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SPECIALIZED AGRICULTURAL WEATHER GUIDANCE FOR SOUTH CAROLINA

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1. INTRODUCTION

The Techniques Development Laboratory (TDL) has developed weather guidance for 21 agricultural locations in South Carolina (see Fig. 1). The guidance consists of maximum (max) and minimum (min) air temperature and max and min 4-in soil temperature forecasts for projections out to 108 hours. Also included in the package are forecasts of daily insolation, and probability of precipitation amount (PoPA) out to 84 hours. The complete agricultural forecast package is valid during the growing season of March through November.

2. METHOD

All the prediction equations were developed with use of the Model Output Statistics (MOS) technique (Glahn and Lowry, 1972). This technique consists of determining statistical relationships between local weather observations (predictands) and the output of numerical models (predictors). A forward stepwise selection procedure was used to derive the multiple linear regression equations. The equations were limited to 10 predictors, with each predictor entering an equation being required to reduce the variance by at least one tenth of one percent.

We used 0000 GMT cycle output from the six-layer Primitive Equation (PE) model (National Weather Service, 1977) to develop all the prediction equations. Some of the PE forecast fields were spaced-smoothed over 5, 9, or 25 grid points in order to reduce the effects of small scale noise inherent in numerical output. The PE forecasts were then interpolated from the grid points to the location of each of the stations.

The variables available to the regression program as potential predictors of air and soil temperature, daily insolation, and PoPA included 1000-, 850-, and 500-mb temperatures; 1000-, 850-, 700-, and 500-mb heights; boundary layer, 850-, and 500-mb winds; 1000-850 mb and 1000-500 mb thicknesses; several low and middle level mean relative humidities; 750-mb vertical velocity; surface pressure; boundary layer potential temperature; precipitation amount; and precipitable water. In addition to screening all the predictors in continuous form, we screened several as binary predictors. We also screened several trigonometric functions of the day of the year, the maximum possible number of hours of sunshine per day, and the daily insolation at the top of the atmosphere.

The max air temperature, and the max and min soil temperature predictands were for 24-h periods, generally ending at approximately 7 a.m. local time. For Blackville, the 24-h periods end at 5 p.m. Observations of min air temperatures were also for the same 24-h periods, although we tried to eliminate cases where the reported minimum for a particular day really occurred on the morning of the previous day. We did this by comparing Clemson's 7 a.m. air temperature observation with its 24-h min reported the following morning. If the two observations were the same, we did not include Clemson's min, as well as mins at all other stations for that morning, in the developmental sample. We used Clemson's temperature comparison for all other stations because 7 a.m. observations were not available at the other stations.

The PoPA predictands were the occurrences of greater than or equal to .01, .10, .25, .50, and 1.00 inches of precipitation in 24-h periods ending at 7 a.m. Daily insolation predictands were measurements for calendar day periods.

We also developed climatic forecast equations for all of the predictands. In these, trigonometric functions of the day of the year, daily insolation at the top of the atmosphere, and maximum possible number of hours of sunshine were used as predictors. We then applied the equations to produce forecasts of the expected climatic value for each day of the year.

3. EQUATION CHARACTERISTICS

Initially, we developed the prediction equations for projections of 84 hours and less from observations taken during April-November, 1973, and March-November, 1974-76. These months correspond to the approximate growing season for South Carolina. We then tested these equations on a single growing season of independent data (March-November, 1977) by comparing the MOS forecasts with forecasts from the climatic equations and also with persistence forecasts. For projections greater than 84 hours, the developmental sample consisted of observations from October and November, 1975, and March through November of 1976-77. No independent test data were saved to test these equations.

Finally, we rederived the equations for projections of 84 hours and less and included the test data in the developmental sample. Table 1 lists the reductions of variance and standard errors of estimate for the air temperature, soil temperature and daily insolation equations. Reductions of variance and Brier scores--defined to be one half of the score proposed by Brier (1950)--for the PoPA equations are given in Table 2.

A. Max/Min Air Temperatures

Single station max and min air temperature equations were developed for all 21 agricultural locations in South Carolina for projections out to 108 hours. Most of these equations contain the maximum limit of 10 terms.

The regression program selected the 1000-850 mb thickness as the best predictor of max air temperature. Other important predictors were the number of hours of sunshine, cosine of the day of the year, 500-mb geostrophic V component of the wind, 1000-mb temperature, and the 850-mb U component of the wind. For min temperature, the most important predictor was the 1000-500 mb thickness. The number of hours of sunshine, precipitable water, the cosine of the day of the year, and the 850-1000 mb thickness were also important predictors.

Table 3 gives the verification results for the equations when tested on independent data. The verification results for the climatic equations and persistence are also presented for comparison. At all projections the MOS forecast max and min were better than both climatic forecasts and persistence. The mean absolute errors for the max temperature forecasts based on MOS ranged from 3.4°F at 24 hours to 4.2°F at 72 hours. The corresponding range for the min forecasts was from 3.0°F to 4.2°F.

B. Max/Min Soil Temperatures

Single station max and min soil temperature equations were developed for 15 locations. Eight of these had bare soil surfaces, while the remainder had grass covered surfaces. Most of the equations contain the maximum limit of 10 terms, although there are fewer terms in some of the equations for long range projections, especially for those under grassy soil surfaces.

The regression program selected the cosine of the day of the year as the best predictor of max soil temperature. The 850-1000 mb and 500-1000 mb thicknesses, daily insolation and 850-mb V component of the wind were also selected frequently. For min soil temperature, the best predictor was the 500-1000 mb thickness. Other important predictors were the cosine of the day of the year, daily insolation, 850-1000 mb thickness and the 500-mb geostrophic wind speed.

Table 3 gives the verification results for the soil temperature forecasts when tested on independent data. For max soil temperatures, the MOS forecasts were better than climatology for the first three days, but were generally worse than persistence. MOS min soil temperature forecasts were also better than climatology for all three days but, again, were worse than forecasts of persistence for the first one to two days.

Despite the fact that persistence forecasts are superior to the raw MOS guidance for some projections, a forecaster using this guidance should be able to significantly improve the guidance by considering stored soil heat, soil moisture, and past error trends in the raw MOS guidance. To substantiate this idea, we conducted a test in which we added the mean error for the past three 12-36 h forecasts to the raw MOS guidance. For example, if the past three 12-36 h max grassy-ground soil temperature forecasts averaged 5°F too low, we added 5°F to all the max grassy-ground guidance generated that day. This modification improved the mean absolute errors for most soil temperature forecasts out to 84 hours, especially for the 12-36 h projection where the average improvement ranged from about 0.5°F for the min grassy-ground soil temperature to 1.5°F for the max bare-ground soil temperature. The verification statistics for these modified MOS soil temperature forecasts are given in Table 3.

C. Daily Insolation

Single station daily insolation equations were developed for three stations in South Carolina for projections out to 72 hours. All of the equations contain the maximum limit of 10 terms.

The two most important predictors in these equations were the maximum possible number of hours of sunshine per day and the surface to 490-mb mean relative humidity. Other frequently selected predictors were the layer 2 relative humidity, cosine of twice the day of the year, and the 850-mb U component of the wind. Table 4 gives a sample daily insolation equation for Clemson, South Carolina, for the 36-48 h projection.

Table 3 shows the verification results for the daily insolation prediction equations when tested on independent data. The MOS forecasts were consistently better than climatic or persistence forecasts. The mean absolute errors for the MOS forecasts ranged from 63 langleys per day for the first day to 76 langleys per day for the third day.

D. Probability of Precipitation Amount

Generalized-operator PoPA equations were developed for projections of 12-36, 36-60, and 60-84 hours. Before deriving the equations, we combined the data for all the stations to obtain a larger developmental data base. This technique is often used when the data from one station will not support the development of a stable equation. Equations were then developed to predict the probabilities of .01, .10, .25, .50, and 1.00 inches of precipitation. We derived the equations for all precipitation amount categories of a given projection simultaneously. Thus, the resulting equations for a particular projection contain the same predictors; of course, the coefficients of these predictors differ for each precipitation amount category. By deriving the equations in this manner, we minimized the chances of inconsistent forecast probabilities between categories.

The most important predictor for forecasting PoPA was the surface to 490-mb mean relative humidity. The layer 2 relative humidity, precipitation amount, 500-mb V component of the wind, and sine of the day of the year were also important.

The verification results for the PoPA forecasts are given in Table 5. Brier scores for the MOS forecasts were consistently better than (less than) those for the climatic forecasts.

We also examined the overall reliability of these forecasts. Reliability diagrams for the 60-84 h probability of greater than or equal to .10 inches and the 12-36 h probability of greater than or equal to .50 inches are shown in Fig. 2 and Fig. 3, respectively. In both cases, the MOS forecasts appear to be quite reliable (i.e., the relative frequency of precipitation associated with each forecast probability nearly equals that probability).

Also, because excessive amounts of precipitation were fairly rare in the developmental sample, the PoPA equations did not forecast high probabilities for the large amount categories, especially at the longer range projections. During the test period, our PoPA equations for the 1.00 inch category did not forecast a probability greater than 50 percent for the 12-36 h projection, and never greater than 30 percent for the 60-84 h projection.

4. MESSAGES AND SCHEDULES

Agricultural weather guidance for South Carolina is transmitted daily to the Eastern Region at approximately 0900 GMT on the overlay circuit. A sample portion of the teletype bulletin, AXUS52, containing the guidance is shown in Fig. 4. Table 6 lists the station abbreviations that appear in the bulletin.

Values of the air and soil temperature guidance in these messages are rounded to the nearest whole degree Fahrenheit. Values of daily insolation are in langleys per day. The PoPA guidance is in tens of percent, with the numbers from left to right in the teletype bulletin being the probabilities of greater than or equal to .01, .10, .25, .50, and 1.00 inches of precipitation.

The max air temperature, max/min soil temperature, and PoPA forecasts are for 24-h periods ending at approximately 7 a.m. local time. The min air temperature forecasts are also valid for 24-h periods, although we tried to eliminate from the developmental sample minima occurring at the start of the 24-h period. At Blackville, the air and soil temperature forecasts are valid from 5 p.m. to 5 p.m. Forecasts of daily insolation are for the calendar day periods.

Dates and times given at the beginning of each bulletin should be used to identify the valid time period for each forecast. Min air and soil temperature, daily insolation, and PoPA forecasts are listed under the date and time approximately corresponding to the end of the period for which they are valid. Max air and soil temperature are listed at midpoint of their valid periods. Blackville's forecasts are listed so that they correspond to those of the other stations.

5. OPERATIONAL CONSIDERATIONS

All the agricultural forecast equations have been developed from output of the six-layer PE model and its barotropic extension. The equations, however, are being applied to output of the seven-layer PE model and the barotropic mesh extension. As a result, the equations do not account for the characteristic differences between old and new versions of these models.

Based on our verification results for soil temperature, the field forecaster should consider stored soil heat, soil moisture, and past errors of the MOS guidance when issuing soil temperature forecasts. This is especially important for early projections, where a forecast of persistence is often better than the raw MOS guidance.

Also, because excessive amounts of precipitation are rare, it is unlikely that the PoPA equations will forecast high probabilities for the large amount categories, especially at the longer range projections.

ACKNOWLEDGMENTS

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Glahn, H. R., and D. A. Lowry, 1972: The use of Model Output Statistics (MOS) in objective weather forecasting. J. Appl. Meteor., 11, 1203-1211.

National Weather Service, 1977: The 7LPE model. NWS Technical Procedures Bulletin No. 218, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, 14 pp.

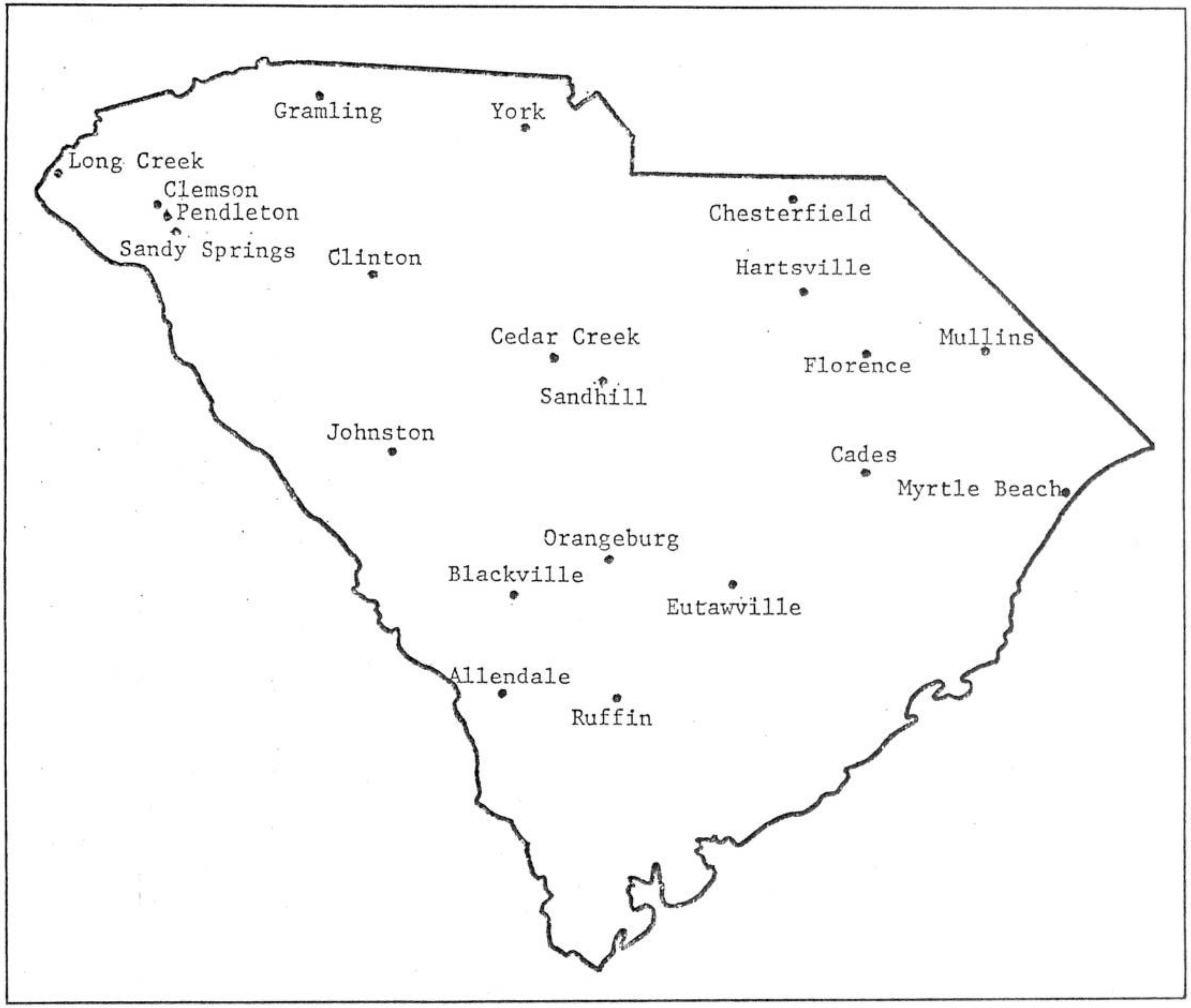

Figure 1. The 21 agricultural stations in South Carolina for which specialized weather guidance is available.

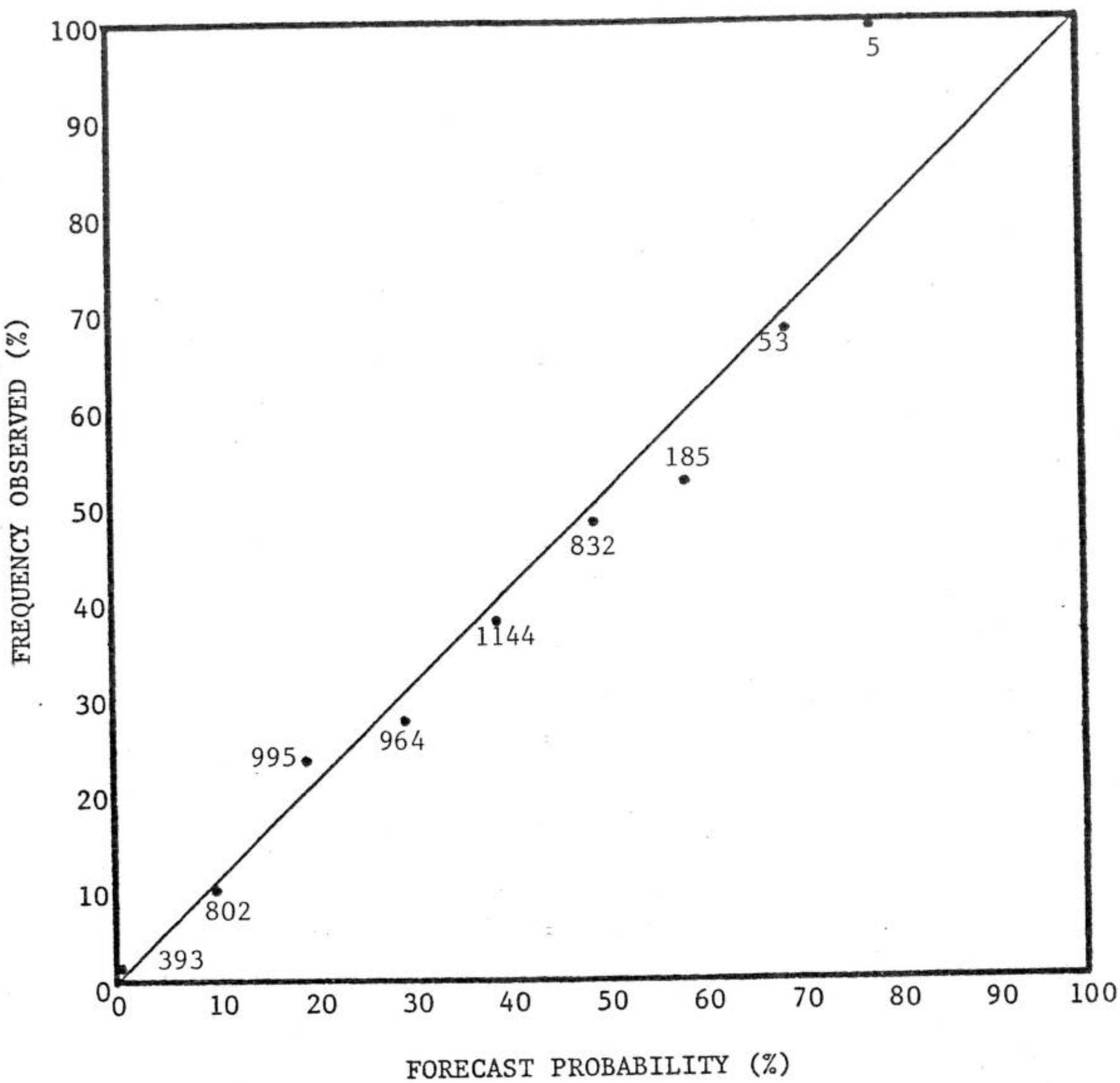

Figure 2. Reliability of the 60-84 h PoPA forecast for greater than or equal to .10 inches of precipitation for the 21 stations in South Carolina. The numbers plotted on the diagram are the number of forecasts of each probability during the independent test period (March-November, 1977).

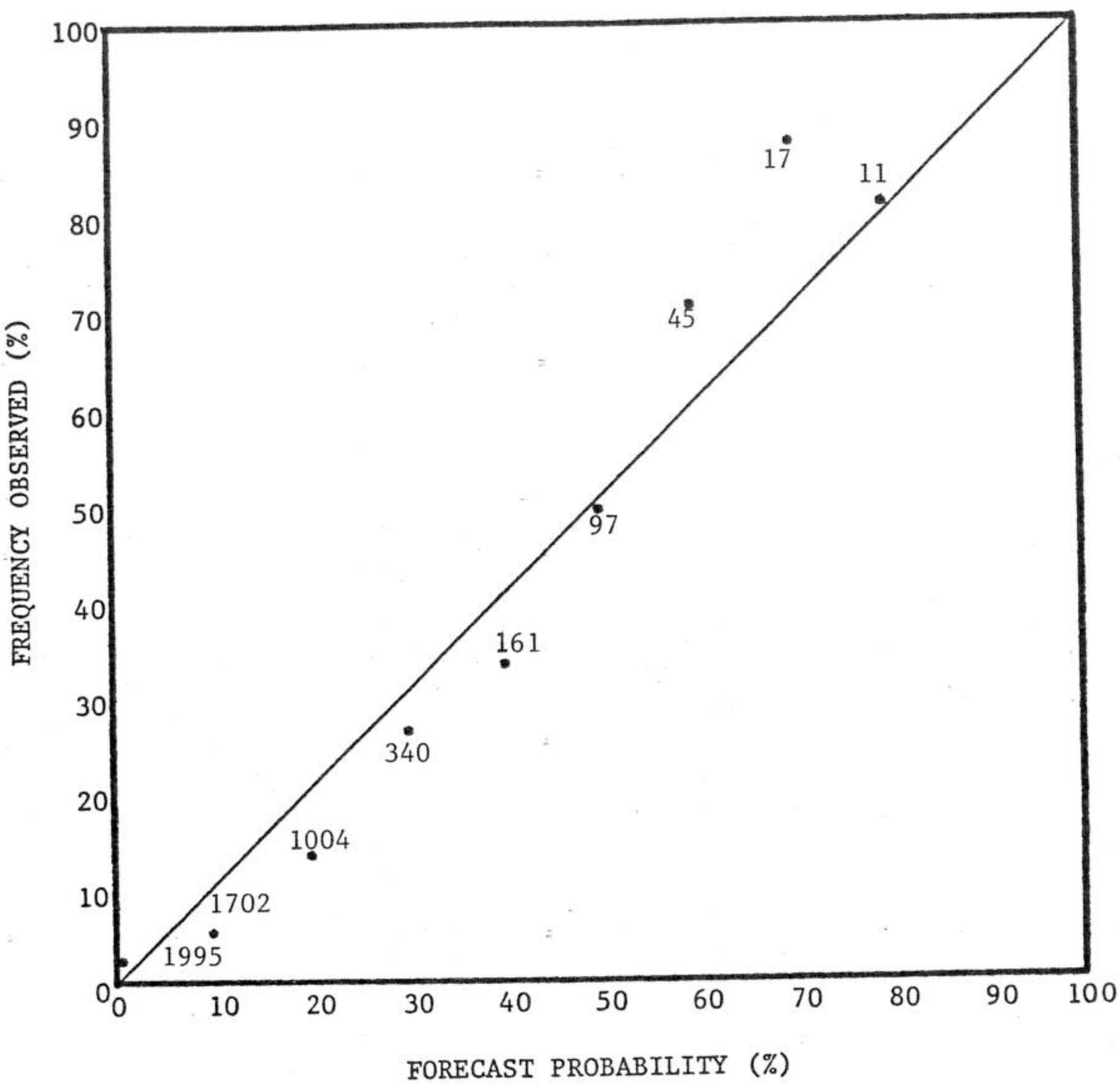

Figure 3. Same as Fig. 2 except for the 12-36 h PoPA forecast for greater than or equal to .50 inches of precipitation.

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AXUS52 KWBC 220000
 AG WEATHER GUIDANCE /MOS/  7/22/77  0000 GMT   SOUTH CAROLINA
              DATE  23    23   24    24   25    25   26    26
               GMT  00    12   00    12   00    12   00    12

ALLN AIR            98    72   92    67   90    68   92    70
     GRASS          90    82   89    81   87    81   85    80
     POPA/24 HR/      32211      10000      21100

BLAK AIR            98.   69   92    62   88    63   91    70
     BARE           90    81   90    79   87    79   89    79
     INSOL         405        418        438
     POPA             32211      00000      11100

CADE AIR            95    70   89    63   87    60   90    67
     BARE           90    77   88    73   85    73   82    72
     POPA/24 HR/      32210      00000      11100

YORK AIR            93    66   86    62   86    65   88    66
     GRASS          89    78   87    75   86    75   84    75
     POPA/24 HR/      32110      10000      21110
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Figure 4. Sample portion of the AXUS52 bulletin.

Table 1. Average developmental reductions of variance (RV) and standard errors (SE) for the air and soil temperature and daily insolation equations for the 21 stations in South Carolina. All the standard errors for the temperature equations are given in ^{o}F, while those for daily insolation are in langleys per day.

Type of Equation	Approximate Forecast Projection (hours from 0000 GMT)							
	12 - 36		36 - 60		60 - 84		84 - 108	
	RV	SE	RV	SE	RV	SE	RV	SE
Max Air Temp	.865	4.01	.838	4.43	.811	4.31	.783	6.49
Min Air Temp	.915	3.72	.889	4.29	.848	5.06	.779	6.23
Max Bare Ground Temp	.864	3.88	.853	4.05	.849	4.13	.848	4.31
Min Bare Ground Temp	.919	2.92	.910	3.08	.911	3.09	.889	3.50
Max Grassy Ground Temp	.895	3.07	.890	3.18	.889	3.20	.890	3.25
Min Grassy Ground Temp	.933	2.43	.929	2.51	.933	2.45	.927	2.61
Daily Insolation	.625	70.9	.558	77.5	.450	86.3		

Table 2. Developmental reductions of variance and Brier scores for the PoPA equations for the 21 stations in South Carolina.

Type of Equation	Approximate Forecast Projection (hours from 0000 GMT)					
	12 - 36		36 - 60		60 - 84	
	RV	BRIER	RV	BRIER	RV	BRIER
Probability of ≥ .01 inches	.304	.142	.224	.160	.146	.175
Probability of ≥ .10 inches	.253	.121	.178	.134	.108	.144
Probability of ≥ .25 inches	.220	.100	.151	.110	.086	.117
Probability of ≥ .50 inches	.171	.072	.118	.077	.059	.081
Probability of ≥ 1.00 inches	.089	.037	.059	.039	.026	.039

Table 3. Average mean absolute errors for the air and soil temperature and daily insolation MOS prediction equations for the 21 stations in South Carolina when tested on one growing season of independent data (March-November, 1977). Mean absolute errors for climatic forecasts and forecasts of persistence are also included. For soil temperatures the mean absolute errors of a modified (MOD) MOS forecast are also given. All the errors for temperature equations are in ^{o}F, while those for daily insolation are in langleys per day.

Type of Equation	Approximate Forecast Projection (hours from 0000 GMT)											
	12 - 36				36 - 60				60 - 84			
	MOS	Pers.	Clim.	Mod.	MOS	Pers.	Clim.	Mod.	MOS	Pers.	Clim.	Mod.
Max Air Temp	3.47	4.23	5.71	--	3.83	5.77	5.71	--	4.19	6.38	5.71	--
Min Air Temp	3.00	3.70	6.60	--	3.40	5.80	6.60	--	4.20	7.00	6.60	--
Max Bare Ground Temp	4.09	2.46	5.02	2.61	4.28	3.35	5.02	3.35	4.39	3.82	5.02	3.41
Min Bare Ground Temp	2.84	1.76	4.25	1.90	2.88	2.94	4.25	2.34	3.01	3.69	4.25	2.52
Max Grassy Ground Temp	2.78	1.96	3.48	2.09	2.94	2.57	3.48	2.46	2.92	2.92	3.48	2.55
Min Grassy Ground Temp	2.08	1.23	3.06	1.56	2.20	2.07	3.06	1.90	2.17	2.61	3.06	2.02
Daily Insolation	63.3	84.4	89.7	--	68.9	106.5	89.7	--	76.3	115.0	89.7	--

Table 4. Sample equation for the Day 2 (approximately 36-48 h) daily insolation at Clemson, South Carolina.

Predictor	Units	Smoothing (Points)	Forecast Projection (Hours)	Cumulative Reduction Of Variance	Coefficients
Regression Constant	--	--	--	--	517.
1. Hours of Sunshine	h	--	--	.269	56.5
2. PE Mean Relative Humidity	%	5	48	.491	-1.45
3. PE Precipitation Amount	m	9	72	.507	-5787.
4. PE Layer 2 Relative Humidity	%	5	36	.515	-.650
5. PE 850-mb U wind	m/s	5	36	.522	4.32
6. PE 500-mb Geostrophic V Wind	m/s	5	48	.529	-1.03
7. PE 1000 mb Height	m	9	60	.533	.215
8. Cosine of Twice the Day of Year	--	--	--	.536	-11.4
9. PE 500-mb Geostrophic Wind Speed	m/s	5	48	.539	-2.08
10. PE 500-mb Height	m	5	36	.543	-.138

Multiple Correlation Coefficient	.737
Standard Error of Estimate	79.1

Table 5. Brier scores for MOS and climatological forecasts of PoPA for the 21 stations in South Carolina when tested on a single growing season (March-November, 1977) of independent data.

Type of Equation	Approximate Forecast Projection (hours from 0000 GMT)					
	12 - 36		36 - 60		60 - 84	
	MOS	Clim.	MOS	Clim.	MOS	Clim.
Probability of ≥ .01 inches	.155	.206	.166	.206	.181	.206
Probability of ≥ .10 inches	.126	.158	.136	.158	.145	.158
Probability of ≥ .25 inches	.102	.126	.112	.126	.118	.126
Probability of ≥ .50 inches	.071	.084	.077	.084	.082	.084
Probability of ≥ 1.00 inches	.036	.041	.038	.041	.039	.041

Table 6. The four-letter abbreviations used for agricultural stations in South Carolina.

ALLN	Allendale
BLAK	Blackville
CADE	Cades
CEDR	Cedar Creek
CHES	Chesterfield
CLEM	Clemson
CLIN	Clinton
UTAW	Eutawville
FLRN	Florence
GRML	Gramling
HART	Hartsville
JONS	Johnston
LONG	Long Creek
MULL	Mullins
MYRT	Myrtle Beach
ORAN	Orangeburg
PEND	Pendleton
RUFF	Ruffin
SHIL	Sandhill
SSPR	Sandy Springs
YORK	York