An Analogue Method for Weather Forecasting Using the 500/1000 mb Relative Topography

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ABSTRACT

Assuming that the relative topography (RT) 500/1000 mb (thickness pattern, 1000–500 mb) is more conservative than other meteorological variables used for weather forecasting by the analogue method, the RT 500/1000 mb properties have been investigated. On the basis of a number of experiments performed, it is concluded that both the extended and the long-range weather forecasts made using RT 500/1000 mb analogues could have a practical usefulness. An operational method of making such forecasts is formulated.

1. Introduction

It has been noticed that weather patterns over certain areas and over the entire Northern Hemisphere tend to repeat themselves from time to time. Using this property of the atmosphere, classification of the macroweather situations over Europe was made by Baur (1948); this classification was developed further by Hess and Brezovski (1952). Namias (1951) and his colleagues have formulated a four-stage cycle of the general circulation indexes in the atmosphere.

These, as well as some other similar studies, led a number of authors to investigate the possibilities of improving weather forecasts by the analogue method. The method is based on the assumption that the general circulation of the atmosphere is a unique physical mechanism whose course of development is continual and dependent on the given initial conditions. Thus, if two similar weather situations are found on the weather chart records, future development of the weather situations should be similar. This means that if a good analogue can be found for the current weather chart, the weather forecast for a given period of time is to be obtained by reading directly from the series of the previously observed weather charts.

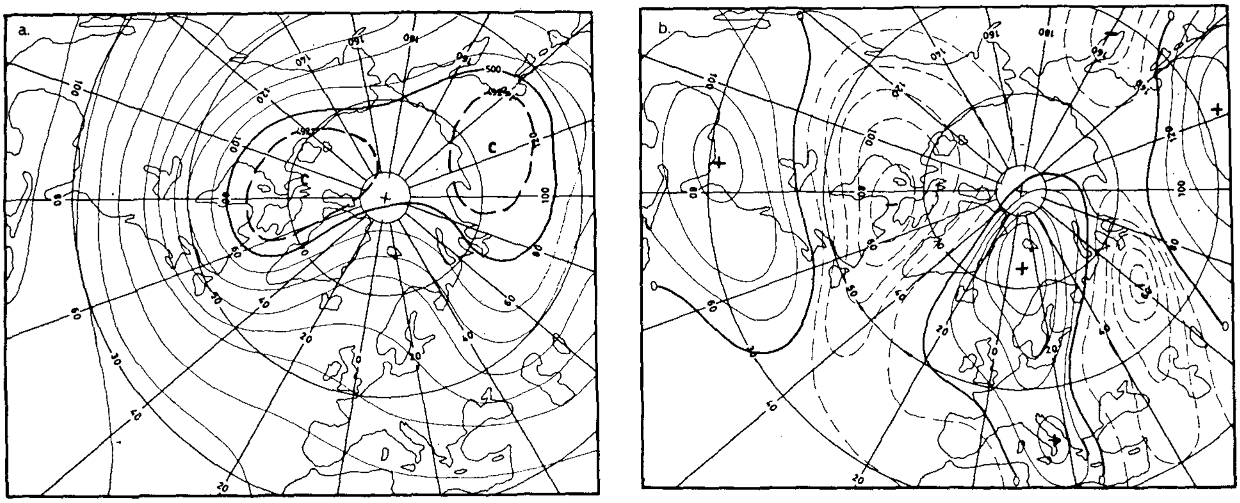
From the theoretical standpoint, the analogue method has limited possibilities, since the analogue chart one finds is still going to differ from the current observed chart. However, it is very practical as a quick, cheap, and objective way to issue weather forecasts in which orographic, diabatic, and other local influences are included. The analogue method and its study are especially useful when dealing with both extended-range and long-range weather forecasts, considering that dynamic methods have so far been successfully applied for short-range (1 to 3 days) predictions and as guidance for extended-range (3 to 5 days) weather forecasts (Shuman and Hovermale, 1968).

In the past, several analogue methods have been formulated, being different in their basis or by their method of analogue selection. Both within the Meteorological Services in the United States and in the Federal Republic of Germany, sea-level pressure distribution was used as the analogue basis (Namias, 1951). The shape, intensity, and other characteristics of the centers of action were used in France (Grappe, 1953). In Norway, the speed and direction of fronts, and air mass movements with respect to a fixed point, were the basis for the analogue (Grytöyr, 1950). In England, monthly analogues of the surface temperature and other parameters were used (Ratcliffe, 1973).

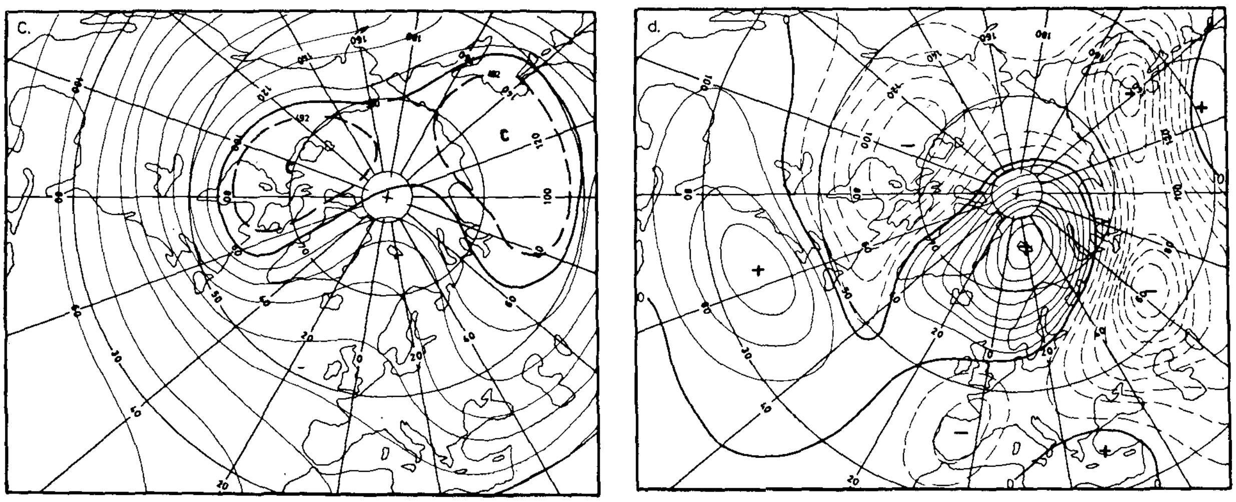
A common characteristic of these analogue methods was a relatively great variability, in space and time, of the variable chosen as the basis for analogues. The results and the experience gained by Similä (1957) within the Swedish Meteorological and Hydrological Institute were very useful to us in our search for a more stable basis for analogue selection.

When studying the distribution and quantity of cold air over certain sectors of the Northern Hemisphere, Similä noticed that some patterns of the RT 500/1000 mb (relative topography, i.e., thickness pattern, 1000–500 mb) on hemispheric charts often reflect basic characteristics of the general circulation of the atmosphere, and that these are rather stable. This is evident from the following examples which illustrate the stability of the long-range relative topography trends.

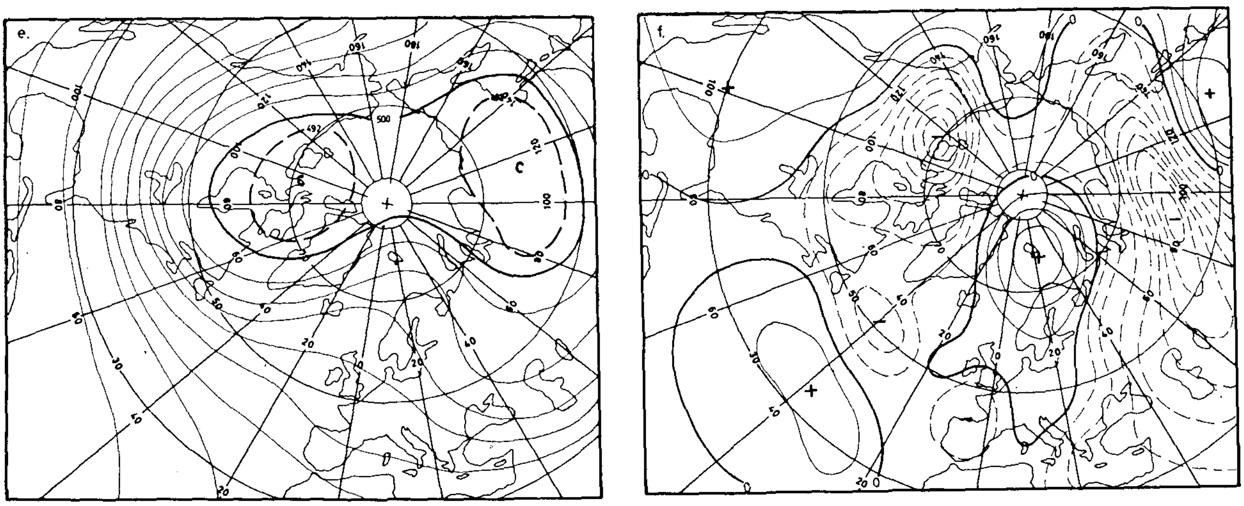
In Fig. 1 the polar cap at every 15 days of the period from 15 December 1971 to 28 February 1972 is represented on the RT mean monthly charts. In this case, the polar cap has two cold centers—one over Siberia and the



15 DECEMBER 1971 TO 15 JANUARY 1972



JANUARY 1972



15 JANUARY 1972 TO 15 FEBRUARY 1972

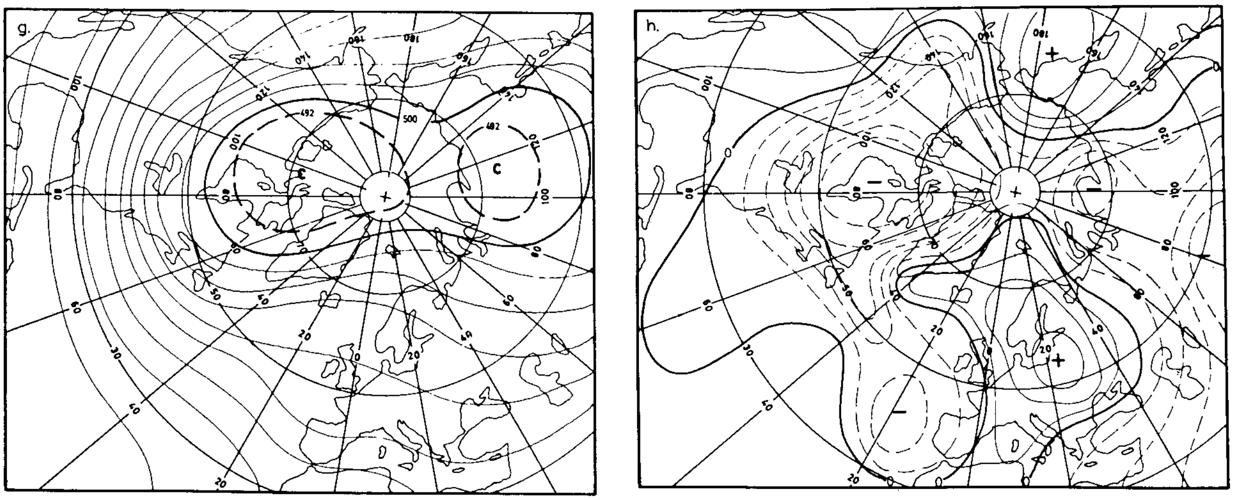


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FIG. 1. Mean monthly 1000–500 mb thickness (a, c, e, g) and thickness anomaly (b, d, f, h) charts for period mid-December 1971 through February 1972.

other over Canada. For such a shape of the polar cap, the wave type of the general circulation is characteristically that of the low index circulation state.

Another characteristic polar thermal pattern is the presence of one cold center over the area of the Pole. To illustrate this shape the period from 15 December 1962 to 28 February 1963 was taken; the charts are shown in Fig. 2. When such a pattern is present, the general circulation of the atmosphere has a predominantly zonal character, i.e., it is of the high index type.

Besides the two types mentioned, the polar circulation can have an eccentric position in relation to the Pole. Thus, a pattern with the center over Siberia, which represents domination of the Siberian cold air center (Fig. 3), can appear.

Under domination of the Siberian cold air center, a meridional circulation is maintained with a very large trough over the Eurasian continent. The zonal type of circulation prevails, at the same time, over the western half of the Northern Hemisphere, with a polar front located far north of the normal position.

The other case of the eccentric position is when the center of cold air appears over Canada (Fig. 4).

The characteristic of the cold air polar pattern on the RT 500/1000 mb mean monthly charts is very persistent and can clearly be noticed on the mean 5-day charts and even on some of the daily weather charts of the periods considered. This indicates that the large scale distribution of the cold air over the Northern Hemisphere has a considerable inertia and may be so persistent as to influence the values of the mean meteorological elements over certain areas for periods longer than one month.

2. Basis and technique of the method

When the Division for Extended-Range Weather Forecasting within the Federal Hydrometeorological Institute was set up in 1959, an archive of RT 500/1000 mb charts for the Northern Hemisphere was established, to be used as the basis of the analogue method. Thus, a number (9131) of daily (0000 GMT), RT 500/1000 mb charts (scale 1:50 000 000) were prepared, covering the period from 1 January 1949 to 31 December 1973.

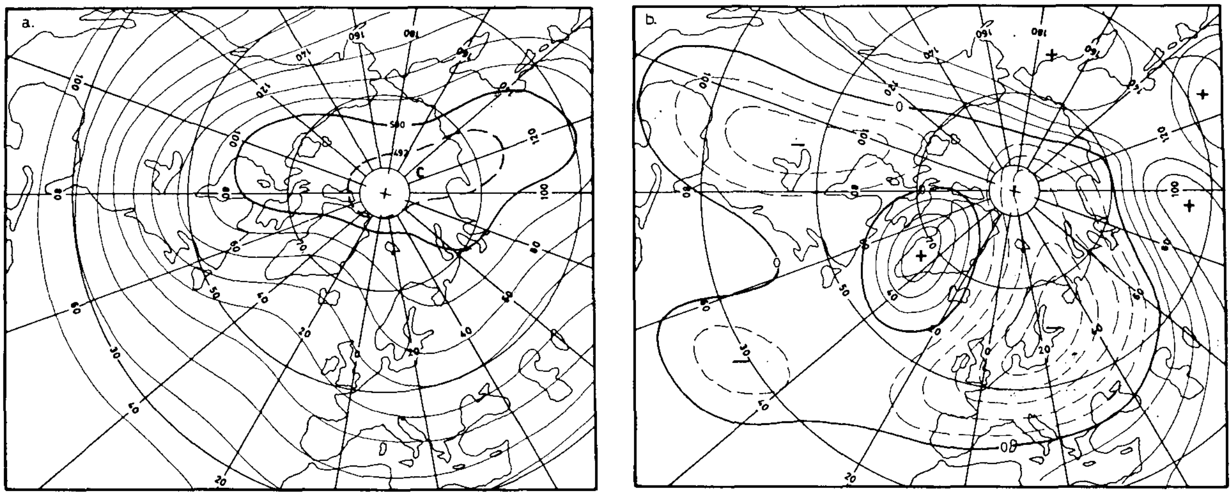
In order to obtain the RT 500/1000 mb mean chart records and to follow continuously the long-range trends, a series of overlapping mean charts of various lengths centered on successive days was computed. In this way, 9127 5-day, 9122 10-day, 9117 semi-monthly, and 9102 mean monthly charts for the 25-year period were obtained.

The introduction and development of the above mentioned analogue method was based on the following premises:

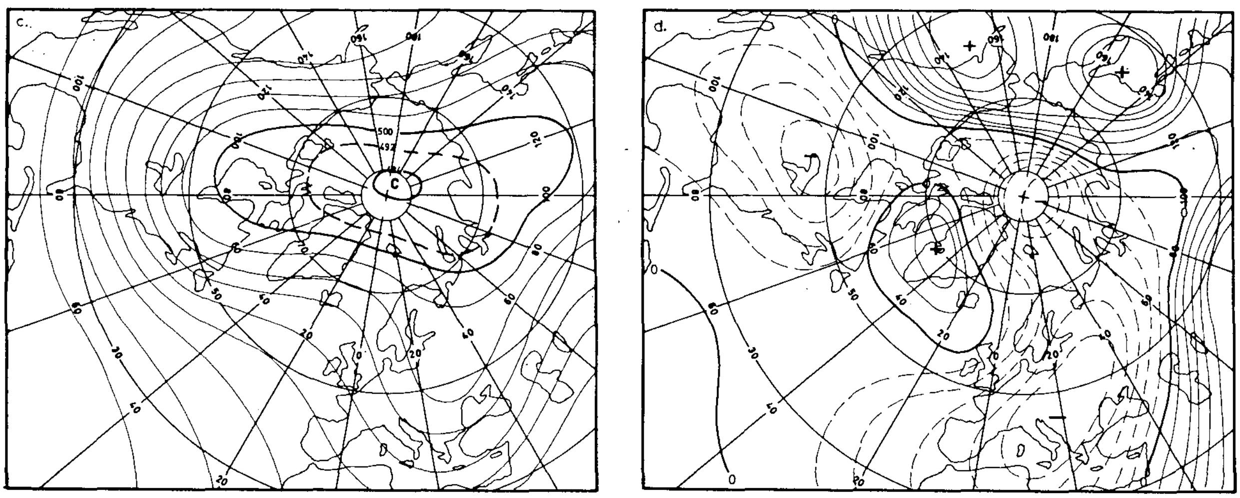
1) That the RT 500/1000 mb value (which represents the thermal state of the lower half of the atmosphere expressed by a mean temperature of the layer) is less variable, in space and time, than the surface temperature, sea-level pressure, absolute 500 mb topography and other meteorological variables used so far as the basis of the analogue method.

2) That the patterns of the RT 500/1000 mb charts are closely connected with the type of the general circulation of the atmosphere and with the general character of the weather over a given area.

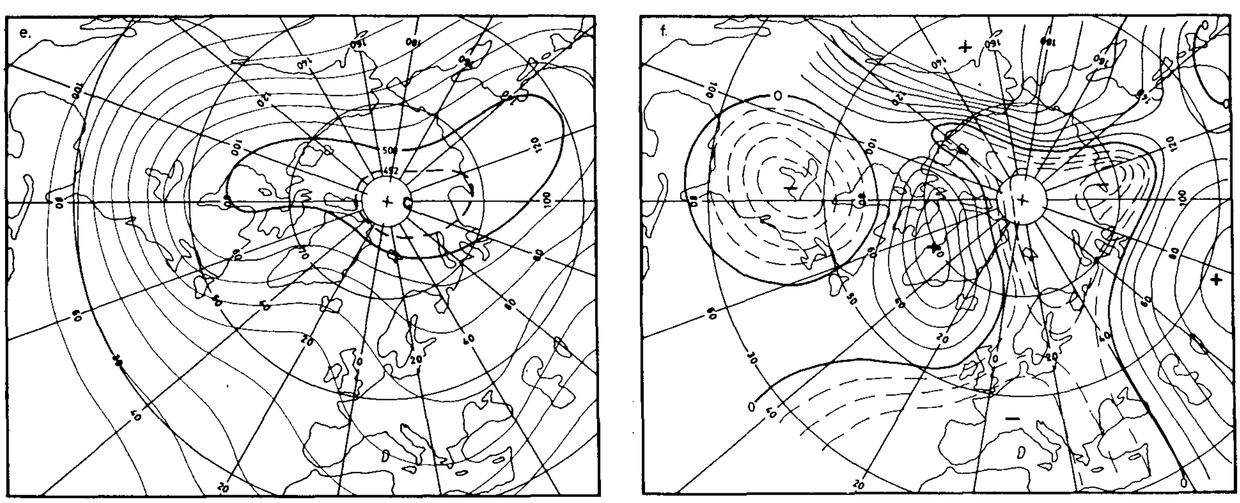
On the basis of these premises, it was considered that the RT 500/1000 mb can better serve for weather fore-



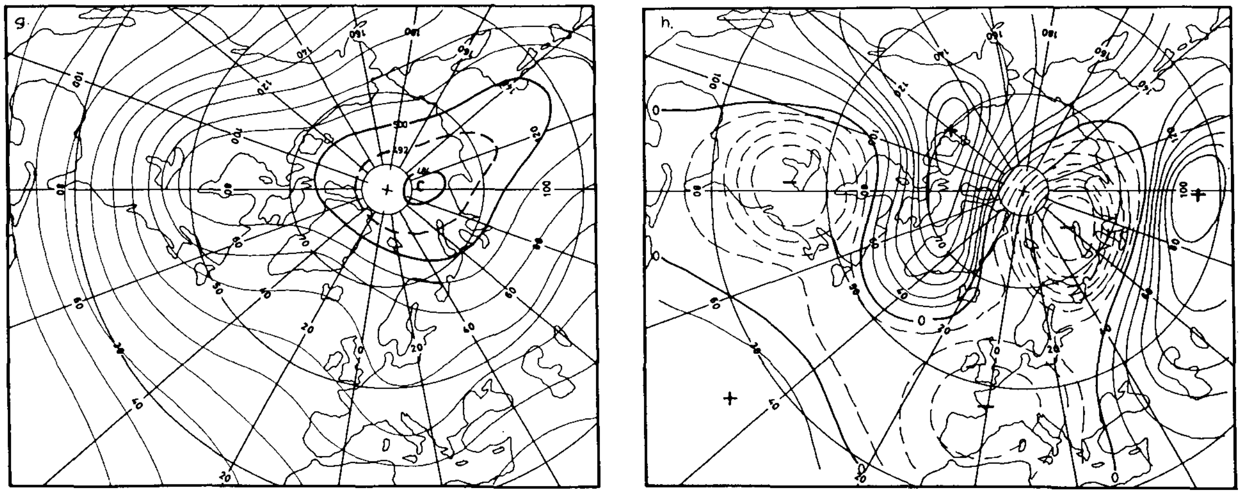
15 DECEMBER 1962 TO 15 JANUARY 1963



JANUARY 1963



15 JANUARY 1963 TO 15 FEBRUARY 1963



FEBRUARY 1963

FIG. 2. As in Fig. 1, for period mid-December 1962 through February 1963.

casting, based on the analogue method, than other meteorological elements used so far.

To check the possibilities of the method, a technical procedure for its application was formulated and an experiment consisting of four different tests was made. The technique was defined to be as follows:

1) The Northern Hemisphere is covered with a rectangular grid consisting of 120 equidistant points.

2) Daily, 5-day, 10-day, semi-monthly, and monthly RT deviations from the normal values are computed at all points of the grid.

3) Comparing the anomalies within the grid on the current chart with these anomalies of the chart records, the selection of the best analogue is made. The method used for that selection will be explained in more detail later.

4) When the best analogue for the current chart is chosen, a weather forecast is issued, consisting of forecast elements identical to these that followed the chosen analogue.

3. Correlation of the randomly chosen RT charts

One each of the daily, 5-day, 10-day, semi-monthly, and monthly RT charts was selected at random for each calendar month from the period of 25 years. These charts were called the reference charts. Then, for each of these reference charts from the same period were selected, at random, 10 charts to be correlated with the reference charts. In this way the number of archive charts from which these 10 charts were chosen at random for each month was 700, 750, or 775, depending on the number of days in each month.

The computer program was written so that in addition to the correlation coefficient between the reference chart and these charts selected at random, it also gave the number of points in which the RT anomalies had the same sign.

The average number of points having the same RT anomaly sign is represented by a dashed line in Fig. 5, while the average correlation coefficient, among the charts selected at random for 10 cases, is represented by a solid line.

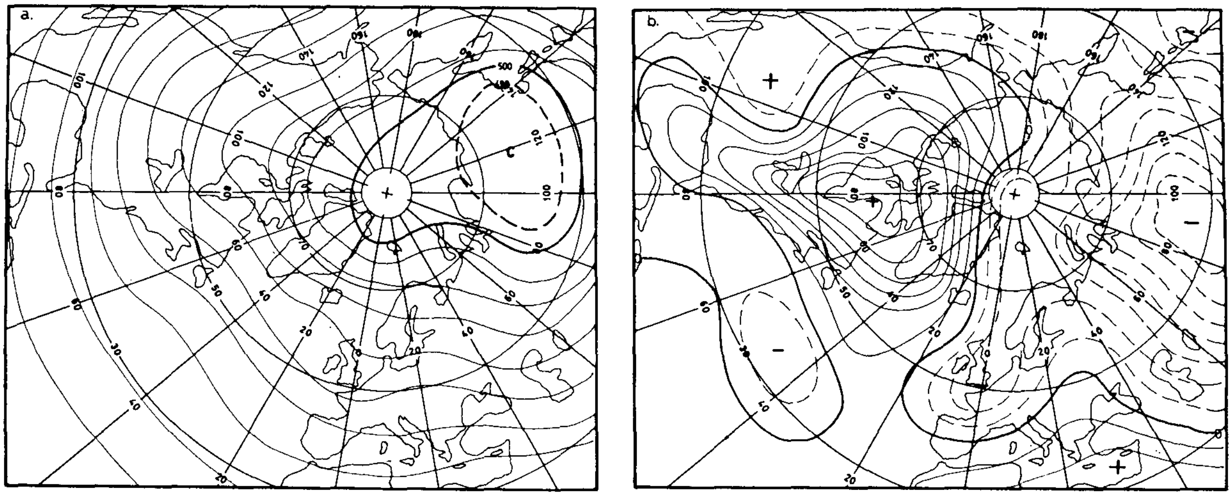
From the total number of 600 correlated anomalies of the RT charts selected at random, the same sign was obtained, on the average, at 71 points, i.e., 59%, while the mean correlation coefficient was computed to be 0.002.

These data show that for a large number of the RT charts selected at random the correlation coefficient is close to zero, which means that there is no noticeable connection among the RT charts selected at random.

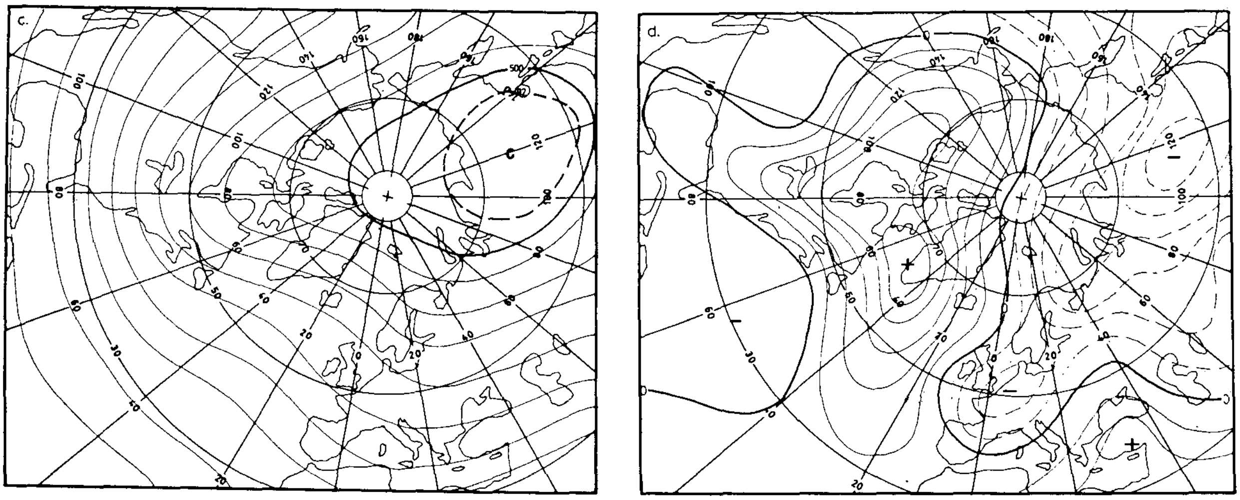
The mean charts for a longer period of time were seen to show a greater number of points with the same sign of anomaly, than the mean charts for a shorter period. This is due to the fact that two charts chosen at random within a 30-day period have an increasing probability of having one or more days in common as the length of averaging increases from a few days to a month.

4. The RT 500/1000 mb persistence

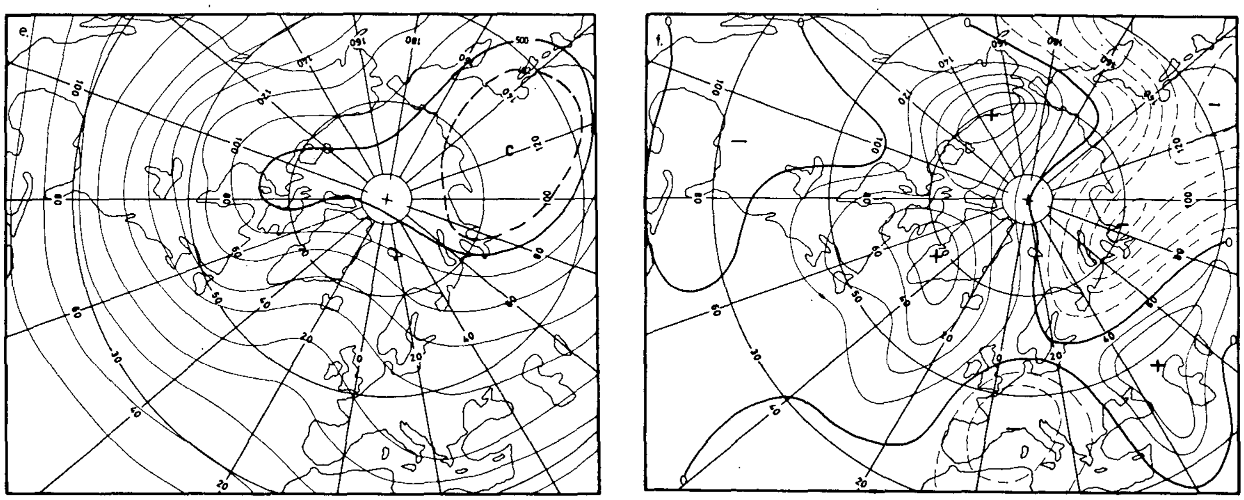
As another test, the similarity between a chart selected at random and charts immediately following was checked. For this test each reference chart was correlated with 10 following charts, namely, the daily charts with 1 day of time-lag, the 5-day charts with 2 days of time-lag, the 10-day and semi-monthly with 5 days of time-lag, and monthly charts with a time-lag of 15 days. In this way, after the correlation coefficients as well as the number of points in which the anomalies had the same sign were calculated, an evaluation of the



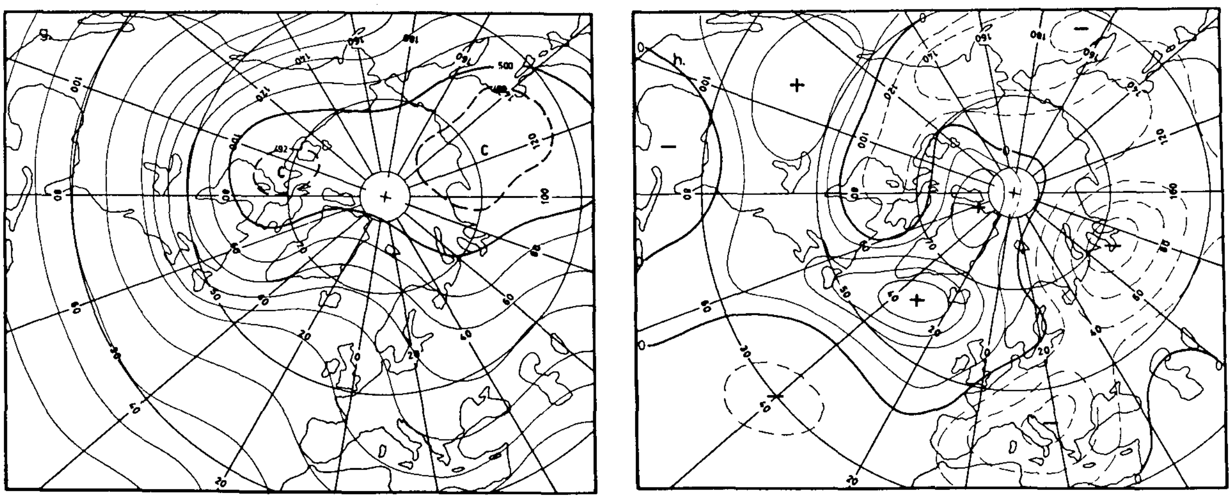
15 NOVEMBER 1952 TO 15 DECEMBER 1952



DECEMBER 1952



15 DECEMBER 1952 TO 15 JANUARY 1953



JANUARY 1953

FIG. 3. As in Fig. 1, for period mid-November 1952 through January 1953.

degree of similarity between the reference chart and charts close to it was obtained as a function of time. These results are shown in Fig. 6. This shows that the RT persistence decreases more slowly on the RT mean charts for longer periods of time than for shorter ones. On the other hand, it can be seen that the persistence decreases to approximately the level of the randomly-selected charts: on daily charts after 5 days, on the 5-day charts after 10 days, on the 10-day charts after 20 days, on the semi-monthly charts after 30 days, and on the monthly charts after 45 days.

5. The search for the best analogue

The search for the best analogue is done by a program comparing the chart records with anomalies from the current chart. In this way, the chart that has the same sign of anomalies as the current one at the greatest number of points, as well as that having the highest correlation coefficient with the current one, is selected from the records.

In Table 1 are shown the average number of points having the same sign of anomalies and the average values of the correlation coefficient which are obtained for ten daily, 5-day, 10-day, semi-monthly, and monthly RT charts for each month in the year. These average values are obtained by searching the best analogue for the ten RT daily charts, 5-day, 10-day, semi-monthly, and monthly RT charts in all years available.

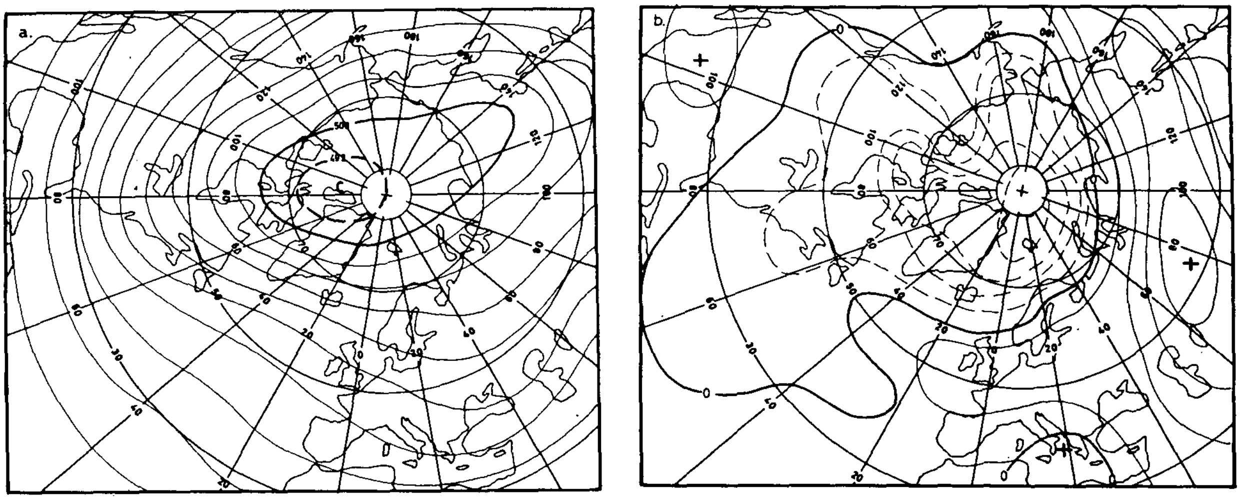
6. Persistence of the RT analogue charts

To examine the analogue persistence (maintenance of similarity with time) for all randomly selected reference charts, the best analogue was found and the series following the reference charts and these analogue charts were correlated with the same time-lag as in the previous section. The average values of the number of points having the same sign of deviation from the normal value, and the correlation coefficient between the charts following the pair of analogue charts, are shown in Table 2.

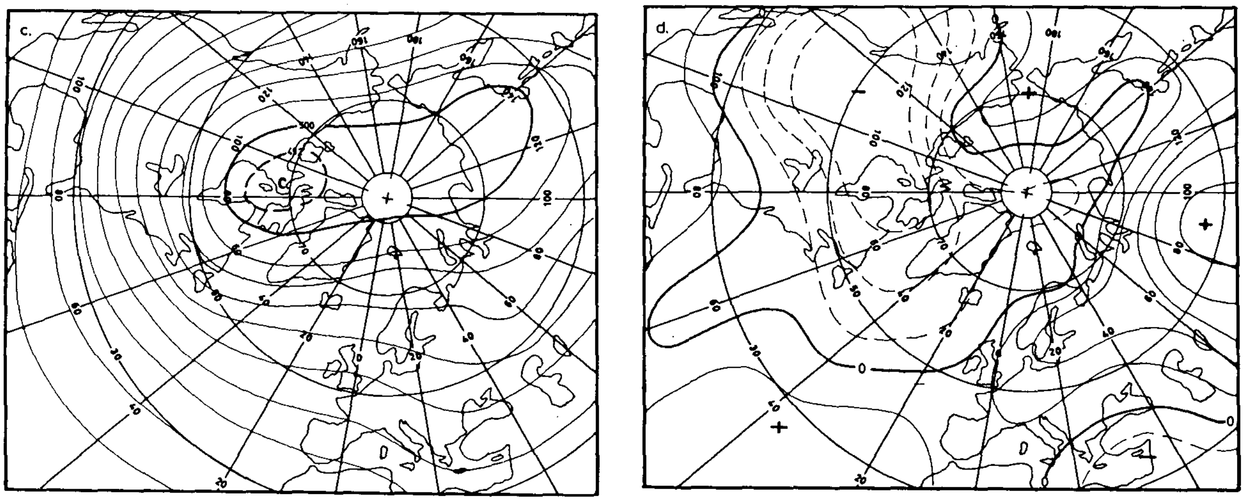
The Table shows that even the average similarity can also increase as well as decrease with time in the period following the analogue charts. This means that the processes in the atmosphere may quite often be developing in such a way as to approach more similar patterns of the relative topography charts. Moreover, by comparing the tabular data with Fig. 6 it can be concluded that the similarity among the RT charts following the analogue pair is for a relatively long time greater and more constant than among the sets of successive charts composing one series. This, of course, is what one expects, considering that the atmosphere is a system dependent on the initial conditions, and represents the basis of the described method for making weather forecasts for a longer period of time.

7. Relationship among relative topography, surface temperature, and precipitation

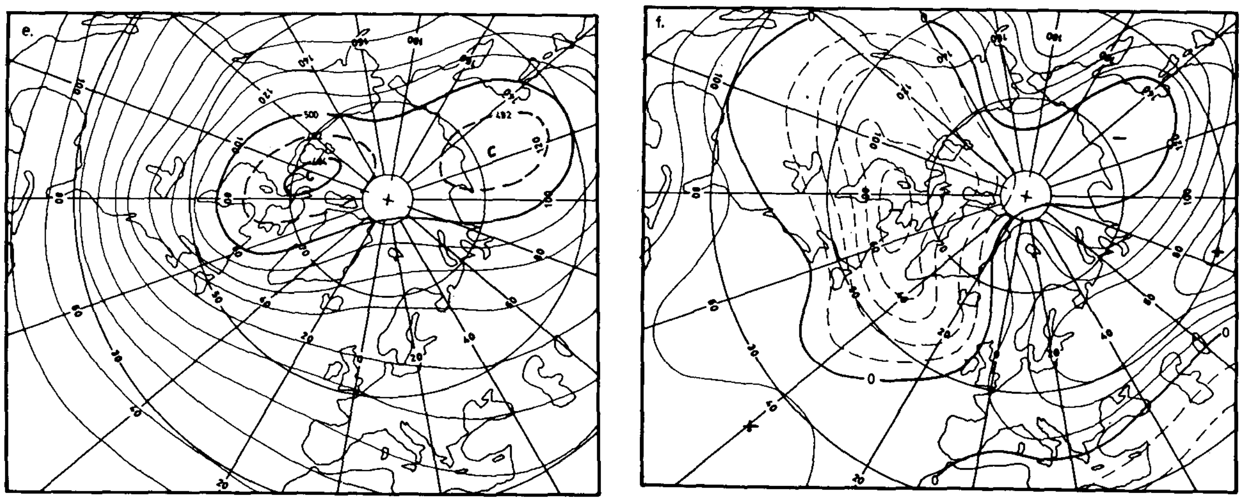
To predict the meteorological elements on the basis of the field of relative topography, it is necessary to know the relationship between them. To demonstrate the existence of such a relationship in Yugoslavia, the correlation coefficient between the RT 500/1000 mb anomalies and surface temperature anomalies, as well as between the RT anomalies and anomalies of the precipitation amount, for Belgrade for January, April, July, and October, was computed. In such a manner, a 0.74 average correlation coefficient for the RT and the surface temperature daily anomalies in Belgrade was obtained, while for the monthly anomalies it was 0.83.



15 NOVEMBER 1951 TO 15 DECEMBER 1951



DECEMBER 1951



15 DECEMBER 1951 TO 15 JANUARY 1952

FIG. 4. Mean monthly 1000–500 mb thickness (a, c, e) and thickness anomaly (b, d, f) charts for period mid-November 1951 through mid-January 1952.

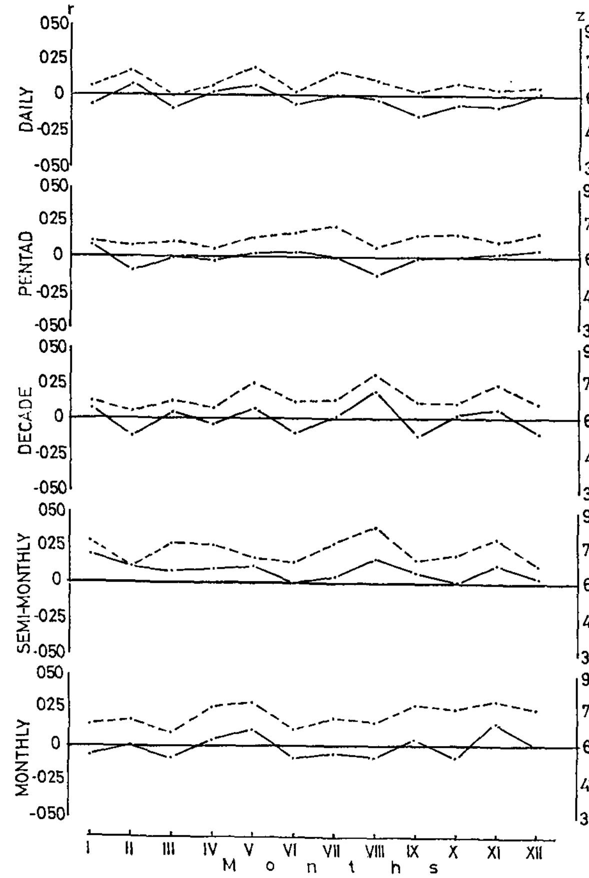


FIG. 5. Correlation of the randomly chosen RT 500/1000 mb charts, where r (solid line) is coefficient of correlation and Z (dashed line) is number of points in which the RT anomalies have the same sign.

Precipitation shows a weaker relationship for shorter periods of time and a stronger relation for longer periods. Thus, a −0.56 coefficient of correlation was obtained for the 5-day anomalies of the precipitation amounts for Belgrade, while it was −0.89 for the monthly ones.

Having established the existence of the relationship between temperature and precipitation, on the one hand, and the RT 500/1000 mb, on the other, we are faced with the problem of how to formulate the prediction of these elements for different periods. The analogue method, in principle, enables a very detailed prediction of processes and meteorological elements. Nevertheless, considering that there are no perfect analogues, detailed predictions should not be given on such a basis. Consequently, one should rather forecast the general trend of the development of the macro processes and of the meteorological elements, within some limits of accuracy.

For this purpose, the following statistics were developed. It was supposed that both the temperature and

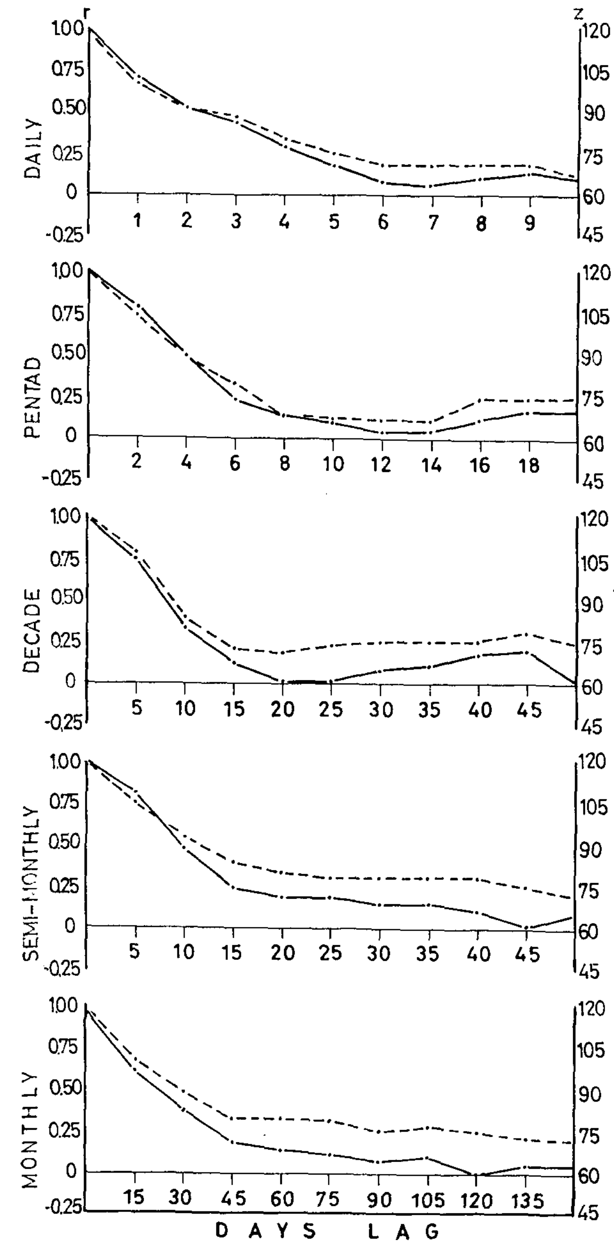


FIG. 6. RT 500/1000 mb persistence, where r (solid line) is coefficient of correlation and Z (dashed line) is number of points in which the RT anomalies have the same sign.

precipitation values follow the Gaussian curve of frequency distribution. Then, the normal error

$$\sigma=\left(\frac{\sum x_i^2}{n}\right)^{\frac{1}{2}}$$

was computed, where x_i is deviation from the mean value of the temperature (or precipitation amount), and n is the number of cases. Using this value, a prob-

TABLE 1. Average number of points with the same sign of anomaly (Z) and the average value of the coefficient of correlation (r) among the RT charts which were selected as the best analogue.

RT Charts	Months / Parameter	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Mean
Daily	Z	94	102	102	95	99	110	90	106	104	102	92	101	100
	r	0.54	0.68	0.80	0.64	0.71	0.82	0.52	0.82	0.82	0.76	0.60	0.74	0.70
Pentad	Z	99	97	100	102	99	98	102	109	104	92	106	99	101
	r	0.72	0.67	0.75	0.76	0.70	0.57	0.59	0.81	0.64	0.62	0.80	0.59	0.68
Decade	Z	94	93	93	90	91	110	90	108	98	96	100	98	97
	r	0.65	0.59	0.61	0.56	0.55	0.71	0.51	0.70	0.58	0.57	0.63	0.55	0.60
Semi-monthly	Z	104	104	97	104	95	109	102	112	111	103	109	105	105
	r	0.65	0.78	0.64	0.77	0.57	0.76	0.68	0.81	0.77	0.81	0.86	0.84	0.74
Monthly	Z	108	104	106	95	98	104	114	106	95	112	103	91	103
	r	0.79	0.60	0.78	0.48	0.57	0.72	0.81	0.73	0.54	0.74	0.64	0.48	0.66

able error (r) was computed from the formula

$$r=0.6745\sigma.$$

The probable error represents a measure of density accumulation around the arithmetic mean. After Namias' classification, this can be used to define the limits of temperature and precipitation intervals. In such a manner, the following temperature intervals were defined:

	$>\bar{T}+\frac{3}{2}r$	Considerably above normal (CA)
from	$\bar{T}+\frac{1}{2}r$ to $\bar{T}+\frac{3}{2}r$	above normal (A)
from	$\bar{T}-\frac{1}{2}r$ to $\bar{T}+\frac{1}{2}r$	normal (N)
from	$\bar{T}-\frac{3}{2}r$ to $\bar{T}-\frac{1}{2}r$	below normal (B)
	$<\bar{T}-\frac{3}{2}r$	considerably below normal (CB).

The intervals $<\bar{T}-\frac{3}{2}r$ and $>\bar{T}+\frac{3}{2}r$ each contain 12.5%, while the three remaining intervals each contain 25% of all the temperature values.

A similar method was used for precipitation amounts. Because of their great variability, these were analyzed to only three intervals:

	$>\bar{P}+\frac{1}{2}\sigma$	above normal (A)
from	$\bar{P}-\frac{1}{2}\sigma$ to $R+\frac{1}{2}\sigma$	normal (N)
	$<\bar{P}-\frac{1}{2}\sigma$	below normal (B).

Each of these three intervals contains $33\frac{1}{3}$% of all the precipitation amounts. Such intervals, for temperature and precipitation, were computed for several stations in Yugoslavia (Belgrade, Zagreb, Ljubljana, Sarajevo, Skopje, Titograd, and Split) for daily, 5-day, 10-day, semi-monthly, and monthly periods of the year.

8. Results of a forecasting experiment

Using daily,. 5-day, 10-day, semi-monthly and monthly anomalies of the RT 500/1000 mb chart records, and synoptic charts and climatological data records, a forecasting experiment having as its aim to show the merit of this forecast method was performed.

For that forecasting experiment, 10 each of the daily, 5-day, 10-day, semi-monthly, and monthly periods for each month of the year within the set of 25 years were selected at random. Thus, 120 cases for each of the above mentioned forecast periods were obtained.

For the daily forecasts, temperature increase and decrease, and the occurrence of precipitation, after the RT chart succeeding the analogue one, were forecast only. For all other forecasts the interval of the temperature averages and precipitation amounts was forecast for a given forecast period. In other words, temperature averages and precipitation amounts, obtained from the corresponding period succeeding the RT analogue charts, were used as the forecast.

Such temperature and precipitation forecasts for a specific location are uniquely defined and their performance can easily be evaluated. To evaluate the temperature and precipitation forecasts, Tables 3 and 4 were

TABLE 2. Average number of points with the same sign of anomaly (Z) and average value of the coefficient of correlation (r) among the RT charts succeeding the pair of analogue charts.

Charts RT	Parameters	Pairs of the RT charts succeeding the analogue ones 1	2	3	4	5	6	7	8	9	10
Daily	Z	96	87	88	82	84	77	74	78	78	78
	r	0.66	0.53	0.54	0.41	0.35	0.19	0.13	0.22	0.22	0.22
Pentad	Z	101	100	90	85	83	81	84	85	86	85
	r	0.70	0.63	0.61	0.54	0.49	0.21	0.36	0.40	0.42	0.40
Decade	Z	100	98	93	86	72	70	68	72	71	70
	r	0.65	0.54	0.42	0.36	0.10	0.05	0.00	0.04	0.07	0.08
Semi-monthly	Z	103	92	94	86	88	78	75	73	73	69
	r	0.71	0.50	0.59	0.43	0.36	0.30	0.06	0.02	0.01	−0.03
Monthly	Z	101	93	87	78	74	72	72	68	66	68
	r	0.68	0.51	0.38	0.10	0.06	0.03	−0.05	−0.08	−0.16	−0.02

used (Similä, 1957) where F denotes forecast and R realization of the meteorological elements concerned.

On the basis of the given codes, all forecasts obtained within the experiment, when using the RT analogue method and persistency method for the same weather periods, were evaluated. The results are shown in Table 5.

Table 5 shows that using the RT analogue method, an average improvement in the temperature forecasts of 33 percentage points was gained, while the precipitation forecasts were improved 24 percentage points over using persistence. These figures are the averages for all the lengths of periods tested.

TABLE 3. Code to evaluate the temperature forecast (%)

F \ R	CA	A	N	B	CB
CA	100	90	50	10	0
A	70	100	55	10	0
N	10	45	100	45	10
B	0	10	55	100	70
CB	0	10	50	90	100

TABLE 4. Code to evaluate the precipitation forecast (%)

F \ R	A	N	B
A	100	50	0
N	25	100	25
B	0	50	100

TABLE 5. The temperature (T) and precipitation (R) forecasts realized in %.

Period	Forecast T	Forecast P	Persistency T	Persistency P	Difference T	Difference P
Daily	86.0	62.8	50.8	37.4	35.2	25.4
Pentad	82.7	65.4	48.8	35.7	33.9	29.7
Decade	79.3	63.7	46.3	39.0	33.0	24.7
Semi-monthly	77.6	60.8	47.2	36.5	30.4	24.3
Monthly	75.4	58.7	42.4	39.1	33.0	19.6

9. Conclusion

The experiment showed that the analogue method based on the RT/1000 mb charts gives temperature and precipitation forecasts, for different periods of up to one month, significantly superior to the persistence forecasts.

In addition, the described analogue method is thoroughly objective, simple to use, cheap to apply, and can be used at any forecasting center supplied with an electronic computer.

Moreover, it may be possible to further improve the technique by increasing the number of the RT chart records, studying the relationship between the RT field and meteorological elements, and improving the criteria for selecting analogues.

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