Measurement Strategies for Estimating Long-Term Average Wind Speeds

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October 1980

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SUMMARY

The uncertainty and bias in estimates of long-term average wind speeds inherent in continuous and intermittent measurement strategies are examined by simulating the application of the strategies to 40 data sets. Continuous strategies have smaller uncertainties for fixed duration measurement programs, but intermittent strategies make more efficient use of instruments and have smaller uncertainties for a fixed amount of instrument use. Continuous strategies tend to give biased estimates of the long-term annual mean speed unless an integral number of years' data is collected or the measurement program exceeds 3 years in duration. Intermittent strategies with three or more month-long measurement periods per year do not show any tendency toward bias.

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MEASUREMENT STRATEGIES FOR ESTIMATING LONG-TERM AVERAGE WIND SPEEDS

INTRODUCTION

Long-term average wind speed is one measure of the quality of a potential wind energy conversion site. Techniques for using the long-term average speed to estimate the energy output of wind energy conversion systems (WECS) have been published by Justus et al. (1976), Cliff (1978), Justus and Mikhail (1978), and Justus (1978). They are also described in A Siting Handbook For Small Wind Energy Conversion Systems by Wegley et al. (1980). The purpose of this paper is to provide guidance in estimating the long-term average speed through short measurement programs. Other methods of estimating the long-term average and methods of enhancing observed data by comparison with data from other locations are not discussed.

Whenever a wind measurement program is contemplated for the purpose of estimating long-term climatological characteristics, factors to be considered include: the cost of the measurements, the availability of instruments, the time constraints on the measurements, and the probable uncertainty in the characteristic estimates following the measurements. The first three of the factors are reasonably easy to assess; the last factor is more difficult. Uncertainty is inherent in estimation. It can be reduced by selecting an optimum measurement strategy and using proper measurement techniques, but it cannot be eliminated.

This paper describes the uncertainties of potential measurement strategies and the systematic variation of the uncertainties, assuming proper measurement techniques. This information, alone, will not identify a "best" measurement strategy. But, when used with information on the other important factors, it will assist in identifying or selecting measurement strategy that may be best among the possible alternatives.

Forty data sets from 37 locations in the United States have been analyzed. The results presented are strictly empirical. In a larger sense, however, the results match predictions of statistical wind models that are generally

applicable. In this sense, they are at least qualitatively independent of the specific data sets used in the analysis.

DEFINITIONS

The terms strategy, uncertainty, and bias are used frequently throughout this paper. They are specifically defined in this section to clarify their intended meanings and reduce the possibility of misunderstanding.

STRATEGIES

A wind measurement strategy is simply the way that wind speed measurements are distributed in time. The most common measurement strategy is a "continuous" strategy in which data collection is not interrupted between the beginning of a measurement program and its completion. These strategies are completely described by the duration of the measurement program, e.g., 6 months, 2 years, 10 years. Other possible strategies involve alternating periods with and without measurements in an overall measurement program. For instance, measurements might be made each January and July for a period of 5 years. The duration of the measurement program is 5 years, but measurements are made in only 2 months per year. This type of strategy will be referred to as an intermittent strategy. To define intermittent strategies, the duration of the measurement program, the number of measurement periods per year and the length of the measurement periods must be specified. For this paper the measurement periods are assumed to be evenly distributed throughout the year and to be 1 month in duration. All months are assumed to have 30 days. The errors in this last assumption are negligible.

The specific intermittent measurement strategies examined range in duration from 1 to 5 years and have 1, 2, 3, 4 and 6 data collection periods per year. Continuous measurement strategies from 1 month to 5 years in duration are examined. The continuous strategies are a limiting case of intermittent strategies, i.e., there are 12 data collection periods per year and the time between measurement periods is reduced to zero.

Possible intermittent strategies are not limited to those discussed. Measurement periods could be reduced to a week or extended to 2 months or more. However, reducing the measurement period would increase the effect of individual wind events, thus increasing the uncertainty in estimates of the long-term average. Increasing the measurement period would reduce the uncertainty somewhat, but the reduction would not be directly proportional to the increase in averaging time because of the correlation resulting from systematic seasonal wind speed trends. Thus, monthly averages are a reasonable compromise use in the intermittent strategies. Random spacing of the measurement periods is also possible, but it does not provide any significant advantages over a planned systematic approach to sampling. In the case where the seasonal variation of wind speed is pronounced, random sampling may be less efficient than systematic sampling.

UNCERTAINTY

It is a basic premise of this paper that the long-term average speed is an unchanging characteristic of the wind at a potential WECS installation site. Further, it is assumed that wind speed measurements made during a relatively short period can be used to estimate this long-term average. Uncertainty is used to describe the margin for error inherent in the use of a specific measurement strategy to obtain the data for making this estimate. The average wind speed for the total measurement program is statistically the best estimate of the long-term average, and as more information is included in this average the chances for significant error are reduced. Thus, uncertainty is reduced.

The standard deviation of errors in estimates of the long-term average speed obtained by repeated application of a measurement strategy has been selected as the measure of uncertainty for the strategy. The strategy that uses a single observation to estimate the long term average speed has the greatest uncertainty. If standard deviations of errors of other strategies are divided by the standard deviation for the single observation strategy, a relative uncertainty is obtained. Relative uncertainty is useful as an index of the chance for significant error because it permits comparison of

uncertainties for all locations and strategies on a common, dimensionless zero-to-one scale. If the relative uncertainty of a strategy is near one, the strategy is not much better than a single observation strategy. As the relative uncertainty approaches zero the chances for significant error are reduced. When a relative uncertainty of 0.1 is reached, typical errors associated with a strategy will be 1/10 the magnitude of errors associated with the single observation strategy.

The degree to which the chance for significant error is reduced cannot be adequately assessed as a measurement program is being conducted; however, the general reduction characteristics can be evaluated by simulating various measurement programs. For example, 10 years' wind speed data consisting of monthly averages can be treated as 120 estimates of the long-term average if individual monthly averages are used. These same data can be used to produce a single estimate of the long-term average using the average speed for the full 10 years; they can also be used to develop many different estimates of the long-term average by simulating intermediate measurement strategies. The results presented in the following sections were achieved by simulation, using existing data sets. The average speed for the entire period of record has been assumed to be the true long-term average, and the standard deviations of the differences between other estimates of the long-term average and this value have been used as the measure of uncertainty for the various measurement strategies.

Mathematically these definitions can be summarized as follows: estimates of the long-term, climatologically representative wind speed are computed according to

$$\hat{U}_i = \frac{1}{nk} \sum_{j=0}^{nk-1} u_{i+j} \quad (1)$$

where

$\hat{U}_i$ are the estimates of the long-term average for a given strategy

u_i are the individual monthly averages

- k is the number of measurement periods per year
- n is the number of years of measurement in the strategy
- s is the number of months between the start of consecutive measurement periods ($s = 12/k$).

Both k and n are fixed once a strategy is defined. The range of i is limited to those values such that $i + 12n - s$ is less than or equal to the total number of months for which data are available. We further define the long-term average $\bar{U}$ by

$$\bar{U} = \frac{1}{N} \sum_{i=1}^N u_i \quad (2)$$

where N is the total number of months for which data are available.

The standard deviation of the estimates resulting from the use of individual monthly averages, σ_0 , is

$$\sigma_0 = \left[\frac{1}{N-1} \sum_{i=1}^N (u_i - \bar{U})^2 \right]^{1/2} ; \quad (3)$$

the standard deviation for other strategies, σ , is given by

$$\sigma = \left[\frac{1}{(N-12n+s-1)} \sum_{i=1}^{N-12n+s} (\hat{U}_i - \bar{U})^2 \right]^{1/2} \quad (4)$$

and the relative uncertainty R_u is

$$R_u = \sigma / \sigma_0 . \quad (5)$$

BIAS

Relative uncertainty is not the only concern. For a strategy to be useful, it must estimate the desired average. If a strategy produces estimates of

some value other than the long-term average speed it is biased. Bias is of particular concern when strategies use less than a full year's data. Take intermittent strategies that involve two measurement periods per year as an example. If the strategy is unbiased, the specific combination of months selected--January and July, February and August, March and September, April and October, May and November, or June and December--will not affect the estimate of the long-term average speed. If any one of these combinations gives an estimate that is significantly different than that obtained from another combination, the strategy is biased and at least one of the estimates is consistently too large or too small.

Standard analysis of variance techniques using one-way classification of the data were used to test measurement strategies for bias [e.g., Brownlee (1965)]. The null-hypothesis tested was that the long-term average estimates are equal regardless of the particular combination of calendar months used to obtain the estimates. The criterion for rejection was that the difference in any estimates be greater than that which would be expected as a result of chance 95% of the time. A 99% criterion was also used.

Rejection of the hypothesis does not mean that all estimates of the long-term mean obtained by a particular strategy are biased; rather, it indicates that at least two combinations of months give significantly different estimates of the mean. For example, a 6-month data collection period may be primarily in a windy season, it may be in a calm season, or it may include parts of both calm and windy seasons. The data obtained during a windy season will over-estimate the mean wind speed, those obtained during a calm season will under-estimate it, and those from a period that includes a portion of both windy and calm seasons should give an approximately correct estimate. The analysis of variance determines if there is a significant difference between the highest and lowest estimates of the mean speed, given the duration of the measurement period and the variation of the estimates. If this difference is significant, the strategy is classified as tending to be biased.

DATA SETS

The data used in this study were taken from the climatological records for the Hanford Meteorology Station operated for the Department of Energy near Richland, Washington, and monthly and annual Local Climatological Data Summaries, published by the National Oceanic and Atmospheric Administration for the 36 other locations, that were available at the Pacific Northwest Laboratory. The locations from which the data sets originated are shown in Figure 1. A key to location identifiers is given in Table 1 along with the number of years for which data were available, mean wind speed, standard deviation of monthly speeds (σ_0) and height of measurement for each data set. Only data sets with 5 or more years of measurement at a single height were used in the analysis. Three of the sites had data sets for two different measurement heights that met the minimum duration criterion. As a result there were 40 data sets in total.

FIGURE 1. Origins of the Data Sets

TABLE 1. Data Set Parameters

Identifier	Location	Height of Measurement (m)	Years	Mean Wind Speed (ms ⁻¹)	Standard Deviation of Monthly Average Speeds (ms ⁻¹)
HMS	Hanford WA	15.2	30	3.44	0.71
OLM	Olympia WA	6.1	13	3.16	0.49
SEA	Seattle WA	6.1	18	3.74	0.64
GEG	Spokane WA	6.1	15	3.96	0.68
YKM	Yakima WA	6.1	12	3.26	0.61
AST	Astoria OR	6.1	9	3.75	0.50
PDT	Pendleton OR	6.1	13	4.15	0.63
PDX	Portland OR	6.1	16	3.62	0.68
SXT	Sexton Summit OR	17.7	13	5.22	0.85
BOI	Boise ID	6.1	14	3.85	0.60
PIH	Pocatello ID	6.1	13	4.34	0.82
BIL	Billings MT	7.6	15	5.12	0.80
GTF	Great Falls MT	6.7	18	5.33	1.16
HVR	Havre MT	6.1	12	4.47	0.67
HLN	Helena MT	6.1	12	3.50	0.50
CPR	Casper WY	8.8(a)	5	5.80	0.93
		6.1	13	5.71	1.18
CYS	Cheyenne WY	10.1	16	5.97	0.97
LND	Lander WY	9.8(a)	18	3.04	0.53
SHR	Sheridan WY	6.1	9	3.42	0.63
RAP	Rapid City SD	9.8(a)	5	5.05	0.55
TOP	Topeka KS	21.9(a)	5	5.36	0.77
ICT	Wichita KS	9.4	5	5.64	0.83
INL	International Falls MN	7.0	7	3.67	0.55
MSP	Minneapolis MN	6.4	7	4.46	0.65
BRL	Burlington IA	10.1(a)	5	4.77	0.80
SUX	Sioux City IA	7.3	7	4.93	0.77
LSE	LaCrosse WI	11.9(a)	5	4.45	0.64
MSN	Madison WI	6.4	6	4.14	0.60
MKE	Milwaukee WI	6.1	7	4.98	0.70
ORD	Chicago IL	6.1	5	4.70	0.84
PIA	Peoria IL	6.1	7	4.53	0.81
FNT	Flint MI	10.7(a)	5	4.11	0.73
IND	Indianapolis IN	6.1	6	3.92	0.87
TOL	Toledo OH	6.1	5	3.92	0.82
RDU	Raleigh NC	6.1	7	3.78	0.70
ILM	Wilmington NC	13.1(a)	11	4.63	0.80
		6.1	10	3.66	0.56
CAE	Columbia SC	11.0(a)	8	3.18	0.52
		6.1	5	2.90	0.43

(a)Anemometer located on roof

Long-term average wind speeds for the data sets ranged from 2.90 to 5.97 ms^{-1} . The standard deviations of monthly average speeds ranged from 0.43 to 1.18 ms^{-1} ; they generally increased as the long-term average speed increased. A few of the sets had missing values. Long-term monthly average wind speeds were substituted for the missing values. In no case did the number of missing values exceed 5% of a data set.

In evaluation of specific measurement strategies, the only data sets used were those with total periods of record that were at least twice as long as the duration of the strategy. Thus, all 40 data sets were used for evaluation of strategies with durations of 2 years or less, 30 sets were used for evaluation of strategies with a duration of 3 years, 22 for strategies of 4 years duration and 19 for strategies of 5 years duration.

RESULTS

Relative uncertainty decreases as measurement strategies incorporate additional information. Figure 2 shows the average decrease in relative uncertainty for continuous measurement strategies. The rate of decrease is initially large, but as the duration of the measurement period increases the rate becomes small. The bulge in the curve between 12 and 24 months is the result of systematic seasonal variations in wind speed. Although not obvious in Figure 2 there is evidence of a similar but much less pronounced bulge between 24 and 36 months. The error bars shown indicate the range of the central 50% of the observed relative uncertainty values.

Systematic seasonal variation in mean wind speed, which causes the bulge in the relative uncertainty curve, contributes to bias in estimates of the long-term mean wind speed. The percentage of data sets tending to be biased is shown in Figure 3 as a function of the number of months of continuous measurement. The seasonal variation in monthly mean wind speeds is statistically significant at 39 of the 40 locations included in the data sets. As the number of months averaged increases, the percentage of sites showing a tendency toward bias decreases until a full year's data have been collected;

FIGURE 2. Relative Uncertainties of Continuous Measurement Strategies

FIGURE 3. Probability of Bias in Estimates of Long-Term Mean Wind Speeds in Continuous Measurement Programs

at this point there is no bias by definition. As data are collected in the second and third years of a measurement program, the tendency toward bias reappears, reaching maxima at 18 and 30 months, respectively. Beyond the third year the seasonal variations in mean wind speed do not produce a significant tendency toward bias, because the weight of the extra season's data is small when compared to the weight of the remainder of the data set. The criteria for tendency toward bias used in Figure 3 were rejection of the hypothesis of equality of mean wind speed estimates at the 95% and 99% confidence levels using analysis of variance.

One possible means of reducing or eliminating the tendency toward bias is an intermittent measurement strategy. When intermittent measurement strategies were examined for bias, those strategies with 3 or more measurement periods per year were found to be free from bias at all sites in the data set. For 30% of the locations, the strategies involving 2 measurement periods in 1 year tended to be biased. This percentage decreased to about 10% as the number of years of measurement increased to 5. The strategies involving 1 measurement period per year showed a strong tendency (greater than 75% of the sites) toward bias even when the duration of the program was increased to 5 years.

Relative uncertainties for intermittent measurement strategies are given in Table 2. The tabulated values show the benefits to be obtained by increasing the amount of wind data collected in a measurement program. The smaller the relative uncertainty, the better the estimate of the long-term mean wind speed. Relative uncertainties decrease as the number of measurement periods per year and the number of years increase. However, there is a limit to the decrease in relative uncertainty that can be achieved by increasing the number of measurement periods per year; that limit is the relative uncertainty of continuous measurement program, which is given in the bottom row of Table 2. The distribution of observed relative uncertainty values for each strategy involving two or more measurement periods per year is indicated in Table 3.

A relative uncertainty of about 0.35 can be achieved by continuous measurements for a 1-year period; the same relative uncertainty can be achieved

TABLE 2. Relative Uncertainties of Intermittent Measurement Strategies

Measurement frequency, Months per Year	Duration, Years				
	1	2	3	4	5
1(a)	1.00	0.86	0.78	0.72	0.69
2(a)	0.58	0.46	0.39	0.35	0.31
3	0.48	0.35	0.30	0.28	0.24
4	0.42	0.31	0.27	0.24	0.20
6	0.39	0.27	0.24	0.22	0.18
12	0.35	0.25	0.23	0.20	0.16

(a) Strategy shows tendency to be biased

by a strategy of three measurement periods per year for 2 years. This intermittent strategy involves only 6 months of actual data collection, compared to 12 months for the continuous strategy. However, the continuous strategy is completed at the end of 1 year, while it takes 21 calendar months to complete the measurements when the intermittent strategy is used. Clearly if a given uncertainty (accuracy) is desired, there is a trade-off between instrument usage and time required to complete the measurements. If instrument usage is a limiting factor in a measurement program, Table 2 shows that lower relative uncertainties for a given amount of instrument usage can be obtained by intermittent strategies. For example, intermittent strategies of 6 measurement periods per year for 2 years, 4 periods per year for 3 years, and 3 periods per year for 4 years all involve 12 months of instrument usage. Their relative uncertainties are about the same and are significantly lower than the relative uncertainty of a 12-month continuous measurement strategy.

As a further illustration of this concept, Figure 4 compares relative uncertainties for continuous and intermittent strategies as a function of the total number of months of instrument usage. Except for the intermittent strategies involving one measurement period per year, intermittent strategies have significantly lower relative uncertainties than do continuous strategies for a given amount of instrument usage.

The differences in relative uncertainty can be explained in terms of correlation between the average wind speed in consecutive measurement periods. In continuous strategies the wind speeds in consecutive measurement periods generally have a rather high positive correlation, while in intermittent

TABLE 3. Percentage Points of the Cumulative Frequency Distributions for Relative Uncertainty

Strategy		Probability that relative uncertainty will be less than or equal to the calculated value				
Periods Per Year	Years	5%	25%	50%	75%	95%
2	1	0.43	0.52	0.58	0.66	0.79
2	2	0.30	0.39	0.46	0.54	0.68
2	3	0.27	0.34	0.39	0.46	0.58
2	4	0.23	0.29	0.35	0.41	0.52
2	5	0.20	0.26	0.31	0.36	0.46
3	1	0.33	0.41	0.48	0.56	0.70
3	2	0.22	0.29	0.35	0.43	0.56
3	3	0.19	0.25	0.30	0.37	0.49
3	4	0.18	0.23	0.28	0.34	0.45
3	5	0.15	0.20	0.24	0.30	0.40
4	1	0.27	0.35	0.42	0.51	0.66
4	2	0.18	0.25	0.31	0.39	0.54
4	3	0.15	0.21	0.27	0.34	0.48
4	4	0.13	0.19	0.24	0.32	0.46
4	5	0.10	0.15	0.20	0.27	0.42
6	1	0.23	0.31	0.39	0.48	0.65
6	2	0.12	0.19	0.27	0.38	0.63
6	3	0.13	0.19	0.24	0.32	0.46
6	4	0.11	0.17	0.22	0.29	0.44
6	5	0.09	0.14	0.18	0.25	0.39
12	1	0.18	0.27	0.35	0.46	0.69
12	2	0.10	0.17	0.25	0.37	0.63
12	3	0.11	0.17	0.23	0.31	0.49
12	4	0.09	0.14	0.20	0.28	0.46
12	5	0.06	0.11	0.16	0.24	0.43

strategies they tend to be uncorrelated or negatively correlated. The solid line in Figure 4 represents the decrease in relative uncertainty that would be expected if the average wind speed in each measurement period were independent of averages in other periods. As a result of the high positive correlation, the amount of information gained by consecutive measurements is less than would be gained if speeds were independent. As the temporal separation between the end of one averaging period and the beginning of the next increases from zero months for consecutive strategies to 5 months in those intermittent strategies involving 2 measurement periods per year, the correlation of departures of the monthly averages from the long-term annual average speed decreases

and becomes negative. As it decreases the amount of information gained in each measurement period increases. When the correlation becomes negative more information is gained from each period than would be gained if the periods were independent.

FIGURE 4. Comparison of the Efficiencies of Instrument Usage in Continuous and Intermittent Measurement Strategies. Open symbols denote strategies showing tendency toward bias; closed symbols are for strategies that do not.

The improvement in relative uncertainty attainable with intermittent strategies is shown more dramatically when the relative uncertainty for each intermittent strategy is divided by the relative uncertainty of the continuous strategy with equal instrument usage. Small ratios indicate that the intermittent strategy is an improvement over the continuous strategy, and ratios near one indicate that there isn't much difference between the two types of

strategies. Table 4 gives 10%, 50% and 90% points for the distribution of this ratio for intermittent strategies with two to six measurement periods per year estimated from the data analyzed. These data strongly indicate that intermittent strategies make more efficient use of instruments than continuous strategies.

TABLE 4. Percentage Points in the Cumulative Frequency Distributions of the Ratio Between Relative Uncertainties for Intermittent Strategies and Continuous Strategies with Equal Instrument Usage

Strategy		Probability that ratio will be less than or equal to the stated value		
Periods Per Year	Years	10%	50%	90%
2	1	0.48	0.68	0.87
2	2	0.42	0.59	0.93
2	3	0.48	0.63	0.87
2	4	0.53	0.65	0.90
2	5	0.58	0.70	1.05
3	1	0.40	0.61	0.84
3	2	0.39	0.59	0.87
3	3	0.50	0.68	0.81
3	4	0.53	0.74	0.85
3	5	0.50	0.69	0.84
4	1	0.39	0.60	0.89
4	2	0.46	0.64	0.88
4	3	0.54	0.67	0.86
4	4	0.49	0.65	0.79
4	5	0.49	0.62	0.78
6	1	0.45	0.68	0.90
6	2	0.54	0.80	1.03
6	3	0.53	0.73	0.84
6	4	0.65	0.74	0.87
6	5	0.63	0.69	0.89

Returning to consideration of Figure 4 and Table 2, we see that in any measurement program the greatest reduction of uncertainty occurs in the first year. It also appears that the value of an additional year of measurements decreases as the number of years of completed measurements increases. This is illustrated more clearly in Figure 5. The curve in the figure is generally representative of the observed decrease for all strategies.

FIGURE 5. Decrease in Relative Uncertainty Gained by Collecting an Additional Year of Data with the Same Measurement Strategy

Relative uncertainty provides a consistent method of comparing data from locations with different long-term mean wind speeds and variability in monthly average speeds. For the present data sets the standard deviation of monthly average speeds, σ_0 , is related to the long-term mean wind speed in meters per second by

$$\sigma_0 = 0.052 + 0.052 + 0.154 \bar{U} \quad (6)$$

with a correlation coefficient of 0.76. Justus et al. (1979) have shown that the distribution of individual monthly average speeds about the long-term monthly mean speed can be assumed to be Gaussian. If we assume that the distribution of the individual monthly averages is also Gaussian, (6) provides sufficient information to relate relative uncertainty to percent error in estimates of long-term mean. This relationship is shown in Figure 6.

Because we are dealing with probability, it is necessary to accept some risk. If the line labeled 90% confidence is used, there is a 10% chance that actual percent error in an estimate will exceed the value determined from the figure. If the 99% confidence line is used the chance of underestimating the percent error is 1%. Table 2 shows that the relative uncertainty for 12 months

of continuous measurement is 0.35. Entering this value in Figure 6 shows that at the 90% confidence level an estimate of the long-term mean based on 12 months' data will be within 10% of the true mean. This result is consistent with results published by Corotis et al. (1977) and Justus et al. (1979). Choice of an intermittent strategy involving collection of 4 months' data in a single year would increase the error from 10 to 11.5% at the 90% confidence level.

FIGURE 6. Relationship Between Relative Uncertainty and Percent Error in Estimates of the Long-Term Mean

The actual distributions of the monthly averages are not Gaussian. The average coefficients of skewness and kurtosis for the 40 data sets were 0.18 and 2.68 respectively. For Gaussian distributions the corresponding values would be 0 and 3. As a practical matter the Gaussian assumption is reasonable and will not result in significant errors as long as it is not used to estimate extreme values.

CONCLUSIONS

Monthly average wind data for 37 sites (40 data sets) have been used to examine potential wind measurement strategies for uses in estimating the long-term average speed. The relative uncertainties and biases of continuous and selected intermittent strategies have been evaluated. The results indicate that intermittent strategies tend to be more efficient (in terms of instrument usage) in reducing relative uncertainty in the estimate of the long-term average. They also indicate that estimates obtained from continuous measurement programs tend to be biased unless the estimates are based on data for an integral number of years.

On the basis of these results it appears to be reasonable to consider intermittent measurement strategies when instrument resources are limited or instrument costs are high, where the long-term mean speed is to be estimated at several sites and time is a significant factor, and when the wind instruments can be moved easily and relatively inexpensively. However, final selection of a strategy must be based on the specific details related to each program. If a continuous measurement program is selected, it is recommended that all available data be used if the duration of the program is less than 1 year. Beyond the first year, data should be added in yearly increments. That is, the first year's data should be used until 2 years' data are available, and 2 years' data should be used until the third year's data are available. For continuous measurement programs extending beyond 3 years all data may be used without fear of bias, but the reduction in uncertainty is sufficiently slow that the effort to update the estimate of the long-term more frequently than annually is probably not worthwhile.

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