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ON THE DEVELOPMENT OF COVARIATES FOR THE EVALUATION OF OPERATIONAL SEEDING PROJECTS IN AREAS WITHOUT PHYSIOGRAPHIC INFLUENCES

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ABSTRACT

An important aspect of the Operational Seeding Evaluation Techniques (OSET) project is to investigate the usefulness of environmental covariates for reducing the large natural convective rainfall variability in the evaluation. Covariates derived from surface meteorological observations have been compared with precipitation within a 1000 km^2 area of the fine scale METROMEX precipitation network operated in the St. Louis area in 1971-1975. The area around St. Louis is typical of most of the grain producing areas of the eastern half of the United States and of many parts of the world with similar climate. There are no unique physiographical/mechanical (forced upslope flow) or physiographical/dynamical (mountain induced ciruclations, sea and lake breezes) forcing that cause convective precipitation locally. Further, precipitation falls within diverse weather systems. Not unexpectedly, the correlations were low, usually less than 0.3. However, a combination of from 6 to 10 variables can explain anywhere from 40% to 50% of the rainfall variance when covariates calculated at sites outside the raingage network are included in the regression.

1. INTRODUCTION

Hundreds of operational weather modification projects have been undertaken, most performed in the often dry western half of the United States. Although difficult to evaluate, evaluation of certain operational projects has helped establish that rainfall could be purposefully modified to get 10%-15% increases (NAS, 1973).

The OSET project has been directed towards this central and continuing problem of weather modification - the evaluation of operational, commercial, weather modification projects (Changnon et al., 1979). This fits well within the broad weather modification research and services program of the Illinois State Water Survey.

Analyses are being concentrated on convective precipitation and operational projects extending over areas of 1000 to 10,000 km^2. The development of techniques involves two highly coordinated investigations. First, and most importantly, there is the testing of various statistical evaluation techniques to find those best for the verification of operational projects. The second part of the project involves the study of environmental variables potentially useful as covariates (predictor variables) in the evaluation of operations (Neyman and Scott, 1967).

2. COVARIATE SELECTION

Achtemeier and Schickedanz (1979) evaluated environmental variables derived from rawinsonde observations as possible covariates for the HIgh PLains Cooperative EXperiment (HIPLEX) Kansas site. The data taken at Dodge City, Kansas, for Junes 1958-1970 were compared with daily rainfall from 22 sites within a 175 km square centered over Dodge City. None of the variables was able to explain more than 10% of the rainfall variance. Possible explanations for the low correlations were: 1) the daily averages were noisy because of the sparcity of the gages (Huff, 1970), 2) there was little physical relationship between the covariates and the rainfall, and 3) the rainfall-producing environment was poorly measured. They showed that the third factor was contributing to the weak correlations and they presented patterns of correlation coefficients between rainfall and spatial analyses of surface data that showed strongest correlations at some distance removed from the rainfall measuring site.

The OSET covariate studies are to determine whether covariates derived from surface data fields are useful for the evaluation of operational seeding projects (Changnon, et al., 1979). The use of 5-min rainfall data from the dense (one gage per 20 km^2) METROMEX raingage network operated by the Illinois State Water Survey from 1971-1975 eliminates gage spacing as a cause for weak covariate-rainfall correlations.

After extensive literature searches (Ackerman et al., 1976; Westcott, 1979), consulting with those with field experience in the Midwest, and considering data limitations, 24 covariates derived from surface data (Table 1) were selected for testing. They are self explanatory with the following exceptions: The geostrophic wind direction and the observed wind direction are presented in line projections that avoid bipolar distributions that can result from the transition from 360^o to 0^o. The projections are given by

$$P_i = 5(1+\cos(\alpha-\alpha_1)) \qquad \alpha_i = 90, 135, 180, 225 \text{ degrees.}$$

As an example, wind directions of 90^o, 180^o, and 270^o projected onto the east-west axis ($\alpha_1 = 90$) will yield $p_1 = 10.0$, 5.0, and 0.0, respectively.

To obtain the cumulative lift, calculate the vertical velocity at the top of a 1 km deep layer by assuming that the layer average convergence is equal to the surface convergence. Then add to this the vertical velocity induced by flow over unlevel terrain. Find the average vertical velocity over a 6-hr period by averaging with previously calculated vertical velocities. The 6-hr. period was chosen as representative of the residence time of a typical mesosystem between observation sites with average separation similar to the station spacing within the NWS surface network. Multiply the average vertical velocities by the time period to convert to net vertical displacements. In the pressure trough analysis, the locations of pressure troughs are found emperically by a computer program and the trough intensities are calculated from the curvature of the pressure field normal to the trough axis. Convergences are computed upon the assumption that the atmosphere is initially at rest and the trough is stationary for 3 hours. The convergences are converted to vertical displacements at the top of a 1 km deep layer upon the assumption that the layer convergence is equal to the surface convergence.

3. COVARIATE-RAINFALL RELATIONSHIPS

The surface data for June, July, and August, 1971-1975 were supplied by the National Severe Storms Forecast Center (NSSFC) in raw form and edited for the OSET analyses. Data from a subset of 48 stations located in or near the region shown in Fig. 1 was used to produce objective analyses on the 252 point 14 x 18 mesh with a grid point separation of 56 km. After covariates that included derivatives of the basic variables were calculated, the grid density was reduced from 252 points to 63 points.

Five minute rainfall amounts at 55 gages within a 1000 km^2 subset of the METROMEX raingage network were used to identify the period and intensity of macroscale rain events. The rain event was defined as a period with rain somewhere within the network, with rainless gaps not exceeding 6 hours. The start date and time, the end date and time, the maximum gage amount, and the total rainfall were tabulated. These 187 rain events were merged with covariates for surface observations taken 1 to 3 hours before the rain event beginning time. When covariate data were missing, the corresponding rain events were dropped from the data set, reducing the number of cases in the statistical analysis to 171.

Patterns of correlation coefficients between maximum gage amount and the covariates and between total rainfall and the covariates showed weak relations from point to point; no one variable explained more than 15% of the rainfall variance. There are no unique physiographical/mechanical (forced upslope flow) or physiographical/dynamical (mountain induced circulations, sea and lake breezes) forcings that initiate convective precipitation locally. Therefore, all of the covariates had about the same correlations with rainfall while precipitation falls within diverse weather systems, and the data can be stratified according to weather system type, the differing rates and directions of motion will lead to smaller point correlations.

Patterns of the correlation coefficients between total rainfall and mixing ratio and between total rainfall and pressure trough analysis are shown in Fig. 1. Heavier rains tend to be associated with copious amounts of moisture, as evident in positive correlations with mixing ratio, strongest over southern Missouri. Pressure trough correlations may be revealing of differing physical systems that produce heavier rains over the network. One area of relatively high positive correlations extends from eastern Missouri across the network into southern Illinois. A second area of smaller positive correlations extends from southeast Iowa to western Missouri. Positive correlation means that pressure troughs tend to occur in areas of heavier rains.

The first two columns of Table 2 summarize the relation between total rainfall and the 24 covariates, had the covariates been calculated for only the raingage network sites. Pressure trough, explaining 15% of the rainfall variance, was by far the most important variable. Only 10 covariates explained

TABLE 1.

LIST OF CANDIDATE SURFACE COVARIATES AND THEIR ABBREVIATIONS

1. Mixing ratio (MIX)
2-5. Geostrophic wind line projections (DGA-DGD)
6-9. Observed wind line projectsion (OBA-OBD)
10. Divergence (DIV)
11. Vorticity (VOR)
12. Moisture advection by the geostrophic wind (GMA)
13. Moisture advection by the observed wind (OMA)
14. Moisture divergence (MDV)
15. Wet bulb potential temperature (WPT)
16. Cumulative lift (CML)
17. Pressure trough analysis (PTA)
18. Pressure tendency ($t-t_{-3h}$) (PTY)
19. Sky cover (SKY)
20. Cloud base height index (CHT)
21. Pressure (PRS)
22. Temperature (TMP)
23. Dew point temperture (DEW)
24. Spot index (SPT)

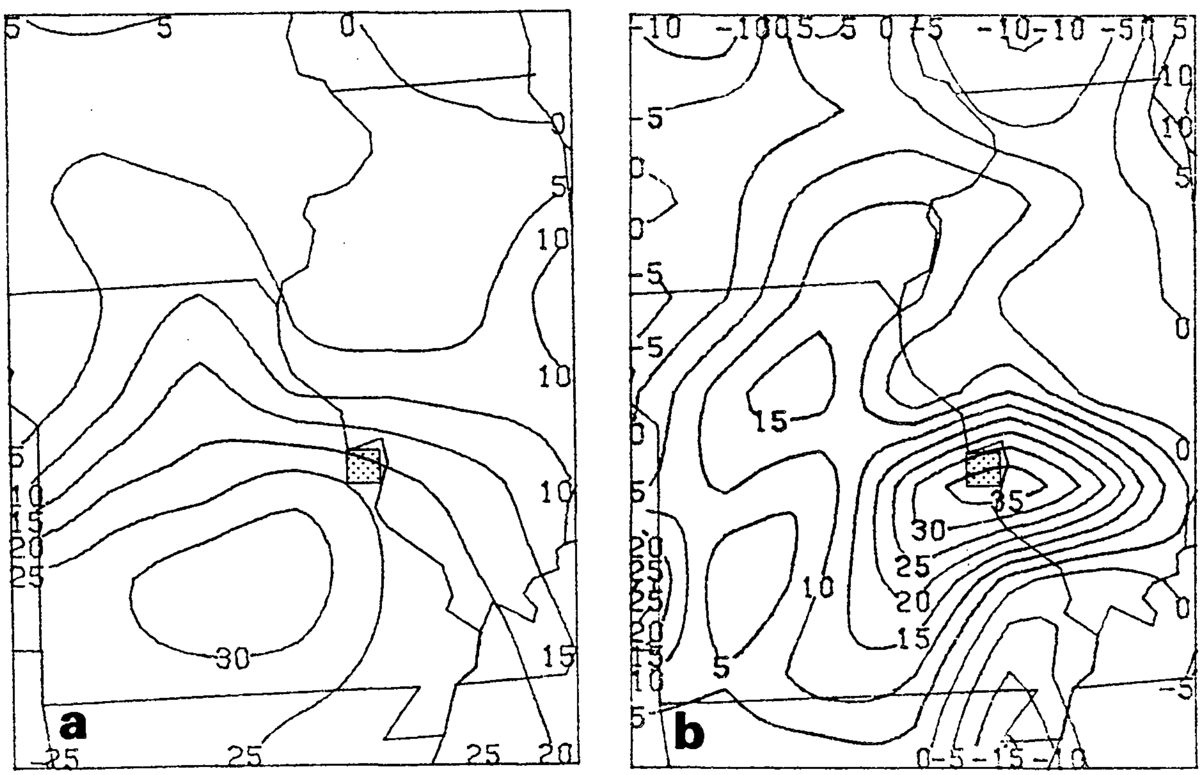

FIGURE 1. Maps of the study area including the METROMEX raingage network (hatched area) showing patterns of the correlation coefficient between total rainfall and (a) surface mixing ratio, and (b) pressure trough analysis.

more than 2% of the rainfall variance. These variables were combined through stepwise and minimum R^2 regression models to find the corporate relationship with rainfall. Four variables (PTA, OMA, MIX, SKY) explained 23% of the rainfall variance (correlation coefficient of 0.48). No other variable met the 0.50 significance level for entry into the stepwise model.

The last three columns of Table 2 summarize the relation between total rainfall and the 24 covariates when the variables within the surrounding areas were included in the stepwise regression. The field correlations are much higher than the site-specific single point correlations. Eight fields explained 23% or more of the rainfall variance - more than could be obtained from the regression on the 24 single points. Three variables explained more than 30% of the variance and 15 points within the pressure trough analysis could explain 42% of the rainfall variance. (The number of points retained exceeded the 0.50 significance level for entry into the stepwise model.)

The values of the covariates at the points in the last column of Table 2 were combined into a second stepwise regression model. Only 32 of the 144 covariates met the 0.50 significance level for inclusion. Table 3 summarizes statistical results (cumulative correlation coefficient, cumulative rainfall variance explained, and mean square error) and point locations (distance and direction from the rainfall network) for the first 10 variables selected. These 10 variables were found to explain 53% of the rainfall variance (correlation coefficient 0.73). Pairs of the same variable at different locations were retained for the pressure trough analysis (PTA), the geostrophic moisture advection (GMA) and the south-north projection of the geostrophic wind (DGC).

The first variable selected, PTA26, was located at the raingage site; all others were located elsewhere. Variables 2 and 3 were found west of the site, the direction from which storms frequently move and the direction from which some weather systems advect copious amounts of moisture into the St. Louis area. The geostrophic moisture advection (variables 4 and 5) represent a class of storms for which copious moisture amounts are brought in from the south. The residual variance is left to the remaining variables and their physical relationship with rainfall is more difficult to explain.

4. DISCUSSION

The findings in this study support the results presented by Achtemeier and Schickedanz (1979) that the use of covariates calculated at sites removed from the rainfall measurement location can significantly strengthen the covariate-rainfall relationship. Only 23% of the variance of convective rainfall observed at the METROMEX raingage network from June to August 1971-1975 could be explained by the 24 site specific covariates. When covariates calculated at sites removed from the raingage network were included in the stepwise regression, the explained rainfall variance increased to 53%.

Generally the use of this type of regression model with independent data will reduce the explained rainfall variance to approximately 50%-70% of that shown here. Thus, tests with independent data including spatial covariates would probably explain 30%-40% of the rainfall variance and site

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TABLE 2.

Statistical relationships between 24 covariates derived from surface data and total rainfall over a 1000 km^2 area within the METROMEX raingage network

Variable	Single Point at Site: Abs. Value Corr. Coef.	Single Point at Site: Percent Variance	Stepwise regression with Field: Correlation Coefficient	Stepwise regression with Field: Percent Variance	Stepwise regression with Field: Number Points
MIX	.22	5	.44	20	3
DGA	.03	0	.47	22	7
DGB	.08	1	.48	23	8
DBC	.07	0	.59	35	13
DBD	.03	0	.47	22	8
OBA	.02	0	.24	6	2
OBB	.06	0	.36	13	6
OBC	.12	1	.29	8	2
OBD	.08	1	.31	10	2
DIV	.12	1	.51	26	8
VOR	.15	2	.38	15	5
GMA	.01	0	.58	34	9
OMA	.25	6	.44	20	7
MDV	.16	3	.53	28	8
WPT	.16	3	.52	27	5
CML	.11	1	.42	18	6
PTA	.38	15	.65	42	15
PTY	.17	3	.54	29	8
SKY	.17	3	.38	15	4
CHT	.10	1	.22	5	2
PRS	.12	1	.22	5	2
TMP	.05	0	.46	22	6
DEW	.22	5	.43	19	3
SPT	.23	5	.45	21	5

TABLE 3. Cumulative correlation coefficient, cumulative rainfall variance explained, mean square error, and covariate location for the first 10 covariates selected by stepwise regression.

Variable Number	Variable Name	Cumulative Correlation Coefficient	Cumulative Percent Variance	Mean Square Error	Distance from Site (km)	Direction from Site
1	PTA26	.38	15	237	0	0
2	MIX17	.48	23	216	225	WSW
3	PTA15	.54	29	200	500	W
4	GMA13	.58	34	187	225	SSE
5	GMA12	.61	37	179	200	S
6	MDV44	.63	40	171	425	NW
7	DIV34	.66	44	162	150	NE
8	DGC18	.68	47	155	150	SW
9	DGC41	.71	50	145	225	NNE
10	OBB56	.73	53	139	450	NE

specific covariates would explain about 10%-15% of the variance.

Additional studies to determine the behaviour of the covariate-rainfall relationship with time are underway. These results combined with the results presented here may make it possible to determine where, when and how frequently observations should be taken in order to find the best covariates for the evaluation of operational, commercial weather modification projects.

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