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EXPERIMENTAL FORECASTS OF CONVECTIVE GUST POTENTIAL--PHASE II

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1. INTRODUCTION

During the summers of 1977 and 1978, the Techniques Development Laboratory (TDL) produced convective gust potential (CGP) guidance for 10 stations in the Western Region of the National Weather Service (NWS). The CGP forecast system (Carter and Grayson, 1977) used a combination of classical statistical techniques and Model Output Statistics (MOS) to obtain probabilistic forecasts of thunderstorm-induced surface wind gusts of 25 knots or more. Two types of forecasts were disseminated for each station; one was a standard probability estimate based solely on numerical model output, while the other was "interactive" in the sense that it required the field forecaster to input variables from local upper-air and surface observations to complete the forecast. The guidance was issued during the 1200 GMT forecast cycle and was valid for an 8-h period centered at 0000 GMT. Thus, the forecast projection was approximately 12 hours.

Grayson et al. (1978) verified the CGP guidance for three stations in Nevada for the summer of 1977. The results showed that the automated forecasts generally were better than those produced by a procedure based on the observed K index (Hambidge, 1967).

Recently, the operational CGP forecast system was expanded to include seven additional NWS stations (two more in the Western Region, two in the Southern Region, and three in the Central Region). For the 1200 GMT cycle, the prediction equations for the original stations were rederived to include 2 more seasons of developmental data (May through September of 1977 and 1978). In addition, we developed equations to provide CGP guidance from 0000 GMT cycle model output for a projection of approximately 24 hours. For more details about the new system, see Technical Procedures Bulletin No. 264 (National Weather Service, 1979).

Before deriving the new prediction equations, we conducted a series of tests involving the original equations and several types of experimental equations. The tests consisted of two parts. First, we developed and tested six different sets of CGP forecasts for the original 10 stations. Next, using a larger developmental sample, we rederived three of these sets of equations for both the 10 original stations and the seven new ones. As before, forecasts were produced from and verified on independent data. In conjunction with the second series of tests, we investigated the feasibility of developing equations to predict gusts of 30 knots or greater.

The overall verifications indicate that the automated CGP forecasts were skillful. Specifically, the various types of MOS predictions for gusts in excess of 25 knots generally were better than similar forecasts based on either the observed K index or climatology. To a lesser extent, the MOS forecasts of gusts over 30 knots also were better than climatic forecasts.

2. APPROACH

Most of the CGP prediction equations were derived using the MOS technique (Glahn and Lowry, 1972). This technique consists of relating an observed weather element (predictand) to forecast output from one or more numerical models (predictor data). In this particular application, the predictand was the occurrence (within ± 4 hours of 0000 GMT) of a surface wind gust of 25 knots or greater in conjunction with some indication of atmospheric instability, such as a report of a thunderstorm, virga, or towering cumulus at, or in the vicinity of, the test station. Generally, the gusts were associated with "high-level" thunderstorms similar to those described by MacDonald (1976). Gusts produced by frontal passages or strong, synoptic scale pressure gradients were not included in the predictand data sample. Four basic sets of predictor data were available for the development of multiple linear regression equations. These included: (a) 0000 GMT and 1200 GMT cycle forecasts from the Limited-area Fine Mesh (LFM) model (Gerrity, 1977), (b) observed and computed variables from 1200 GMT radiosonde reports, (c) weather elements from 0300 GMT and 1500 GMT surface observations, and (d) climatic variables such as the sine and cosine of the day of the year.

We developed and tested six types of prediction equations. Each equation was comprised of variables from one or more of the basic predictor data sets. The equation types and corresponding sources of predictor data are shown below:

(1) MOS-OBS equations based on 0000 GMT cycle LFM forecasts, 0300 GMT surface weather elements, and the climatic variables;

(2) MOS-PROB1 equations based solely on 1200 GMT cycle LFM forecasts;

(3) MOS-PROB equations based on 1200 GMT cycle LFM forecasts and the climatic variables;

(4) MOS-RS-OBS equations based on 1200 GMT cycle LFM forecasts, 1200 GMT radiosonde variables, and 1500 GMT surface weather elements;

(5) RS-K equations based solely on the value of the K index (George, 1960) computed from the 1200 GMT radiosonde;

(6) CLIMAT equations based solely on the climatic variables.

These six types of equations, the sources of their predictor data, and the corresponding forecast projections are depicted in Fig. 1. The length of the forecast projection for the 0000 GMT cycle is approximately 24 hours; for the 1200 GMT cycle, it is approximately 12 hours.

In the first series of experiments, we developed separate sets of MOS-OBS, MOS-PROB, RS-K, and CLIMAT equations for each of the 10 original CGP forecast stations shown in Table 1 by using data from May through September of 1973-76. The MOS-PROB1 and MOS-RS-OBS equations, which were used operationally during the summers of 1977 and 1978, had been derived from the same period of record. All six sets of equations were tested by generating forecasts on independent data from May through September of 1977 and May through July of 1978.

Next, using data from May through September of 1973-77, we derived MOS-OBS, MOS-PROB, and CLIMAT equations for both the original stations and the seven new ones shown in Table 1. Test forecasts for the period of May through September of 1978 were then verified. As a control, we also generated a forecast based on persistence. Specifically, the persistence forecast for a particular station was set equal to 100% if a gust of 25 knots or more had occurred the previous afternoon; otherwise, it was set equal to zero.

In conjunction with the second set of tests, we also derived another set of MOS-PROB and CLIMAT equations for each of the 17 stations. For this experiment, the predictand consisted entirely of gusts of 30 knots or greater. As before, equations were developed on 1973-77 data and forecasts were produced for the period of May through September of 1978. We conducted this final test to determine if the automated guidance could accurately forecast the stronger, more operationally significant gusts.

Two measures, the Brier score and the reliability, were used to evaluate the accuracy of the various types of CGP forecasts. The Brier score that was used here is one half of the score defined by Brier (1950). The reliability is simply a comparison of forecast probability frequencies and corresponding observed frequencies for intervals of 10%.

3. RESULTS

Table 2 shows, for each of the original 10 stations, the Brier scores associated with the six different types of CGP forecasts that were evaluated in our first series of tests. Please note that the RS-K forecast was not available for Ely, Nevada because Ely is located above the 850-mb level. For the other 9 stations, we computed the K index from the station's radiosonde or from an upper-air report at a nearby location (National Weather Service, 1979). Overall, the results in Table 2 indicate that the MOS-PROB1, MOS-PROB, and MOS-RS-OBS forecasts were about 10% more accurate than those produced by either the CLIMAT or RS-K equations; the corresponding improvement for the longer-projection MOS-OBS equations was approximately 7%. There was very little difference in the average scores for the MOS-PROB1, MOS-PROB, and MOS-RS-OBS forecasts.

The Brier scores in Table 2 also show that the accuracy of the various types of equations differed greatly on a station-by-station basis. In particular, the MOS-PROB1 and MOS-PROB forecasts were substantially better than both the RS-K and CLIMAT predictions for several stations in the northern and central sections of the Western Region. However, for the two stations in Arizona (Phoenix and Tucson), the CLIMAT and RS-K forecasts were slightly more accurate than those produced by all four of the MOS-based systems. These differences may reflect the LFM model's inability to accurately forecast the low-level surges of moisture that often contribute to the development of thunderstorms in southern Arizona (Hales, 1974). Additionally, even though the CGP predictand was comprised primarily of surface wind gusts induced by high-level thunderstorms, we were unable to fully discriminate between the moisture sources for each storm. Hence, the developmental samples for the stations in southern Arizona probably contained a mixture of gusts produced by both types of thunderstorms.

Reliability diagrams for the MOS-OBS, MOS-PROB1, MOS-PROB, and MOS-RS-OBS predictions are given in Fig. 2. Each of these diagrams is a composite of the forecasts and observations for all 10 stations involved in the first series of tests. Similar diagrams are not presented for the RS-K and CLIMAT equations because those two equation types did not produce any probabilistic forecasts higher than 40% and 30%, respectively. In general, the results in Fig. 2 indicate that the MOS-PROB and MOS-RS-OBS forecasts were the most reliable over the entire range of probabilities (i.e., the predicted frequencies were somewhat closer to the observed frequencies). However, all four types of MOS equations exhibited a tendency to overforecast; this was the most noticeable for probabilities higher than 50%.

Table 3 shows the Brier scores for the second set of tests involving all 17 stations and four types of CGP forecasts (MOS-OBS, MOS-PROB, CLIMAT, and PERSISTENCE). Here, we see that the MOS-PROB forecasts were the most accurate overall with almost a 15% improvement over CLIMAT; the longer-range MOS-OBS forecasts were approximately 8% more accurate than CLIMAT. The MOS-OBS, MOS-PROB, and CLIMAT forecasts were significantly more accurate than the forecasts based on persistence.

As is the case with the previous tests, the scores in Table 3 differ greatly on a station-by-station basis. For all stations, the MOS-PROB forecasts were more accurate than those produced by the CLIMAT equations. Unlike the first tests, the MOS-PROB forecasts were slightly more accurate than the CLIMAT predictions for Phoenix and Tucson. This may be the result of the additional season of data that was included in the development of the second set of test equations. Also, different synoptic scale weather patterns during the summers of 1977 and 1978 may have influenced the results.

Reliability diagrams for the MOS-OBS and MOS-PROB forecasts for all 17 stations combined are given in Fig. 3. These results show that, except for the predictions of 90%, both types of forecasts were very reliable during the test period (May through September of 1978). For this sample, the CLIMAT equations did not produce any forecasts higher than 50%.

Table 4 shows the MOS-PROB and CLIMAT Brier scores for the final test involving gusts of 30 knots or more. The results indicate that the MOS-based estimates were approximately 10% better overall than the climatic forecasts. However, these findings must be viewed with some caution because of the small size of the test sample. Compared to the previous test, the total number of gusts dropped by about 42%. As a result, some of the Brier scores for individual stations were extremely small. The corresponding reliability diagrams in Fig. 4 show that the MOS-PROB forecasts were reliable, but values over 50% were seldom predicted. The corresponding forecasts for CLIMAT never exceeded 40%.

4. CONCLUSIONS

The first set of tests revealed that there is little difference in the average Brier scores for the various types of MOS forecasts based on 1200 GMT cycle data. In particular, the MOS-PROB1, MOS-PROB, and MOS-RS-OBS forecasts are more accurate than those produced by the RS-K and CLIMAT equations. The corresponding reliability diagrams indicate that the MOS-PROB and MOS-RS-OBS forecasts are slightly more reliable than those produced by the other sets of MOS equations. The average Brier scores for the 0000 GMT MOS-OBS forecasts also are better than those for the RS-K and CLIMAT forecasts, but to a lesser extent than the 1200 GMT cycle predictions. The second series of tests for a large number of stations produced similar results. Adding another season of data to the developmental sample appears to improve many of the MOS predictions.

The verification results for forecasting gusts in excess of 30 knots also are encouraging; the MOS-PROB forecasts are better than the CLIMAT predictions. However, we feel that more developmental data should be collected before a threshold value of 30 knots is used to derive the operational CGP prediction equations.

Of course, these conclusions do not apply uniformly for each station involved in the tests. The accuracy of the MOS forecasts is particularly impressive for locations such as Salt Lake City and Pocatello where high-level thunderstorms are common (MacDonald, 1976). The MOS forecasts do not perform as well as for stations like Tucson and Phoenix where low-level surges of moisture contribute to the development of thunderstorms; however, increasing the developmental data sample of the MOS prediction equations seems to produce better forecasts for these locations.

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Table 1. Stations used to test various types of CGP prediction equations.

Original Stations	New Stations
Great Falls, Montana	Casper, Wyoming
Billings, Montana	Cheyenne, Wyoming
Salt Lake City, Utah	Denver, Colorado
Pocatello, Idaho	Winnemucca, Nevada
Boise, Idaho	Winslow, Arizona
Reno, Nevada	Albuquerque, New Mexico
Ely, Nevada	Amarillo, Texas
Las Vegas, Nevada	
Phoenix, Arizona	
Tucson, Arizona	

Table 2. Brier scores for the six different types of CGP forecasts at 10 stations on independent data from May through September of 1977 and May through July of 1978. See Section 2 of the text for an explanation of the MOS-OBS, MOS-PROB1, MOS-PROB, MOS-RS-OBS, RS-K, and CLIMAT prediction equations. The * denotes the best (lowest) Brier score among the six forecasts. The scores for Ely, Nevada were not used in computing the nine-station averages. A value of 25 knots was used to determine if a gust occurred.

Station	MOS-OBS	MOS-PROB1	MOS-PROB	MOS-RS-OBS	RS-K	CLIMAT	Number of Gusts
Great Falls	0.150	0.140	0.133*	0.147	0.172	0.168	51
Billings	0.171	0.162	0.159	0.154*	0.185	0.188	60
Salt Lake City	0.175	0.156*	0.156*	0.160	0.192	0.199	61
Pocatello	0.164	0.154*	0.154*	0.160	0.198	0.205	63
Boise	0.121	0.108*	0.112	0.109	0.118	0.114	31
Reno	0.110*	0.118	0.110*	0.124	0.114	0.117	30
Ely	0.174*	0.176	0.176	0.174*	---	0.209	69
Las Vegas	0.117	0.114*	0.114*	0.119	0.121	0.127	38
Phoenix	0.115	0.115	0.115	0.110	0.108*	0.108*	31
Tucson	0.147	0.144	0.152	0.137	0.117*	0.121	36
10 Stn. Avg.	0.144	0.139	0.138*	0.139	---	0.155	Total
Imp. over CLIMAT	7.1%	10.3%	11.0%	10.3%	---	---	470
(9 Stn. Avg.)	(0.141)	(0.134)*	(0.134)*	(0.135)	(0.147)	(0.150)	

Table 3. Same as Table 2 except for four types of CGP forecasts, 17 stations, and independent data from May through September of 1978.

Station	MOS-OBS	MOS-PROB	CLIMAT	PERSISTENCE	Number of Gusts
Great Falls	0.159	0.156*	0.195	0.385	37
Billings	0.146	0.134*	0.166	0.331	32
Casper	0.180	0.171*	0.189	0.372	39
Cheyenne	0.210	0.199*	0.251	0.473	62
Denver	0.185	0.184*	0.199	0.351	40
Salt Lake City	0.127	0.118*	0.140	0.236	26
Pocatello	0.143	0.130*	0.165	0.324	31
Boise	0.127	0.113*	0.135	0.236	23
Winnemucca	0.121	0.108*	0.132	0.257	23
Reno	0.087*	0.094	0.100	0.176	16
Ely	0.184	0.173*	0.181	0.277	38
Las Vegas	0.093	0.087*	0.103	0.149	19
Winslow	0.187	0.163*	0.190	0.270	45
Phoenix	0.088	0.076*	0.079	0.128	12
Tucson	0.152	0.148*	0.168	0.257	33
Albuquerque	0.216	0.175*	0.230	0.358	55
Amarillo	0.172	0.160*	0.179	0.304	39
					Total
17 Stn. Avg.	0.152	0.141*	0.165	0.287	570
Imp. over CLIMAT	7.9%	14.5%	--	-73.9%	

Table 4. Same as Table 3 except for two types of CGP forecasts, and a value of 30 knots was used to determine if a gust occurred.

Station	MOS-PROB	CLIMAT	Number of Gusts
Great Falls	0.125*	0.150	25
Billings	0.098*	0.106	18
Casper	0.120*	0.134	24
Cheyenne	0.206*	0.216	42
Denver	0.107	0.101*	17
Salt Lake City	0.078*	0.095	16
Pocatello	0.111*	0.122	21
Boise	0.077*	0.080	13
Winnemucca	0.057*	0.065	10
Reno	0.042*	0.051	7
Ely	0.111*	0.138	24
Las Vegas	0.040*	0.046	7
Winslow	0.124*	0.131	24
Phoenix	0.055*	0.057	9
Tucson	0.096*	0.097	17
Albuquerque	0.148*	0.177	36
Amarillo	0.094*	0.105	19
17 Stn. Avg.	0.099*	0.110	Total 329
Imp. over CLIMAT	10.0%	--	

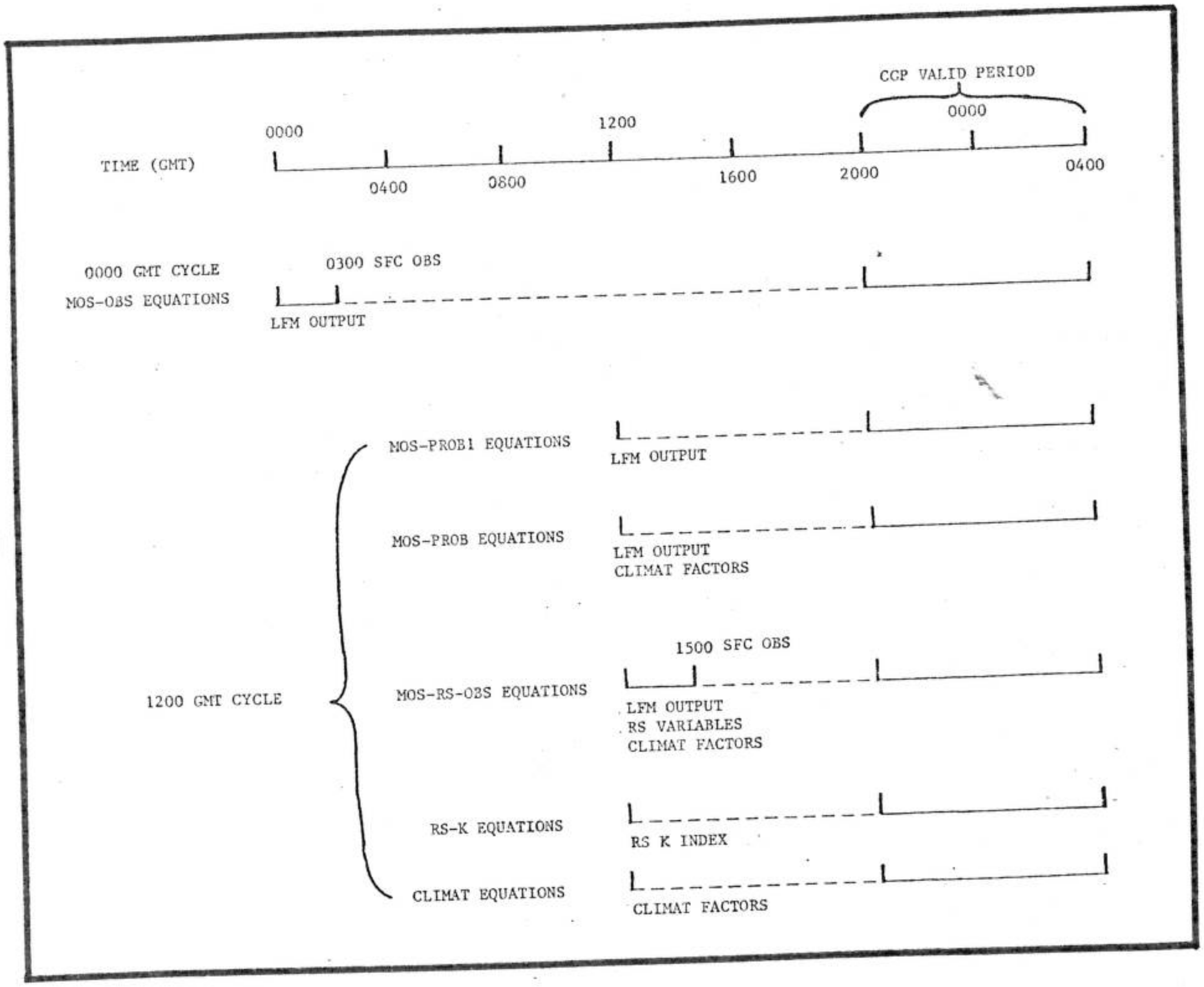

Figure 1. The sources of predictor data and the corresponding forecast projection for each of the six basic types of CGP prediction equations. (Note: RS--radiosonde; CLIMAT FACTORS--sine and cosine of the day of the year).

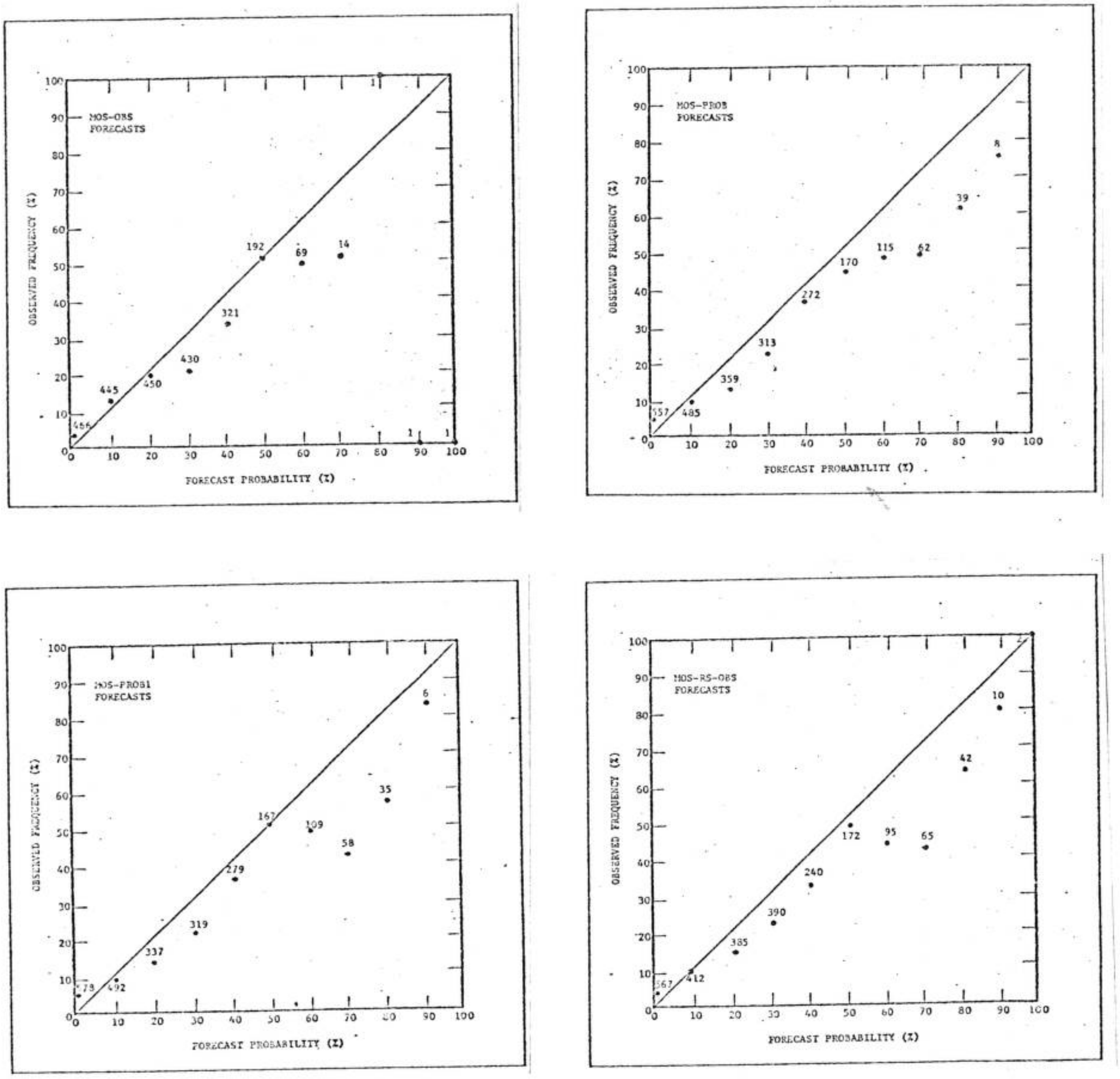

Figure 2. Reliability diagrams for four different types of CGP forecasts. The numbers plotted on the diagram are the number of forecasts for all 10 stations combined during the test period of April through September of 1977 and May through July of 1978. A value of 25 knots was used to determine if a gust occurred.

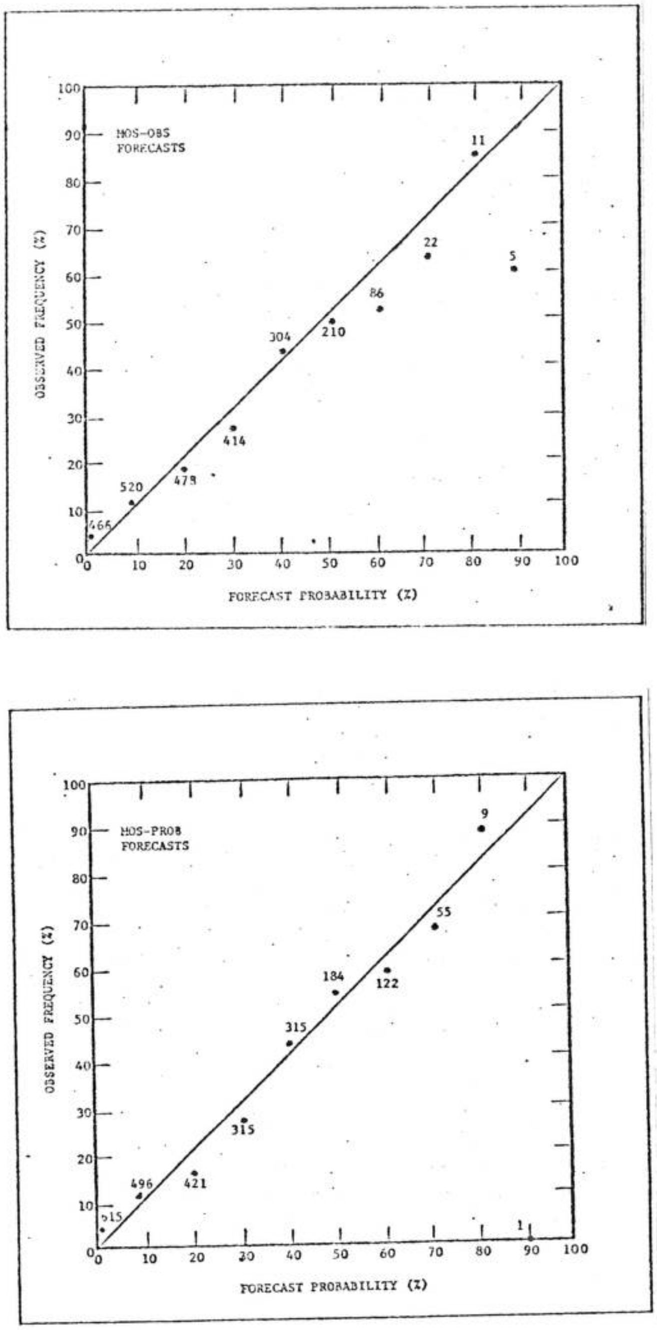

Figure 3. Same as Fig. 2 except for two types of CGP forecasts, 17 stations, and the period of May through September of 1978.

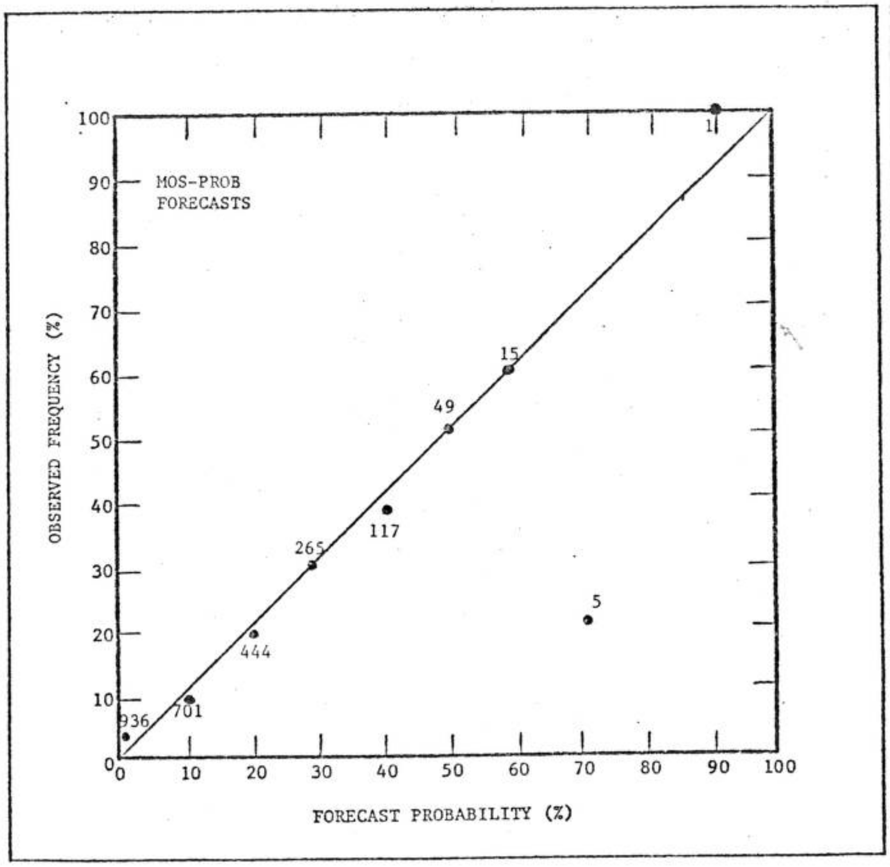

Figure 4. Same as Fig. 3 except for one type of CGP forecast, and a value of 30 knots was used to determine if a gust occurred.