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INCLUSION OF ROUTINE WIND AND TURBULENCE FORECASTS IN THE SAVANNAH RIVER PLANT'S EMERGENCY RESPONSE CAPABILITIES

by

M. M. Pendergast

E. I. du Pont de Nemours & Co.
Savannah River Laboratory
Aiken, SC 29808

and

D. B. Gilhousen

Techniques Development Laboratory
Systems Development Office
National Weather Service, NOAA
Silver Springs, MD 20910

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M. M. Pendergast

E. I. du Pont de Nemours & Co.
Savannah River Laboratory
Aiken, SC 29808

D. B. Gilhousen

Techniques Development Laboratory
Systems Development Office
National Weather Service, NOAA
Silver Springs, MD 20910

ABSTRACT

The Savannah River Plant's emergency response computer system was improved by the implementation of automatic forecasts of wind and turbulence for periods up to 30 hours. The forecasts include wind direction, wind speed, and horizontal and vertical turbulence intensity at 10, 91, and 243 m above ground for the SRP area, and were obtained by using the Model Output Statistics (MOS) technique.

A technique was developed and tested to use the 30-hour MOS forecasts of wind and turbulence issued twice daily from the National Weather Service at Suitland, Maryland, into SRP's emergency response program. The technique for combining MOS forecasts, persistence, and adjusted-MOS forecast is used to generate good forecasts any time of day. Wind speed and turbulence forecasts have been shown to produce smaller root mean square errors (RMSE) than forecasts of persistence for time periods over about two hours. For wind direction, the adjusted-MOS forecasts produce smaller RMSE than persistence for times greater than four hours.

INTRODUCTION

An emergency response system called Weather Information and Display (WIND) began operating at the Savannah River Plant (SRP) in 1975 [1, 2, 3]. The Wind system collects meteorological data from seven onsite towers and the nearby 330-m WJBF-TV tower located at Beech Island, South Carolina. The development of the computer system has allowed improved assessments of routine atmospheric releases from the Department of Energy facilities at SRP, Aiken, SC, and provided a basis for research in the atmospheric sciences. Until recently, the computer codes that calculate pollutant trajectories generally used the latest observed wind information to predict the future path of a pollutant. However, calculations based on the assumption that meteorological conditions in the future will be the same as the latest observations, i.e., a "persistence" forecast, can be considerably in error when wind conditions are changing.

In July 1979, the WIND system capability was improved by inclusion of automatic forecasts of wind and turbulence for periods up to 30 hours. The wind forecasts originate at the National Weather Service in Suitland, MD, and are transmitted to SRP on teletype twice daily. These forecasts are based on Model Output Statistics (MOS), which is a forecast technique that statistically relates the output of numerical weather prediction models to the meteorology of a particular site. This technique was done for SRP starting in 1977 in collaboration with the Techniques Development Laboratory of the National Oceanic and Atmospheric Association by using four years of data from the nearby 330-m WJBF-TV tower. The MOS system provides 30-hour forecasts of wind direction, wind speed, and horizontal and vertical turbulence intensity at 10, 91, and 243 m above ground for the WJBF-TV tower twice daily starting at 0000 and 1200 GMT.

A complete description of the MOS forecasts for SRP is given by Gilhousen and Pendergast [4]. Their conclusions show that MOS forecasts of wind speed were better than persistence for both day and night. MOS forecasts of wind direction were found to be only slightly better than persistence. MOS forecasts of turbulence were clearly better than persistence during the daytime, but only slightly better than persistence during night.

This study describes the methodology used to implement the MOS forecasts into the SRP's emergency response program. Also presented is an independent validation of the MOS predictions with the first six months that MOS forecasts became operational (May through December 1979).

As noted previously, 30-hour MOS forecasts have a base time of either 0000 or 1200 GMT. The times that these forecasts are transmitted to SRP are 0430 and 1630 GMT, respectively. In the SRP application, a forecast may be required to start at any hour of the day or night. For this reason, a method was developed to use realtime validation of a portion of the available MOS forecast to adjust the remainder of the MOS forecasts. This validation showed that for some start times and predictands adjusted-MOS forecasts were found to provide lower Root Mean Square Errors (RMSE) than the available MOS forecasts.

The following sections describe the results and methods used to determine which combination of MOS forecast, adjusted-MOS forecast, and persistence provides the best forecast for each predictand and start time.

PERSISTENCE FORECASTS

RMSE of MOS forecasts and persistence forecasts for each predictand were determined from data for the period May through December 1979. Figure 1 shows comparisons of the RMSE by using MOS forecasts and

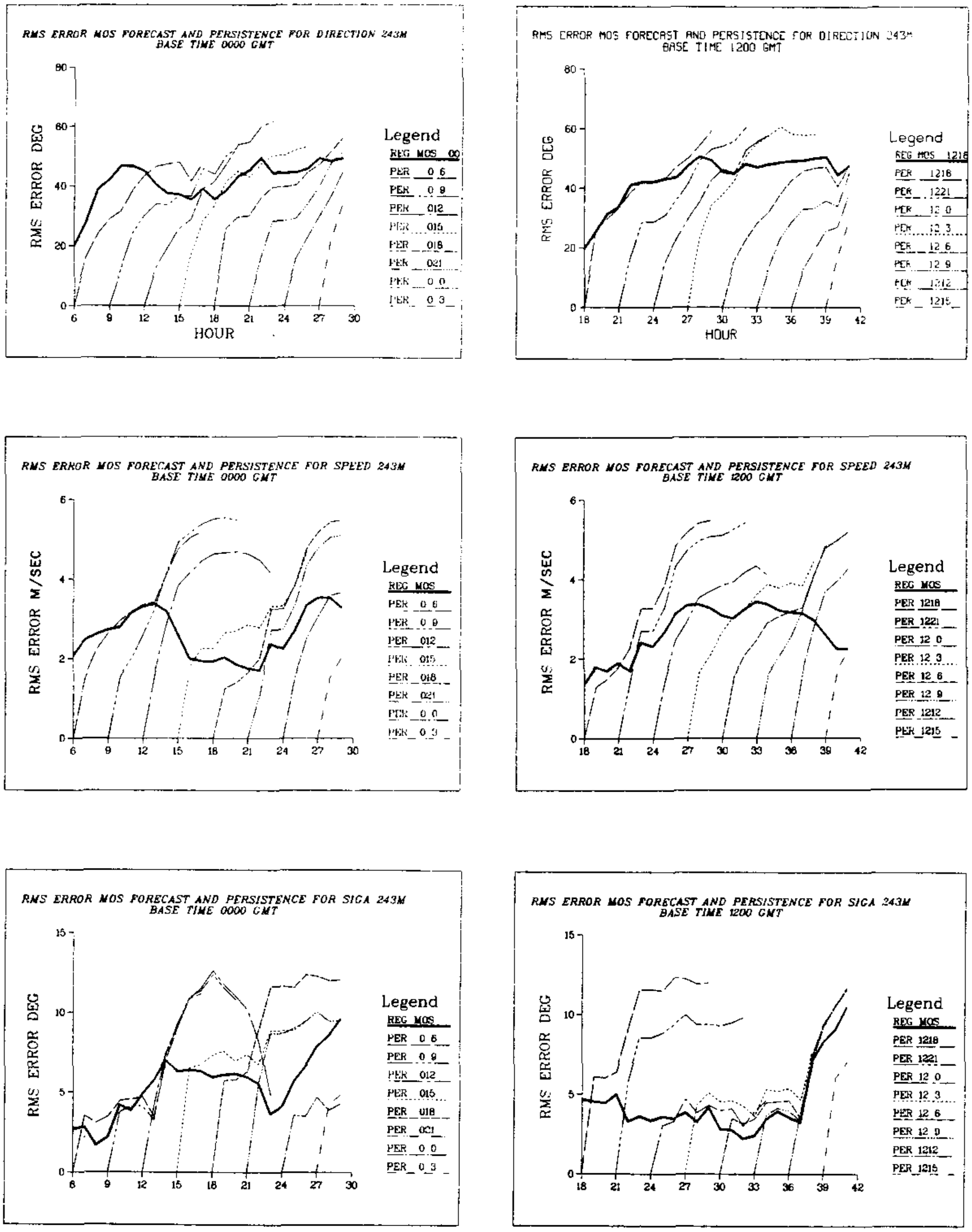

Fig. 1. RSME values of MOS forecasts and persistence for different start times for wind direction (θ), wind speed (u), and standard deviation of wind azimuth (σ_θ) for base times of 0000 and 1200 GMT.

persistence for different predictands and base times. The darkened curves show the RMSE of the MOS forecasts as a function of time. Note that the RMSE values are not directly proportional to the duration of forecasts. The remaining curves in Figure 1 represent persistence forecasts starting at three-hour intervals. Most persistence curves intersect the corresponding MOS forecasts after a short elapsed time. This elapsed time will be called the MOS persistence time and is shown to be a function of the predictand, time of day, and base time of the MOS forecast.

MOS persistence times for all predictands are presented in Table 1. Note MOS persistence times do not show a consistent relationship with the elapsed time from the base time. They do show a slight correlation with time of day. For example, MOS persistence times for wind direction (θ) for 0000 GMT base times are largest at 1200 and 1500 GMT and smallest at 0900 GMT. For 1200 GMT base times, MOS persistence times for wind direction are largest at 0600 GMT and smallest at 0000 and 0300 GMT.

The persistence curves in Figure 1 exhibit a varying dependence upon time of day. Many persistence curves show a rapid increase in the RMSE and then approach a limiting value. The magnitude of the limiting value varies from one start time to another. For other start times and other predictands, the persistence curves show a steadily increasing value of RMSE. A careful examination of the MOS forecast RMSE curves show that they are well correlated with the magnitude of the limiting values of each persistence curve. Thus, the RMSE of the MOS forecasts are smallest for valid times when persistence forecasts produce smallest RMSE.

Table 1 shows average MOS persistence times for all start times for each predictand. Note the value of the average MOS persistence times decreases from about seven hours for wind direction to about four hours for wind speed and about two hours for σ_θ and σ_ϕ.

ADJUSTED-MOS FORECAST

A combination of persistence forecasts and MOS forecasts can be used to provide reasonable predictions for each predictand at any start time. The following describes a method used for adjusting the MOS forecast. The goal of the adjustment process is to produce a forecast which produces a RMSE smaller than that of the MOS forecast or persistence. Since persistence times for σ_θ and σ_ϕ are quite small, about two hours, the methodology was tested by using wind direction and wind speed. The adjustment procedure was evaluated for start times that were 18 hours after base times.

The MOS forecasts, F, for each of the five predictands U, V, wind speed, σ_θ and σ_ϕ can be represented by

Table 1. MOS Persistence Times for 0000 and 1200 GMT MOS Forecasts for all Predictands for the Period May-December 1979

Start Time (GMT)	Elapsed Time (hr)	MOS Persistence Times for Base Time 0000 GMT									
		10 m			91 m			243 m			
		u	σ_θ	σ_ϕ	u	σ_θ	σ_ϕ	θ	u	σ_θ	σ_ϕ
0900	9	5	1	5	3	2	2	5	5	1	4
1200	12	2	2	2	2	1	1	11	3	1	3
1500	15	6	1	6	4	1	1	11	2	1	8
1800	18	4	1	3	4	4	1	8	4	3	4
2100	21	3	1	2	4	1	1	8	2	2	2
0000	24	6	1	-	5	-	-	-	4	-	-
Avg Persistence Times		4.3	1.2	3.6	3.7	1.8	1.2	8.6	3.3	1.6	4.2

Start Time (GMT)	Elapsed Time (hr)	MOS Persistence Times for Base Time 1200 GMT									
		10 m			91 m			243 m			
		u	σ_θ	σ_ϕ	u	σ_θ	σ_ϕ	θ	u	σ_θ	σ_ϕ
2100	9	2	1	1	2	1	2	6	2	1	3
0000	12	6	1	1	5	3	1	4	9	4	4
0300	15	3	1	6	4	1	2	4	7	1	5
0600	18	3	3	7	4	1	1	11	6	1	2
0900	21	4	1	4	3	4	2	9	4	2	4
1200	24	2	1	3	5	1	1	6	3	1	1
Avg Persistence Times		3.3	1.3	3.7	3.8	1.8	1.5	6.7	5.2	1.7	3.2

$$F_i \Big|_{i=1,N} \qquad (1)$$

where i represents the valid time of the forecasts starting at hour 1 and continuing to hour N. The observed value of each predictand is represented by

$$O_i \Big|_{i=1,M} \qquad (2)$$

for the times 1 to M. Forecasts are verified by determining the error in the MOS forecast for each time interval given by

$$E_i \Big| = F_i - O_i \Big|_{i=1,M} \qquad (3)$$

and then determining the average error, $\overline{E}$, defined by

$$\overline{E} = \sum_{i=1}^{M} W_i E_i \,, \qquad (4)$$

where W_i is a weighting function. This average error becomes the basis for adjusting MOS forecasts.

An adjusted forecast, F', is calculated by using

$$F'_i \Big| = F_i - G_i \overline{E} \Big|_{i=M+1,N} \qquad (5)$$

for times beginning at M+1 and continuing to time N. G_i is a weighting function which may or may not be equal to W_i.

Three different weighting functions were used. They are termed constant, linear, and nonlinear and are defined by

$$W_i = \frac{1}{j} \quad \text{constant}$$

$$W_i = \frac{2i}{j(j+1)} \quad \text{linear}$$

$$W_i = \frac{i^2}{j^2} \quad \text{nonlinear}$$

where j is the number of hours measured forward or backward from the start time and i varies from 1 to j.

Table 2 shows a comparison of RMSE for adjusted-MOS forecasts from different weighting functions compared with MOS forecasts and persistence forecasts for wind direction and wind speed at the 243-m height. The start times were 18 hours beyond base times of 0000 GMT and 1200 GMT. The adjusted-MOS forecasts were obtained by using i=3 hours for the determination of the average error (Equation 4 and weighting function W_i), and i=6 hours for the adjustment period (Equation 5 and weighting function G_i).

The adjusted-MOS forecast for wind speed (u) produced smaller RMSE than persistence forecasts for elapsed times of 5 hours. The adjusted-MOS forecasts of u produced RMSE smaller than the RMSE of MOS forecasts for all valid times. The lowest RMSE in adjusted-MOS forecasts resulted when nonlinear weighting functions were used for both the determination of average error and the adjustment period.

An adjusted-MOS forecast of direction produced smaller RMSE than the RMSE of MOS forecasts for elapsed times of three hours. However, none of the adjusted-MOS forecasts produced RMSE less than the RMSE of persistence by using an adjustment period of six hours. Experiments were conducted with different adjustment periods. It was found that for wind direction, an adjustment period of 12 hours made a significant improvement.

Since the nonlinear weighting function produced lowest RMSE values for 18-hour adjusted-MOS forecast, it was used for the remaining sensitivity studies. The final phase of the MOS validation studies was to compare RMSE of adjusted-MOS forecasts with both persistence and MOS forecasts for all release times. Table 3 presents persistence times determined from RMSE of persistence and adjusted-MOS forecasts. Note the adjusted-MOS persistence times are less than MOS persistence times shown in Table 1. The average adjusted-MOS persistence time for wind speed for all levels and base times is 2.0 hours. This represents a 50% reduction from the average MOS persistence time of 3.9 hours. The average adjusted-MOS persistence time for σ_θ and σ_ϕ is 1.3 hours, which is about 43% less than the average MOS persistence time of 2.2 hours. The average adjusted-MOS persistence time of 6.6 hours for direction with an adjustment period of six hours represents an improvement of 14% of the average MOS persistence time of 7.7 hours. The use of a 12-hour adjustment period produced an overall adjusted-MOS persistence time of 3.6 hours representing an improvement of nearly 53%.

Table 4 shows an example of the effectiveness of MOS forecasts by comparing RMSE values of adjusted-MOS forecasts and persistence forecasts with RMSE values of MOS forecasts for a height of 243 m. The RMSE values represent averages for all start times listed in Table 1 for both 0000 and 1200 GMT base times. The duration of the forecasts compared are 3, 6, 9, and 12 hours. An adjustment period of 12 hours was used for all predictands.

Table 2. Adjusted-MOS Forecasts — Start Time 18 Hours from Base Time

RMSE Wind Direction 243 m

Elapsed Time	Regular MOS	Persist-ence	W_i=Linear G_i=Linear	Nonlinear Nonlinear	Constant Constant	Linear Nonlinear	Nonlinear Linear	Constant Linear	Constant Nonlinear
0	42.56	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	43.06	11.42	55.84	26.51	42.65	49.54	64.57	53.85	55.01
2	42.65	19.12	52.86	45.77	44.45	65.07	59.96	51.28	60.55
3	46.19	21.54	51.52	63.70	44.58	57.75	57.27	50.32	55.48
4	45.27	22.64	48.91	54.29	48.07	49.73	52.57	48.17	48.84
5	43.81	31.94	44.02	43.96	50.18	43.02	46.12	43.80	42.76
6	39.82	33.75	39.82	39.82	39.82	39.82	39.82	39.82	39.82
7	45.73	34.74	39.82	39.82	45.73	39.82	39.82	45.73	39.82
8	40.24	38.18	39.82	39.82	40.24	39.82	39.82	40.24	39.82
9	43.88	40.57	39.82	39.82	43.88	39.82	39.82	43.88	39.82
10	43.16	39.16	39.82	39.82	43.16	39.82	39.82	43.16	39.82
11	47.61	49.64	39.82	39.82	47.61	39.82	39.82	47.61	39.82

RMSE Wind Speed 243 m

Elapsed Time	Regular MOS	Persist-ence	W_i=Linear G_i=Linear	Nonlinear Nonlinear	Constant Constant	Linear Nonlinear	Nonlinear Linear	Constant Linear	Constant Nonlinear
0	2.19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	2.05	1.25	1.73	1.47	1.62	1.30	1.51	1.91	1.39
2	2.27	1.85	2.06	1.89	2.12	2.04	1.94	2.16	1.87
3	2.34	2.19	2.21	2.07	2.46	2.18	2.13	2.27	2.36
4	2.43	2.44	2.35	2.28	2.59	2.34	2.30	2.38	2.38
5	2.53	3.03	2.51	2.50	2.84	2.50	2.48	2.52	2.52
6	2.90	3.55	2.90	2.90	2.90	2.90	2.90	2.90	2.90
7	3.14	3.96	2.90	2.90	2.90	2.90	2.90	2.90	2.90
8	3.36	4.75	2.90	2.90	2.90	2.90	2.90	2.90	2.90
9	3.67	5.40	2.90	2.90	2.90	2.90	2.90	2.90	2.90
10	3.58	5.71	2.90	2.90	2.90	2.90	2.90	2.90	2.90
11	3.35	5.79	2.90	2.90	2.90	2.90	2.90	2.90	2.90

Table 3. Persistence Times for 0000 and 1200 GMT Adjusted MOS Forecasts for all Predictands for the Period May-December 1979

Start Time (GMT)	Elapsed Time (hr)	Adjusted MOS Persistence Times for Base Time 0000 GMT										
		10 m			91 m			243 m				
		u	σ_θ	σ_ϕ	u	σ_θ	σ_ϕ	θ^*	θ	u	σ_θ	σ_ϕ
0900	9	5	1	5	2	2	1	5	5	5	1	4
1200	12	1	1	1	1	1	1	1	3	2	1	1
1500	15	1	1	1	1	1	1	5	11	1	1	1
1800	18	1	1	1	1	4	1	7	8	2	1	1
2000	21	1	1	1	1	1	1	2	8	1	1	1
0000	24	1	1	1	4	1	-		-	4	-	-
Avg Persistence Times		1.7	1.0	1.7	1.7	1.7	1.0	4.0	7.0	2.5	1.0	1.6

Start Time (GMT)	Elapsed Time (hr)	Adjusted MOS Persistence Times for Base Time 1200 GMT										
		10 m			91 m			243 m				
		u	σ_θ	σ_ϕ	u	σ_θ	σ_ϕ	θ^*	θ	u	σ_θ	σ_ϕ
2100	9	1	1	1	1	1	1	4	6	1	1	1
0000	12	1	2	1	5	1	1	1	4	3	1	1
0300	15	1	1	1	2	1	1	1	1	3	1	2
0600	18	1	2	1	1	1	1	2	11	6	1	1
0900	21	1	1	4	1	1	1	8	9	4	1	1
1200	24	1	1	1	1	2	1	-	6	2	1	1
Avg Persistence Times		1.0	1.3	1.5	1.8	1.2	1.0	3.2	6.2	3.2	1.0	1.2

* Denotes wind direction forecasts adjusted using 12-hour adjustment period.

Table 4. A Comparison of RMSE of Adjusted-MOS and Persistence Forecasts with MOS Forecasts at a Height of 243 m

(AM represents RMSE Adjusted-MOS/RMSE-MOS;
P represents RMSE Persistence/RMSE-MOS;
Both are expressed as a percentage)

Predictand	Hours from Base Time							
	3 hr		6 hr		9 hr		12 hr	
	AM(%)	P(%)	AM(%)	P(%)	AM(%)	P(%)	AM(%)	P(%)
Direction	66.1	61.5	93.2	90.9	97.6	114.2	99.9	136.0
Speed	67.7	74.1	89.1	129.9	96.8	171.2	99.9	182.2
σ_θ	96.0	127.4	95.9	157.6	97.9	161.4	99.9	159.3
σ_ϕ	69.8	85.2	83.7	131.2	92.7	125.1	99.7	90.7

For the three-hour forecasts, the adjusted-MOS forecasts provided about a 30% improvement over MOS forecasts of wind speed and direction. For wind turbulence, the adjusted-MOS forecasts provide about a 10% improvement. For six-hour forecasts, adjusted-MOS forecasts show about a 10% improvement over MOS forecasts for all predictands. For 9- and 12-hour forecasts adjusted-MOS forecasts are only slightly better then MOS forecasts. Persistence forecasts show RMSE values much larger than MOS forecast for all predictands and elapsed times except for three- and six-hour forecasts of direction. For these times, the persistence forecasts show a relative improvement in the MOS forecasts comparable to that archived by the adjusted-MOS forecasts.

CONCLUSIONS

A technique was developed and tested to use the 30-hour MOS forecasts of wind and turbulence issued twice daily into SRP's emergency response program. This study showed the technique for combining MOS forecasts, persistence, and an adjusted-MOS forecast (by using a non-linear weighting function) can be used to generate good forecasts at any time of day. Wind speed and turbulence forecasts have been shown to produce smaller RMSE than forecasts of persistence for time periods over about two hours. For wind direction the adjusted-MOS forecasts produce smaller RMSE than persistence for times greater than four hours. The adjusted-MOS forecast technique is fully implemented into the SRP emergency response program.

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