27-83 25 (1)
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Estimating Long-Term Mean Winds From Short-Term Wind Data

W. R. Barchet
W. E. Davis

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August 1983

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
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PNL-4785

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PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America
Available from
National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

NTIS Price Codes
Microfiche A01

Printed Copy

Pages	Price Codes
001-025	A02
026-050	A03
051-075	A04
076-100	A05
101-125	A06
126-150	A07
151-175	A08
176-200	A09
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ESTIMATING LONG-TERM MEAN WINDS
FROM SHORT-TERM WIND DATA

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DE83 017417

W. R. Barchet
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ESTIMATING LONG-TERM MEAN WINDS FROM SHORT-TERM WIND DATA

W. R. Barchet and W. E. Davis

SUMMARY

The estimation of long-term mean winds from short-term data is especially important in the area of wind energy. It is desirable to obtain reliable estimates of the long-term mean wind speed from as short a period of on-site measurements as possible. This study examined seven different methods of estimating the long-term average wind speed and compared the performance of these techniques. Three linear, three weather pattern, and one eigenvector methods were compared for measurement periods ranging from 3 months to 36 months. Average errors, both relative and absolute, and the rms errors in the techniques were determined. The best technique for less than 12 months of measurement was the eigenvector method using weekly mean wind speeds. However this method was only slightly better than the linear adjusted method. When 12 or more months of data were used, the difference in errors between techniques was found to be slight.

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1.0. INTRODUCTION

The long-term mean wind speed is an important measure of the quality of a potential site for use in wind energy conversion. In many cases candidate sites; that is, sites which are candidates for the deployment of wind turbines, that appear promising do not have a long period of meteorological record. Thus it is necessary to develop techniques which will indicate how long a period of measurement will be needed to accurately estimate the long-term mean wind speed. The purpose of this study is to demonstrate the capabilities of various techniques to estimate the long-term average wind speed from a short period of record. Furthermore, an estimation of the uncertainty associated with each technique is determined. The result of this study should provide both a technique for using a short period of measurement to estimate the long-term mean and the expected error in using the technique. Ramsdell et al. (1980) used existing long periods of measurement of wind speed at Hanford, Washington, and other sites throughout the United States to establish the period of measurement that should be used to estimate the long-term average. This analysis was not in itself a method of estimating the long-term average wind speed but only an indicator of how long a period of measurement was necessary until the measured mean wind speed approached the long-term average.

In this study seven techniques for extrapolating a short period of wind speed measurement to represent the long-term mean speed are presented. Linear methods that make use of the observed short period mean speed in a linear fashion and scale this speed to represent the long-term mean (Justus et al. 1978, Hiester and Pennell 1981) are tested. Linear techniques require the least amount of computational power and information about other measurement locations.

Three methods based on the weather pattern type (WPT) climatology at a site (Barchet 1982) were tested. In these methods the long-term climatology of the occurrence of various weather patterns is available independently of the period of observation. But the mean speed associated with each weather pattern

is determined at the candidate site for the measurement period. A linear combination of the observed speed for each WPT weighted by the frequency of occurrence gives the long-term mean. These methods require skillful analysis of the meteorology during the period of measurement to identify the weather pattern types.

A recent paper by Barros and Ser'o (1981) demonstrated the use of principal component analysis (PCA) to estimate the annual average at a station where only a short period of record was available. Barros' technique is extended here to obtain the long-term mean speed. PCA has been widely used in meteorology in recent years.^(a) Barnett (1977) estimated a two-component wind field pattern in the Pacific trade winds and in the San Francisco bay area. Bhumralkar et al. (1978) used PCA along with modeling wind flow over local terrain in a wind turbine siting study. The weights computed in this technique were for the stations rather than for each individual wind measurement during the period of concurrent measurement as in Barros' application. PCA techniques require a substantial amount of computation power as well as wind data from sites other than the candidate site.

(a) Smyth, V. G. 1982. A Wind Energy Resource Survey of New Zealand. PhD thesis presented at the University of Canterbury in New Zealand.

2.0 EXTRAPOLATION TECHNIQUES

2.1 LINEAR

Linear approaches to estimating the long-term mean from a short period of record are the most straight forward of the approaches tested in this study. The linear approaches require minimal computation. The most widely used linear technique is to assume the short period of measurement represents the long-term mean:

$$VLS = 1/(P-L) \sum_{i=1}^P OS_i$$

where VLS is the estimated long-term mean wind speed at the candidate site, L and P represent start and end of the period of observations at the candidate site, and OS_i is the series of observations of wind speed at the site. This technique for extrapolating a short series of observations to the long-term mean will be referred to in subsequent discussions as the "linear" technique.

A variation of the linear technique was described by Justus et al. (1978), and Hiester and Pennell (1981). In this approach, it is assumed that a reference station with a long period of record is available in the vicinity of the candidate site. The ratio of the mean wind speed observed at the candidate site and at the reference site during a period of concurrent observation is used to scale the reference site long-term mean wind speed to approximate the long-term mean at the candidate site:

$$VLS = VLR * VS/VSR$$

where VLR is the long-term mean at the reference site, and VS and VSR are the mean speeds for the short period of concurrent record at the candidate site and reference sites, respectively. In terms of the series of observations made at these sites, these mean speeds are defined as:

$$VLR = 1/M * \sum_{i=1}^M OR_i$$

where M is the total number of observations of wind speed, OR_i , at the reference site,

$$VSR = 1/(P-L) * \sum_{i=L}^P OR_i$$

where L and P mark the start and end of the period of concurrent observations at the reference and candidate site such that $1 \leq L < P \leq M$, and

$$VS = 1/(P-L) * \sum_{i=L}^P OS_i .$$

This approach will be referred to as the "adjusted" approach to indicate that the mean speed observed at the candidate site has been adjusted by the mean speeds observed at a reference site.

Corotis (1978, Renné and Corotis 1981) also used information from a nearby long-term reference station. His technique was to determine the long-term mean based on the short-term mean wind speed at the site plus an adjustment to the long-term mean wind at the reference station using the spatial correlation between the short-term measurements at the site to the short-term measurements at the long-term reference station. A variance was developed between the site and the reference station for use as an error estimate on the estimated long-term mean wind. This technique was not included in this study.

In the above discussion, VLS is referred to as the estimate of the long-term mean speed at the candidate site. Generally this is taken to mean the long-term annual mean speed. However, the linear approaches can be used to estimate the seasonal mean speed. In this case, season is taken to be the same time period as the sample period in every calendar year. Application of the

linear method to estimate the long-term seasonal mean speed, hereafter referred to as the "seasonal" technique, is discussed further in the section on measures of technique performance.

2.2 WEATHER PATTERN TYPING

Barchet (1982) recently gave the frequency of occurrence of nine weather pattern types for the Great Plains. One objective of this work was to characterize the wind regime of each weather pattern type (WPT) so that the long-term mean speed could be reconstructed from the mean speed associated with each WPT and the frequency of occurrence of the WPT:

$$VLS = \sum_{k=1}^9 fS_k * VS_k$$

where fS_k is the frequency of occurrence of WPT k at the candidate site and VS_k is the mean wind speed for WPT k observed at the candidate site. The short period of record at the candidate site is used to "calibrate" the mean speed associated with the weather pattern. The frequency of occurrence is determined from the climatology of WPT occurrence over the Great Plains given by Barchet (1982). This technique will be referred to as the "WPT" method of extrapolation. As in the linear approaches describe above, a reference station can be used to help calibrate the mean speed for a WPT and give the estimate of the long-term mean as:

$$VLS = \sum_{k=1}^9 fS_k * VLR_k VS_k / VSR_k$$

where VLR_k and VSR_k are equivalent, respectively, to VLR and VLS as defined above in the "linear adjusted" technique except that the speeds refer to those observed for a particular WPT. This technique for short record extrapolation will be referred to as the "adjusted WPT" technique.

By restricting the comparison of VLS to the same calendar period in other years, the WPT approach can be made into a "seasonal WPT" technique. Evaluation of this technique is discussed in the section on technique performance.

2.3 EIGENVECTOR (PCA)

The eigenvector or principal component analysis (PCA) approach has been applied to the generation of annual time series of wind data by Barros and Ser'o (1981). The application here extends Barros' work to generate time series for periods on the order of eight years. This approach relies on having one or more reference stations at which a long series of wind speed observations is available. These stations provide the basis for generating a long series of wind speeds from a short period of observation at a candidate site.

A matrix V is formed using as columns the reference sites and the rows as the individual wind measurements at the reference sites. The elements of V , v_{ij} , give the wind speed for observation i and reference station j . The PCA assumes that V can be described by the product of two orthonormal matrices

$$V = A M$$

in which A is formed by the eigenvectors of the matrix formed by the product of V and its transpose, V^T . The multiplier matrix, M , is obtained by a linear algebra solution of this expression.

If the number of reference stations is N and the number of observations in the long time series is M then matrix V is of the order $M \times N$. The product of V and V^T is of the order $M \times M$ as is the eigenvector matrix A . That is, matrix A contains M eigenvectors. However, the number of eigenvectors with non-zero eigenvalues is usually less than or equal to the number of reference stations, N . In practice, time series can be reconstructed with good fidelity using the eigenvectors associated with the first few largest eigenvalues, N' , so that the eigenvector matrix, A' , that needs to be dealt with is of the order $M \times N'$.

To generate a long time series of wind speed values from a short series obtained at a candidate site it is necessary that the time series at the candidate site be concurrent with part of the time series at the reference sites.

The PCA approach assumes the time series at the candidate site, V_s , can be constructed from a subset of eigenvectors associated with the reference sites, A' and a multiplier vector M_s :

$$V_s = A' M_s.$$

The elements of V are

$$V_{s_i} = \sum_{n=1}^{N'} a'_{in} m_{s_n}$$

where a'_{in} are the elements to A' and m_{s_n} are the elements to M_s . The vector V_s is the reconstructed time series of observations at the candidate site. Barros and Ser'o (1981) showed that a time series of reasonable fidelity could be formed from as few as three eigenvectors. However, in this study, five eigenvectors ($N'=5$) were always used to construct the time series.

The root-mean-square (rms) error in the reconstruction of the time series is

$$E_s = \sum_{i=1}^P \left(OS_i - \sum_{n=1}^{N'} a'_{in} m_{s_n} \right)^2.$$

where OS_i are the observed wind speeds at the candidate site. The error is minimized by setting

$$\frac{\partial E_s}{\partial m_{s_n}} = 0$$

which creates a set of N' equations with N' unknowns. Linear algebra methods are used to solve for the vector M_s .

Once M_s is known, the long-term mean for the candidate site is estimated by

$$VLS = 1/M \sum_{i=1}^M \sum_{n=1}^{N'} a'_{in} ms_n .$$

This approach to extrapolating a short data record will be referred to as the "PCA" method.

3.0 DATA BASE

Eleven stations on the Great Plains with a period of record at constant anemometer height from eight to ten years long were chosen to test the various extrapolation techniques described above. Figure 1 shows the location of these stations on the Great Plains. The stations are listed in Table 1 along with the period of record, anemometer height, and mean wind speed for the period of record and for the eight year period used in the PCA evaluation. The mean speed was determined from an analysis of data on the TD1440 tapes obtained from the National Climatic Center (NCC 1975) for these stations.

The linear and WPT approaches used daily mean wind speeds computed from the hourly observations. The daily mean values approximate what would be obtained with a wind-run anemometer read at 1 pm local time. The PCA-based technique used weekly (7-day) and monthly (30-day) mean speeds calculated by averaging the appropriate number of daily mean values.

TABLE 1. Great Plains Stations Used to Evaluate Short Record Extrapolation Techniques

WBAN	Station	State	Start Period	End Period	Anemometer Height (ft)	Mean Wind Speed (m/s)	
						Total Period	550101- 621231
1. 13967	Oklahoma City	OK	550101	641231	55	5.98	6.01
2. 13996	Topeka	KS	550101	640809	72	5.50	5.43
3. 14918	Intern'l Falls	MN	550101	630929	23	4.34	4.37
4. 14931	Burlington	IA	550101	641231	33	4.80	4.80
5. 14940	Mason City	IA	550101	641231	20	5.51	5.65
6. 14942	Omaha	NE	550101	630331	74	5.26	5.26
7. 23054	Las Vegas	NM	550101	641231	26	5.52	5.23
8. 23065	Goodland	KS	550101	640322	31	5.66	5.57
9. 24023	North Platte	NE	550101	640811	32	5.00	4.97
10. 24028	Scottsbluff	NE	550101	640801	50	5.34	5.28
11. 24090	Rapid City	SD	550101	641231	32	5.13	5.09

FIGURE 1. Stations Used in the Evaluation of Extrapolation Techniques

4.0 RESULTS

4.1 MEASURES OF TECHNIQUE PERFORMANCE

The short record extrapolation techniques described above were tested using simulated short periods of observation of 3, 6, 12, 24 and 36 months out of the total available period of record. For the linear and WPT techniques, these periods were represented by sequences of 91, 182, 365, 730, and 1095 days, respectively. For the PCA technique 13, 26, 52, 104 and 156 weeks, respectively, were used to represent the test periods. Seasonal techniques were not tested for sample periods longer than 12 months. The number of estimates of the long-term mean for each sample period is given in Table 2. This is the maximum number of samples of the specified duration that can be obtained from the period of record.

TABLE 2. Number of Estimates of the Long-Term Mean for Simulated Observation Periods

<u>Period Duration (mo)</u>	<u>Days in Period</u>	<u>Samples in 10-year Record</u>	<u>Weeks in Period</u>	<u>Samples in 8-year Record</u>
3	91	3561	13	403
6	182	3470	26	390
12	365	3287	52	364
24	730	2922	104	312
36	1095	2559	156	260

Three measures of performance are calculated for each sample period and short record extrapolation technique. The average error for all samples for a candidate site is given by

$$AVEs = 1/G \sum_{g=1}^G (VLS_g - VTs)$$

where VTs is the true, observed long-term mean over the period of record at the candidate site as shown in Table 1, G is the number of samples in the total

period of record (approximated in Table 2), and VLS_g is the estimate of the long-term mean by the extrapolation technique for sample g . The average, absolute error for all samples is given by

$$ABSs = 1/G \sum_{g=1}^G (VLS_g - VTs) .$$

And, the root-mean-square error for the samples is given by

$$RMSs = \left[1/G \sum_{g=1}^G (VLS_g - VTs)^2 \right]^{1/2}$$

for each candidate site.

Performance of the seasonal linear and seasonal WPT techniques is not measured against the long-term annual mean speed. Rather, VTs represents the long-term mean of each season for every calendar year in the period of record. Season here is taken to be the same calendar period as the short term sample. To illustrate, if the 3-month sample went from May 5, 1956 to August 4, 1956, VLS obtained from this period would be compared to VTs determined from all May 5 to August 4 periods within the total record for the candidate site. Application of seasonal techniques is meaningful only for sample periods of 12 months or less.

Mean values of these performance measures for various subsets of the eleven Great Plains stations are used as the final measure of technique performance. The linear, WPT and full PCA techniques made use of the complete set of eleven stations. Out of the eleven stations used in the study two clusters of four stations each were identified for additional study. Scottsbluff, Nebraska, was chosen as the focal point for one cluster; Omaha, Nebraska, for the other. These clusters were used to test adjusted extrapolation techniques and PCA techniques using a small set of reference stations. Table 3 shows the station pairs that were used to arrive at the performance measures.

TABLE 3. Station Pairs Used to Test the Linear and WPT Techniques that Require a Reference Station

			Reference Station WBAN									
			1	1	1	1	1	1	2	2	2	2
			3	3	4	4	4	4	3	3	4	4
			9	9	9	9	9	9	0	0	0	0
Candidate Site			6	9	1	3	4	4	5	6	2	2
WBAN	Station	State	7	6	8	1	0	2	4	5	3	8
13967	Oklahoma City	OK										
13996	Topeka	KS				X	X	X				
14918	Intern'l Falls	MN										
14931	Burlington	IA		X			X	X				
14940	Mason City	IA		X		X		X				
14942	Omaha	NE		Xa		Xa	Xa					
23054	Las Vegas	NM										
23065	Goodland	KS								X	X	X
24023	North Platte	NE							X		X	X
24028	Scottsbluff	NE							Xa	Xa		Xa
24090	Rapid City	SD							X	X	X	

(a) Reference stations used in PCA technique with 1,2, or 3 reference stations

Performance of the PCA technique using from one to three reference stations was based on only one or three samples for each of only two stations (see note with Table 3).

4.2 TECHNIQUE PERFORMANCE

The performance of the seven extrapolation techniques presented above is shown in Table 4 for each performance measure. In these tables the performance measures are given as the mean for the set of sites of the average percentage departure from the true long-term mean at each candidate site.

The mean average error (Table 4a) is always rather small. This indicates that over all samples the errors in estimating the long-term mean nearly

TABLE 4. Performance of the Extrapolations for the Set of Great Plains Stations

a. Mean Average Error (*) for the Various Techniques

Extrapolation Technique	Months in Sample Period				
	3	6	12	24	36
Linear	-0.05	-0.24	-0.33	-0.38	-0.40
Adjusted	0.42	0.29	0.15	0.01	-0.10
Seasonal	-0.14	-0.09	-0.13	---	---
WPT	-3.79	-1.36	-0.47	-0.49	-0.47
Adjusted WPT	-2.43	-0.28	0.20	0.04	-0.08
Seasonal WPT	-2.53	-0.81	-0.28	---	---
PCA-weekly	-0.69	-0.53	-0.49	-0.41	-0.30
PCA-monthly	---	-2.05	-1.20	-0.97	-0.84

b. Mean Average Absolute Error (*) for the Various Techniques

Extrapolation Technique	Months in Sample Period				
	3	6	12	24	36
Linear	9.26	6.83	4.42	3.53	2.46
Adjusted	6.91	5.62	4.20	3.28	2.39
Seasonal	6.10	5.23	4.42	---	---
WPT	10.35	7.03	4.46	3.58	2.49
Adjusted WPT	7.75	5.64	4.14	3.17	2.27
Seasonal WPT	6.72	5.30	4.47	---	---
PCA-weekly	7.38	5.57	4.18	3.21	2.41
PCA-monthly	---	9.24	5.25	3.94	2.84

c. Mean Average Root-Mean-Square Error (*) for the Various Techniques

Extrapolation Technique	Months in Sample Period				
	3	6	12	24	36
Linear	11.40	8.42	5.33	4.17	2.80
Adjusted	8.63	6.99	5.18	3.86	2.71
Seasonal	7.52	6.38	5.31	---	---

TABLE 4. (contd)

Extrapolation Technique	Months in Sample Period				
	3	6	12	24	36
WPT	12.59	8.67	5.41	4.26	2.82
Adjusted WPT	9.62	7.05	5.12	3.79	2.61
Seasonal WPT	8.42	6.56	5.39	---	---
PCA-weekly	9.23	6.82	4.94	3.64	2.73
PCA-monthly	---	12.72	6.50	4.57	3.29

(*) expressed as the mean over all sites tested of the average percentage departure from the long-term mean at each candidate site

cancel. However, for the WPT techniques there seems to be a small bias toward an underestimation of the long-term mean by a few percent for the 3-month sample period. PCA techniques also consistently underestimate the long-term mean. This may be due to the use of only five eigenvectors in the construction of the time series.

The mean average absolute error (Table 4b) and mean average root-mean-square(rms) error (Table 4c) are more discriminating measures of technique performance. As expected, both show the same trends with the rms error consistently larger than the absolute error. In the discussion to follow, the rms error will be used to compare the performance of the various extrapolation techniques.

The trend for all extrapolation techniques is for the mean average absolute and mean average rms errors to decrease as the sample period is lengthened. Ramsdell et al. (1980) found the same trend in evaluating several measurement strategies and using essentially the linear method to estimate the long-term mean. The greatest variability in results is found with the 3-month sample period. Techniques gave mean average rms errors ranging from 7.5 to 12.6%. Whereas, with a 36-month sample the mean average rms error for all techniques converged to about 2.7% of the long-term mean. Even with a 12-month sample, the rms performance of the techniques is so similar (range from 4.94 to

6.50%) that the techniques are virtually indistinguishable. The difference in techniques for 3-month and 6-month sample periods offers more opportunity for discussion of results.

Linear techniques performed better than weather pattern based techniques by about one percentage point for the 3-month sample period. This appears to indicate that a 3-month sample is too short to adequately "calibrate" or characterize the mean wind speed associated with a particular WPT. In part this is due to seasonal variations in weather system intensity. However, a comparison of the seasonal techniques still shows the WPT techniques performed slightly poorer than their linear counterparts. But, the affect of seasonal variations in weather system intensity on the long-term estimate is shown by the improvement of the seasonal methods over both linear and WPT methods by about four percentage points and one percentage point over the adjusted techniques. Approaches which use a reference station to adjust the short period observation at the candidate site show about a three percentage point improvement over their unadjusted counterparts.

The PCA technique using 7-day mean wind speeds (PCA weekly) compared closely to the linear adjusted technique at three months and showed slight improvement over other techniques for sample periods of six months or more. With monthly mean wind speeds (PCA monthly) this technique was definitely poorer than the other techniques. This was to be expected considering tht PCA monthly uses about one-fourth the data points of PCA weekly. Still, the difference between PCA monthly and the other techniques is less than two percentage points for sample periods of twelve months or longer.

An important difference between the linear adjusted and PCA techniques is that the adjustment in the linear method is based on the mean speed over the sample period. A single adjustment is made to arrive at VLS. In the PCA-weekly approach, every data point (the 7-day mean speeds) is adjusted so that a new time series of adjusted wind speeds is created for the whole 8-year period of record. This new time series is averged over the period of record to obtain VLS.

The PCA technique using one, two, and three reference stations in the immediate vicinity of a candidate site was applied to two sites: Omaha,

Nebraska (14942) and Scottsbluff, Nebraska (24028). The results for the PCA and other extrapolation techniques applied to these sites are shown in Table 5. In general all techniques performed better for these two stations than the 11-station average. Furthermore, the trends seen in Table 4c are maintained. However, with a 3-month sample, the PCA technique showed a significantly improved performance over the 10-station result by using from one to three reference stations. Scottsbluff (24028) was very well characterized by a set of three near neighbors. But individually the same three neighbors did poorer. On the other hand, at Omaha, PCA technique performance deteriorated as additional near neighbors were used. An explanation is that reference stations in the vicinity of a candidate site should experience very similar meteorological conditions as at the candidate site and thus serve to better construct the time series at the candidate site. As the network of reference sites expands, distant sites add little additional information to the reconstructed time series. However, geographical proximity may not be nearly as important as having reference sites with an exposure to the wind that is similar to that at the candidate site.

One result that is quite interesting is the reduction in rms error by using the linear adjusted technique for sample periods of three and six months. Our results for using the longer 12-month period show what Justus et al. (1978) found: little or no improvement occurred when using the linear adjusted technique for a 12-month sample period (see Tables 4 and 5). However, it does appear that the linear adjusted technique is useful in reducing rms errors for sample periods less than 12 months.

TABLE 5. Mean Average Root-Mean-Square Error of Extrapolation Techniques Applied to Two Great Plains Sites

Extrapolation Technique	Months in Sample Period				
	3	6	12	24	36
Linear					
14942	10.31	7.47	5.04	3.53	1.62
24028	10.95	7.46	3.42	3.15	2.45
Adjusted					
14942	7.68	6.54	5.27	4.19	3.00
24028	7.93	5.81	3.60	2.50	1.49
WPT					
14942	11.64	7.42	4.89	3.45	1.47
24028	11.86	7.91	4.06	3.75	2.80
Adjusted WPT					
14942	8.31	6.27	5.02	4.01	2.66
24028	9.23	6.16	3.59	2.43	1.37
PCA-10 station					
14942	8.15	5.30	3.96	2.63	1.79
24028	8.71	5.21	3.29	2.02	1.23
PCA-3 station					
14942	5.75	5.15	4.54	3.49	2.42
24028	6.01	4.02	2.10	1.43	0.88
PCA-2 station					
14942	5.58	4.69	3.84	2.71	1.69
24028	6.40	4.19	2.26	1.52	1.18
PCA-1 station					
14942	5.58	4.59	3.63	2.46	1.35
24028	7.02	5.46	3.78	2.64	2.30

5.0 SUMMARY AND CONCLUSIONS

This study set out to select and test different techniques for estimating long-term average wind speeds at a site with only a short-term record. Techniques selected for testing included linear methods, weather pattern typing methods, and a PCA method.

Table 6 shows the rank of the various extrapolation techniques for each sample period and an overall rank. The PCA-weekly method performed the best overall but was only slightly better than the adjusted linear technique. With a 12-month or longer sample, the difference between techniques is so slight as to make a definitive choice impossible.

Inadequate calibration of the wind speed for a WPT with a short sample period kept the WPT techniques from performing well at the 3- and 6-month sample periods. However, with adequate data ($\Rightarrow$ 12 months) the adjusted WPT was marginally superior to both adjusted linear and PCA techniques.

The requirements for data and the need for computer processing of the data are important factors in choosing an extrapolation technique. PCA methods require the most information and need the greatest amount of computer power. Adjusted techniques, both linear and WPT, need data from at least one other station and only modest computational resources. A definite drawback to the WPT techniques is that they need a fairly sophisticated analysis of the meteorology over the sample period to be useful.

If only three months of data are available at a candidate site and if there are nearby sites with similar wind exposure and long-term record, it is recommended that the PCA-weekly method be applied to estimate the long-term mean. The accuracy of such an estimate should be on the order of 10% of the long-term mean speed. If computer resources are limited, the two adjusted techniques are recommended.

TABLE 6. Ranking of Extrapolation Technique Performance Based on Lowest RMS Error

Extrapolation Technique	Rank by Sample Period					Overall Rank
	<u>3</u>	<u>6</u>	<u>12</u>	<u>24</u>	<u>36</u>	
PCA-weekly	2	1	1	1	3	1
Adjusted linear	1	2	3	3	2	2
Adjusted WPT	3	5	2	2	1	3
Linear	4	3	4	4	4	4
WPT	5	4	5	5	5	5

6.0 ACKNOWLEDGEMENTS

Contributions to this work by Keith Packard and Neal Hara are gratefully acknowledged by the authors. This work has been funded for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830.

7.0 NOMENCLATURE

OR _i	Time series of observed wind speed at reference site
OS _i	Time series of observed wind speed at candidate site
VT _s	Observed long-term mean wind speed for station s
VLS	Long-term mean wind speed from extrapolation technique
VLS _g	Calculated long-term mean for station s and sample g
VLR	Long-term mean wind speed at reference site
VS	Short-term mean wind speed observed at candidate site
VSR	Short-term mean wind speed observed at reference site
VLR _k	Long-term mean wind speed for weather pattern type k at reference site
VS _k	Short-term mean wind speed for weather pattern type k at candidate site
VSR _k	Short-term mean wind speed for weather pattern type k at reference site
fS _k	Long-term frequency of weather pattern occurrence at candidate site
V	Matrix of wind speed observations at all reference sites
Vs	Vector of candidate site computed wind speeds
A	Eigenvector matrix for reference sites
A'	Subset of eigenvectors used in time series construction
a' _{in}	Element of A'
M	Multiplier matrix for reference sites
Ms	Multiplier vector of eigenvector subset to generate Vs
ms _n	Element of Ms
M	Total number of observations in long-term time series
L	Start of measurement period at candidate site
P	End of measurement period at candidate site
G	Number of samples of given length in the period of record
i	An index for the time series observation
k	An index for the weather pattern type
n	An index for the eigenvector
Es	Sum of squared error in time series construction
AVEs	Average error for station s
ABSS	Average absolute error for station s
RMSs	Average root-mean-square error for station s

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