See Namias article Oct. 1949. M.W.R.

*J. M. 10
450-456*

FORECASTING WINTER PRECIPITATION 36 TO 48 HOURS IN ADVANCE AT DES MOINES, IOWA

An Experiment Using the Prognostic Chart as a Data Source

SIDNEY TEWELES, JR., AND ALBERT L. FORST

Short Range Forecast Development Section, U. S. Weather Bureau, Washington, D. C.

[Manuscript received November 5, 1953]

ABSTRACT

To determine the accuracy with which a precipitation forecast can be made from the features of the prognostic charts currently disseminated, an objective forecast system using only those features has been developed for the Des Moines, Iowa, area. As a means of finding predictors, sets of composite sea level and 700-mb. charts were made up for very dry situations and for situations in which heavy precipitation occurred. In the final system, the various predictors are combined in scatter diagrams to give a forecast, comparable in accuracy with that of the district forecast, of the occurrence of precipitation at Des Moines during a 12-hour period beginning 12 hours after the valid time of the 30-hour sea level prognostic chart.

CONTENTS

	Page
Introduction.....	357
Selection of the forecast problem.....	357
Familiarization with the area.....	358
Composite charts.....	358
Development of objective system.....	358
The search for parameters.....	358
The 700-mb. parameters.....	360
The sea level parameters.....	361
Analysis of the scatter diagram.....	362
Forecast categories.....	362
Using the system.....	363
Verification of results.....	363
Quantitative forecasting.....	364
A comparison with the district forecasts.....	364
Application of the forecasts to other stations.....	366
Conclusion.....	366
References.....	367

system was developed using perfect prognostic charts of the surface and 700-mb. level, that is, actual weather maps but consisting of only those items to be found on currently transmitted prognostic charts. The completed forecast system was tested on an independent series of perfect prognostic charts. This test indicates the degree to which the system is independent of the particular period covered by the charts used in developing the system. A further test was then made using the prognostic charts from the independent series. This test has the purpose of measuring both the skill of the system under actual working conditions and the amount by which the skill drops off due to the lack of identity between features of the actual prognostic and perfect prognostic charts.

The principal aim of this study was to get a measure of the skill that may be attained in forecasting precipitation through the use of prognostic charts. Since we are looking forward to a time when prognostic charts will be made by the electronic computer using numerical methods, the skill of the prognosticator is eliminated as a variable by the use of predictors taken from perfect prognostic charts. There remains the question of how much prognostic charts will ultimately be improved by the use of numerical methods.

SELECTION OF THE FORECAST PROBLEM

Precipitation was chosen as the element to be forecast. The initial problem attempted here was to devise a system of forecasting the precipitation for the daytime hours of one day (0630-1830 cst) from the prognostic charts *valid the previous evening*. This forecast, as issued by the district and local forecasters, is made in the even-

In the last ten years, increasing emphasis has been placed on the use of the prognostic chart as an auxiliary aid to weather forecasting. To improve the quality of the charts, typing and analogue systems, kinematic equations, objective aids, and graphical techniques have been devised. More recently Charney [1] and others have designed mathematical procedures amenable to performance by electronic computers. Such recent efforts to improve prognostic charts have raised the important question of the manner in which predictors derived from prognostic charts may be used in forecasting weather.

The work described here is one of the several studies (for example [2, 3, 4]) in which the prognostic chart is used as a source of predictors upon which the occurrence of some weather element is dependent. In this study, a forecast

ing two days earlier from the 1830 CST surface chart and 0900 CST upper air charts. Available to the forecaster are the prognostic 30-hour surface and 36-hour 700-mb. charts valid the following evening at 1830 and 2100 CST, respectively. It is from these prognostic charts that the data for the method to be described are obtained, although in developing the method actual observed charts (perfect prognostics) for those times were used.

Several parts of the United States were considered in selecting a locality for which to forecast. A study by Bristol on the selection of forecast research problems [5] indicated that forecasting aids would be very useful in the region between the Mississippi River and the Rockies. Des Moines was selected within this region because of its central location within its area of service responsibility.

Some thought was given to working out the system so that it would be applicable to all seasons of the year, but because of the many differences between precipitation-producing situations in the warm and cold months, the system constructed applies only to the months of December, January, and February.

FAMILIARIZATION WITH THE AREA

Familiarization with the precipitation-producing synoptic situations of central Iowa was aided by lists, made for each of the 4 seasons, of 10 dates on which large amounts of precipitation occurred within the selected 12 hours and 10 dates on which there was no precipitation in the Des Moines area. For this purpose 3 months were assigned to each season, e. g., "winter" consists of December, January, and February. In order that the no-precipitation dates should represent exceptionally dry conditions, it was further specified that there be no precipitation in the entire State on that date and none at Des Moines for at least 2 days before and after. Most of the dry days were actually in periods of severe drought. Cases were selected, not from the entire period of record, but only from the period since November 13, 1945, for which map data are available on punched cards.

Although examination of the individual maps was of value in learning to recognize weather potentialities, the possibility remained that important indications beyond the immediate vicinity of the forecast area would go unnoticed. For this reason, the 8 lists of 10 dates described above were submitted to the Weather Bureau's Machine Tabulation Unit where punched cards containing sea level pressure data at 1830 CST and 700-mb. height data at 2100 CST for the western half of the Northern Hemisphere were processed to get average pressure and height values from which composite sea level and 700-mb. charts, for dry and precipitation situations were plotted and analyzed.

COMPOSITE CHARTS

The composite charts for the winter season are shown in figures 1-4. Several important differences between the dry and wet situations are apparent. Dry conditions

accompany a strongly developed subtropical high pressure belt between 30° and 40° N., with strong zonal flow from 40° to 55° N., since in this situation, traveling cyclones with their attendant precipitation pass north of the Des Moines area. Heavy precipitation is preceded by a trough aloft west of Des Moines; surface Lows move in from the southwest but pass to the south of the city.

The composite charts can be treated in various ways to bring out their essential differences. Although some differences, such as the path of contours running from Des Moines to the west or the strength of the westerly currents through northern Washington and Montana, are evident at a glance, a more objective means is necessary to bring out the more subtle differences between the two sets of charts. For this purpose the following auxiliary charts were prepared:

- Pressure difference (fig. 5) and height difference (fig. 6) between dry and precipitation composites. Isopleths of the pressure (or contour) difference form a pattern which may be studied to find axes along which the pressure (or contour) gradient difference between charts is a maximum.
- Relative topography (mean isotherms) and mean flow between sea level and 700-mb. composites. With these charts, the advection patterns of the sea level to 700-mb. layer may be compared.
- Sea level and 700-mb. composites of the charts 24 hours earlier than the initial set of charts.
- Composite pressure and height change in the 24 hours preceding the time of the initial set of charts.

DEVELOPMENT OF THE OBJECTIVE SYSTEM

THE SEARCH FOR PARAMETERS

Initially, the patterns of the sea level and 700-mb. composites and of the auxiliary charts (figs. 1-6) were examined to find parameters related to one or more of the primary precipitation variables: moisture supply, thermodynamic instability, and lifting mechanism. Since only situations of *heavy* precipitation make up the precipitation composites, it was necessary to examine the less homogeneous situations associated with small amounts of precipitation to define additional types of precipitation producers.

The parameters selected are, in general, related to more than one of the primary precipitation variables. This is particularly true in the case of southerly wind components in the lower levels, for not only does the principal moisture source lie to the south, but also southerly winds tend to occur with approaching troughs with whose eastern portions are associated convective instability and several types of lifting mechanism. The lifting mechanism may be upglide of the warm moist air over a slower moving cold airmass, sudden lifting of the warm moist air by a cold front, the pre-frontal squall line, or quite often some less definable process such as might be associated with a great field of divergence in the high levels of the troposphere with upward motion between it and a compensating field of convergence in the lower levels. As shown by Klein [2]

FIGURE 1.—Composite sea level pressure chart for ten winter cases of heavy 12-hour precipitation at Des Moines, Iowa. Isobars are labeled in millibars, hundreds omitted. State of Iowa is indicated by shading.

FIGURE 2.—Composite sea level pressure chart for ten winter cases of dry conditions at Des Moines, Iowa. Isobars are labeled in millibars, hundreds omitted. State of Iowa is indicated by shading.

FIGURE 3.—Composite 700-mb. chart for ten winter cases of heavy 12-hour precipitation at Des Moines (same cases used for fig. 1). Contours are in hundreds of feet. State of Iowa is indicated by shading.

FIGURE 4.—Composite 700-mb. chart for ten winter cases of dry conditions at Des Moines (same cases used for fig. 2). Contours are in hundreds of feet. State of Iowa is indicated by shading.

FIGURE 5.—Pressure difference chart, in millibars, computed by subtracting sea level pressure on composite charts for dry conditions (fig. 2) from sea level pressure on composite charts for heavy 12-hour precipitation (fig. 1). State of Iowa is indicated by shading.

FIGURE 6.—Height difference chart, in hundreds of feet, computed by subtracting 700-mb. height on composite charts for dry conditions (fig. 4) from 700-mb. height on composite charts for heavy 12-hour precipitation (fig. 3). State of Iowa is indicated by shading.

and Riehl [6] conditions favorable for precipitation are most likely to be found in the portion of an upper-level wave pattern from the trough line eastward to the next ridge.

The difficulty of the forecasting problem in this area is increased by the fact that, especially in winter when the mean westerly component over the Iowa area is large, the State is often in the rain shadow of the mountain ranges to the west. Very often the flow in the lower levels does originate in the Gulf of Mexico area but the very storm whose approach brings the necessary lifting mechanism drives before it a large mass of dehydrated air, effectively deflecting to the east of Des Moines the tongue of moist air flowing from the south. Precipitation then tends to break out along and beyond a northeast-southwest line not very far to the east of Des Moines. This line separating the area having little or no precipitation from the area of heavier precipitation is usually so well marked that we refer to it as the "arid line."

Figures 7 and 8 illustrate the array of parameters which at one time or another were tested in this study. The majority of these were selected by careful examination of the various composite charts. Some form of stratification was greatly desired, so the first parameters selected were taken from the areas where the patterns in figures 5 and 6 are most dissimilar.

THE 700-MB. PARAMETERS

Comparison of the 700-mb. composites (figs. 3 and 4) with the aid of the difference chart (fig. 6) shows that heavy precipitation at Des Moines is associated with southerly wind components in the area from the Continental Divide to the Mississippi River, while dry conditions tend to occur when there is west-northwesterly flow in that area and a ridge at 120° W. These observations suggest that a measure of the wind flow in this area should be useful as a predictor.

FIGURE 7.—Map of sea level parameters used in the system or tested during the investigation. Joined points indicate pressure difference parameters.

The best of the parameters selected from the area are the height differences, Columbia, Mo. minus North Platte, Nebr. $\Delta H_{CBI-LBF}$, and North Platte minus St. Cloud, Minn. $\Delta H_{LBF-STC}$. When combined in a scatter diagram (fig. 10), this pair measures the mean geostrophic wind over the Columbia-North Platte-St. Cloud triangle centered slightly to the west of Des Moines. Parameters complementing rather than duplicating the resolutions of cases attained in figure 10 are difficult to find. Only two of the other upper air parameters tested showed any success in this regard, the height differences Dodge City, Kans., minus Columbia, $\Delta H_{DDC-CBI}$, and Oakland, Calif., minus N (32.5° N., 135° W.)*, ΔH_{OAK-N} . The parameter ΔH_{OAK-N} serves to measure the north-south wind component just off the west coast. Strong north winds in this area are associated with developing trough situations inland which in turn often produce precipitation over Iowa. Strong southerly components just off the west coast, on the other hand, are a clue to the presence of a ridge over the western two-thirds of the United States, and therefore a dry condition over Iowa. At times, however, such a ridge has buried within it a trough at lower latitudes. The height difference $\Delta H_{DDC-CBI}$ is designed to detect such a precipitation producer.

The parameters $\Delta H_{CBI-LBF}$ and $\Delta H_{LBF-STC}$ were combined in a single diagram (fig. 10) with precipitation as the variate plotted within the diagram. An analysis of this diagram according to the method described in the next section results in a family of lines from which may be read off the values of a dependent variable X_2 . In the same way the height differences ΔH_{OAK-N} and $\Delta H_{DDC-CBI}$ were combined in a single scatter diagram (fig. 12) to give values of the dependent parameter X_4 .

*Point N, during the period of the observations used in this study, was the location of Ship N. On December 6, 1953, Ship N was moved to 31° N., 140° W. Therefore, from maps after that date the 700-mb. height for use in determining ΔH_{OAK-N} should be interpolated for the former location.

FIGURE 8.—Map of 700-mb. parameters used in the system or tested during the investigation. Joined points indicate height difference parameters.

THE SEA LEVEL PARAMETERS

From an examination of the sea level composites (figs. 1 and 2) and the difference chart (fig. 5) a number of pressures and pressure differences were selected, again from areas of greatest flow difference. These parameters were tested against the observed precipitation to find those which not only are most closely related to precipitation occurrence but which also tend to *add* information to that already obtained from the 700-mb. parameters.

The pressure differences Wichita, Kans. minus Columbia, Mo. $\Delta P_{ICT-CBI}$, and Columbia minus Duluth, Minn. $\Delta P_{CBI-DLH}$, which when combined in a scatter diagram (fig. 9) give an indication of the mean surface wind over the Wichita-Columbia-Duluth triangle, were found to be the most helpful of the sea level parameters. However, each of these two pressure differences has a special significance. $\Delta P_{ICT-CBI}$ is a timing, or "cut-off", parameter testing whether a storm is approaching or is no longer a threat. $\Delta P_{CBI-DLH}$, on the other hand, is an indirect measure of the slope of the isentropic surfaces between Columbia and Duluth. Analysis of this scatter diagram results in a family of curves of the variable X_1 .

A second pair of sea level parameters, the pressure at

Amarillo, Tex. P_{AMA} , and the pressure difference between Brownsville, Tex. and Amarillo, $\Delta P_{BRO-AMA}$, is used to give the values of the dependent variable X_2 (fig. 11). The parameter P_{AMA} , tends to measure the seriousness of the threat southwest of Des Moines, while $\Delta P_{BRO-AMA}$ serves to diminish this value in the case of excessive westerly components.

Parameters X_1 and X_2 were combined (fig. 13Y₁) to give another dependent variable Y_1 , essentially a function of the surface and the 700-mb. wind over the Des Moines area.

X_3 and X_4 were also combined (fig. 13Y₂) to allow evaluation of another dependent variable Y_2 , which is a rough measure of a wave pattern aloft and the availability of moisture in the lower layers. A last combination was made of Y_1 and Y_2 as dependent parameters, again with precipitation as the plotted variate, to form the Z chart (fig. 14).

The use of one more sea level parameter, the pressure difference between Columbia and Huron, N. Dak. $\Delta P_{CBI-HON}$, is required to resolve the cases falling into the Q area of the Z chart. This parameter is an additional measure of the surface wind over the Iowa area.

FIGURE 9.—Work Chart: X_1 . Ordinate is the sea level pressure difference, Wichita, Kans. minus Columbia, Mo.; abscissa, sea level pressure difference, Columbia, Mo. minus Duluth, Minn. Values of X_1 less than 20 (heavy line) indicate a no-precipitation forecast provided X_2 (fig. 10) is less than 40. Dot=no precipitation; T=trace. Observed 12-hour precipitation amounts are in hundredths of an inch. The fractions between parametric lines are ratios of precipitation cases to total cases within the two lines.

FIGURE 10.—Work Chart: X_2 . Ordinate is the 700-mb. height difference Columbia, Mo. minus North Platte, Nebr.; abscissa, 700-mb. height difference, North Platte, Nebr. minus St. Cloud, Minn. Values of X_2 less than 20 (heavy line) indicate a no-precipitation forecast. Dot=no precipitation; T=trace. Observed 12-hour precipitation amounts are in hundredths of an inch. The fractions between parametric lines are ratios of precipitation cases to total cases within the two lines.

ANALYSIS OF THE SCATTER DIAGRAM

On each of the scatter diagrams a family of curves numbered by tens from 10 to 90 has been drawn subjectively but with attention to a large amount of detail. Not only were precipitation amounts for the proper 12-hour period entered on the working charts but also the following information:

1. Amounts occurring in the 6 hours preceding and/or following the period.
2. Amounts occurring in the proper period at certain stations within 50 miles of Des Moines.
3. Additional cases in which amounts of more than 0.25 inch occurred in months of November and March adjacent to the winters of the dependent sample.

Both the percentage of precipitation reports and the presence of large amounts were considered in analyzing the charts. Although the values assigned to the parametric lines do not have a precise physical meaning, they are arranged so that the higher values correspond in general to a greater probability of precipitation and to a greater probable amount. The values assigned to the parametric lines on the four X charts (figs. 9-12) have approximately the same meaning with respect to precipitation occurrence. On the two Y charts (fig. 13) the overall percentage of precipitation is higher than on the X charts and the values of the parametric lines correspond to somewhat higher percentages and amounts of precipitation. Attempts made to analyze the charts with families of lines defined with respect to just one type of

FIGURE 11.—Work Chart: X_3 . Ordinate is the sea level pressure at Amarillo, Tex.; abscissa, sea level pressure difference, Brownsville, Tex. minus Amarillo. Values of X_3 less than 20 (heavy line) indicate a no-precipitation forecast. Dot=no precipitation; T=trace. Observed 12-hour precipitation amounts are in hundredths of an inch. The fractions between parametric lines are ratios of precipitation cases to total cases within the two lines.

precipitation statistic showed little promise because of the low frequency of precipitation at Des Moines and the resulting sparse distribution of precipitation on the charts.

FORECAST CATEGORIES

From the analyzed scatter diagram, parametric values for each case were extracted and compared with observed precipitation to establish limits for the necessary forecast categories. To facilitate the bookkeeping required, the symbols N_1 are used to indicate no-precipitation forecasts and R_1 , precipitation forecasts. Requirements for definitions of the categories follow.

$$N_A: X_1 < 20 \text{ and also } X_2 < 40$$

$$N_B: X_2 < 20$$

$$N_C: X_3 < 20$$

$$N_D: X_4 < 20$$

$$N_E: X_1 < 59 \text{ for all } i$$

$$R_1: Y_1 \geq 65 \quad R \text{ area of } Z \text{ chart}$$

$$R_2: Y_2 \geq 65 \quad R \text{ area of } Z \text{ chart}$$

$$N_Z: N \text{ area of } Z \text{ chart}$$

$$N_Q: Q \text{ area of } Z \text{ chart and } \Delta P_{\text{CBI-HON}} > 0$$

$$R_Q: Q \text{ area of } Z \text{ chart and } \Delta P_{\text{CBI-HON}} \leq 0$$

FIGURE 12.—Work Chart: X_4 . Ordinate is the 700-mb. height difference Dodge City, Kans. minus Columbia, Mo.; abscissa, 700-mb. height difference, Oakland, Calif. minus N, 32.5°N , 135°W . (former location). Values of X_4 less than 20 (heavy line) indicate a no-precipitation forecast. Dots=no precipitation; T=trace. Observed 12-hour precipitation amounts are in hundredths of an inch. The fractions between parametric lines are ratios of precipitation cases to total cases within the two lines.

The relative frequency with which precipitation occurred in these categories for both dependent and test data is given in table 1.

USING THE SYSTEM

The steps leading to a forecast are summarized in figure 15. Sea level pressures for Wichita, Columbia, Duluth,

Brownsville, Amarillo, and Huron and 700-mb. heights for Columbia, North Platte, St. Cloud, Oakland, point N (32.5°N , 135°W), and Dodge City must be interpolated from the prognostic charts. For more than one-third of the cases, a forecast of N_1 ($i=A, B, C, D$ or E) is given by the value of one or more of the X parameters and the process need be carried no further. The R_1 and R_2 forecasts (about one-eighth of all cases) follow directly from the values of the Y parameters. About one-half of all the cases must be carried into the Z chart.

Figure 16 is a sample work sheet illustrating the manner in which the data can be arranged for daily use and monthly tabulation. Some of the steps are omitted when the forecast is reached at an early stage.

VERIFICATION OF RESULTS

Two of the more usual scores used in verifying forecasts are the percentage correct and the skill score. Although both of these scores have certain advantages each has serious deficiencies when used in testing systems such as this. The percentage correct has the disadvantage of being deceptively high in the regions where precipitation is infrequent. For example, if one forecasts no precipitation for every one of the 722 winter daytime periods included in this study, his score will be 85 percent correct. Since, in the Iowa area, a forecaster does well if precipitation occurs on just half of those days on which he forecasts it, it will be seen that even this good forecaster will end up with a score of 85 percent correct. The use of the percentage correct diminishes his incentive to try anything but a no-precipitation forecast. But the skill score

FIGURE 13.—Work Charts: Y_1 and Y_2 . Ordinates are X_1 and X_3 , and abscissae, X_2 and X_4 , respectively. Shaded areas indicate values which were previously eliminated as no-precipitation forecasts on the basis of individual X_i . Dot=no precipitation; T=trace. Observed 12-hour precipitation amounts are in hundredths of an inch. The fractions between parametric lines are ratios of precipitation cases to total cases within the two lines.

FIGURE 14.—Work Chart: Z. Ordinate and abscissa are Y_1 and Y_2 respectively. The N area indicates a no-precipitation forecast; the R area, a precipitation forecast. The Q area indicates a precipitation forecast unless $\Delta P_{CB1-HON}$ is greater than zero. Dot = no precipitation, T = trace. Observed 12-hour precipitation amounts are in hundredths of an inch. Fractions are ratios of precipitation cases to total cases within each area.

FIGURE 15.—System organization chart. "P" indicates sea level pressure; "H", 700-mb. height. Other symbols indicate values and forecasts explained in the text.

also has its deficiencies as pointed out by the tests of our system. For example, if precipitation occurs in less than one-fourth of all cases, the skill score can be increased if certain sections of the scatter diagram are designated as precipitation-forecast areas even though only one out of four of the cases within those areas is actually a precipitation case. Obviously except for specialized purposes no forecaster wishes to forecast rain with only a 25 percent probability of success.

In determining the R and N categories of this system it was desired to have as high a skill score as possible. At the same time, to make the R categories acceptable to the forecaster, the percentage of precipitation cases in these categories was kept above 50. The final percentages for the principal R categories, R_1 and R_2 , indicate a

MONTHLY WORK SHEET
Feb. '53 (Range)

Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
AP	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
CB1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
CB2	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
CB3	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64
CB4	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
CB5	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106
CB6	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127
CB7	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148
CB8	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169
CB9	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190
CB10	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211
CB11	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232
CB12	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253
CB13	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274
CB14	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295
CB15	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316
CB16	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337
CB17	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358
CB18	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379
CB19	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400
CB20	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421
CB21	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442
CB22	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463
CB23	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484
CB24	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505
CB25	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526
CB26	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547
CB27	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568
CB28	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589
CB29	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	607	608	609	610
CB30	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631
CB31	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650	651	652
CB32	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673
CB33	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694
CB34	695	696	697	698	699	700	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715
CB35	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736
CB36	737	738	739	740	741	742	743	744	745	746	747	748	749	750	751	752	753	754	755	756	757
CB37	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778
CB38	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799
CB39	800	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820
CB40	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841
CB41	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858	859	860	861	862
CB42	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883
CB43	884	885	886	887	888	889	890	891	892	893	894	895	896	897	898	899	900	901	902	903	904
CB44	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925
CB45	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946
CB46	947	948	949	950	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967
CB47	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988
CB48	989	990	991	992	993	994	995	996	997	998	999	1000	1001	1002	1003	1004	1005	1006	1007	1008	1009
CB49	1010	1011	1012	1013	1014	1015	1016	1017	1018	1019	1020	1021	1022	1023	1024	1025	1026	1027	1028	1029	1030
CB50	1031	1032	1033	1034	1035	1036	1037	1038	1039	1040	1041	1042	1043	1044	1045	1046	1047	1048	1049	1050	1051
CB51	1052	1053	1054	1055	1056	1057	1058	1059	1060	1061	1062	1063	1064	1065	1066	1067	1068	1069	1070	1071	1072
CB52	1073	1074	1075	1076	1077	1078	1079	1080	1081	1082	1083	1084	1085	1086	1087	1088	1089	1090	1091	1092	1093
CB53	1094	1095	1096	1097	1098	1099	1100	1101	1102	1103	1104	1105	1106	1107	1108	1109	1110	1111	1112	1113	1114
CB54	1115	1116	1117	1118	1119	1120	1121	1122	1123	1124	1125	1126	1127	1128	1129	1130	1131	1132	1133	1134	1135
CB55	1136	1137	1138	1139	1140	1141	1142	1143	1144	1145	1146	1147	1148	1149	1150	1151	1152	1153	1154	1155	1156
CB56	1157	1158	1159	1160	1161	1162	1163	1164	1165	1166	1167	1168	1169	1170	1171	1172	1173	1174	1175	1176	1177
CB57	1178	1179	1180	1181	1182	1183	1184	1185	1186	1187	1188	1189	1190	1191	1192	1193	1194	1195	1196	1197	1198
CB58	1199	1200	1201	1202	1203	1204	1205	1206	1207	1208	1209	1210	1211	1212	1213	1214	1215	1216	1217	1218	1219
CB59	1220	1221	1222	1223	1224	1225	1226	1227	1228	1229	1230	1231	1232	1233	1234	1235	1236	1237	1238	1239	1240
CB60	1241	1242	1243	1244	1245	1246	1247	1248	1249	1250	1251	1252	1253	1254	1255	1256	1257	1258	1259	1260	1261
Forecast	N ₁	N ₂	N ₃	N ₄	N ₅	N ₆	N ₇	N ₈	N ₉	N ₁₀	N ₁₁	N ₁₂	N ₁₃	N ₁₄	N ₁₅	N ₁₆	N ₁₇	N ₁₈	N ₁₉	N ₂₀	N ₂₁
Observed	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O

TABLE 1.—Category statistics, contingency tables, skill scores, and percent correct for (1) development data, (2) test using "perfect" prognostics, and (3) test using actual prognostic charts. The skill scores given are calculated by the common definition of skill over chance

Development cases, December 1945, December, January, February 1946-49

Forecast group	Total cases	No rain or trace	Measurable rain										Observed	Forecast		
			Number of cases	Percent of total cases	0.01-0.09 inches		0.10-0.24 inches		0.25-0.49 inches		≥0.50 inches			Rain	No rain	Total
					Number	Percent	Number	Percent	Number	Percent	Number	Percent				
NABCD---	63	63	0	0												
NE-----	73	73	0	0												
Nz-----	113	100	13	12	11	10	2	2								
NQ-----	34	30	4	12	1	3	2	6	1	3						
R1-1-----	45	20	25	56	9	20	8	18	2	5	6	13				
RQ-----	33	18	15	45	12	36	1	3	1	3	1	3				

Observed	Forecast		
	Rain	No rain	Total
Rain....	40	17	57
No rain..	38	266	304
Total..	78	283	361
Skill score: 0.50.			
Percent correct: 85.			

Test cases—perfect prognostics, December 1949, December, January, February 1950-53

													Forecast				
													Rain	No rain	Total		
N _A B _C D----	75	70	5	7	4	6	1	1					Observed	Rain----	35	15	50
N _E -----	63	61	2	3	2	3								No rain--	64	247	311
N _Z -----	88	83	5	6	4	5	0	0	1	1							
N _Q -----	36	33	3	8	2	5			1	3							
R ₁ -----	52	30	22	42	6	11	10	19	4	8	2	4		Total	99	262	361
R _Q -----	47	34	13	27	10	21	2	4	1	2			Skill score: 0.35.				
													Percent correct: 78.				

Observed	Forecast		
	Rain	No rain	Total
Rain....	35	15	50
No rain..	64	247	311
Total..	99	262	361
Skill score: 0.35.			
Percent correct: 78.			

Test cases—actual prognostics, December 1949, December, January, February 1950-53

														Forecast				
														Rain	No rain	Total		
NABCD---	57	47	10	18	9	16	1	2						Observed	Rain....	15	35	50
NE-----	66	63	3	5	3	5									No rain..	64	257	311
Nz-----	125	110	15	12	5	4	5	4	4	3	1	1			Total..	69	292	361
NQ-----	44	37	7	16	3	7	3	7	1	2					Skill score: 0.11.			
R1-----	36	27	9	25	6	17	2	5	0	0	1	3			Percent correct: 75.			
RQ-----	33	27	6	18	2	6	2	6	2	6								

Observed	Forecast		
	Rain	No rain	Total
Rain....	15	35	50
No rain..	64	257	311
Total..	69	292	361
Skill score: 0.11.			
Percent correct: 75.			

TABLE 2.—Comparison of objective and district forecasts for about eight of the test months

Forecast used	Verifying by precipitation at Des Moines, 0600-1800 cst					Verifying by precipitation at Des Moines midnight to midnight, or at stations within 35 miles, 0600-1800 cst			
		Forecast		Skill score	Percent correct	Forecast		Skill score	Percent correct
		Rain	No rain			Rain	No rain		
Objective forecast for 0600-1800 cst day after tomorrow; latest data 1230 cst surface chart.	Rain..... No rain.....	10 40	24 162	} 0.08	73	15 35	43 143	} 0.06	67
District forecast for 0600-1800 cst day after tomorrow; latest data 1830 cst surface chart.	Rain..... No rain.....	10 42	24 160			} 0.07	72		
District forecast for 0600-1800 cst tomorrow; latest data 1830 cst surface chart.	Rain..... No rain.....	14 31	21 172	} 0.22	78			24 21	36 157
Objective forecast for 0600-1800 cst tomorrow; latest data 2100 cst 700-mb. chart.	Rain..... No rain.....	26 51	9 162			} 0.33	75	37 40	23 138
District forecast for 0600-1800 cst today; latest data 0030 cst surface chart.	Rain..... No rain.....	24 35	11 170	} 0.40	81			35 24	25 156

quarter of the State, statements about the weather for the entire State, or for the central, the south, the west, or the southwest portions, were taken as applying to Des Moines.

Any forecast in which no mention was made of precipitation other than drizzle or flurries was taken as a no-precipitation forecast. All others were interpreted as requiring measurable precipitation for verification. Two classes of precipitation occurrence were recognized: (a) A measurable amount (>0.005 inch) at Des Moines in the 12-hour period 0600 to 1800 cst; (b) A measurable amount at Des Moines anytime in the 24-hour period from midnight to midnight, or within the 12-hour period 0600-1800 cst at any two of four Iowa stations—Ames, Dexter, St.

Charles, and Knoxville—within 35 miles of Des Moines. This latter gives the forecaster credit for near misses in space and time.

Because of the rapid decay of verification scores with time, the difference in time projection between the official forecasts and the forecasts made by the system should be taken into account. In making the forecasts for the day after tomorrow, the district forecaster has before him the surface map for 1830 cst. In contrast, the last chart available in making the prognostic chart used by the objective system is that for 1230 cst. The district forecasts for tomorrow, in table 2, bracket the objective forecast with which they are compared, in the one case by being made without use of the 2100 cst 700-mb. chart and

in the other case by having the advantage of information on the 0030 csr surface chart.

It can be seen in table 2 that the variation in the scores is definitely a function of the projection time of the forecast. There is little to indicate a significant difference between the objective method and the district forecast except perhaps when credit is given for near misses. However, this alternative definition of the occurrence of precipitation was made on the recommendation of a district forecaster as a means of giving credit for what the forecaster feels is a satisfactory job done when the projection time is as long as 36–48 hours. It is quite likely that his forecast is designed with such a definition in mind while the objective system is specifically designed to forecast only for the 12-hour period at Des Moines.

Thus we reach the same conclusion as that of most other objective forecast studies. It is possible to devise an objective forecast system, based on a small number of fairly crude parameters, that will attain very nearly the same degree of success as that of an experienced and able forecaster, but it is difficult, even with a very complex system, to exceed his record in the mean. This is particularly true if the forecaster is aware of the principles upon which the system is based.

APPLICATION OF THE FORECASTS TO OTHER STATIONS

There often arises the important question of how large an area is really being forecast for successfully by a system which, like this one, depends on parametric data from stations far from the point of the forecast. One might also ask whether the point for which the system was designed lies in the center of the area and, if not, whether there is not some other point nearer the center for which the system forecasts with greater skill. It was relatively simple to verify the forecasts of precipitation for Des Moines against the precipitation observed at surrounding stations. A first group of stations was selected and from the results, a second group was added to the list as follows:

<i>First group</i>	<i>Second group</i>
Chicago, Ill.	Indianapolis, Ind.
Moline, Ill.	Madison, Wis.
Minneapolis, Minn.	Omaha, Nebr.
Sioux City, Iowa	Grand Island, Nebr.
Kansas City, Mo.	Wichita, Kans.
St. Louis, Mo.	Oklahoma City, Okla.
	Little Rock, Ark.
	Springfield, Mo.
	Columbia, Mo.

The application of the Des Moines forecasts to other stations indicates a rapid falling off of skill to the north (fig. 17). The skill scores tend to be higher at Moline than at Des Moines, and remain at a high level to the south even as far away as Little Rock.

If the results shown in figure 17 are reliable, we are led to conclude that objective forecast systems may very well cover geographically uniform areas as large as 100,000 square miles. Thus a limited number (perhaps

FIGURE 17.—Skill scores attained at various points in the Midwest when forecasts for Des Moines, made by applying the system to data from perfect prognostic charts for the 12 test months in the period, December 1949 to February 1952, are verified against the precipitation occurring at the indicated stations.

30 or 40) of carefully designed systems could be used to forecast precipitation during a particular period for the entire country.

CONCLUSION

The simplicity of the system and of the parameters involved might make the reader wonder whether better results could not be obtained through some elaboration. Much time was spent in attempting to improve the results by using a variety of parameters from synoptic charts available to the forecaster or taken from the prognostic chart. Although many types of parameters used in other objective methods were tested, their use did not increase the skill already attained. Another question might arise with respect to the omission of parameters from upper levels other than 700 mb. It was thought inadvisable to use parameters from prognostic charts which, like those for the 500-, 400-, 300-, and 200-mb. levels, have been constructed for only short, irregular periods, because the skill of such parameters could not be adequately tested.

The primary aim of this work was to find a means by which the features of the prognostic charts currently issued could be used to forecast precipitation. That the flow pattern can have such an ability has been demonstrated, at least with the perfect prognostic. However, the fact that the skill score of the system diminishes so greatly when it is tested upon actual prognostics, indicates that the average skill of prognosticators is not great enough

at present to allow optimum use of a system such as this. There are several ways in which prognostic charts may be improved. Among these are more careful selection and training of prognosticators, and improvement of the methods they utilize.

As matters now stand, the skill of the system when tested upon parameters taken from actual prognostics is sufficiently mediocre to suggest that it might be more expedient to bypass the prognostic chart by using parameters taken from the maps available to the forecaster at the time he is making his forecast. This is the type of objective technique used by Schmidt [7, 8] in several recent papers. After such a system had been developed to its fullest extent, an attempt could be made to improve the results by applying parameters taken from prognostic charts available to the forecaster. In this way, at least the main portion of the system would not be affected by the uncertainties of the prognostic procedure.

At present it seems likely that the most promising means of improving the prognostic chart is through the use of numerical methods now being developed to solve physical equations with the aid of the electronic computer. Since the product of numerical methods may be in the form of the future distribution of quantities such as vertical motion directly associated with the precipitation process, it is not unlikely that the precipitation forecast of the future will be completely objective—produced by the computer directly from the raw data.

REFERENCES

1. J. G. Charney, "Dynamic Forecasting by Numerical Process," *Compendium of Meteorology*, American Meteorological Society, Boston 1951, pp. 470–482.
2. W. H. Klein, "An Objective Method of Forecasting Five-Day Precipitation for the Tennessee Valley," U. S. Weather Bureau, *Research Paper No. 29*, April 1949, 60 pp.
3. L. P. Carstensen, and A. V. Hardy, Relation of Precipitation to the Pressure Pattern in New York City Area in Winter, U. S. Weather Bureau, 1951. (Unpublished.)
4. C. L. Bristor, Relating Prognostic Charts to Winter Precipitation at Sioux City, Iowa, U. S. Weather Bureau, 1952. (Unpublished.)
5. C. L. Bristor, Selecting Research Problems for Forecast Improvement, U. S. Weather Bureau, 1952. (Unpublished.)
6. H. Riehl et al. "Forecasting in Middle Latitudes," *Meteorological Monographs*, vol. I, No. 5, American Meteorological Society, June 1952.
7. R. C. Schmidt, "A Method of Forecasting Occurrence of Winter Precipitation Two Days in Advance," *Monthly Weather Review*, vol. 79, No. 5, May 1951, pp. 81–95.
8. R. C. Schmidt, "A Method of Forecasting Precipitation 28–40 Hours in Advance During October," *Monthly Weather Review*, vol. 79, No. 6, June 1951, pp. 116–124.