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WIND FORECASTS FOR THE CENTRAL UNITED STATES FROM THE LOCAL AFOS MOS PROGRAM

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1. INTRODUCTION

The Techniques Development Laboratory (TDL) has undertaken a project entitled the Local AFOS MOS Program (LAMP) (Glahn and Unger, 1986). LAMP is designed to provide updated Model Output Statistics (MOS) guidance for all stations in a Weather Service Forecast Office's (WSFO's) area of responsibility and to run locally at the WSFO on a minicomputer. LAMP will provide public and aviation forecast guidance for hourly projections out to about 20 hours.

The input to LAMP are the latest MOS guidance, the latest hourly observations, and output from three, simple numerical models. The three models used are a sea level pressure (SLP) model (Unger, 1982), a moisture model, based on the SLYH model (Younkin et al., 1965; Unger, 1985), and an advection model called CLAM (Grayson and Bermowitz, 1974). The models are driven by 500-mb height forecasts from the current NMC model (at this time, the LFM is being used) and objective analyses of the surface data (from the latest observations). The LAMP objective analyses are used for initialization and to provide predictors for MOS updates.

The development and testing of LAMP forecast equations for hourly wind direction and wind speed at 151 stations in the central United States are described in this paper. Each station had a regression equation developed for each of the forecast hours, starting with 1 hour and ending with 20 hours, with an initial time of 0800 GMT. The LAMP equations were verified against persistence and the performance of the equations compared to that of wind equations developed earlier for the Washington, D.C. WSFO (WBC) region (Glahn, 1984).

2. PREDICTANDS

The surface wind observation contained in the hourly report is for wind measured at a specific point and time at 10 meters above the ground and averaged over 1 minute. The forecast variables are obtained from these observations and are defined similarly.

The predictand data are for 151 stations located in and around the area to be used for the Modernization and Restructuring Demonstration. The data consist of the wind speed and the U- and V-components of the wind from observations for each hour from the initial time (0800 GMT) until the 20-h projection. The hourly data are from the hourly data archive of TDL which have been checked by an automated error checking process. Data frequencies from all the stations were then checked to ensure there were sufficient data to develop the equations for that station for each hour.

The data consist of five cool seasons (1 October-31 March) from October 1977, through March 1982. The first four cool seasons were used to develop the equations (1 October 1977-31 March 1981) and the fifth season (1 October 1981-31 March 1982) was used as independent data for verification.

3. PREDICTORS

The possible predictors for the wind equations come from four sources: (1) the hourly observations, (2) the MOS guidance forecasts, (3) output from the SLP model, and (4) the LAMP wind analyses. The possible predictors are listed in Table 1.

The possible predictors include the U- and V-wind components and wind speed from the surface hourly observation (0800 GMT) and also the same variables interpolated to the station from the objective analyses. The wind components are earth oriented, and all predictors can be used for every projection.

The MOS forecasts for the U- and V-components of the wind and the wind speed were offered as predictors. The MOS wind speed forecasts were inflated because that is the way they are received on station in normal operations. The MOS forecasts for the 67 non-MOS stations were interpolated from the 84 MOS station forecasts. The interpolation consisted of a simple weighted average of the MOS forecasts of surrounding stations, as indicated in Table 2. Also, the MOS forecasts are for every 6 hours, but LAMP requires forecasts for every hour. To obtain MOS forecasts for every hour, a linear time interpolation was performed for each station.

The SLP model supplied the 1000-mb geostrophic U- and V-wind components and wind speed as possible predictors for all 151 stations and for each projection.

4. EQUATION DEVELOPMENT

A forward stepwise regression procedure was used to develop all of the equations simultaneously. The procedure selects the predictor with highest reduction in variance (RV) for any of the stations, projections, and predictands (U- and V-components of the wind and wind speed) as the first predictor. The second (following) predictor selected has the largest RV combined with the first (all the preceding) predictor(s) for any combination of station, projection, and predictand. This process was continued until an additional RV of less than 0.005 was encountered or until a maximum of 20 predictors were selected. Developing single station equations simultaneously requires all the equations to use the same predictors (except that the MOS and SLP predictors are of the same projection as the projection of the predictand in a particular equation), thus ensuring there will be consistency in the forecasts while still accounting for some of the local effects that produce different local winds.

LAMP equations for wind were developed previously for the Washington D.C. area (Glahn, 1984). After numerous experiments for stations within the area of responsibility of the Washington area WSFO (WBC), it was found that only the 9 predictors shown in Table 3 were needed.

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[1] Inflation renders the variance of regression-produced estimates equal (on the development sample) to the observed variance. The formula

$$\hat{\hat{Y}} = \frac{\hat{Y} - \bar{Y}}{R} + \bar{Y}$$

is used, where $\hat{Y}$ is the regression estimate, $\bar{Y}$ the predictand mean, R the multiple correlation coefficient associated with the regression analysis, and $\hat{\hat{Y}}$ the inflated estimate (Glahn, 1984).

Experiments were run on two subsets of stations in the central U.S. to determine whether the nine predictors used for the Washington equations would be sufficient for that area. Each regression procedure was run with 50 stations and a maximum of 13 predictors possible in the equations. The stations in each group were somewhat evenly distributed over the area. The order of the predictor selection for the two runs was similar, except in one of the runs, the fourth and fifth predictors selected were not one of the nine used in the Washington area wind equations. The two predictors were the analyzed surface wind speed and V-component of the wind. Also, the last two predictors selected in each equation were the wind direction (observation) and the analyzed surface U-component; however, these two were eliminated because the additional RV for many individual equations was near zero percent.

Two equations were developed for all 151 stations, one with nine predictors and the other with 11 predictors. Both equations had the nine predictors used in the Washington area wind equations, but the 11-term equations also had the analyzed surface wind speed and V-component. The forecast quality was virtually the same for both equations, even on dependent data, as measured by the Mean Absolute Error (MAE) of the wind direction and speed. Thus, the nine term equation was used as the final equation. The two extra predictors, analyzed surface V-component and wind speed, are highly correlated with the observed V-component and wind speed which could lead to problems due to overfitting in some equations. The RV's of the nine term equations are shown in Table 3. These equations were used to produce forecasts for which the verification is shown below.

5. RESULTS AND EVALUATION

Wind forecasts are issued in the form of a wind direction and a wind speed; therefore, even though equations were developed for U- and V-components instead of wind direction, verification was done in terms of direction and speed. The wind speed forecasts were inflated before they were verified. Inflation draws the forecast away from the mean to the more important forecasts of stronger wind speeds. This causes the root mean squared error (RMSE) to increase, but studies have shown that the bias by category will improve, and the Heidke skill score (NWS, 1982) will remain about the same (Carter, et al., 1983).

The LAMP forecasts (referred to as LAMP) were compared to persistence (referred to as PERSIST) on independent data. The relative frequency (RF) of wind direction errors and the MAE were used to verify the wind direction. To verify the wind speed, the MAE and the Heidke skill score were used.

Wind Direction

Figure 1 shows the MAE for wind direction when the verifying observation of wind speed was $\geq$ 10 kts. The MAE of persistence is initially close to the MAE for LAMP but increases much more rapidly with time. There were about 5,500 cases in the morning and evening hours and up to about 10,000 cases in the afternoon hours due to more frequent wind speeds at 10 kts or above at that time. When all the forecasts were used, including those with wind speeds less than 10 kts, the scores were about 5° worse for all projections, since light wind speeds are generally accompanied by highly variable wind directions (results not shown).

Shown in Figs. 2 and 3 are the RF of wind direction within 30° and 10° of the verifying observation, respectively, with the verifying wind speed $\geq$ 10 kts. Fig. 2 shows that the RF for LAMP gradually falls until about the 10-h projection when it begins to level off at around 85 percent, while persistence falls to about 40 percent. Fig. 3 shows that the RF for LAMP being within 10° of the observation starts at about 81 percent and falls until the 20-h projection at which time the forecasts are within the interval just over half of the time. Persistence is within 10° of the verifying observation only about one-fifth of the time at the same projection. The results were computed with about 5,000 to 9,000 cases for each projection; the number of cases increased in the afternoon because the wind speeds are above 10 kts more frequently.

Wind Speed

Figure 4 shows the MAE for the wind speed forecasts. The MAE for LAMP is about the same as that for persistence at 1 hour but increases much more slowly with time. At about the 14-h projection (1600 CST), the MAE begins to improve for both LAMP and persistence, due to the normal diurnal decrease in the wind speeds from the afternoon maximum. The sample size for each projection is about 18,000 cases.

The Heidke skill scores are shown in Fig. 5. The skill score for LAMP is slightly better than that for persistence at the 1-h projection. The skill score for LAMP decreases slower than that for persistence with time. The skill scores were computed from the following categories: < 8, 8-12, 13-17, 18-22, 23-27, 28-32, and > 32 kts. There were about 18,000 cases used in the skill score results for each projection.

LAMP forecasts for wind at the 21 mountain stations, (all west of Denver, Colorado), are generally worse than the forecasts for the non-mountain stations. The MAE for wind speed in the mountains is about a half knot worse for all projections than for non-mountain stations, which can account for a lowering of a tenth of a knot in the overall scores when both regions are combined. The MAE for direction for the mountain stations is twice that of the MAE for non-mountain stations. Forecasts for wind direction in the mountains have a MAE of about 10° more than those from the non-mountain stations for all projections.

Heidke skill scores for wind speed and RF's of direction errors were used to compare the results from the central U.S. with those from the WBC area (Glahn, 1984). The comparisons are shown in Figs. 6 and 7. The Heidke skill scores in Fig. 6 show the results for the central U.S. to be slightly worse than those for WBC area for all projections. Note that the sample size for the WBC area is much smaller than that for the central U.S., and the mountain stations in the central U.S. will lower the scores for that area slightly. In view of this, the difference in the skill of the LAMP forecasts between the areas is very small. Fig. 7 shows a similar comparison for the RF of wind direction. Figs. 6 and 7 show that for wind direction and speed the LAMP equations have about the same accuracy for both areas.

6. SUMMARY AND CONCLUSIONS

The LAMP equations for wind speed and direction were developed and tested for 151 stations in the central U.S. The equations were developed from four cool seasons of data and tested on independent data for a single season.

The final predictors used were the three MOS forecasts (U- and V-components and inflated wind speed), the three observations (U- and V-components and wind speed) and the three 1000-mb geostrophic wind predictors (U- and V-components and wind speed). The observation predictors were the strongest in the first few hours, the SLP model predictors were strong in the middle projections, and the MOS predictors were strongest in the final projections.

Finally, the nine predictors used for the WBC region seem to be the best predictors for the central U.S. area in forecasting the wind. Adding more terms to the equations resulted in little or no significant improvement to the forecasts. The results for the central U.S. were very similar to those for the Washington area.

Final equations that can be used operationally were developed for all stations with all five seasons of data. These equations were similar to the developmental equations and their performance in terms of forecasts accuracy was essentially the same.

7. ACKNOWLEDGMENTS

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Table 1. Possible predictors for the wind prediction equations.

Predictor	Source
U-component of wind	MOS
V-component of wind	MOS
Wind speed	MOS
U-component of wind	Hourly Observation
V-component of wind	Hourly Observation
Wind speed	Hourly Observation
Wind direction	Hourly Observation
1000-mb Geostophic U	SLP
1000-mb Geostrophic V	SLP
1000-mb Geostrophic wind speed	SLP
Surface U (earth oriented)	Objective analyses
Surface V (earth oriented)	Objective analyses
Surface wind speed (earth oriented)	Objective analyses

Table 2. List of Non-MOS stations with the weighting formulation used for the determination of MOS forecasts. For example, ADM=(OKC+DFW+MLC)/3 and AKO=(2*DEN+GLD+LBF)/4.

Non-MOS Station	Weighting Formulation
ADM	OKC, DFW, MLC
AKO	DEN(2), GLD, LBF
ATY	HON, ABR
AUW	EAU, GRB, LSE
BAD	SHV
CAG	GJT, RKS
CAO	PUB, TCC, AMA
CDR	RAP, BFF(3), VTN(2)
CDS	AMA, HBR, LBB
CGI	EVV, STL, JBR
CHB	HON, PIR, VTN
CID	ALO, DSM, BRL
CNM	ELP, MAF, ROW
CNU	TOP, ICT, TUL, SGF
COD	BIL, LND, SHR
CVS	TCC
DAL	DFW
DHT	TCC, AMA, GAG
DUG	TUS, ELP, DMN
DYS	ABI
EGE	GJT(2), DEN
ELD	LIT, SHV(2), TXK(2)
EMP	TOP, ICT
END	OKC, ICT, GAG, TUL
E74	TUS, DMN
FOD	MCW, SUX, DSM, ALO
FOE	DDC, GLD
FRI	CNK, TOP
FSI	OKC, HBR
FTW	DFW
FYV	FSM, SGF, TUL
GCC	SHR
GCK	DDC
GDP	ELP, MAF, ROW
FFF	SHV, DFW, LFK, TXK
HRO	SGF, FSM, LIT
IAB	ICT
INK	ELP, MAF(3)
JLN	SGF, TUL
LAR	CYS(2), CPR
LHX	PUB(2), DDC
LTS	OKC(2), LBB, HBR
MCK	LBF, GLD
MKC	MCI
MLU	SHV, JAN, AEX
OFF	OMA
OTM	DSM, BRL

Table 2. Cont'd

Non-MOS station	Weighting formulation
PNC	ICT, OKC, TUL, GAG
P02	STL, LIT, JBR(2)
P28	DDC, RSL
P35	COU, DSM, MCI, OMA
P70	ABQ, TCC(2), ROW
RCA	RAP
REE	LBB
RWF	FSD, MSP
RWL	RKS,CPR
SLN	RSL, CNK, ICT
SNY	BFF(3), GLD, LBF
SZL	MCI, COU
TAD	PUB(3), TCC, ALS
TCS	DMN, HMN
TIK	OKC
TYR	DFW, LFK, SHV
UIN	BRL, SPI, COU
VIH	SGF, COU,STL
WRL	LND, SHR
1K5	DDC

Table 3. Predictors, each with its source, used in the Washington, D.C. area wind equations. Also shown is the maximum RV associated with each predictor, forced into the central U.S. equations in the order indicated, for some station, projection, and predictand.

Predictor	Source	RV
U-component of wind	MOS	0.825
V-component of wind	MOS	0.820
Wind speed	MOS	0.615
1000-mb geostrophic U-component	SLP	0.239
1000-mb geostrophic V-component	SLP	0.370
1000-mb geostrophic wind speed	SLP	0.348
U-component of wind	Hourly Observation	0.364
V-component of wind	Hourly Observation	0.358
Wind speed	Hourly Observation	0.433

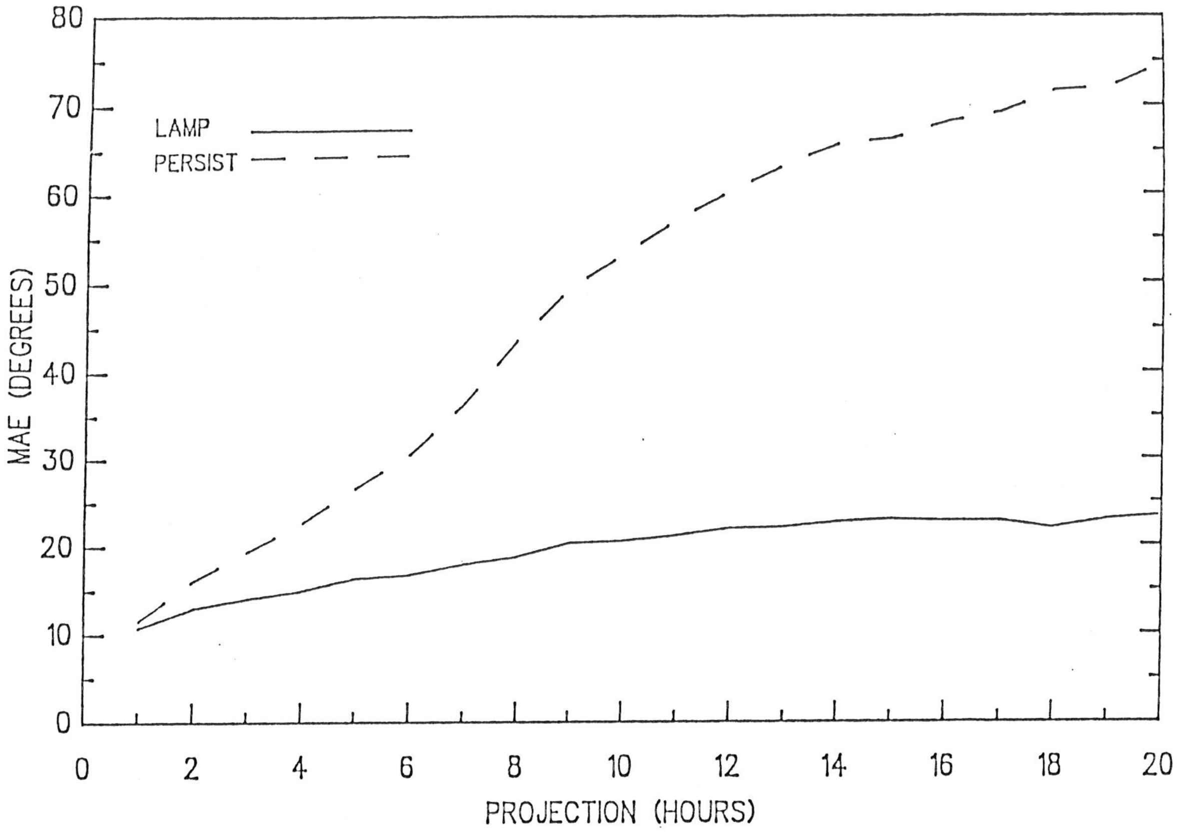

Figure 1. Mean Absolute Error (MAE) for LAMP and Persistence (PERSIST) forecast of wind direction from cases where the verifing wind speed was $\geq$ 10 kts.

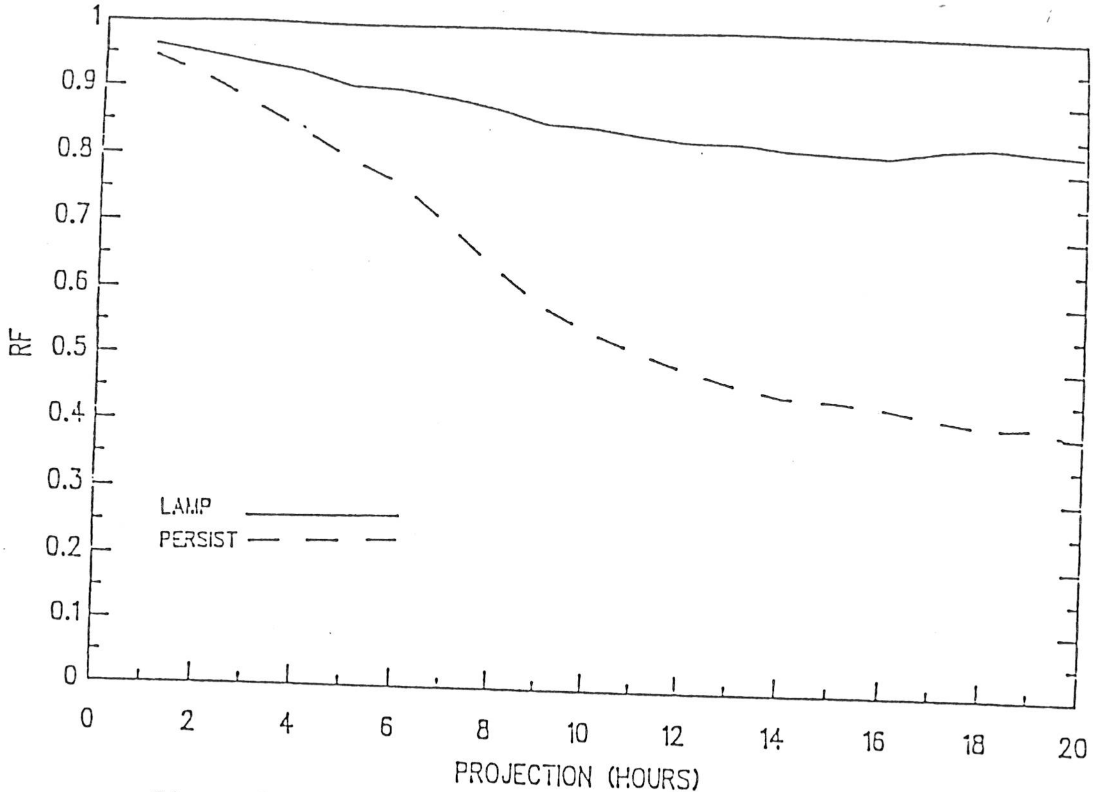

Figure 2. Relative Frequency (RF) of wind direction for LAMP and Persistence (PERSIST) forecast being within 30° of the verifing observation. Only cases with the verifing wind speed ≥ to 10 kts were used.

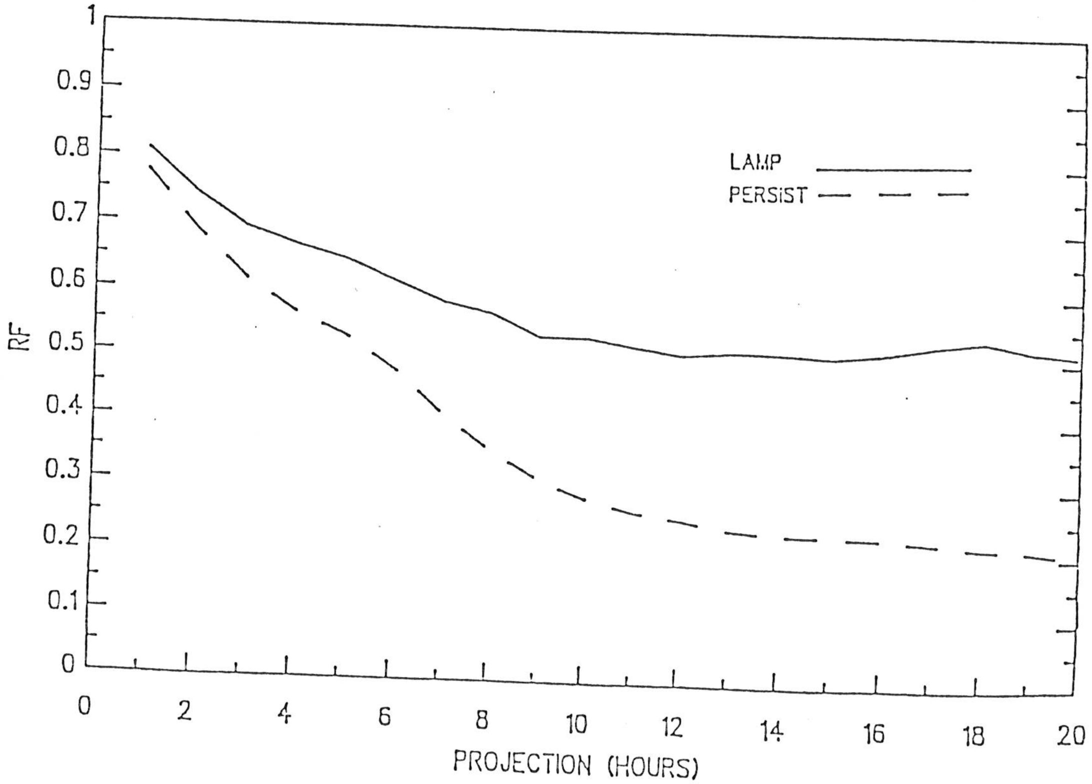

Figure 3. Same as Figure 2. except for forecast that are within 10° of the verifing observation.

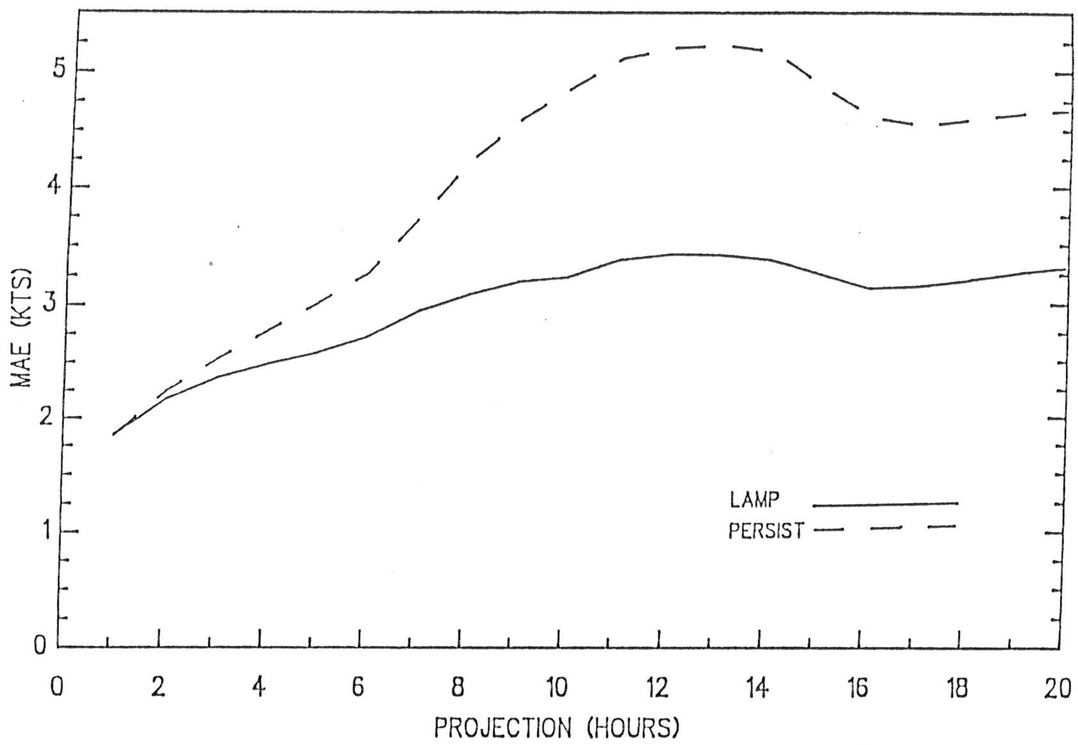

Figure 4. Mean Absolute Error (MAE) for wind speed forecasts from LAMP and Persistence (PERSIST).

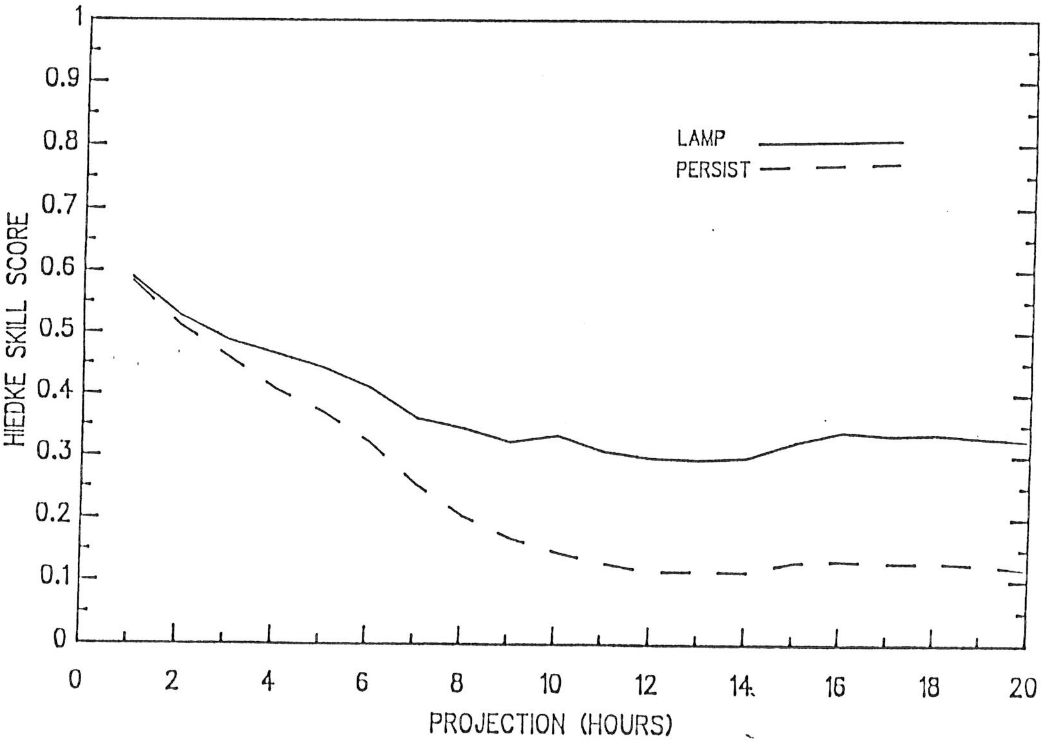

Figure 5. Hiedke skill score for LAMP and Persistence (PERSIST) forecasts for wind speed.

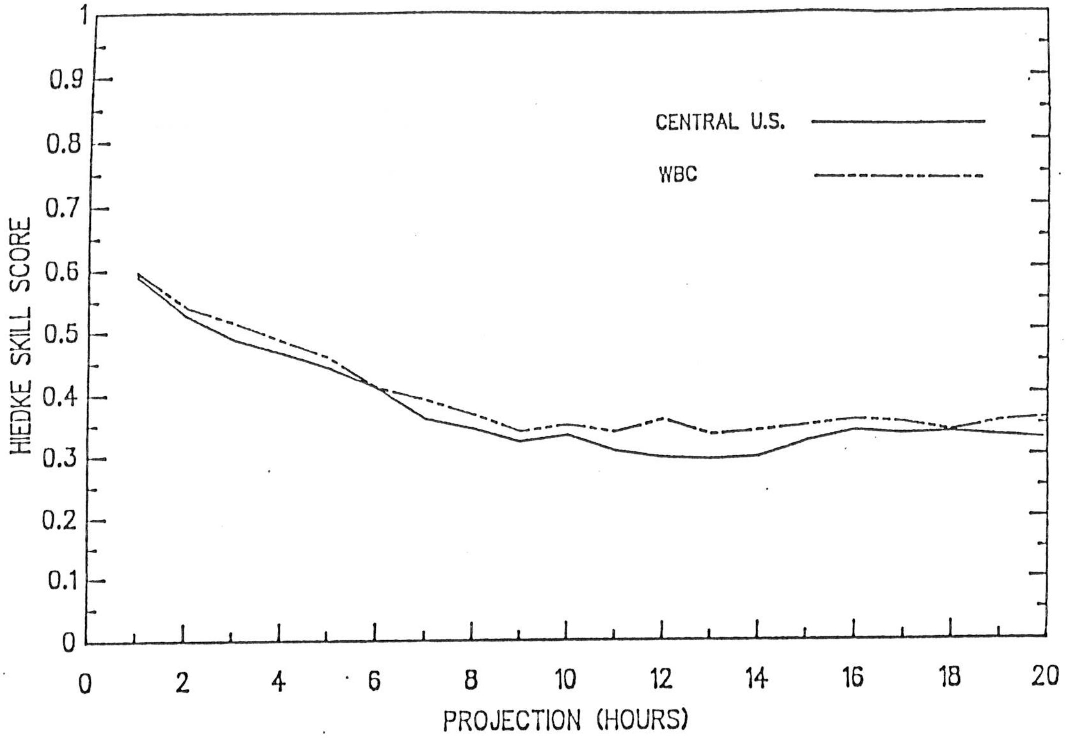

Figure 6. Hiedke skill score for LAMP wind speed forecasts for the central U.S. and the WBC areas. Both are for a 0800 GMT start times and for the cool season.

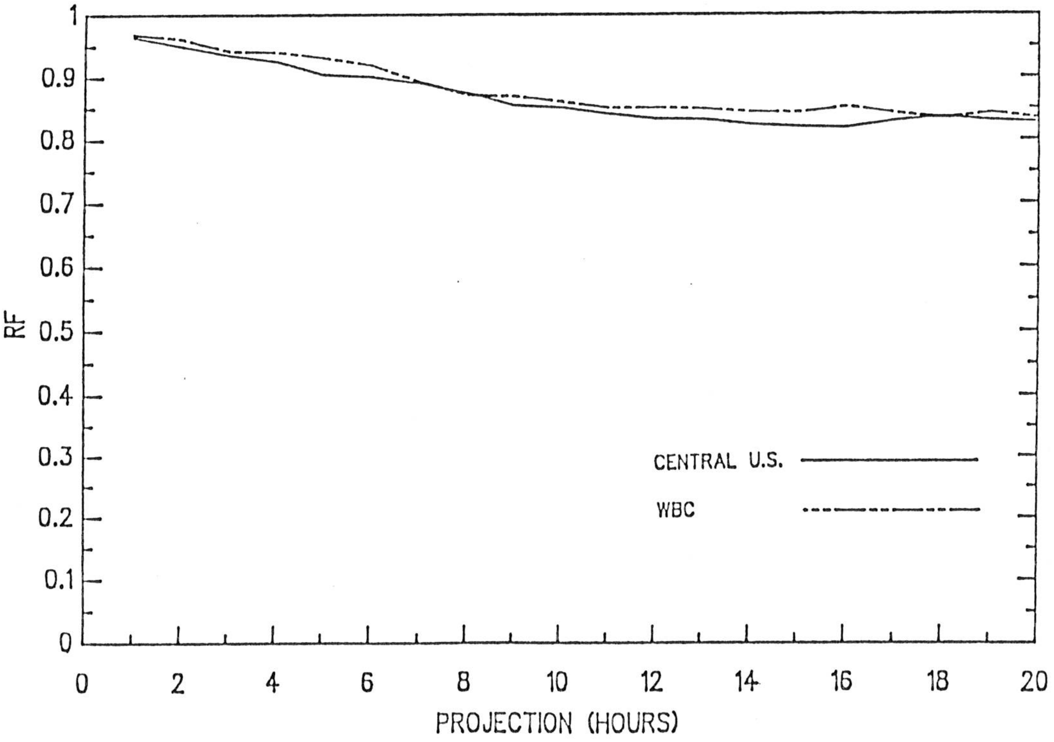

Figure 7. Same as Fig. 6 except for relative frequency for wind direction within 30° when the verifing wind speed was ≥ 10 kts.