and dates.

Location	Dates	Number of Samples
Fire Lab: Large valley, no slope, 970 m (3,200 feet)	13 July to 21 July	696,500 1-sec. 11,587 1-min.
Butler Creek: West aspect, mid-slope, ~11 percent slope, 1,075 m (3,550 ft)	22 July to 25 July	269,500 1-sec. 4,471 1-min.
Point Six Radar Mountain peak, 2,400 m (7,922 ft)	29 July to 8 Aug	863,205 1-sec. 14,135 1-min.

A power problem at the Butler Creek site caused the logger to shut down after 3 days. And about 240 observations (4 hours) were removed from the Point Six dataset due to a moisture related problem with the 6-meter sensor during a thunderstorm.

The one-second data were post-processed to compute the magnitude of the wind speed (m/s):

$$\text{Wind Speed} = (u^2 + v^2 + w^2)^{½} .$$

The one-second wind magnitudes were further processed into running 2- and 10-minute averages for each observation (second). The one-second data were sub-sampled to create a one observation per minute data set for easier handling and observation independence. The final data set for each site contains a mean 2- and 10-minute averaged wind speed and standard deviation, every minute, for each anemometer. The standard deviations reflect the variance of the one-second sampling rate.

Figure 1. Portable anemometer tower at Butler Creek**.** Instruments are at 1.8, 6, and 10 meters above ground.

We illustrate the character of the distributions and then focus on relationship between the 10-meter, 2-minute and 6-meter, 10-minute wind speeds. Our attempt in this initial work is to quantify that relationship, and then characterize potential gustiness within a 10-minute averaged wind at 6 meters.

3. RESULTS AND DISCUSSION.

Table 2 shows some general descriptive statistics of the wind speeds at the three sites for each instrument height and averaging time. Point Six at 2,400 m was by far the windier site with mean wind speeds ranging from 3.9 to 5.3 m/s from the 1.8 to 10 meter heights, with maximum 2 and 10 minute average winds at the 10 meter tower reaching 18 and 16 m/s respectively. The valley site near the Fire Lab was the least windy with mean wind speeds averaging about 2 m/s with maximum means of about 10 m/s. The probability distributions at each site can be represented by the Weibull function. Figure 2 illustrates the frequency distribution of 6-m, 10-minute wind speed at the Butler Creek site with a fitted Weibull function (alpha=1.59, beta=2.97).

Figure 3 illustrates a 14-hour sequence of mid-morning to late night wind speed at three heights for one of the windier days at the Butler Creek site based on 2-minute averaging. Figure 4 displays the same period but with 10-minute averages and the obvious smoothing over the 2-minute winds. Comparison of these figures indicate larger differences at higher winds speeds, particularly at the 1.8 meter level.

Table 2. Descriptive statistics of three sites, for three heights and two averaging times.

	10 Minute Avg.(m/s)			2 Minute Avg.(m/s)		
	1.8m	6m	10m	1.8m	6m	10m
Fire Lab (n=11587)						
Mean	1.7	2.1	2.2	1.7	2.1	2.2
Sd	1.0	1.4	1.5	1.1	1.4	1.6
Minimum	0.1	0.1	0.1	0.1	0.0	0.0
Median	1.4	1.7	1.8	1.4	1.7	1.8
Maximum	5.8	8.0	8.7	6.6	9.1	9.8
Skew	1.0	1.1	1.1	1.0	1.1	1.1
Kurtosis	0.5	0.6	0.7	0.6	0.7	0.8
Butler Creek (n=4471)						
Mean	1.9	2.3	2.6	1.9	2.3	2.6
Sd	1.2	1.8	1.9	1.2	1.8	2.0
Minimum	0.3	0.1	0.1	0.2	0.1	0.0
Median	1.5	1.8	2.0	1.5	1.8	2.1
Maximum	6.8	8.7	9.3	7.5	9.6	10.
Skew	1.8	1.6	1.5	1.8	1.6	1.4
Kurtosis	3.3	2.5	2.0	3.1	2.4	1.9
Point Six (n=14135)						
Mean	3.9	4.9	5.3	3.9	4.9	5.3
Sd	2.3	2.7	2.7	2.3	2.8	2.8
Minimum	0.3	0.4	0.4	0.2	0.2	0.3
Median	3.5	4.5	5.0	3.5	4.5	5.0
Maximum	14.	16.	16.	16.	18.	18.
Skew	0.8	0.7	0.6	0.8	0.7	0.6
Kurtosis	0.5	0.1	0.0	0.4	0.0	0.0

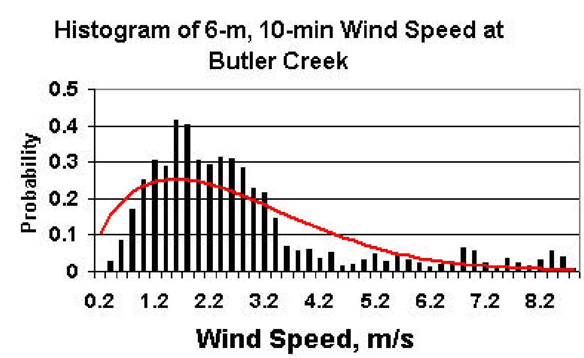

Figure 2. Histogram of Butler Creek wind speed with fitted Weibull distribution function (alpha=1.59, beta=2.97, n=4471)

The primary focus of this initial investigation is the relationship between the 10-meter 2-minute and the 6-meter 10-minute observations. This is the crosswalk between NWS forecast models and forecasters and NFDRS observations. Figure 5 displays these two traces, again for a day at the Butler Creek site. Again the greater departure is at the higher wind values.

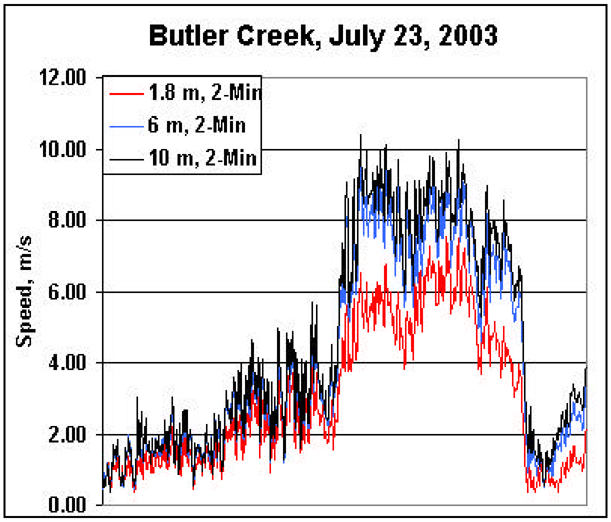

Figure 3. 2-minute wind speeds at 3 heights, every minute from 0900 to 2300 on 07/023 at Butler Creek.

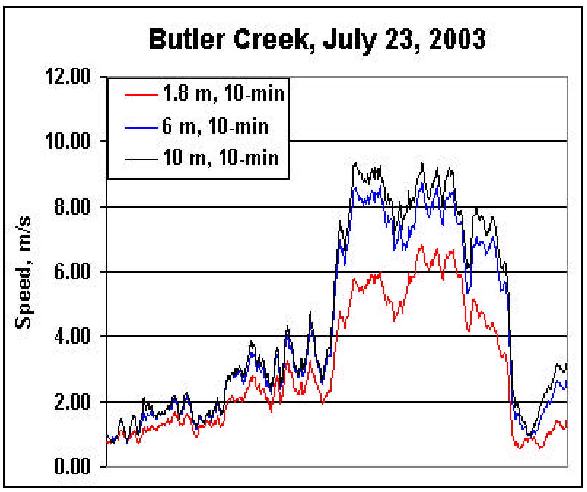

Figure 4. 10-minute wind speeds at 3 heights, every minute from 0900 to 2300 on 07/023 at Butler Creek.

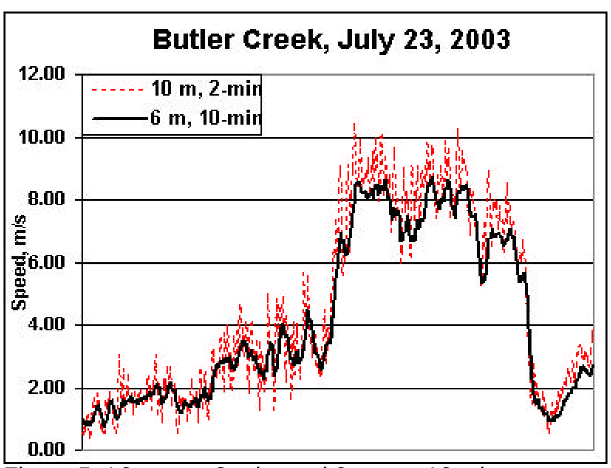

Figure 5. 10-meter, 2-min. and 6-meter 10-min. average wind speed from 0900 to 2300 at Butler Creek.

For each site, and the combined data, a simple linear regression (y intercept forced through zero) was done for each of the five height-averaging time wind speeds using the 10-meter, 2-minute wind as the independent variable. Table 3 contains the regression results. Regression plots for 6-meter, 10-minute wind speeds for each site are shown in figure 6. Although the distributions of wind speeds are not normal, the residuals were distributed normally and linear regression is useful here.

The R^2 and scatter plots indicate a good fit for estimating the 10-minute wind at 6 meters from an observed (or forecast) 10 meter wind. This is not surprising and matches well with the logarithmic wind reduction from 10 meters to 6 meters. Using the roughness length in Whiteman (2000) the logarithmic profile reduction factor is exactly 0.93 for 10 to 6 meters in open country (roughness length = 0.03)—the same as the regression reduction for the 10-meter, 2 minute to 6-meter 2-minute.

The relationship between the 10-meter, 2-min and 10-meter 10-minute (0.98, R^2=0.94) indicates about a 0.01 or 0.02 reduction in wind speed values strictly from the averaging time difference. (Last row in table 3.) Similar differences are noted in both the 6-meter, 2-minute to 6-meter 10-minute, and, 1.8-m, 2-minute and 1.8-m 10-minute coefficients. This can be interpreted that for the overall reduction of about eight percent from the 10-m, 2-min to the 6-m, 10-minute wind speed, seven percent is from the height difference and one percent is from the averaging time.

A similar interpretation can be made for the 1.8 meter wind speeds. Here again the difference between the 2- and 10-minute averages is about one or two percent, while the overall reduction factor was 0.72 and 0.73 for 10-min, and 2-min wind speeds at 1.8 meters. And again, this reduction is close to the logarithmic reduction, where the 1.8 meter wind in open country is computed to be about 76 percent of the 10 meter wind speed.

Table 3. Regression results for 3 sites plus combined datasets for 6-m, 10- and 2-minute, 1.8m, 10- and 2-minute, plus 10-m, 10-minute wind speed. Independent variable is 10-m, 2-minute wind speed. (Intercept forced through zero.)

		Fire Lab	Butler Creek	Point Six	All
	N	11587	4471	14135	30195
6-m, 10-min	Coeff. R^2	0.91 0.90	0.88 0.92	0.92 0.83	0.92 0.89
6-m, 2-min	Coeff. R^2.	0.93 0.99	0.90 0.99	0.93 0.89	0.93 0.94
1.8-m 10-min	Coeff. R^2	0.71 0.86	0.67 0.82	0.73 0.71	0.72 0.81
1.8-m 2-min	Coeff. R^2.	0.73 0.94	0.68 0.88	0.74 0.75	0.73 0.84
10-m, 10-min	Coeff. R^2	0.99 0.92	0.98 0.92	0.97 0.90	0.98 0.94

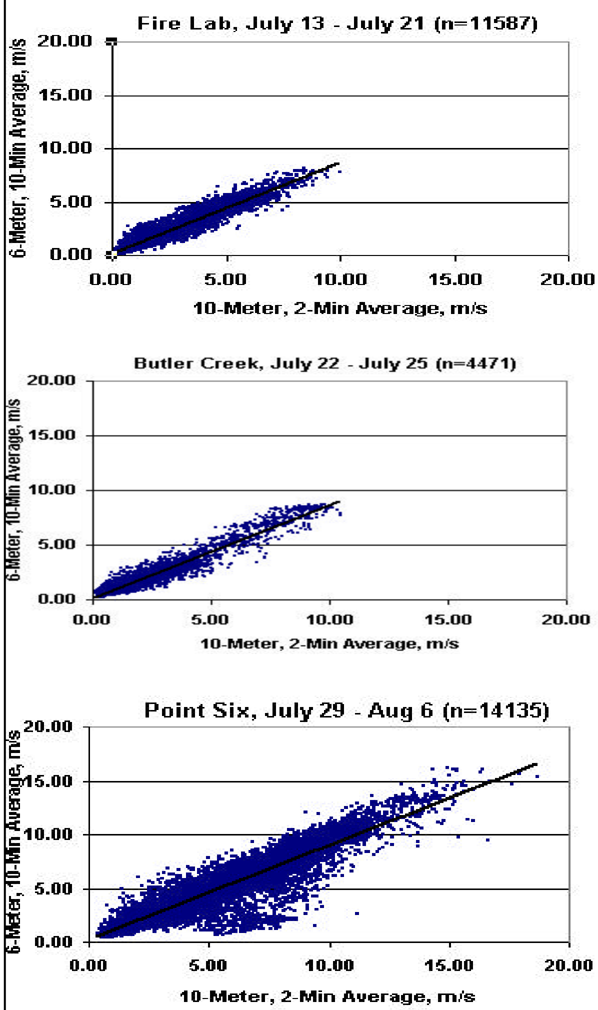

Figure 6. Regression plots for three 6-meter, 2-min from 10-meter 2-min wind at three sites. Regression coefficients and R^2 values are given in table 3.

Only the Point Six data set has any scatter of significance—an under prediction for a subset of 10-m, 2-minute winds speeds from about 5 to 8 m/s. An initial look at this subset indicates this is probably a time-lag effect between the 2 and 10 minute averages at the onset of gustiness and increasing winds. A similar, but less apparent lag effect is above the trend line at the higher wind speeds when winds start subsiding.

It was noted in the discussion of figures 3-5 that there appeared to be more variation between the sampling heights and times with increasing wind speed. We also ran a linear regression on winds greater than or equal to 7 m/s, and less than 7 m/s for the 6-m, 10-minute wind. The coefficient was about the same (0.90) but the R^2 dropped to about 0.60, indicating the reliability of the relationships decreases at wind speeds above 7 m/s (~15 mph).

The final analysis was to characterize the variability in the 6-m, 10-minute wind. To do this we computed the mean standard deviation of the wind speed for categorical values of the 6-m, 10-minute wind. Remember that the standard deviations associated with each minute's observation are based on the one-second raw data. Table 4 illustrates this analysis which in which the +2 SD compares very well with a Wind Conversion chart available on a NOAA website (http://www.seawfo.noaa.gov/fire/olm/fire/10togust.htm) which is based on several hundred observations over several fire seasons from Salem, MO.

Table 4. Tabulation of mean standard deviation by 6-m, 10-minute wind speed. Standard deviation as percent of wind is listed, along with expected maximum wind gust at +1 to +3 standard deviations

6-m, 10-minute Wind, m/s	N	Mean SD m/s	SD, % of Wind	+1 SD 67%	+2 SD 95%	+3 SD 99%
0	702	0.19		0.2	0.4	0.6
1	6646	0.37	37	1	2	2
2	6945	0.63	32	3	3	4
3	4150	0.84	28	4	5	6
4	3022	1.00	25	5	6	7
5	2553	1.19	24	6	7	9
6	1854	1.27	21	7	9	10
7	1712	1.20	17	8	9	11
8	1010	1.21	15	9	10	12
9	516	1.24	14	10	11	13
10	562	1.26	13	11	13	14
11	244	1.30	12	12	14	15
12	112	1.55	13	14	15	17
13	102	1.40	11	14	16	17
14	44	1.67	12	16	17	19
15	11	2.38	16	17	20	22
16	9	2.34	15	18	21	23

4. SUMMARY AND IMPLICATIONS

This paper presents some initial results for wind speed statistics and relationships among three sonic anemometers located at three heights at three sites in western Montana for short periods of the summer of 2003. Sampling rates of one observation/second generated large data sets in eight to ten days. The one-second data were sub-sample to one-minute by taking every 60th observation.

For the open terrain that reflected the sampling locations, the difference in the averaging time accounted for only about one to two percent of the reduction in wind speed from the 10-meter height to the 6, and 1.8 meter heights.

The majority of the wind reduction is from the surface frictional drag. The regression coefficients for reducing winds to lower (6-m and 1.8-m) heights for the same averaging time closely follow the standard logarithmic profile for sites over open surfaces (roughness length = 0.03). Overall for 30,195 one-minute observations, the reduction factor for estimating a 6-meter, 10-minute wind from a 10-meter, 2-minute wind was about 0.92 (R^2 =0.89), which is 0.01 less than both the reduction factor computed from the logarithmic profile and the data collected during this study. At higher wind speeds (> 7 m/s) the coefficient 0.90 but the R^2 dropped to 0.60.

The overall value of 0.92 differs from the 'rule of thumb' in the BehavePlus fire modeling system, which uses a value of 0.85. (The Bulter Creek value was 0.88 but there were only 4471 data points.) But for surface fire behavior calculations the wind speed is reduced by a wind adjustment factor that ranges 0.1 to 0.6 so the mid-flame wind speed difference is reduced to a few tenths of a meter/second. For example using a 10 m/s wind and a 0.5 wind adjustment factor the estimated wind speeds would be:

10 * .85 * .5 = 4.25 m/s
10 * .92 * .5 = 4.60 m/s (.35 m/s difference).

In terms of implications on the NFDRS these data seem to indicate that the impacts of the different averaging times (one or two percent) are almost negligible and may almost be less than the accuracy of the instrumentation.

We were somewhat surprised by the relatively minor influence the averaging time made. And we caution that these results are preliminary. These data and analysis may require further review. But if these results are valid, and we believe they are, it is clear that accurate knowledge of an anemometers height and exposure is much more critical than whether it is a 2- or 10-minute averaged wind.

We intend to continue this work at sites with more varied exposure and also at sites with higher mean wind speeds to be able to provide additional characterization of wind speeds from weather stations that support fire management activities.

5. REFERENCES

Andrews, P.L. 1986. BEHAVE: fire behavior prediction and fuel modeling system --BURN subsystem, Part 1. USDA Forest Service Gen. Tech. Rep. INT-194. 130 pp.

Andrews, P.L., C.D. Bevins, and R.C. Seli. 2003. BehavePlus fire modeling system, version 2.0: User's Guide. USDA Forest Service Gen. Tech. Rep. RMRS-GTR-106WWW. 132 pp.

Deeming, J.D., R.E. Burgan, and J.D. Cohen. 1977. The National Fire Danger Rating System -1978. USDA Forest Service, Gen. Tech. Report INT-39, 63 pp.

Whiteman, C.D. 2000. Mountain Meteorology: fundamentals and applications. Oxford University Press. 335 pp.

6. ACKNOWLEDGMENTS

Thanks to Robert Schuette for design and fabrication of the portable tower and to Kyle Shannon for getting the equipment together and working. And thanks to Jack Cohen for the use of his 'back yard' in Bulter Creek and Bruce Bauck (MIC, Missoula Forecast Office) for facilitating the use of the Point Six NWS radar site.