

TDL OFFICE NOTE 80-2

SURFACE WIND FORECASTING USING GENERALIZED
OPERATOR MODEL OUTPUT STATISTICS

Donald L. Best, Major, USAF

1. INTRODUCTION

This paper addresses the problem of forecasting wind speed and direction at the surface for any random location. The procedure used is an extension of the regionalized Model Output Statistics (MOS) equations concept used at TDL for most of its MOS products. The extension is termed as a generalized operator (G.O.) in the context that the entire conterminous United States (CONUS) is considered as one region. As such, the use of such an equation will be valid at any location within the CONUS--an essential and vital condition. This paper presents an experiment comparing the ability of a simple G.O. MOS equation's ability to forecast surface winds with a set of single station (S.S.) MOS equations used as the control or competitor. An enhancement of the G.O. through local unbiasing is also considered with encouraging results.

2. THE GENERALIZED OPERATOR MOS MODEL

The idea of a generalized operator equation is not new. Harris, et al. (1963, 1965) successfully demonstrated this concept as a diagnostic tool. They detailed a basic philosophy behind a statistical generalized operator and proceeded to illustrate their point by developing equations that would estimate ceiling, visibility, and total cloud amount as viewed by a surface observer given only basic upper air information. NWS/TDL has for many years used the G.O. approach for many MOS products by using a regional collection of station data to stabilize their forecast equations. Although not purely a "general" approach, these regional equations that were derived from civilian airports' meteorological data can be applied to other locations within the same region. The Air Weather Service (AWS) employs this capability to make twice-daily operational MOS forecasts of ceiling, visibility, cloud amount, probability of precipitation, etc., for U.S. Air Force and Army locations within the CONUS. Two MOS forecast elements not available for this special support, however, are surface temperature and wind. These two products are available only from single station equations and valid only at select civilian locations. Since the AWS needs these elements, a potential solution is to use the G.O. approach. Therefore, a G.O. MOS model for forecasting surface wind is specifically addressed in this paper and experiment.

Equations are developed from all available data within the realm of solution (e.g., the entire CONUS), pooled together as one large database. The data includes surface observations, LFM numerical model outputs, and location specific constants such as latitude, longitude, elevation, etc. From this one database the standard multiple linear stepwise regression solution provides the coefficients necessary to forecast wind speed (S), east-west wind component (u), and north-south wind component (v)--direction is computed by trigonometry from the u and v component forecasts. The data are unaltered; that is, means are not removed, standardized, normalized, or otherwise modified. TDL has a hardwired limitation in the screening regression software which limits the maximum

at around 10 to 12 predictors, this 20 predictor limitation is not considered too binding on the G.O. model. At least the G.O. model has an opportunity to pick several predictors that may be important to only a few stations throughout the country beyond the basic common ones such as the 850-mb and boundary layer wind.

Harris et al. (1963, 1965) found that the preferred choices in predictors were those with means removed (called anomaly variables) with a few raw predictors being picked up. No standardized predictors were selected. Since the TDL MOS system does not have the operational facility to remove means before entering regression, this experiment focuses first on the ability of only raw predictors to hold up in a G.O. approach and secondly to examine if a post removal of lack of fit from the forecasts could improve local verifications.

Therefore, the G.O. model in this experiment will have two configurations: unaltered and local unbiasing. The unaltered version refers simply to the G.O. model being applied at all locations without consideration of local effects. The local unbiasing version refers to an attempt to improve on the G.O. model's forecasts by considering the bias at each separate location. Using a local bias as a correction will be referred to as the equivalent single station (E.S.S.) model. The corrections used by the E.S.S. model are determined by solving the G.O. at each forecast location over the dependent sample and computing the difference between the local forecast and local observed means for S, u, and v. These corrections are then used to adjust the G.O. model's output simply by subtraction. For example, if the G.O. model makes a forecast S' and the local bias is $b = \bar{S}' - \bar{S}$, then the E.S.S. forecast would be $S'' = S' - b$.

3. EXPERIMENTAL DESIGN

Before the operational acceptance of a G.O. MOS equation set for surface wind forecasting is made, it must be established that this procedure makes useful and sufficiently accurate forecasts. Sufficiency can be in the eye of the beholder, of course, but here it will be defined more objectively in terms of error analysis. Specifically, the G.O. model will be judged adequate if its errors are no worse than one reportable value from forecasts made by the control model--the single station MOS equations. These limits are 1 kt and 10° for wind speed and direction, respectively

Twenty test sites were selected for the independent verification.

No.	Call		No.	Call	
	Letters	Name		Letters	Name
12842	TPA	Tampa, Fla.	23050	ABQ	Albuquerque, N. Mex.
12916	MSY	New Orleans, La.	23065	GLD	Goodland, Kans.
12921	SAT	San Antonio, Tex.	23154	ELY	Ely, Nev.
13874	ATL	Atlanta, Ga.	23188	SAN	San Diego, Calif.
13994	STL	St. Louis, Mo.	24021	LND	Lander, Wyo.
14733	BUF	Buffalo, N.Y.	24157	GEG	Spokane, Wash.
14740	BDL	Hartford, Conn.	24229	PDX	Portland, Oreg.

(1) Dependent sample: April-September seasons for 1973-75 (3 years).

(2) Independent sample: April-September seasons for 1976-77 (2 years).

Single station MOS equations valid at 18 hours were developed over the dependent sample for each of the 20 test sites. These equations are the control.

Generalized operator MOS equations valid at 18 hours were developed from a large sample of available CONUS surface reporting stations excluding the 20 test sites. The G.O. MOS equation set used 213 other stations over the dependent sample.

Verification statistics for wind speed are valid for all nonmissing verifying observations, but wind direction samples were deleted if either forecast or observed wind speed was less than 2 kts. Comparisons were made at each of the 20 test sites plus overall scores. Key measures were the differences in statistics and the percent improvement. The two variables examined were wind speed and wind direction--the u and v components were not verified explicitly. Wind speeds were inflated before verification. All conclusions were based on the independent verification sample of dates and locations given above.

4. EXPERIMENTAL RESULTS

Verification for each station is displayed on a series of figures (1 through 4). These figures illustrate not only how the G.O., E.S.S., and S.S. models performed at each test site, but also how they performed and compared spatially across the country. This suggests that some variations are due to location parameterizations for which the G.O. model may not be accounting.

Fig. 1 compares the mean absolute error (MAE)² differences between the S.S. and G.O. models for wind speed forecasts. Notice that in no case was the difference between the models greater than 1 kt. The line separating S.S. vs. G.O. model advantages is scalloped for ease of subjective interpretation but should not be completely believed to reflect such easily collectable areas of advantage. In other words, it appears that the S.S. model is superior along the Atlantic through Gulf coastal states, but there is no strict guarantee of this--just a hint.

Fig. 2 is similar to Fig. 1, but compares the S.S. and E.S.S. verifications. One station had a difference exceeding the 1 kt criterion (1.67 at Fresno, Calif.).

Figs. 3 and 4 provide spatial comparisons between the S.S. vs. G.O. and S.S. vs. E.S.S., respectively, for wind direction MAE's. A significant analysis here is the number of stations which favored the S.S. model by 10⁰ or more.

*Why
50 lines
dependent*

using bias adjustments on the G.O. model (i.e., the E.S.S. model), 15 locations still are better with the S.S. model, but now only 3 exceed the 10^0 criterion.

Table 1 compares MAE and root mean square error (RMSE)³ among the three forecast models. The G.O. produces a degradation to the forecasts on the average of only 0.2 kt MAE or 5.5% over the S.S. model. The E.S.S. model does not improve the MAE score, being on the average 0.3 kt or 10% degraded. RMSE percentages reflect the same relative conclusion. TDL's wind speed MOS forecasts are also judged on their ability to verify in fixed ranges, or categories, of speeds. As depicted in Table 2 the E.S.S. model gains a noticeable advantage over the G.O. model in terms of percent correct forecasts and Heidke skill score. Given that the possible range of improvement is defined by the difference of scores between the S.S. and the G.O. models, the E.S.S. accounts for 56% (.018/.032) of the potential improvement in percent correct and 85% (.039/.046) in skill score.

Table 3 compares the three MOS models for wind direction verification in terms of MAE and RMSE. Category verification is not made for wind direction. These statistics support the comments made about Figs. 3 and 4; that is, the E.S.S. model improves the G.O. model considerably and becomes very competitive and useful. The MAE, for example, is 45.0^0 for E.S.S. and 42.8^0 for S.S., a mere difference of 2.2^0 (much less than the 10^0 criterion). The E.S.S. is only 5% below the S.S. model's verification, but more importantly is nearly 9% better than the G.O. model.

5. REMARKS AND CONCLUSIONS

A. Generalized Operator Equation

Table 4 gives the G.O. equation. Notice that 75% of the 20 predictors are wind related terms, and at least one is a location constant (station longitude).

B. Special Notes

There are several interesting results and asides which deserve particular attention. First, in terms of wind speed forecasting, both the G.O. and the E.S.S. models did sufficiently well in comparison to the control S.S. model.

As a special set of variations on the theme, I tried to improve the E.S.S. by using local observed means and an estimated local correlation coefficient for the inflation procedure. The result of these attempts is that the global values of S and R are the correct values to use.

Figure 5 shows the CONUS-wide biases between the G.O. equation for wind speed and the local observed mean wind speed. Examination suggests that such a bias field is analyzable and interpretable, particularly in the smoother terrain areas of the country. This is an important feature for the E.S.S. model if it is to be applied to locations not originally in the development sample or for those locations that have no history upon which to base a climatology.

and v components before computing wind direction (a trigonometric solution) is borne out as a desirable feature.

C. Corroboration and Potential Improvements

There are also some very important details to point out with regard to constructing a G.O. model.

(1) Harris, et al. (1963, 1965) describe the predictand data to be standardized and normalized before entering regression against predictors which are either in their raw or anomalous form. Apparently, the variations of the elements about their local means have more predictive qualities than their raw measures. This G.O. MOS wind experiment did not have this feature available and, therefore, was not included. Pure, unadjusted values were used in regression. It was only with the E.S.S. model that any attempt was made to allow for local biases.

(2) The experiment in this paper attacked the problem of forecasting surface winds--a very locally influenced meteorological element. Lee (1975) regards surface winds to depend to a large degree on atmospheric stability and surface, or terrain, roughness. This experiment did not have any surface roughness constants available, nor did it consider any stability indices as potential predictors. This speaks of possible sources of improvement to already acceptable results. Anthes and Warner (1974) also deemed variations in topography as important forcing functions that modify mesoscale wind flow. Harris and MacMonegle (1965) in forecasting total cloud amount introduced local orographic and coastal effect terms into their generalized operator model, of which some were selected as predictors.

(3) Lange (1973) did some particularly pertinent work in the forecasting of surface winds. He used prediction errors from the previous dynamic model forecasts as feedback predictors. He also used orographic effects in the wind forecast models and found that short-range forecasts using purely statistical predictors such as persistence were useful. However, dynamic predictors become necessary for longer period forecasts. More importantly, Lange found that straight, unaltered computer produced forecasts from his regional equations were better than coastal single station forecasts in both wind direction and speed and competitive with the better results of the inland single station models. Since Lange had more apparent success than this experiment in "beating" the S.S. model, it is again encouraging that the lack of certain predictors such as orographic effects and error feedback is part of the G.O. model's shortfall. The objective of this experiment, mind you, was not to beat the S.S. model, but to attain an acceptable closeness that would make a simple G.O. or E.S.S. model have some operational utility. If it turned out to be superior, so much the better.

What then are some of the benefits of a G.O./E.S.S. MOS system? First, development of new equations could be greatly simplified and accelerated with fewer equations to solve and check. Second, the G.O./E.S.S. models would allow for the support of many more points than available to the S.S. solution. This is particularly important to current MOS support to the AWS and to future FAA support. Third, considerable mass storage savings could be gained over S.S. models. Typical savings for this one product alone, for example, is in the area of a 95% reduction (about 5 cylinders for IBM 360/195 disc space down to 5 tracks). Fourth, potential applications could escape the confines of a large computer complex. A regional computer system using smaller units could generate MOS wind forecasts upon demand if selected LFM values were made available. This can be particularly appealing to military applications in making point forecasts in a tactical, mobile environment where reliance on centralized production support can often be interrupted.

6. ACKNOWLEDGEMENTS

I want to express my deepest gratitude to Captain Charles French for bearing the brunt of work involved in cranking out all the trial G.O. and E.S.S. equations. Mr. Gary Carter deserves many thanks for helping design this test, picking the 20 test sites, and furnishing the control single station equations. Dr. Robert G. Miller provided the basic hope and direction to the G.O./E.S.S. concepts and appropriate understanding when problems arose. Thanks to Marge Brown of the Systems Development Office who typed this paper.

REFERENCES

- Anthes, F. A. and T. T. Warner, 1974: Prediction of mesoscale flows over complex terrain. R&D Tech. Report ECOM-5532, ASI US Army Electronics Command, 101 pp.
- Harris, R., J. G. Bryan, and J. E. MacMonegle, 1963: Terminal weather prediction studies. Tech. Note No. 3, Contract AF19(626)-16, System 433L, The Travelers Research Center, Inc., 103 pp.
- _____, 1965: Diagnosis of surface weather conditions from observed and prognostic upper-air parameters. ESD-TR-65-2, 433L Systems Program Office, AFSC/ESD (USAF), L. G. Hanscom Field, Bedford, Mass., 135 pp.
- _____, R. G. and J. E. MacMonegle, 1965: Terminal weather prediction techniques. ESD-TR-65-471, 433L Systems Program Office, AFSC/ESD (USAF), L. G. Hanscom Field, Bedford, Mass., 30 pp.
- Lange, A., 1973: Statistical surface wind prediction in Finland. Tech. Report No. 6, Finnish Meteorological Institute, Helsinki, Finland, 23 pp.
- Lee, R. J., 1975: Objective determination of surface winds in data sparse areas. TEC 823, Environment Canada-Atmospheric Environment Service, Downsview, Ontario, 18 pp.

for the three sets of forecasts: single station (S.S.), generalized operator (G.O.), and equivalent single station (E.S.S.).

STATION	MAE			RMSE		
	S.S.	G.O.	E.S.S.	S.S.	G.O.	E.S.S.
TPA 12842	2.12	2.87	2.40	2.74	3.56	3.15
MSY 12916	1.99	2.42	2.41	2.61	3.13	3.12
SAT 12921	2.43	2.62	2.50	3.07	3.34	3.23
ATL 13874	2.43	2.47	2.60	3.18	3.11	3.27
STL 13994	2.66	2.63	3.07	3.37	3.46	3.81
BUF 14733	3.07	3.17	3.15	3.97	4.04	4.00
BDL 14740	2.85	3.17	3.11	3.61	4.04	3.97
BTW 14742	2.83	3.35	3.12	3.59	4.31	4.05
GRB 14898	3.00	2.84	2.85	3.83	3.70	2.71
SUX 14943	2.99	2.91	3.13	3.81	3.75	3.98
ABQ 23050	3.34	3.32	3.30	4.82	4.99	5.02
CLD 23065	3.76	4.03	4.24	4.76	5.09	5.38
ELY 23154	4.31	4.17	4.03	5.41	5.51	5.24
SAN 23188	2.45	3.24	3.19	3.26	4.01	3.97
LND 24021	3.52	3.09	4.09	4.51	4.07	5.31
GEG 24157	2.93	2.94	2.64	3.63	3.79	3.46
PDX 24229	2.78	2.77	3.21	3.69	3.60	3.97
FAT 93193	1.98	2.41	3.65	2.63	3.30	4.39
BAL 93721	2.50	2.64	2.62	3.20	3.36	3.34
DTW 94847	3.08	3.00	3.25	3.92	3.84	4.18
Overall	2.84	3.00	3.13	3.74	3.95	4.08

computed from 5 category contingency tables. The 5 categories are <8, to <13, 13 to <18, 18 to <23, >23 kt.

STATION	Percent Corr.			Heidke Skill		
	S.S.	G.O.	E.S.S.	S.S.	G.O.	E.S.S.
TPA 12842	54.6	51.7	51.1	.202	.162	.179
MSY 12916	64.0	63.4	62.6	.327	.310	.297
SAT 12921	53.1	49.7	49.7	.223	.215	.217
ATL 13874	60.0	60.6	60.6	.276	.286	.264
STL 13994	59.7	55.4	54.0	.368	.324	.289
BUF 14733	48.0	47.1	45.7	.272	.248	.231
BDL 14740	50.0	47.1	47.1	.231	.215	.215
BTW 14742	54.6	46.0	48.3	.274	.193	.208
GRB 14898	49.1	52.0	50.3	.259	.300	.276
SUX 14943	47.7	49.7	45.1	.250	.279	.221
ABQ 23050	54.3	49.7	51.4	.207	.168	.169
CLD 23065	40.9	38.9	35.7	.196	.154	.121
ELY 23154	48.9	44.6	41.7	.233	.155	.141
SAN 23188	50.6	42.3	43.1	.092	-.021	-.007
LND 24021	70.3	53.7	76.9	.188	.164	.102
GEG 24157	51.1	52.0	56.3	.208	.226	.301
PDX 24229	62.0	54.9	66.6	.152	.100	.093
FAT 93193	69.4	62.6	73.4	.104	.138	.155
BAL 93721	53.1	51.1	51.4	.252	.231	.238
DTW 94847	45.1	48.9	46.6	.203	.260	.242
Overall	54.3	51.1	52.9	.293	.247	.286

depleted for any case where the forecast or observed wind speed was < 2 kt.

STATION	MAE			RMSE		
	S.S.	G.O.	F.S.S.	S.S.	G.O.	F.S.S.
TPA 12842	43.2	61.2	43.3	61.1	79.7	59.2
MSY 12916	44.0	55.3	47.3	60.1	72.6	64.4
SAT 12921	33.3	32.2	32.8	47.5	45.5	46.1
ATL 13874	44.1	41.6	39.9	60.3	55.9	54.7
STL 13994	35.0	35.6	35.8	49.7	49.6	49.7
BUF 14733	31.8	33.3	34.6	47.2	46.7	48.8
BDL 14740	40.1	40.1	39.6	55.7	56.2	55.1
BTV 14742	38.4	48.6	48.2	54.3	67.4	63.3
GRB 14898	36.9	37.3	37.2	53.9	54.0	53.9
SUX 14943	27.7	28.8	28.8	42.2	43.6	43.7
ABQ 23050	57.6	68.5	59.9	74.2	84.6	77.2
CLD 23065	40.0	43.6	43.9	58.2	61.4	60.9
ELY 23154	54.0	53.6	55.0	72.4	71.0	72.2
SAN 23188	38.6	50.6	43.3	47.9	64.7	53.6
LND 24021	73.2	99.0	84.4	88.3	113.2	98.7
GEG 24157	39.2	58.0	49.2	56.9	74.1	65.3
PDX 24229	56.6	71.1	66.8	74.7	88.3	84.7
FAT 93193	57.9	68.6	60.7	75.2	86.9	77.3
BAL 93721	38.1	36.8	36.8	53.0	53.3	53.3
DTW 94847	32.2	31.1	33.0	48.2	45.9	47.8
Overall 1	42.8	49.3	45.0	59.9	67.4	61.8

G.O. MOS equation to forecast CONUS surface winds at any location. Predictors 1 through 19 are all terms taken from NMC's LFM. Predictors are in the same order as the screening regression solution. Abbreviations used are East-West wind component (U), North-South wind component (V), boundary (BL), and relative humidity (RH). The predictors were either unsmoothed or passed through a five-point smoother as noted by the numbers in parentheses.

Projection Hour	Predictor Description	U-component	Coefficients V-component	Speed
0	Constant	-5.9429	2.3240	17.106
18	BL V (5)	-.048099	.33950	-.003
24	850-mb V (5)	-.17071	.23297	.267
24	BL U (5)	.26536	-.0051883	-.066
24	700-mb V (0)	.0090272	-.0070011	-.162
24	BL V (5)	.058289	.22539	-.091
18	850-mb Geostrophic V (0)	-.0013232	.028699	-.065
24	850-mb Geostrophic U (5)	.095835	.045361	-.310
18	BL U (5)	.32716	.21299	.022
12	850-mb U (0)	.29993	-.041197	-.043
12	850-mb Height (0)	.0015617	.0003457	-.007
12	850-mb Speed (0)	.023402	.033577	.134
24	700-mb Speed (5)	.026652	-.059801	-.098
24	500-mb Relative Vorticity (5)	.05696	.0064022	.096
18	850-mb Geostrophic Speed (0)	.019944	-.014572	.066
18	850-mb Speed (5)	.046210	-.065162	.227
24	850-mb Speed (5)	-.016567	.031666	.338
12	850-mb V (0)	-.023138	.25658	.108
18	RH, Top of BL to 720 mb (5)	-.0089797	-.026422	-.014
18	RH, BL 6-hour change (5)	-.0040505	-.0073639	.035
0	Station Longitude (0)	.028722	-.0053546	-.006
MEAN =		1.340	1.160	9.220
CORRELATION COEFFICIENT =		.668	.705	.556

SIZE = 90357

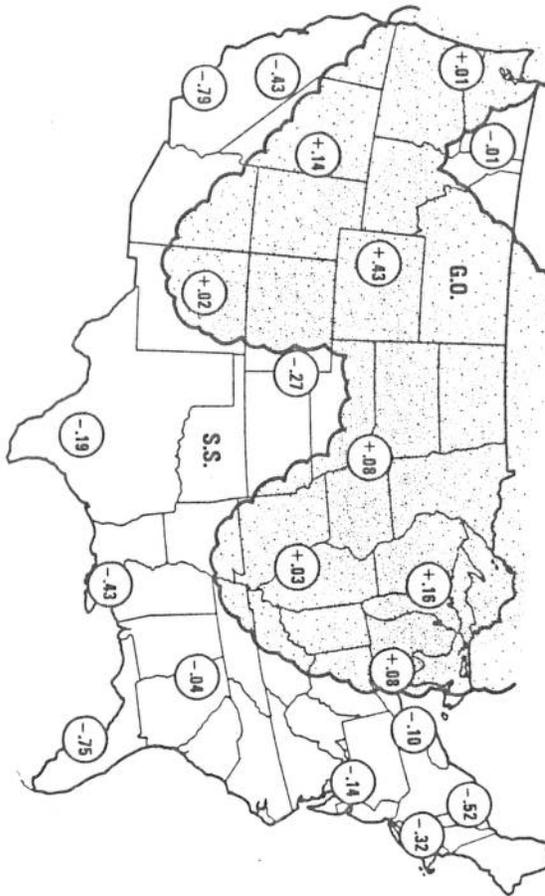


Figure 1. Speed comparisons of MAE between single station (S.S.) and generalized operator (G.O.) equations. Values are MAE of the S.S. minus MAE of the G.O. in units of knots.

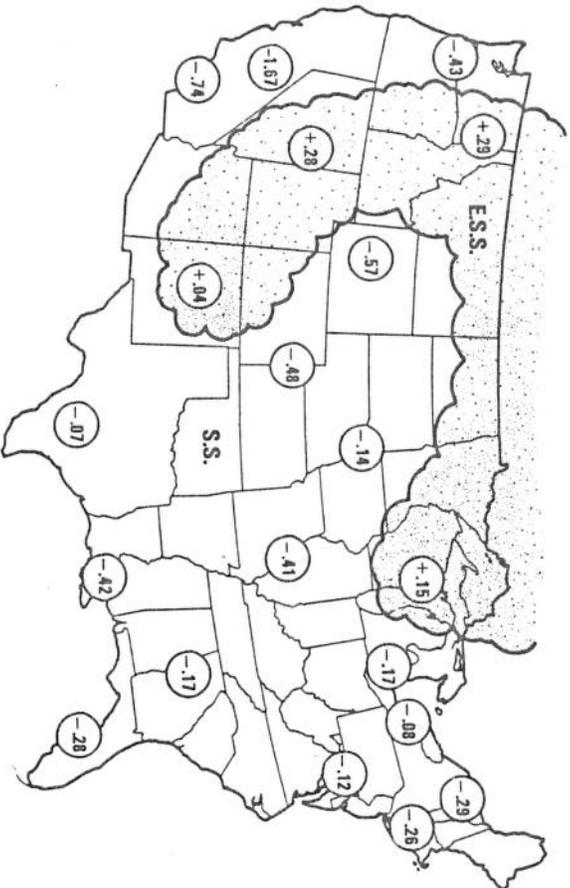


Figure 2. Speed comparisons of MAE between single station (S.S.) and ESS equations. Values are MAE of the S.S. minus MAE of the ESS in units of knots.

Figure 5. Analysis of wind speed biases for the generalized operator MOS equation over the dependent sample. Units are knots. Bias is the mean forecast wind speed minus the mean observed wind speed. Bias is computed at each location separately and contoured. Shaded area is negative bias. Clear area is positive bias.

