An experiment in forecasting monthly mean temperature in Stockholm

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ABSTRACT

A simple method of forecasting the mean monthly temperature in Stockholm has been developed. It is based mainly on data from a 96 year long record of local temperature. In addition to persistency other statistical interrelations, dynamical methods and synoptic experience have been used. The result from a 10 year test period shows that the forecasts have caught about one third of the possible amount above guessing. The presented method gives results which are significantly better than the results of pure persistency and of the US monthly forecasts. This systematic method may be used for other places and could be combined with other methods.

1. Introduction

Much work has been carried out in the field of long range forecasting in many countries (1962). Many different and in general laborious techniques have been used and the results have often been described as successful. In this article a method will be presented, the result of which is also considered as successful to some extent. One difference to most other methods is, however, that it is rather simple, once the background data has been analyzed.

It is well known that the temperature in Northern Europe—as in other parts of the world—has a considerable persistency and it is of course not only permissible but often also advantageous to use this knowledge in forecasting in a systematic way. It has even been claimed that a forecast giving no better result than persistency is no real forecast. Such forecasts are supposed to lack skill. This is of course a question of definition—forecasts based on other principles than persistency are sometimes published although they give a result inferior to a persistency forecast. Such forecast methods may, however, be improved and one day pass the persistency method. Before that day any practical value of the method is of course questionable.

2. Forecast method

The method described here is mainly based on persistency and on other climatological statistics although some dynamical forecasting is also involved. Observational data in Stockholm from 96 years have been used to compute monthly means, five-day means and daily means. The monthly mean data for each month (and also for periods commencing on the 16th of each month) have been divided into eight equally sized groups (i) from 1–8. A similar system was used by Namias (1953). The same grouping has been made of the mean temperature for the last five days in each period (j), the mean temperature for the last day in each period (p), and the mean temperature for the first day in each period (r).

In a fourdimensional contingency table have been marked all cases X_{ijpr} referring to the same date e.g. the mean temperature of the month of May 1939 class 5 ($i=5$), the five-day mean of 27–31 May class 7 ($j=7$), the daily mean of 31 May class 8 ($p=8$) and the daily mean of 1 June the same year class 3 ($r=3$). The whole material has been recorded in the table. Only a part is reproduced in Table 1. We then studied what class of monthly temperature followed in each case and we found

Table 1. *Part of contigency table and the prognostic class*

	j = 1			p = 7	r = 5	
i = 1	X_{1111} 1	X_{1112} 1	X_{1113} 1	X_{1475} 2	X_{1675} 2	X_{1888} 6
i = 4	X_{4111} 1	X_{4112} 1	X_{4113} 1	X_{4475} 5	X_{4675} 6	X_{4888} 8
i = 8	X_{8111} 3	X_{8112} 3	X_{8113} 4	X_{8475} 8	X_{8675} 8	X_{8888} 8

e.g. that the most frequent value of the mean monthly temperature following X_{5783} was 6. Other class figures were found for other X_{ijpr}. The number of figures in each X_{ijpr} was rather small and the mean class figures were randomly distributed. A certain smoothing had therefore to be made so that in the final table a lower value of i or (jpr) should not give a higher forecast class than a higher value o the same index all other indices being equal.

One finds that there is such a persistency of the monthly temperature that a *very warm* (or very cold) month is very often followed by another very warm or warm (cold) month. A warm (or cold) month is also more often than not followed by a warm (or cold) month but less frequently than in the case of a *very warm* (or very cold) month. If the previous month has a temperature that is normal persistency is small. However, in that case the weather type may have changed during the last part of the month and if the last five-day mean is very high, the probability is high that the following month will be warm. If both monthly and five-day means are normal there may be a temperature change during the last day of the month which, when taken into account, will also improve the statistical forecast a little. Thus for each combination of past data means, monthly (i), five-day (j), last day means (p) and means of the first day of the following month (r) there is one most likely forecast.

In the application of the forecast method a five-day forecast from the weather service is introduced as the last parameter (r). However, when developing the forecast tables no five-day forecasts were available in the 96 year period used. Therefore the true known temperature during the first day of the forecast month was used instead of the five-day forecast. It was assumed that the five-day forecast would have about the same prognostic effect as the known mean of the temperature of the first day of the forecast month.

The verification of the forecasts has been made in the following way. Classes 2 and 3 were combined into one class as well as classes 4 and 5 and also 6 and 7. The five classes thus formed were called Much Below (MB) (1), Below (B) (2 and 3), Normal (N) (4 and 5), Above (A) (6 and 7) and Much Above (MA) (8). The verification table has been proposed by E. Hovmöller and it has been used in the Swedish Meteorological and Hydrological Institute during many years. It is shown in Table 2.

This table should give a score of about 50 by random forecasts. If the forecast class is correct the score will be 100. Other tables built on these principles would give very similar results.

The first 96-year period gave a score of 65. When Table 1 was tested on an independent series of 96 years from the long record in Stockholm the result became 64. The method therefore was considered sufficiently stable and acceptable.

The result of a permanent forecast of e.g. MA also gives the score 50 when the original material is used, in accordance with the grouping of the material in classes. When the forecast table is used on new data it is not sure that the same type of permanent forecast would give exactly 50- If the number of forecasts is small, random deviations are to be expected and if

Table 2. *Verification table*

		Observed				
Forecast		MB	B	N	A	MA
MB	1	100	90	50	10	0
B	2–3	70	100	55	10	0
N	4–5	10	45	100	45	10
A	6–7	0	10	55	100	70
MA	8	0	10	50	90	100

there is a trend in the material other deviations may occur.

The random deviations in short series are of course inaccessible. The standard deviation in the 10-year series is estimated to 3.3. Those deviations which depend on a trend in the material may be considered if the trend is known or rather if it is possible to forecast it.

The material shows that a permanent forecast of MA or A during the 10-year period would have given a score considerably above 50, but still below the result of the persistency method. Correspondingly permanent forecasts N, B or MB would have given scores below 50. By introducing—subsequently at the end of the period—an estimated trend, the value of a permanent MA-forecast could be reduced to some value closer to 50. The scores of other permanent forecasts would also approach 50. As at the same time the limits of the classes—both for forecasts and occurred values—would be changed, the score of the actual forecasts would probably be changed only one or two points. The test on 96 independent years referred to above confirms this and also a test upon the 10-year period made under the assumption that a temperature increase of 1°C has occurred from the time of the original period till the last ten years. As the trend is uncertain and as it was not known at all, when the forecasts were made, it has been disregarded.

3. Results

The application of the forecasting method on new data has taken place since the thirty-first of December 1963. One forecast has been issued the last of each month and one on the 15th of each month up till 31 December 1973.

There are thus 240 forecasts. As the fourth parameter has been changed to a five-day forecast since the tables were made the result of the experiment may be expected to change slightly. However, the change was not expected to become significant during a period of only 10 years.

During 8 years it has been possible to compare our forecasts with the forecasts based on persistency of the monthly mean temperature and with the forecasts issued by the U.S. Weather Bureau (Table 3). The mean value for 8 years obtained with the presented method is 67.5, with the US method 51.7 and with the monthly persistency method 63.6. It is obvious that it is difficult to forecast the temperature in Stockholm without knowledge of the local conditions especially if persistency is neglected in the method.

I. Holmström (1969) analyzed monthly

Table 3. *Result, in percentage, obtained in forecasting mean monthly temperatures in Stockholm in the years 1964–1973*

											Mean value	
											8	10
Prognosis by	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	years	years
Nyberg	70.0	56.9	65.0	72.5	62.9	72.9	60.4	59.0	66.7	80.9	67.5	66.7
US Weather Bureau	—	—	50.0	45.8	53.5	60.4	56.0	53.6	57.5	36.5	51.7	—
Difference 1–2	—	—	15.0	26.7	9.4	4.0	4.0	5.4	9.2	44.4	15.8	—
Persistence of monthly mean temperature	60.8	51.3	60.0	65.8	68.3	65.8	50.4	53.6	69.8	75.2	63.6	62.1
Difference 1–3	+9.2	+5.6	+5.0	+6.7	−5.4	+7.1	+10.0	+5.4	−3.1	+5.7	+3.9	+4.6
Difference 2–3	—	—	−10.0	−20.0	−14.8	−5.4	+5.4	±0	−12.3	−38.7	−11.9	—

Table 4. *Forecast results during 1964–1973 of mean temperature in Stockholm for different length of period*

24 hours	5 days	1 month
Ca. 85 %	77 %	67 %

temperature data series from Stockholm with empirical orthogonal functions and found that the monthly persistency was the dominating term. The second term was a sinusoidal part giving high temperatures in the beginning of the first month low temperatures in the middle and again high temperatures at the end of the month. This term also indicated a forecast of high temperature. This is in agreement with my result that normal monthly temperature combined with high five-day mean temperature at the end of the month indicates high temperature forecast. I. Holmström has so far made no attempt to formulate quantitative forecasts but experiments may start soon.

A comparison with the 24-hour forecasts and the five-day forecasts issued by the weather service in Stockholm is presented in Table 4. The values relating to the 24 hours—and to the five-days—have been obtained in a different way. However, they are used here to indicate the decrease of the score in relation to the period of the forecast. One may guess that a certain skill or at least a score of more than fifty may be obtained even if the period is extended as long as to a season (3 months).

The quality of the forecasts seems to be variable during the year. It must be remarked that for each period there are only 10 forecasts so that the variability of a verification score for such a sample is considerable. E.g. the forecast for August gives a score of 88 whereas the score for the period 16 August–15 September is 42. Through a system of smoothing

$$A_{i-\frac{1}{2}} = \sum[a_{(i-4)} + 2a_{(i-3)} + 3a_{(i-2)} + 4a_{(i-1)} + 4a_i + 3a_{(i+1)} + 2a_{(i+2)} + a_{(i+3)}]$$

the curve represented in Fig. 1 is obtained. The best result, 71, is obtained in the middle of the summer. In the mid winter the result is almost as good whereas in the spring and especially in the fall the values are below the mean value for 10 years 66.7. There is a possibility that special tables for different seasons or even months could give slightly better results than

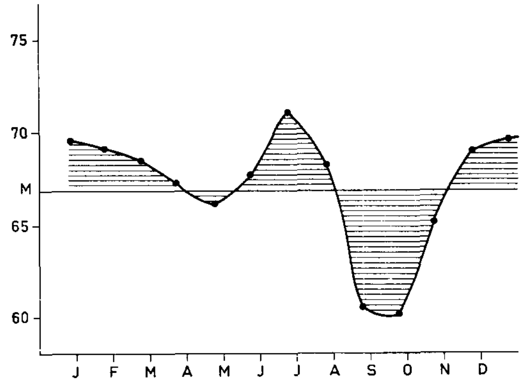

Fig. 1. Smoothed results of forecasting mean monthly temperatures during the year. Mean value 66.7.

the tables used which have been prepared for the whole year. During some years the method of the persistency of the monthly temperature mean is giving a better result than the presented method but in eight of the ten years the presented method is giving better results and in some cases the score has a value, which is as much as 10 higher. As a mean for 10 years the presented method gives a score which is 4.6 higher than the simple persistency method, which in this period was about 62 i.e. 12 above 50.

The skill of the forecast method could be expressed as the difference between the actual prognostic result and the result of the persistency of the monthly mean, divided by 50 i.e. $(66.7 - 62.1)/50 = 9.2\%$. Let us forget here that by the system of using classes the accuracy of the forecast is reduced. However, the usefulness of a forecast is a function of the percentage obtained and in this connection it may be noticed that the eight year forecasts have caught 33.6% of the possible amount. The maximum score above guessing is $100 - 50$ i.e. 50 and the obtained result above guessing is $66.8 - 50$ i.e. 16.8:50 or 33.6%.

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ЭКПЕРИМЕНТ ПО ПРОГНОЗУ СРЕДНЕЙ МЕСЯЧНОЙ ТЕМПЕРАТУРЫ В СТОКГОЛЬМЕ

Построен простой метод прогноза средней месячной температуры в Стокгольме. Метод основан, главным образом, на данных по локальной температуре за 96 лет. В дополнение к инерционности используются статистические соотношения, динамические методы и синоптический опыт. Результаты десятилетнего периода испытаний показывают, что прогнозы примерно на одну треть лучше случайных. Представленный метод дает результаты, значительно лучшие, чем чисто инерционный метод и месячные прогнозы США. Данный системный метод может быть использован для других пунктов и может комбинироваться с другими методами.