NOTES

Predictor Variables of the Maximum Radar Echo Activity on Convective Days

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ABSTRACT

Digital radar data and atmospheric sounding information were analyzed with the intention of beginning a search for atmospheric parameters which are easily attainable, are independent of whether or not clouds are seeded, and either individually or in concert with others can be used to predict the potential size, intensity and coverage of convective precipitation as estimated by radar. Stability indexes and upper level wind speeds seemed to be the dominant predictor variables.

1. Introduction

The objective of this investigation has been to begin a search for atmospheric parameters which are easily attainable, are independent of whether or not clouds are seeded, and either individually or in concert with others can be used to predict the potential size, intensity and coverage of convective precipitation as estimated by radar. The approach used was to statistically compare the temperature, moisture and stability factors that were computed from a nearby sounding with the maximum size and intensity of radar echo characteristics for each convective cloud system. This was a first attempt to identify potential predictor variables for use in the Bureau of Reclamation's High Plains Cooperative Program (HIPLEX).

2. Data base and methodology

Digital radar data were collected May–July 1976 at Miles City, Montana in support of HIPLEX. The radar used in this study is a sensitive, narrow-beam, 5 cm wavelength system which records echo data on computer-compatible magnetic tape. The antenna scanned continuously in a volume mode of 360° in azimuth and 12° in elevation. The time interval for a complete volume scan was ~5 min. Most of the precipitation echo data were from natural cloud systems; but a few small, isolated clouds that were seeded were also included. The radar data processing and analysis products used in this study are described by Schroeder and Klazura (1978).

Echo characteristics have been compiled for each precipitation system over an area defined by range rings from 25 to 150 km from the radar. These parameters (dependent variables) were all computed from a 5 min volume scan recorded at or near peak convective periods of the day. The time of peak activity was determined through the analysis of composite B-scans, a range-azimuth plot which displays radar reflectivity, and echo top information (Schroeder and Klazura, 1978). All of the composite B-scans for each day were visually scanned and the one which contained the most echo area coverage and highest reflectivities was chosen.

The soundings taken at Miles City were used to search for predictor variables of these echo characteristics. The soundings were taken from 0 to 12 h before the peak convective period.

Relationships between sounding characteristics (predictor variables) and radar reflectivity parameters (dependent variables) were studied using simple and multiple linear correlation and regression analyses.

The radar echo characteristics and sounding variables chosen for this study are defined in Table 1.

As mentioned earlier, the radar echo characteristics were computed over the scanning area between the 25 and 150 km range rings. The maximum echo height, maximum reflectivity factor and maximum rain were obtained from individual radar bins. Maximum rain rate was obtained by converting the maximum reflectivity observed in the 1° elevation sweep (30–150 km range) or the 2° elevation sweep (25–29.9 km range) by using the Marshall and Palmer (1948) *Z-R* relationship. The maximum rain volume was computed by multiplying rainfall rates by their associated bin areas and accumulating them over the entire scanning area. The maximum total volumes were computed by accumulating all bin volumes (whose associated reflectivity exceeded the three thresholds) over the entire 360° by 12° antenna volume scan. The maximum total areas were computed by accumulating all bin areas (whose associated reflectivity exceeded the three thresholds) over each 360° by 1° antenna sweep within the volume scans. The maximum of the 12 possible for each volume scan was the value used. Usually the 1° or 2° sweep contained the largest echoing area.

Schroeder and Klazura (1978) include examples of computer printouts which contain these variables as well as further discussion of them.

The sounding variables were obtained from the output of an operational computer program that is routinely executed on project rawinsonde data. Items 20 through 23 in Table 1 are stability indexes. The lifted index and total totals index are discussed by Galway (1956) and Miller[1], respectively. The *K* index is the sum of the 85 kPa temperature and dew point minus the sum of the 50 kPa temperature and the 70 kPa dew point depression: $KI = (T_{850} + TD_{850}) - (T_{500} + T_{700} - TD_{700})$.

TABLE 1. Radar echo characteristics and sounding variables chosen for study.

Dependent variables (radar echo characteristics)		
1.	TOP_{max}	—maximum echo height
2.	Z_{max}	—maximum reflectivity factor
3.	VOL_{10}	—maximum total volume > 10 dBZ
4.	VOL_{30}	—maximum total volume > 30 dBZ
5.	VOL_{40}	—maximum total volume > 40 dBZ
6.	$AREA_{10}$	—maximum total area > 10 dBZ
7.	$AREA_{30}$	—maximum total area > 30 dBZ
8.	$AREA_{40}$	—maximum total area > 40 dBZ
9.	$RVOL_{MP}$	—maximum rain volume (5 min period) [Marshall-Palmer]
10.	$RRATE_{MP}$	—maximum rain rate [Marshall-Palmer]
Predictor variables (sounding variables)		
1.	EPT_{500}	—equivalent potential temperature at 50 kPa (500 mb)
2.	LEV_{-20}	—height of −20°C level
3.	LEV_0	—height of 0°C level
4.	T_{sfc}	—surface temperature
5.	TD_{sfc}	—surface dew-point temperature
6.	$WDIR_{300}$	—30 kPa wind direction
7.	$WDIR_{500}$	—50 kPa wind direction
8.	$WDIR_{700}$	—70 kPa wind direction
9.	$WDIR_{850}$	—85 kPa wind direction
10.	$WSPD_{300}$	—30 kPa wind speed
11.	$WSPD_{500}$	—50 kPa wind speed
12.	$WSPD_{700}$	—70 kPa wind speed
13.	$WSPD_{850}$	—85 kPa wind speed
14.	WSHEAR	—directional wind shear ($WDIR_{300}$ minus $WDIR_{850}$)
15.	PW_{850}	—precipitable water (surface–85 kPa)
16.	PW_{700}	—precipitable water (surface–70 kPa)
17.	PW_{500}	—precipitable water (surface–50 kPa)
18.	PW_{tot}	—precipitable water (total)
19.	MR	—mean mixing ratio (lowest 10 kPa)
20.	LI_{100}	—lifted index 10 kPA layer, mean mixing ratio, adiabatic
21.	LI_{50}	—lifted index (5 kPa layer, mean mixing ratio and temperature)
22.	TTI	—total totals index
23.	KI	—*K* index

3. Results

Correlation coefficients were first computed for each predictor/dependent and predictor/predictor variable pair. Many of the predictor variables were highly cross correlated (see Table 2). Thus, before proceeding with a stepwise multiple linear regression analysis, the 23 variables were first stratified into five categories. The technique used for the stratifications was a compromise between placing highly correlated variables under the same category and still have the categories define subdivisions whose contents were generally physically related.

The five categories and variables contained therein are:

1) Temperature (T_{sfc}, LEV_{-20}, LEV_0)

2) Water vapor and stability (EPT_{500}, TD_{sfc}, PW_{850}, PW_{700}, PW_{500}, PW_{tot}, MR, LI_{100}, LI_{50}, TTI, KI)

3) Upper level wind direction ($WDIR_{300}$, $WDIR_{500}$, $WDIR_{700}$)

4) Lower level wind direction ($WDIR_{850}$, WSHEAR)

5) Wind speed ($WSPD_{300}$, $WSPD_{500}$, $WSPD_{700}$, $WSPD_{850}$).

Most of the variables within all but one category were cross-correlated at a level higher than 0.50. The exception was the wind-speed category in which only the 30 and 50 kPa wind speeds were highly correlated. The wind shear term, although calculated from the difference between the 30 and 85 kPa height intervals was very highly correlated with the 85 kPa wind direction and, therefore, was grouped with it.

The variable within each category which had the highest individual correlation coefficient was the one allowed to be entered into the stepwise multiple linear regression analysis process. The order in which variables were entered during each of the 10 stepwise regression phases (one for each dependent variable) is shown in Table 3. The multiple correlation coefficients (Mult R) are listed, as are the individual correlation coefficients (Indiv R).

The number of cases analyzed for the 10 dependent variables on the 1976 data set ranged from 23 to 26. For all 10 dependent variables there always was at least one variable which correlated better than ±0.50, and five dependent variables had a predictor variable with a correlation coefficient higher than ±0.60. The highest individual correlation coef-

[1] Miller, R. C., 1972: Notes on analysis and severe-storm forecasting procedures of the Air Force Global Weather Central. Tech. Rep. 200, U.S. Air Force, 190 pp.

TABLE 2. Cross correlation table of predictor variables. Circled values are correlations greater than 0.49 between variables which were not grouped in the same category.

	T_{SFC}	LEV_{-20}	LEV_0	EPT_{500}	TD_{SFC}	PW_{850}	PW_{700}	PW_{500}	PW_{TOT}	MR	LI_{100}	LI_{50}	TTI	KI	$WDIR_{300}$	$WDIR_{500}$	$WDIR_{700}$	$WDIR_{850}$	WSHEAR	$WSPD_{300}$	$WSPD_{500}$	$WSPD_{700}$	$WSPD_{850}$
T_{SFC}	1.00	.59	.57	.29	-.02	.21	.15	.15	.13	.18	-.21	-.29	(.50)	.23	(.57)	(.54)	.49	-.42	(.57)	.12	.05	-.33	(-.62)
LEV_{-20}		1.00	.85	(.68)	.23	.25	.37	.45	.43	.41	-.09	-.05	.08	.12	(.65)	(.50)	.29	-.43	(.60)	.05	.00	-.39	(-.51)
LEV_0			1.00	(.72)	.27	.34	.37	.47	.47	.46	-.21	-.15	.23	.10	(.71)	.42	.26	-.40	(.60)	.12	.20	-.11	-.40
EPT_{500}				1.00	.33	.32	.48	.70	.74	.52	-.14	-.06	.02	.30	.37	.14	.10	-.44	(.53)	.06	.02	-.32	-.31
TD_{SFC}					1.00	.64	.74	.70	.68	.83	-.73	-.71	.46	.53	-.15	-.09	-.07	(-.64)	(.54)	-.20	.10	-.06	-.19
PW_{850}						1.00	.61	.62	.62	.72	-.73	-.68	.63	.47	-.06	.09	.01	(-.59)	(.53)	.08	.14	.05	-.12
PW_{700}							1.00	.91	.89	.92	-.75	-.70	.50	.71	-.12	.02	.04	(-.60)	(.52)	-.08	.03	-.20	-.17
PW_{500}								1.00	.99	.87	-.62	-.55	.39	.75	-.04	.02	-.10	(-.63)	(.58)	-.10	-.06	-.21	-.14
PW_{TOT}									1.00	.85	-.60	-.52	.36	.73	-.04	-.06	-.11	(-.62)	(.56)	-.08	-.05	-.19	-.12
MR										1.00	-.85	-.80	.61	.65	-.09	.01	.02	(-.63)	(.55)	-.07	.17	-.23	-.22
LI_{100}											1.00	.97	-.90	-.72	.24	.09	.05	(.51)	-.40	-.02	-.28	.03	.04
LI_{50}												1.00	-.91	-.71	.24	-.01	-.09	(.53)	-.42	-.01	-.25	.07	.18
TTI													1.00	.65	-.08	.07	.10	-.44	.39	.17	.33	-.01	-.12
KI														1.00	-.28	-.24	-.22	(-.54)	.41	.11	-.14	-.11	.02
$WDIR_{300}$															1.00	.59	.37	-.05	.36	.06	.19	-.17	-.46
$WDIR_{500}$																1.00	.69	-.08	.26	.32	.21	-.29	(-.75)
$WDIR_{700}$																	1.00	-.07	.19	.23	.21	-.28	(-.65)
$WDIR_{850}$																		1.00	-.95	.22	.20	.30	.38
WSHEAR																			1.00	-.18	-.13	-.33	(-.50)
$WSPD_{300}$																				1.00	.73	.30	.00
$WSPD_{500}$																					1.00	.21	-.07
$WSPD_{700}$																						1.00	.49
$WSPD_{850}$																							1.00

ficient was 0.73 and occurred between maximum 5 min rain volume and 70 kPa wind speed. In nine of the dependent variable classes, the wind speed term had the highest individual correlation coefficient seven times and was second highest in the other two. However, it was so insignificant in the maximum echo height class that it was not entered into the regression equation.

The water vapor-stability category also correlated fairly well. It had the highest individual correlation coefficient in three of the classes and the second highest in four others. The stability index variable emerged as the most highly correlated in this category for six of these seven occurrences.

The multiple correlation coefficients (Mult R) ranged from 0.76 to 0.83 for all cases except the maximum reflectivity class which had a value of 0.62. Mult R^2 is the variance explained by the model being tested and ranges from 58 to 69% except for maximum reflectivity in which the explained variance was 38%. The dominance of the wind speed and water vapor-stability terms shows up in the multiple regression analyses also. The wind speed and water vapor-stability terms were the first two to be entered into the equation during the stepwise procedure for eight cases (exceptions: maximum echo height and maximum total area exceeding 10 dBz). The average improvement to Mult R for these eight

TABLE 3. Multiple correlation coefficients (Mult R) for each step in the multiple regression analyses, and individual correlation coefficients (R) from simple linear regression analyses.

Step	TOP_{max} Variable entered	Mult R	Indiv R	Z_{max} Variable entered	Mult R	Indiv R	VOL_{10} Variable entered	Mult R	Indiv R	VOL_{30} Variable entered	Mult R	Indiv R	VOL_{40} Variable entered	Mult R	Indiv R
No. of cases	25			24			26			26			25		
1	LI_{100}	0.66	-0.66	PW_{850}	0.51	0.51	$WSPD_{700}$	0.59	0.59	LI_{100}	0.58	-0.58	$WSPD_{500}$	0.64	0.64
2	LEV_0	0.77	0.52	$WSPD_{700}$	0.56	0.31	LI_{100}	0.76	-0.44	$WSPD_{500}$	0.70	0.55	TTI	0.73	0.54
3	$WDIR_{700}$	0.79	-0.27	$WDIR_{500}$	0.59	-0.28	WSHEAR	0.78	-0.15	$WDIR_{500}$	0.74	-0.23	LEV_0	0.74	0.32
4	WSHEAR	0.81	0.31	LEV_0	0.61	0.23	$WDIR_{500}$	0.78	-0.37	LEV_0	0.77	0.26	$WDIR_{300}$	0.77	0.07
5				$WDIR_{850}$	0.62	-0.21	LEV_{-20}	0.78	-0.25	$WDIR_{850}$	0.79	-0.04	WSHEAR	0.78	0.05

Step	$AREA_{10}$ Variable entered	Mult R	Indiv R	$AREA_{30}$ Variable entered	Mult R	Indiv R	$AREA_{40}$ Variable entered	Mult R	Indiv R	$RVOL_{MP}$ Variable entered	Mult R	Indiv R	$RRATE_{MP}$ Variable entered	Mult R	Indiv R
No. of cases	26			25			25			23			25		
1	$WSPD_{700}$	0.62	0.62	$WSPD_{700}$	0.68	0.68	$WSPD_{700}$	0.55	0.55	$WSPD_{700}$	0.73	0.73	$WSPD_{300}$	0.55	0.55
2	T_{sfc}	0.68	-0.47	LI_{100}	0.73	-0.26	TTI	0.71	0.45	LI_{100}	0.82	-0.35	TTI	0.69	0.50
3	LI_{100}	0.75	-0.23	T_{sfc}	0.77	-0.39	LEV_0	0.74	0.27	WSHEAR	0.82	-0.19	$WDIR_{700}$	0.74	-0.15
4	WSHEAR	0.76	-0.35	$WDIR_{700}$	0.78	-0.41	$WDIR_{850}$	0.75	0.01	$WDIR_{700}$	0.83	-0.52	LEV_0	0.79	0.34
5	$WDIR_{500}$	0.77	-0.43	WSHEAR	0.78	-0.23	$WDIR_{700}$	0.76	-0.13	T_{sfc}	0.83	-0.31	$WDIR_{850}$	0.80	-0.21

cases by bringing in the additional three terms was only 0.06 (range 0.01–0.11).

4. Discussion

With the limited number of cases studied, it is impossible to draw firm conclusions from the present investigation. Also, this analysis cannot be generalized without further testing, preferably in the *a priori* framework. However, results of the present study can at least provide evidence for deciding whether or not further investigation is warranted.

Results are quite encouraging. The stability indexes and wind speed variables seem to exert relatively strong influences on the size, intensity and coverage of convective precipitation that can occur. The water vapor-stability terms provide a measure of the moisture available and the overturning potential of the atmosphere. One may conjecture that the upper level wind maxima are associated with the largest values of upper tropospheric divergence (Newton and Palmen, 1963) which when combined with other pertinent meteorological factors can result in large-scale convective activity. Beebe and Bates (1955) hypothesized that upper tropospheric divergence superimposed over low-level moisture, instability and convergence produce severe weather.

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