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An explanation of persistence in monthly mean temperatures in the Netherlands

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ABSTRACT

Persistence of the anomalies in the monthly mean air temperature has been investigated thoroughly for 15 stations in the Netherlands. All stations used have records of at least 50 years. The persistence is expressed in the correlation coefficient of the air temperature of adjacent months. At all stations the correlation coefficient is high at the end of summer and winter and smaller in the other months. With so many stations in a small area we were also able to resolve large spatial variations. In general, persistence is large close to and over the sea and decreases over land with increasing distance from the coast. We conclude that besides a background persistence caused by the large-scale atmospheric circulation, there is a strong persistence directly controlled by the North Sea, which has a large gradient in the coastal area. The variations of persistence throughout the year can be qualitatively explained by considering (1) the persistence of the sea surface temperature anomaly, (2) the stability of the atmospheric boundary layer over the sea and (3) the stability of the atmospheric boundary layer over land. Finally, we discuss the skill of forecasting schemes based on simple persistence.

1. Introduction

Weather forecasts for tomorrow always take advantage of the persistent character of the weather. A lazy man's forecast, persistence, has a high skill compared to a climatological forecast and there must be safe grounds to predict large changes. The additional skill gained by the prediction of the more spectacular changes in tomorrow's weather is usually disappointing.

In long-range weather forecasting the experience is quite the same, that is: with laborious methods it is difficult to improve lazy forecasts. The lazy methods can be based on long observational records of, for example, the monthly mean temperature. From such records it can be derived that the chances of occurrence of a warm, normal or cold next month are influenced by the temperature of the previous month (Nyberg, 1975; Gordon and Wells, 1976; Metaxas and Vassiliou, 1978) or by the temperature of the sea surface water in the previous month in some key area (Ratcliffe and Murray, 1970). Until now it has been hard to beat such simple statistics.

The simple statistical rules usually contain a great deal of persistence. Although there is some difference between the chances of positive and negative anomalies to be carried to the next month, we use the linear correlation coefficient to quantify the persistence in the monthly mean temperature $\bar{T}$. The correlation coefficient is defined by

$$\rho(\bar{T}_i, \bar{T}_{i+1}) = \frac{\frac{1}{M}\sum_{j=1}^{M}(\bar{T}_{i,j}-\bar{\bar{T}}_i)(\bar{T}_{i+1,j}-\bar{\bar{T}}_{i+1})}{\left(\frac{1}{M}\sum_{j=1}^{M}(\bar{T}_{i,j}-\bar{\bar{T}}_i)^2\cdot\frac{1}{M}\sum_{j=1}^{M}(\bar{T}_{i+1,j}-\bar{\bar{T}}_{i+1})^2\right)^{1/2}} \quad (1)$$

where i is the month ($i = 1 \ldots 12$), j the year, M the total number of years, $\bar{T}_{ij}$ the monthly mean temperature of month i in year j, and $\bar{\bar{T}}_i$ the grand mean temperature of month i.

A peculiar annual variation of the correlation coefficient at De Bilt can be seen in Fig. 1. The calculations are based on observations covering the period 1849 to 1975. There are two maxima

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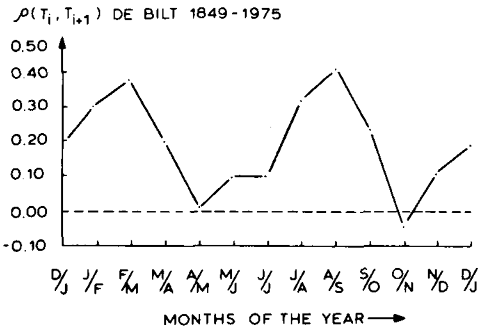

Fig. 1. The correlation coefficient of the monthly mean air temperature in adjacent months at De Bilt (1949–1975). Correlations larger than 0.18 differ from zero at the 95% confidence level.

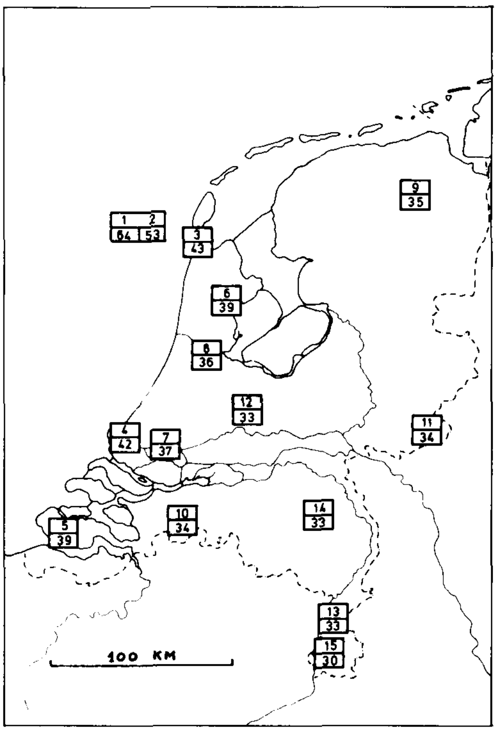

Fig. 2. The geographical location of the stations used in this study. The ranking (upper half of box; 1 to 15) is based on the delay of the annual cycle in the temperature, measured in days (lower half of box; 30 to 64 days).

centred at the end of the winter and summer where values of about 0.4 are reached. In between April to May and October to November and December show negligible mutual correlation. The variations throughout the year at De Bilt are consistent with those observed at other places in north-western Europe (Craddock and Ward, 1962). Craddock and Ward prepared maps of the $\chi_{[2]}$-value of contingency tables for the whole of Europe and for all pairs of adjacent months. These contingency tables showed mainly persistence and therefore the $\chi_{[2]}$-value measures persistence. The variations during the year in the U.S.A. are different; there, mid-summer and mid-winter have the largest persistence (Namias, 1952; Dickson, 1967).

How do we explain this gift by nature as it shows up in Fig. 1? Traditionally, weather is thought to be determined to a large extent by the circulation aloft. So maybe Fig. 1 is nothing else than a translation of the persistence in monthly mean circulation anomalies (Sawyer, 1965). However, there is not much evidence that this is the case. For the 5-year period 1971–1975 the anomalies in the monthly mean height of the 700 mbar level over the atlantic-European area were found to have little pattern correlation from 1 month to the next (Van den Dool and Nap, 1976). Averaged over the year the correlation coefficient amounts to about 0.10. More important is that we do not find maxima at the end of summer and winter. A more extensive research is required to answer questions concerning persistence in the circulation.

We shall explore in some depth an alternative explanation of the results shown in Fig. 1. It is possible that direct anomalous heating by the North Sea causes some persistence in the average air temperature. This direct effect is probably restricted to the atmospheric boundary layer. The maps of Craddock and Ward show impressive maxima of the persistence in the coastal areas of the North Sea and the Baltic. Also a study by Dickson (1967) suggests that in the U.S.A. persistence in $\bar{T}$ is large in areas near the oceans. On a slightly longer time-scale (season) persistence is generally found to be highest in maritime regions (Van Loon and Jenne, 1975; Namias, 1978). Namias even finds evidence of a certain influence of the Great Lakes on the spatial pattern of season-to-season persistence.

The influence of the adjacent water bodies will be investigated here for the area of the Netherlands where a very dense network of climatological stations gives us detailed information. For each station an "influence distance" to the sea will be determined and we plot persistence against this quantity. This will bring to light the strong control by the sea. Further, we shall explain qualitatively why the influence of the sea has an annual variation as observed in Fig. 1. For that purpose we consider the persistence of the anomalies in the sea surface temperatures and the height of the atmospheric boundary layer over the sea and over land, all as a function of the time of the year. Finally, we shall consider the skill of simple forecasts as a function of the distance to the coast. Persistence of the air temperature is a lazy prediction scheme, which makes sense in certain months and areas. Using the sea surface temperature anomaly of the present month as a forecast for the next month's air temperature performs nearly as well.

2. Data

From the many stations in the Netherlands where climatological observations are made, we selected 15 where records of monthly mean temperature longer than 50 years were readily available. In Fig. 2 the geographical distribution of the stations is given. The names of the stations and the beginning and the end of their records are specified in Table 1. The length of the records ranges from 50 to 125 years. One of the series of observations was made at the light-vessel Texel, about 25 km off the coast. The observations at the light-vessel include also an 85-year series of monthly sea surface temperatures. Because the anomalies of the temperature in the sea have a high degree of spatial coherence, we consider these sea surface temperatures representative of the southern part of the North Sea.

Table 1. *The stations used in this study and the beginning and end of their records*

1.	Light-vessel Texel (sea)	1890–1978
2.	Light-vessel Texel (air)	1890–1975
3.	Den Helder	1855–1975
4.	Naaldwijk	1927–1976
5.	Vlissingen	1855–1975
6.	Hoorn (N.H.)	1905–1978
7.	Rotterdam (Fil.)	1893–1958
8.	Amsterdam (Fil.)	1855–1958
9.	Eelde	1881–1975
10.	Oudenbosch	1893–1978
11.	Winterswijk	1894–1978
12.	De Bilt	1849–1975
13.	Sittard	1905–1972
14.	Gemert	1905–1978
15.	Beek	1855–1975

All data were carefully checked by intercomparisons. Suspect values were dropped. The number of missing data is very small, however. In the light-vessel data two gaps of about 5 years occur. For the calculation of the yearly cycle in $\bar{T}$ and the correlation coefficients there is no urgent need to replace missing data.

3. The influence distance to the coast

We want to investigate the influence of the sea on certain climatic features. This requires a clear definition of the influence of the sea. One might think of such things as the shortest distance to the coast or of an average distance weighed by mean wind directions. However, this is not very satisfying because the coastline is irregular. We propose here an "influence distance", which can be derived from the delay of the annual cycle in $\bar{T}$. It is well known that near the coast the temperature response to the forcing by incoming radiation is slower than in the middle of the continent. Because we want to show that an analogous delay works on smaller time-scales, the influence distance (Δ) seems to be very suitable for our purpose.

The idea is visualized in Fig. 3. The smooth curve of annual variation in $\bar{T}$ reaches its extremes Δ_w and Δ_s days after the winter and summer solstices. The influence distance is defined by

$$\Delta = (\Delta_w + \Delta_s)/2$$

The dates of the extremes are computed by simply adapting a parabola to the three coldest (warmest) months. It appears that the delay in summer is 3 to 10 days larger than in winter. In Fig. 2 the geographical distribution of Δ is given. The phase delay ranges from about 50 days over the sea to

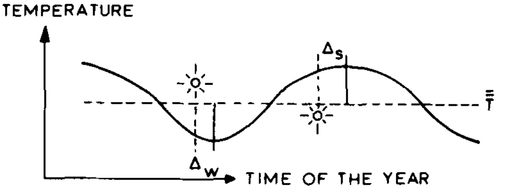

Fig. 3. The annual cycle in the temperature. The minimum and the maximum have a delay of Δ_w and Δ_s days with respect to the winter and the summer solstices.

30 days at a few hundred kilometres inland. It is obvious, however, that the largest gradients in Δ occur in a narrow strip of at most 50 kilometres. The phase delay of temperature of the sea surface waters is about 64 days. The inaccuracy in the value of Δ is probably not more than a few days.

We conclude from Fig. 2 that indeed Δ is a quantity that describes the influence of the sea satisfactorily. Δ will be used as a quantity against which persistence on the month-to-month scale is plotted. The dimension of Δ (days) is dropped.

4. Results

For each of the 15 stations the correlation at a lag of 1 month is computed for all 12 pairs of months. The 12 values are consequently averaged to yield a yearly mean. In Fig. 4 the years means are plotted against Δ. There seems to be a strong relation between month-to-month persistence and the delay by the sea. In Fig. 4 also the correlation at a lag of 2 months is given. Although the correlation is much lower, the influence of the sea is still visible.

In terms of the correlation coefficient the influence of the sea is beyond doubt. But now suppose that we want to apply persistence in a linear regression type of forecast:

$\bar{T}_{l+1} = \rho \bar{T}_l + \text{cst} + \text{error}.$

The accuracy of such forecasts is given by the explained variance, $\rho^2(\bar{T}_l, \bar{T}_{l+1})\, s^2(\bar{T}_{l+1})$, where s is the standard deviation. Now ρ is large near the coast, but s is small. The standard deviation is smaller there, because the sea selectively filters out certain fluctuations of the air temperature. So it is quite possible that the product $\rho^2 s^2$ is the same everywhere. To investigate this, we have plotted in Fig. 5 the yearly mean value of the explained variance versus Δ. We can conclude that the role played by the sea is not only reducing s and thereby increasing ρ, but $\rho^2 s^2$ definitely increases with Δ. So it seems that the sea releases information (a temperature anomaly) which is carried by air. While being advected over land, the air temperature anomaly (originating from the SSTA) gradually disappears as a result of vertical mixing.

In Fig. 6 we have drawn isolines of the correlation coefficient of $\bar{T}$ at a lag of 1 month in a time-Δ diagram. For all values of Δ we can find two peaks in the persistence at the ends of the summer and winter. For larger Δ the peaks become higher and broader and at the light-vessel Texel correlation coefficients as high as 0.60 can be found. It should be noted that over the sea the minimum in persistence in autumn is much lower than that in spring.

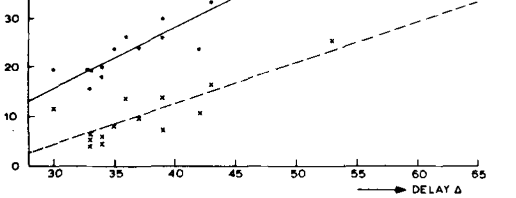

Fig. 4. The yearly mean correlation coefficient (%) of the monthly mean temperature at a lag of 1 month (dots) and a lag of 2 months (crosses), as a function of the influence distance to the sea (or delay). The solid and dashed lines are determined by linear regression. The dot and cross referring to the sea surface temperature (encircled) are not used in the computation of the regression lines.

5. Qualitative explanation

Although there seems to be evidence that the large bodies of water surrounding (and invading)

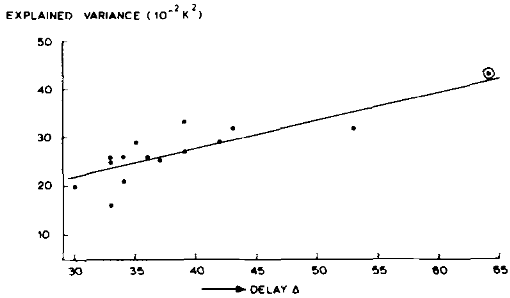

Fig. 5. The yearly mean variance explained by linear regression between the monthly mean temperatures of adjacent months, as a function of the delay. The dot referring to the sea surface temperature (encircled) is not included in the computation of the regression line (solid).

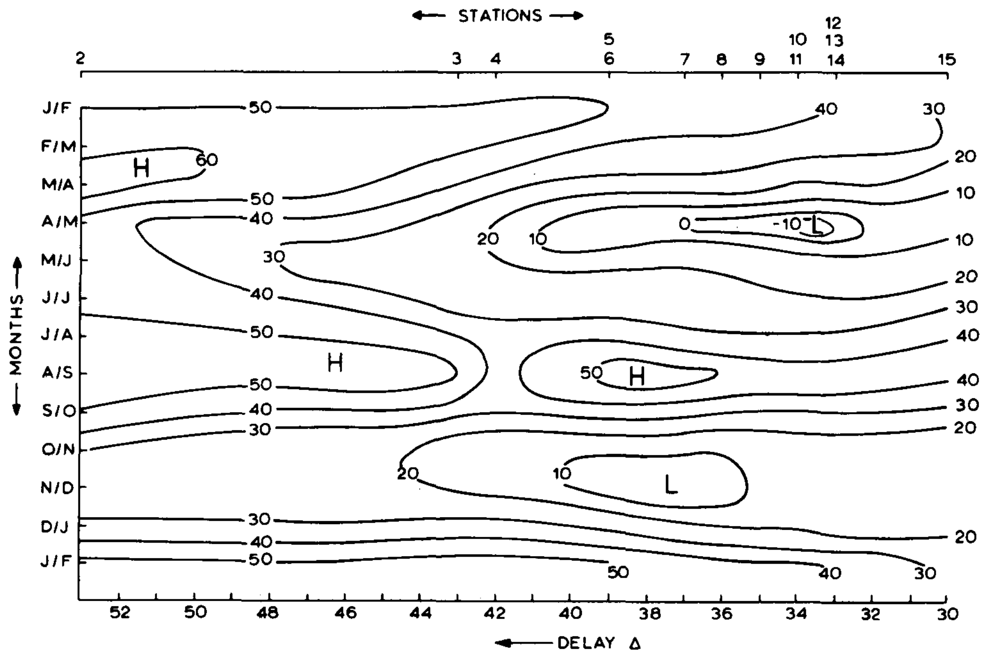

Fig. 6. Isolines of the correlation coefficient (%) of the monthly mean air temperature in adjacent months in a time of the year versus delay plot. The stations involved are indicated with their number in the upper part. The hand analysis has introduced a considerable smoothing of the raw numbers.

the Netherlands cause some persistence in the monthly mean air temperature, we have not explained yet why the correlation coefficient has an annual variation as shown in Figs. 1 and 6. One may argue that the influence of the sea in itself has an annual variation, since the winds change drastically from summer to winter. The difference of Δ_w and Δ_s (3 to 10 days) indicates that, indeed, the influence distance is not a constant during the year. But even after allowance of such variations of Δ the gross features of Fig. 6 are retained. We feel that the following conditions must be fulfilled in order to find persistence in $\bar{T}$:

(1) There should be persistence in the sea surface temperature anomalies (SSTA).

(2) The atmospheric boundary layer over the sea should be stable most of the time.

(3) After being advected to the land, the atmospheric boundary layer should remain stable most of the time.

On the basis of the present data we discuss whether or not these three conditions are fulfilled in certain periods of the year.

ad 1. Persistence in the SSTA can be established from the record of the light-vessel. Fig. 7 shows that in the North Sea an SSTA has a large chance to be carried to the next month. Correlation coefficients less than 0.6 are found only for June–July and October to January. In these months the North Sea gives only weak support to persistence in the air temperature.

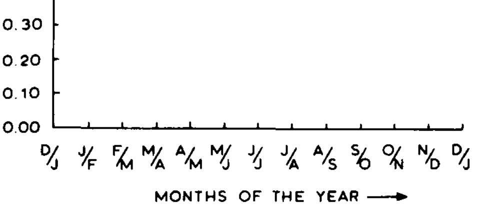

Fig. 7. The correlation coefficient (%) of the monthly mean sea surface temperature in adjacent months at the light-vessel Texel (1890–1978).

ad 2. and 3. An impression of the stability of the atmosphere can be obtained from a comparison of the annual cycle in the air and sea temperatures ($\bar{T}_a$ and $\bar{T}_s$) at the light-vessel and the air temperature at De Bilt ($\bar{T}_b$).

Whenever $\bar{T}_s > \bar{T}_a$, the atmosphere over the sea must be considered unstable most of the time, and as a result the anomalous heat transfer from the sea, although larger, will be dispersed over a deep atmospheric layer.

Whenever $\bar{T}_b > \bar{T}_a$, it is likely that the air advected to the land will be heated from below. This increases the height of the layer that carries the memory of SSTA, and therefore the deviation of the air temperature from normal (originating from the SSTA) will be smaller. In Fig. 8 the three curves of $\bar{T}_s$, $\bar{T}_a$ and $\bar{T}_b$ make roughly clear in which periods persistence in the air temperature is not favoured. From October to mid-January the sea is much warmer than the overlying air and from April to mid-July the air coming from the sea has to be warmed over land.

The three conditions discussed above are recapitulated in Fig. 9. With dashed lines we have indicated those months in which one of the conditions is not or only weakly fulfilled. From bottom to top we find persistence in the *sea water*, stability of the *air over* the *sea* and stability of the *air over land*. Only a few months pass unaffected through these three filters, namely those

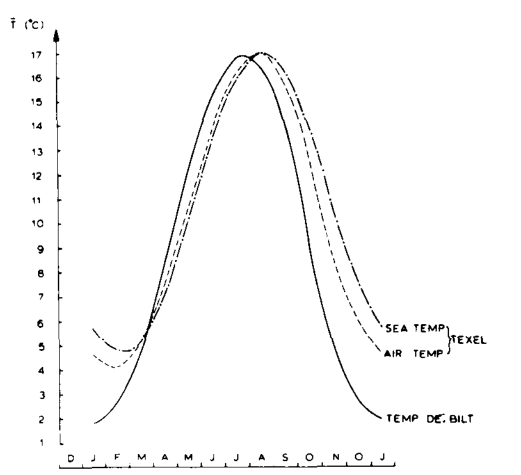

Fig. 8. The yearly cycle in the monthly mean temperature at De Bilt (solid line) and light-vessel Texel (air (dashed line) and sea water (dashed-dotted line)).

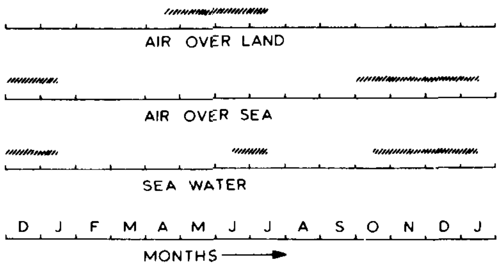

Fig. 9. Periods of the year in which persistence of the air temperature is not favoured by the North Sea. From bottom to top: (1) periods of low persistence in the sea surface temperature, (2) periods in which the sea is much warmer than the overlying air and (3) periods in which air advected from the North Sea to the Netherlands is heated significantly. The periods are dashed.

centred around February–March and August–September. This is in fair, though qualitative agreement with Figs. 1 and 6. Fig. 9 expresses that the absence of persistence in spring and autumn required different explanations. In spring the heating of the air over land is the limiting factor, whereas in autumn the instability of the atmosphere over the sea prohibits much persistence. This makes also clear why persistence in the air temperature over the sea is much smaller in autumn than in spring.

Our qualitative arguments are not a complete explanation of Figs. 1 and 6. Part of the local persistence may possibly be explained from a large-scale background persistence which requires non-local explanations. We emphasized in this section the importance of three factors but we did not prove that other factors such as the variations in wind direction and speed do not play a role in the yearly variations of persistence.

The key factor in our explanation is that the in-situ correlation between temperature anomalies of the surface air over the sea and the SSTA is higher during stable than unstable conditions. This is not necessarily in contrast with the results of Namias (1973) who concludes that the SSTA and the 700–1000 mb thickness are higher positively correlated under unstable than stable conditions. Although during unstable conditions the air-sea heat exchange may be large, the heat gained or lost by the atmosphere has to be spread out over a deep layer. During stable conditions only the lowest 10–100 meters of the atmosphere are in thermal contact with the sea.

6. Application

It is fairly easy to measure the skill of simple forecasting rules for all 15 stations with the data sets mentioned in Section 2. We first make tercile distributions of $\bar{T}$. For each of the stations and for each month the temperatures are subdivided into three classes in such a way that the A (above), N (normal) and B (below) classes have equal chances of occurrence. We will test four prediction schemes here:

(1) Persistence, that is

$A_i \to A_{i+1}$; $N_i \to N_{i+1}$; $B_i \to B_{i+1}$
(i is the number of the month)

(2) Two-class persistence, that is

$A_i \to A_{i+1}$ and N_{i+1}; $N_i \to N_{i+1}$;
$B_i \to B_{i+1}$ and N_{i+1}

(3) Sea-air persistence, that is

$A_i^{sea} \to A_{i+1}^{air}$; $N_i^{sea} \to N_{i+1}^{air}$; $B_i^{sea} \to B_{i+1}^{air}$

(4) Two-class sea-air persistence, that is

$A_i^{sea} \to A_{i+1}^{air}$ and N_{i+1}^{air}; $N_i^{sea} \to N_{i+1}^{air}$;
$B_i^{sea} \to B_{i+1}^{air}$ and N_{i+1}^{air}

These forecasts can be verified on the complete records for each of the stations; Schemes 1 and 2 can even be used to forecast the SSTA at station 1. In Schemes 3 and 4, records of unequal length may occur; in those cases the tercile distribution is recomputed for the overlapping part of the records. The four schemes are applied to all pairs of adjacent months. We will not discuss the skill as a function of the time of year, because this would be a repeat of the foregoing. So, for the sake of simplicity, we have averaged the skill over the whole year. The skill is measured as per cent better than climatological chance. The final verification scores are given in Table 2.

From Table 2 it can be seen that the skill of all prediction schemes decreases with increasing distance to the coast. With two classes for the target month, this decrease is clearer because the numbers are less noisy; also the skills are slightly higher. In the coastal areas monthly mean temperatures can be predicted with a percentage of hits which is 10–15% higher than climatological chance. In certain periods of the year this figure rises even to 20%.[1] Further away from the sea the skill is much lower and hardly exceeds zero in many months of the year.

We can also conclude from Table 2 that persistence of the air temperature gives a better prediction than mixed sea-air persistence, the ratio of the skills being about 1.5. This holds at 13 out of the 14 stations. Nevertheless, the decrease of skill with increasing delay is similar for all prediction schemes. Moreover, when we replace the monthly mean SSTA by the SSTA on the last day of the month there is hardly any difference left. An interpretation might be the following. There is probably a large-scale background persistence in the monthly mean air temperature, which is fairly constant over a distance of 200 to 300 km, but in addition there is a much stronger persistence directly controlled by the North Sea, which has a large gradient in the coastal area.

Gordon and Wells (1976) obtained a skill of 6% with an "optimum probable change" method applied to the Central England series. Their method comes close to our Scheme 2. Since

[1] In order to be able to judge the skill of 10 or 20%, one has to realize that tomorrow's maximum temperature at De Bilt is forecast with a skill of about 40%.

Table 2. *The skill of four prediction schemes measured by the difference of the percentage of hits and climatological chance*

	Station															
Scheme	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average of 2 to 15
(1) persistence	22	16	9	7	9	7	5	7	6	3	4	6	1	5	5	6
(2) 2-class persistence	22	16	11	8	10	9	8	9	8	7	7	7	5	8	7	9
(3) sea-air persistence	—	10	7	1	5	6	4	3	3	2	2	3	3	3	0	4
(4) 2-class sea-air persistence	—	12	8	6	8	8	5	6	5	5	4	5	5	6	3	6

Central England is more continental than the coast of the Netherlands, the value of 6 fits very well in Table 2.

We briefly mention here the skill of seasonal forecasts. Schemes 1 to 4 here are all applicable to seasonally mean temperatures as well. Averaged over the whole year, seasons can be predicted with a skill comparable to that of months. For example Scheme 2 has a value of 9% for months (averaged over stations 2 to 15), while for seasons this figure is 10%.

7. Discussion

There is not much hope that we shall ever be able to predict the atmosphere in all detail 1 month ahead (Lorenz, 1969). The details, like cyclones, being unpredictable after 14 days, one might still try to compute the deviations from the normal (or long-term average). Departures from the normal value can be of only a systematic nature, when the boundary conditions of the atmosphere (such as SST, solar constant, etc.) differ from normal. With General Circulation Models (Rowntree, 1976) or with simplified linear steady-state models (Egger, 1976; Opsteegh and Van den Dool, 1980) the response, or the departure from normal, in terms of the atmospheric large-scale velocity and temperature fields, can be estimated. From such model runs it becomes clear that right over a positive (negative) SSTA the air is not necessarily warm (cold) through the depth of the atmosphere. In contrast, in the present study we find evidence of a direct control of the temperature anomaly of the (surface) air by the sea. Apparently, for long-range weather forecasts one has to combine indirect large-scale circulation effects and direct boundary layer effects of the SSTA distribution of neighbouring and remote seas.

The importance of the direct effect is evident from the analysis of 14 time-series of monthly mean air temperatures in the Netherlands. The closer to the coast, the more important is knowledge of the SSTA for the prediction of the next month's air temperature. We have the impression that the correlation of the monthly mean temperature at the lag of 1 month can, to a large extent, be explained from the presence of the North Sea with its large heat capacity.

In their paper Craddock and Ward (1962) speculated about the origin of persistence at these long time scales. First of all they noted that (quote) "persistence of monthly mean temperature anomalies is associated with certain fairly definite areas and seasons and not with others". Further they wrote (quote) ". . . the regions of high persistence nearly all appear to be associated with water, with freezing or breaking sea ice, or with the extension or decrease of snow cover. Obviously, there is no one process leading to persistence, but there are a number, perhaps depending on the local inertia resulting from the presence of water, which in some way cause certain fringe areas to differ from the continental masses".

The present study confirms to a large extent the conclusions of Craddock and Ward. For the Netherlands the direct influence of the North Sea seems to be the main process leading to persistence. Since the influence of the sea decreases very quickly on the continent, sharp gradients in quantities measuring persistence must occur near the coast. With so many stations in a small area we were able to resolve that gradient. Although they used a tremendous amount of stations over large areas, Craddock and Ward had a much coarser grid but nevertheless found large differences in persistence between, for example, Leningrad and Helsinki, which are 300 km apart. However, using a finer mesh grid of, say, 10–50 km, the gradients turn out to be an order of magnitude larger in some coastal areas.

This paper presents evidence that the sea has an influence on the atmosphere in the next month. We did not explicitly discuss the influence of the atmosphere on the sea. Nevertheless it is worth mentioning that it is easier to predict $\bar{T}_i^{\text{air}} \rightarrow \bar{T}_{i+1}^{\text{sea}}$ than $\bar{T}_i^{\text{sea}} \rightarrow \bar{T}_{i+1}^{\text{air}}$. However, the latter is the most interesting.

8. Acknowledgement

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ОББЯСНЕНИЕ ПОСТОЯНСТВА В СРЕДНИХ ЕЖЕМЕСЯЧНЫХ ТЕМПЕРАТУРАХ В НИДЕРЛАНДАХ

Тщательно исследуется постоянство аномалий в средней ежемесячной температуре воздуха для 15 станций в Нидерландах. Для всех используемых станций имеются данные за последние 50 лет. Постоянство выражается в коэффициенте корреляции температуры воздуха соседних месяцев. На всех станциях коэффициент корреляции высок в конце лета и зимы и меньше для других месяцев. Со стодь большим количеством станций на малой площади можно разрешить большие пространственные применения. Вообще, постоянство велико вблизи моря и над морем и уменьшается над сушей с возрастанием расстояния от побережья. Авторы делают вывод, что кроме фонового постоянства, вызываемого крупномасштабной атмосферной циркуляцией, есть сильное постоянство, прямо контролируемое Северным морем, для которого велик градиент в прибрежной зоне. Вариации постоянства в течение года могут быть качественно объяснены рассмотрением (1) постоянства аномалии температуры поверхности моря (2) устойчивости атмосферного пограничного слоя над морем и (3) устойчивости атмосферного пограничного слоя над сушей. В заключение, авторы обсуждают успешность схем предсказания, основанное на простом постоянстве.