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An indirect estimate of the predictability of the monthly mean atmosphere.

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Abstract

It is sometimes claimed that the near-constant anomalies in external conditions produce an atmosphere signal that could be useful for long-range weather prediction. But, if anomalous external forcing were so important for the time-mean atmosphere, how can we understand why the time-mean atmosphere is so highly variable while the controlling factors are nearly constant ? Apparently, there is a great deal of internal random forcing, probably associated with large-scale transient eddies: the noise. The signal to noise ratio is estimated in this paper by comparing the month-to-month persistence in the monthly mean circulation in models with and without eddies. As a "model" that includes eddies we take the real atmosphere. The model without eddies is the one described by Opsteegh and Van den Dool (1980). This model is forced with constant forcing and a highly persistent atmosphere emerges. A comparison of the high level of persistence in the model (no eddies) and the much lower level of persistence in the real atmosphere yields a signal to noise ratio of 10 to 15% representing a large part of the northern hemisphere. Our estimate is consistent with the one by Madden (1976).

The accuracy of the present signal to noise ratio estimate depends on the quality of the eddy-free model. It is certainly a validation of this model in that it reproduces the annual variation in persistence derived from observations in the real atmosphere.

1. Introduction

For the purpose of forecasting the weather for a period beyond the limit of deterministic predictability (about two weeks) one would wish to be able to estimate the statistics of the atmosphere's behaviour over the period of interest. The simplest statistic is, of course, the time-mean state of the atmosphere, or more practically: the anomalies occurring in that mean state. Anomalies are defined here as deviations from the long term average at a certain location. Hence it is desirable to have a model that computes the quasi-stationary response of the atmosphere to the anomalous part of the forcing. An ideal model would be able to simulate observed time-mean atmospheric anomalies, provided that we had a perfect knowledge of the forcing, that is: perfect knowledge of the spatial distribution of heat sources and mechanical forces. A forecast could then be made with such a model, if we knew the forcing in advance.

The practical situation is that, in spite of considerable efforts (Adem, 1979), our models are far from ideal and moreover we do not know very well the forcing of the atmosphere in the next month, season or year. The latter objection may be overcome by assuming that the forcing remains the same. This is not the worst assumption of all, especially not when we have in mind the slowly changing forcing by sea surface temperature anomalies (SSTA). However, the forcing by anomalous external factors such as SSTA, ice and snow cover and soil moisture, may not be the most important part of the net forcing experienced by the atmosphere. If external factors were so important as long range weather forecasters hope they are (Namias, 1965), how then can we understand why the time-mean atmosphere is so highly variable, while the anomalies in the external factors themselves are quasi-constant.

There are two possible explanations for this apparent inconsistency. The first is that the atmospheric response to an absolutely persistent forcing is not the same in different periods of the year, not even in adjacent months. The second is that there could be a great deal of internal forcing, probably due to large-scale transient eddies, which is not or hardly linked to abnormal external conditions; as a result the net forcing varies considerably even though external factors remain nearly the same. It is the aim of this paper to find the relative importance of these two explanations.

The effect of large-scale transient eddies on the time-mean state can be considered a natural variability (Madden, 1976). As long as we cannot predict, parameterize or prescribe eddies, it is reasonable to regard the effect of eddies as noise in the long range forecast. All we can hope to predict is the signal associated with anomalies in external factors. Unfortunately, the natural variability in the northern hemisphere pressure seems to be frustratingly large (Madden, 1976).

In this paper we will try to estimate the signal to noise ratio, associated with the prediction of the monthly mean atmosphere, by comparing the degree of persistence of the real atmosphere with that of a stationary model without eddies. We expect, of course, that in a model without eddies the response is less variable or: more persistent. The maximum in the persistence from one period to the next in any model will most probably be found when the forcing remains the same. In section 2 we describe the month-to-month persistence of the atmospheric response in a model without eddies in a situation of perfectly persistent forcing. There are variations, in spite of the non-varying forcing, due to changes in the climatological mean zonal wind, stability and meridional temperature gradient. As a result we find a well-defined annual course in the persistence.

In section 3 we describe a diagnostic study to find the degree of persistence in the real atmosphere. In this case we use observations of the real atmosphere over the last thirty years. This period appeared to be about sufficient to find a reliable annual course of the persistence in monthly mean flow patterns over the northern hemisphere. In section 4 we carefully compare the results of sections 2 and 3 in order to arrive at an estimate of the signal to noise ratio.

2. Persistence in a model without eddies

In this section we describe the changes of a stationary model atmosphere in successive periods of the year while keeping the forcing fixed. The model that we use here is described by Opsteegh and Van den Dool (1980). For the present discussion it suffices to recall that it is a stationary, two-layer, linearized primitive equation model on the northern hemisphere. The value of the friction and diffusion coefficients are chosen sufficiently large to suppress the amplitude of resonant waves (Van den Dool and Opsteegh, 1981). In this model the transient eddies are not represented. The equations are linearized with respect to a basic state that consists of a latitude- and height-dependent zonal flow (U_n) and latitude-dependent temperature (T_n) and static stability (σ_n) fields. The model computes anomalies in wind, temperature and pressure that arise from anomalous forcing. Because the magnitude and position of the atmospheric anomalies depend on U_n, T_n and σ_n, the response in two successive months is not the same even though we did not change the forcing.

The model can be considered a January-model by inserting the observed climatological values of U_n, T_n and σ_n. Via the choice of these climatological ingredients the model becomes month- or season-dependent. The climatological data were taken from Oort (1980).

In Opsteegh and Van den Dool (1980) we already showed some maps demonstrating that the response to a given fixed forcing is, indeed, season-dependent. Here, we investigate in more detail the changes (or the absence of changes) from month to month. For one fixed heat source twelve runs were made. The set of twelve experiments was performed for a heat source at three different latitudes, so a total of 36 model runs was made. In all cases the size of the heated area and the magnitude of the heating were the same. The size of the heating is about 23 degrees of latitude and 34 degrees of longitude, that is 7 by 7 gridpoints. In the centre of the area the heating is $+10^{-5}Ks^{-1}$, which decreases according to a parabolic profile to zero at the corners of the 7 by 7 square. This heat source is placed at three latitudes, the centre being situated at (1) 13.7 ^{o}N, (2) 41 ^{o}N and (3) 68 ^{o}N. Because the basic state is independent of longitude, only the latitude of the heat source matters. The three areas of heat release have no overlap.

We will investigate the similarity of the temperature response (or thickness 400-800 mbar) in successive months. The degree of persistence is expressed here as a pattern correlation coefficient:

$$\rho(T^i,T^{i+1}) = \frac{\frac{1}{W}\sum_n w_n T_n^i T_n^{i+1} - \frac{1}{W^2}(\sum_n w_n T_n^i)(\sum_n w_n T_n^{i+1})}{\left[\left(\frac{1}{W}\sum_n w_n T_n^i T_n^i - \frac{1}{W^2}(\sum_n w_n T_n^i)^2\right)\left(\frac{1}{W}\sum_n w_n T_n^{i+1} T_n^{i+1} - \frac{1}{W^2}(\sum_n w_n T_n^i)^2\right)\right]^{\frac{1}{2}}} \qquad (1)$$

where T is the temperature averaged over the 400-800 mbar layer, i is the number of the month, n is an index indicating a gridpoint, $W=\sum_n w_n$ and w_n is the weight factor for the area represented by the gridpoint. The coefficient is computed for the entire northern hemisphere.

In Fig. 1 the pattern correlation coefficients are plotted as a function of thepair of months involved, that is the time

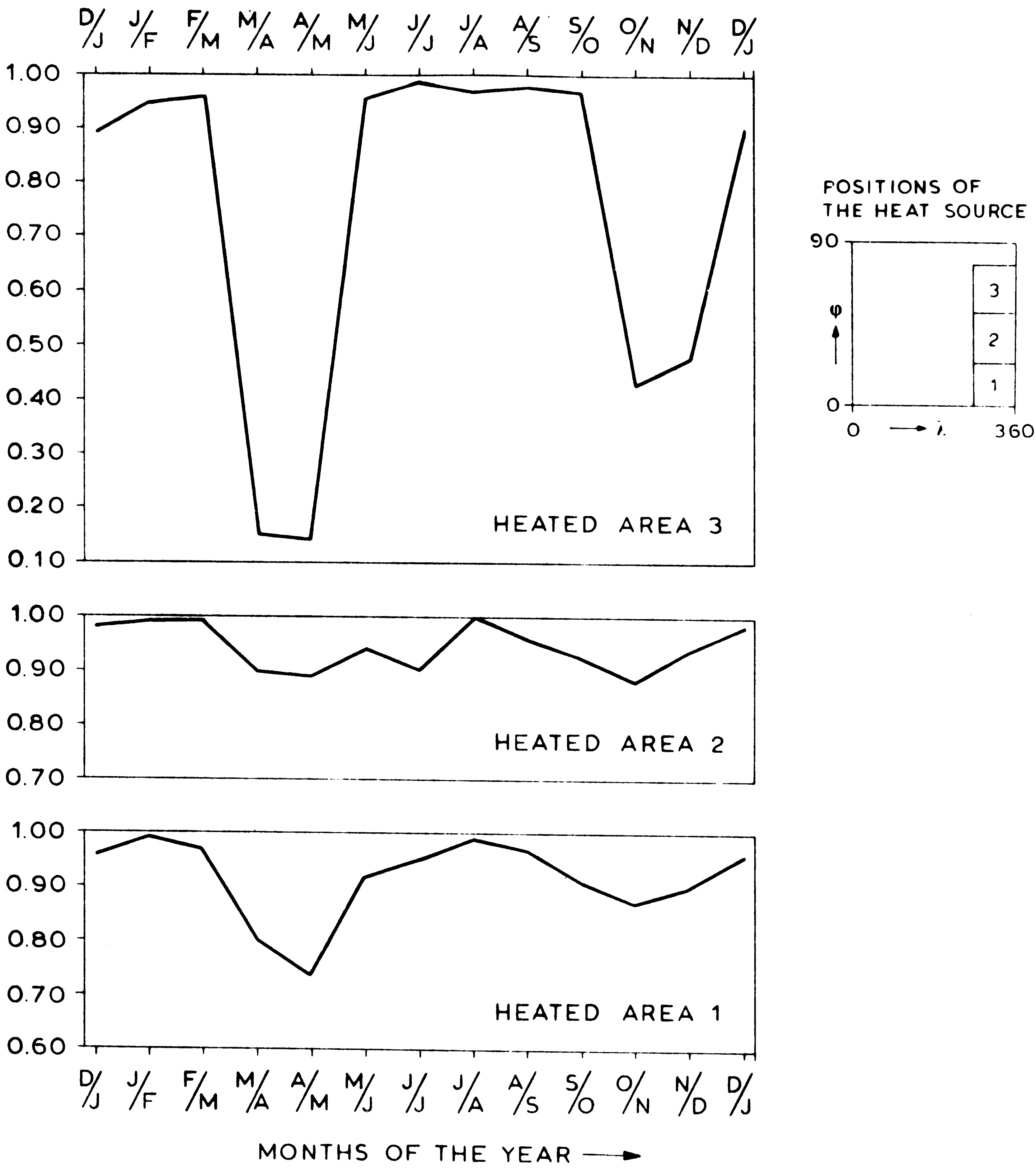

Fig. 1 Month-to-month pattern correlation coefficients of the temperature (400-800 mbar thickness) response of a stationary northern hemisphere atmospheric model; the forcing is the same in all months. The model does not include the effect of eddies. The forcing consists of a heat source, which is situated at high (3), middle (2) and low (1) latitudes respectively.

of the year. From top to bottom we find graphs for the fixed heat source at high, middle and low latitudes. In general the correlation from month to month is very high except for some periods in spring and autumn when it is lower. As far as the time of the year of the extremes is concerned the three graphs are surprisingly consistent.

What determines the times of the year of the extremes in Fig. 1 ? Obviously, when U_n, T_n and σ_n, together defining the basic state, do not change, $\rho(T^i, T^{i+1})$ equals 1. In reality the month-to-month changes in the basic state are always small. The correlation coefficient between the latitudinal profiles of the basic state in successive months is high (0.90 or more, averaged over the three ingredients) and has no very regular annual course. The sensitivity of the model to changes in the basic state is rather complex; the solution strongly depends on the strength of the zonal wind, the latitude of the zero wind line ($\approx 30\ ^{\circ}$N), and for lower values of U_n also on $\partial T_n/\partial y$ and σ_n. Of course, in Fig. 1 all these factors have been taken into account; the model weighs how important changes in the basic state are. Apparently, January-February and July-August are the times of the year with the smallest relevant changes in the basic state, whereas April and November are characterized by crucial changes in the climatology of the atmosphere.

We conclude that imperfect persistence in the atmosphere does not imply that external factors do not control the circulation. That is, in our numerical experiment we have an atmosphere completely controlled by perfectly known external forces, which has, nevertheless, variability in time. It may well be that some of the temporal variability of the real atmosphere has the same origin.

The consistency of the three graphs in Fig. 1 indicates that our conclusions are not too sensitive to the choice of this particular set of three forcings. We feel that any other heat source at 600 mbar, arbitrary in shape and intensity, would have produced a variation of persistence throughout the year similar to Fig. 1.

It cannot be a coincidence that the annual course depicted in Fig. 1 is similar to the observed annual course in persistence in monthly mean surface temperatures at many locations in Northwestern Europe.(Craddock and Ward, 1962). In Fig. 2 we have reproduced (Van den Dool and Nap, 1981) the correlation coefficient of monthly mean surface air temperature at De Bilt for all pairs of adjacent months. (Here we deal with a correlation in time!). The similarity of Fig. 1 and 2 is intriguing. Rather than going into details of persistence at a location near the surface, it would be more relevant to compare Fig. 1 with month-to-month persistence of observed atmospheric temperature patterns of as much of the northern hemisphere as possible. Surprisingly, it is difficult to find any numbers concerning persistence in the monthly mean circulation in literature; one of the few exceptions is a paper by Namias (1952). In the next section we discuss pattern correlation coefficients of the northern hemisphere circulation based on observations since 1949.

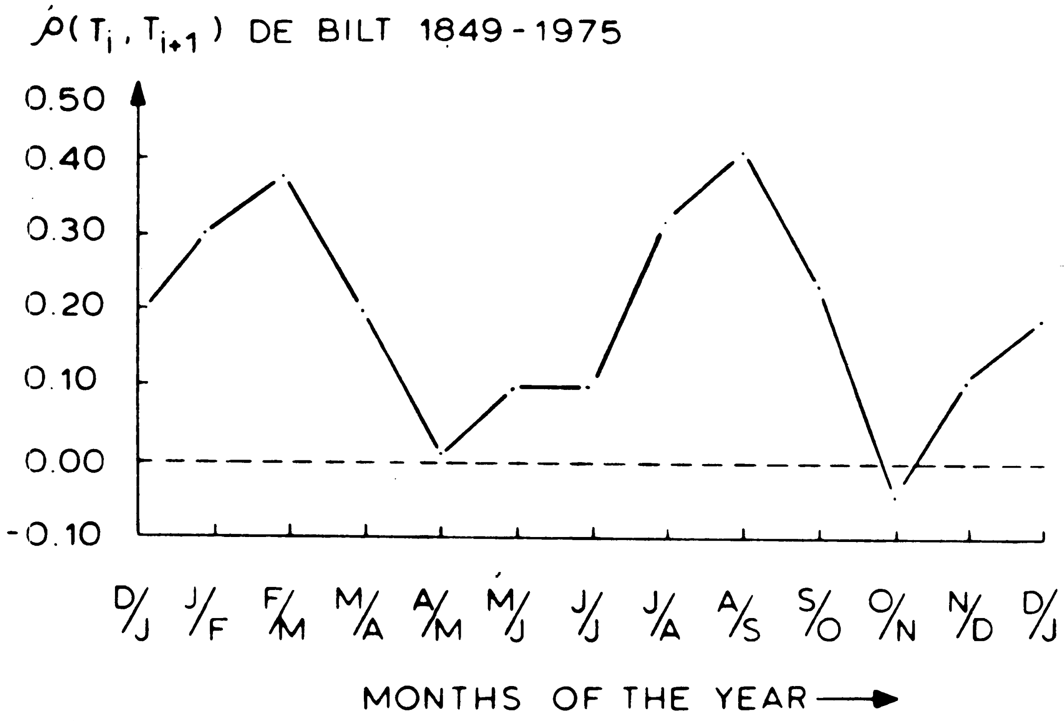

Fig. 2 The temporal correlation coefficient of monthly mean air temperature in adjacent months at De Bilt (1849-1975). Correlations larger than 0.18 differ from zero at the 95% confidence level.

In a verification of ten years of forecasts of monthly mean quantities in Northwestern Europe according to seven methods Nap et al. (1981) have found that the skill of the forecasts is restricted mainly to those months in which nature offers us persistence as a gift. Therefore it is hopeful that we have presented here evidence that a lack of persistence is not identical to a lack of predictability. It seems that the lack of persistence in autumn and spring can be compensated by taking into account the changes in U_n, σ_n and T_n (via a model).

3. Persistence in the monthly mean atmosphere circulation

In the introduction we posed the question of how how we can understand why a near-constant external "control" results in a highly variable time-mean atmosphere. But how variable is the atmosphere? From synoptic experience with time-mean maps we are tempted to say that the changes are almost random. Of course the month-to-month changes in the observed monthly mean circulation can as well be expressed quantitatively in the pattern correlation coefficient according to (1).

Our data base consists of daily maps of the 500 mbar height and surface pressure provided by the German Meteorological Service at Offenbach (FRG). These maps, available on tape from January 1, 1949 to July 31, 1977, are represented by values in a 5^{o}x 10^{o} latitude-longitude grid that covers most of the area north of 20 ^{o}N. Unfortunately, the data coverage is not completely homogeneous in time, and especially at low latitudes and over the Pacific we have to skip many gridpoints in the following calculations.

We first made monthly (calender months) mean patterns from January 1949, February 1949, ... to July 1977. For each calendar month normals can be computed straightforwardly by averaging over 29 (28) individual maps. As the next step, anomaly maps were prepared by subtracting the individual monthly mean from its normal value. We are now in the position of computing a pattern correlation coefficient between anomaly maps of any pair of adjacent months. For the pair January/February, for example, we calculated 29 coefficients for the years 1949 to 1977. Of course the correlation differs widely from year to year and it seems wise to average them over all 29 cases. The result is a climatological value of the correlation coefficients of the atmospheric circulation in adjacent months.

The procedure described above has been applied to the thickness patterns, but for completeness we also give the numbers for the 500 mbar height and surface pressure. The results are shown in Fig. 3 and, more extensively, tabulated in Table 1. From Fig. 3 it becomes evident that there is a small, generally positive month-to-month anomaly correlation in the observed monthly mean atmosphere. On the average, the value of the correlation coefficient amounts to 0.20 for the thickness pattern and to 0.14 and 0.13 for the 500 mbar height and surface pressure respectively. These values differ significantly from zero, as can be judged from the standard deviation reported in Table 1. Further information in Table 1 concerns the highest and lowest values that occurred in the 1949-1977 period.

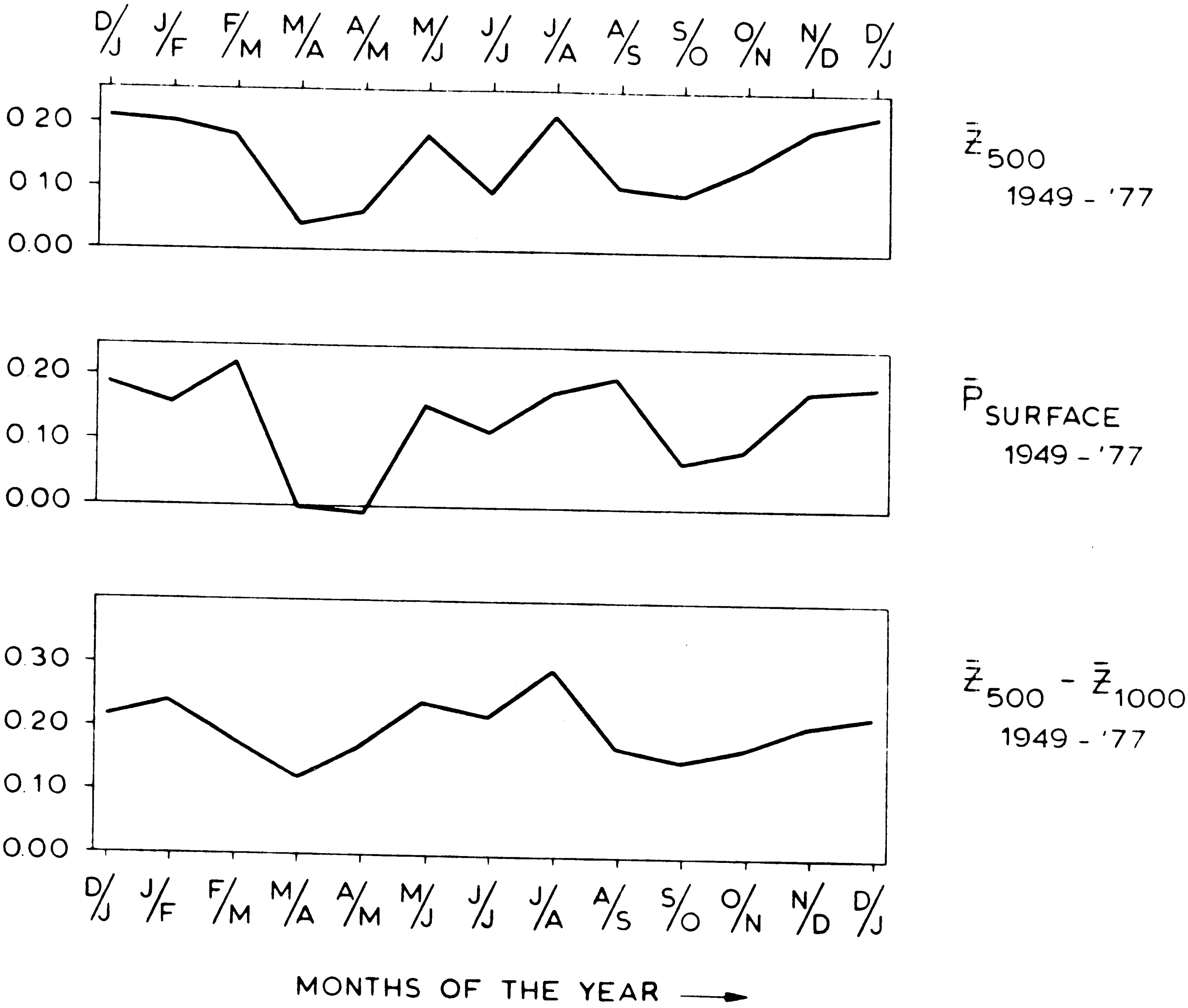

Fig. 3 Month-to-month pattern correlation coefficients of anomalies in observed monthly mean fields of 500 mbar height, surface pressure and 500-1000 mbar thickness. The observations, analyzed at Offenbach, cover most of the area North of 25° N. The graphs represent averages over 29 (28) individual estimates for the years 1949-77 (76). Further information can be found in Table 1.

	J/F	F/M	M/A	A/M	M/J	J/J	J/A	A/S	S/O	O/N	N/D	D/J	Total
						(1) Z_{500}							
$\bar{\rho}$	20	18	4	6	18	9	21	10	9	13	19	21	14
max	72	53	55	35	64	57	54	45	42	74	57	66	
min	-53	-14	-39	-32	-20	-17	-12	-29	-42	-57	-42	-56	
$s(\rho)$	28	20	24	17	20	17	19	20	21	27	24	29	
						(2) $p_{surface}$							
$\bar{\rho}$	16	22	0	-1	16	12	18	20	7	9	18	19	13
max	62	54	53	49	57	42	63	57	35	43	57	80	
min	-42	-25	-47	-48	-40	-17	-38	-21	-33	-48	-38	-48	
$s(\rho)$	29	21	25	20	24	17	25	17	21	21	25	29	
						(3) $Z_{500}-Z_{1000}$							
$\bar{\rho}$	24	18	12	17	24	22	29	17	15	17	21	22	20
max	66	55	58	51	60	62	56	50	42	53	67	60	
min	-39	-29	-23	-10	-1	-10	-4	-17	-25	-57	-33	-31	
$s(\rho)$	27	22	21	15	17	17	16	18	19	25	25	22	

	J/F	F/M	M/A	A/M	M/J	J/J	J/A	A/S	S/O	O/N	N/D	D/J
n.o.y.	29	29	29	29	29	29	28	28	28	28	28	28

Table 1. The month-to-month correlation (%) of anomaly patterns in (1) the 500 mbar height, (2) surface pressure and (3) thickness. J/F denotes January to February, etc. The correlation is determined for the area North of 20° N. The four rows per item contain the average over 1949-77, the highest and lowest values in the 1949-77 period and the standard deviation. Finally the number of years (n.o.y.) is given per pair of months.

Although the values in Fig. 3 are much lower than those in Fig. 1, we note that a similar annual variation is found. Persistence in the circulation, although low, reaches maximum values from January to February and from July to August, whereas the minima are found in spring and autumn. Fig. 3 in particular has much in common with the graphs in Fig. 1, which refer to the heat source in low and middle latitudes.

How to interpret the similarity of Fig. 1 and 3 ? The model, as used in section 2, did not prove to have predictive capabilities so far, but apparently it is sufficiently realistic to simulate successfully the observed annual variation in persistence of the circulation. Therefore we may conclude that just as in the model, part of the anomalies in the real atmosphere are controlled by near-constant forcing. However, we cannot prove at this stage that this near-constant forcing of the real atmosphere is related to external factors, such as SSTA, but this is more likely to be true than a near-constant forcing related to large-scale transient eddies.

Fig. 3 is based on data for the period 1949-77. Namias (1952) used 700 mbar heights covering a smaller area, North America and parts of the oceans, for the early period 1932-1950. Although for many purposes this set of 700 mbar data is out of date, it should be noted that Namias' results are essentially similar to Fig. 3.

Of course, correlation coefficients of a few tenths do not enable us to make a practically useful forecast of the monthly mean circulation. Persistence of observed anomalies will, on the average, explain at most 10% of the spatial variance in the next month. The synoptic experience that monthly mean maps vary almost at random proves to be correct.

We investigated here whether slowly changing external forcing causes persistence on the monthly time scale. However, a small month-to-month correlation might result as well from the interrelation that exists between successive daily values. Assuming a first-order linear Markov process that is $Y_{j+1} = \rho Y_j + \varepsilon_j$, where Y_j is the average value of some variable at day j, ρ is the autocorrelation coefficient at lag one day (whatever the cause of that autocorrelation may be) and ε is a random number, one can derive after some manipulations the autocorrelation coefficient of 30-day mean values at lag 30 days:

$$\rho_{30} = \frac{\rho(1-\rho^{30})^2}{30(1-\rho^2) - 2\rho(1-\rho^{30})} \qquad (2)$$

In Table 2 we list some values of ρ and ρ_{30}. According to Lorenz (1973), a representative northern hemisphere value of the lag-one-day autocorrelation for tropospheric pressure surface heights is 0.75, resulting in a month-to-month value of about 0.07. In Fig. 3 we find values significantly higher than that, indicating that this effect does not explain the observed month-to-month persistence.

Finally, our curiosity is raised as to why thickness patterns are more persistent than circulation patterns (500 mbar height and surface pressure). It turns out that the larger

ρ	ρ_{30}
0.20	0,007
0.40	0.016
0.60	0.033
0.70	0.050
0.80	0.087
0.90	0.208
0.99	0.820

Table 2.
Some values of the month-to-month correlation (ρ_{30}) of monthly mean quantities starting from a first order linear Markov process with an autocorrelation coefficient ρ at lag one day.

correlation of Z_{500}-Z_{1000} in successive months is mainly due to a much smaller spatial variance of the thickness as compared to Z_{500} alone. A large part of the observed anomalies is of an equivalent barotropic nature. Hence the subtraction of Z_{1000} from Z_{500} yields a thickness which is spatially less variable than Z_{500} itself. The subtraction also raises the relative importance of the baroclinic modes in the observed anomaly fields, and apparently the persistent part of the anomalous circulation is mainly composed of baroclinic modes. In a way this is understandable. A diagnostic study of the output of the stationary model (Van den Dool en Opsteegh, 1981) revealed that baroclinic modes are tied to the geographical position of the heat source, whereas barotropic modes are an hemispheric response to a forcing at any place. Assuming that this aspect of the stationary model is realistic, we deduce that the near-constancy of the heat source will make the baroclinic mode persistent.

When persistence of Z_{500}-Z_{1000} is higher than that of Z_{500} and Z_{1000} alone, one wonders whether one can find a constant (α) such that $Z_{500} - \alpha Z_{1000}$ is maximally persistent in the real atmosphere. Indeed, it turns out that there is a marginal improvement when α is taken ~ 0.95 in winter and $\sim 1,60$ in summer. However, the difference with $\alpha = 1$ (Table 1) is small.

4. A signal to noise ratio

By considering Figs 1 and 3 we compare the degree of persistence in a model without and a model with eddies. It is not difficult to imagine a manner to lower the correlation coefficients of Fig. 1. With the inclusion of sufficient random (in time) forcing over and above the constant forcing, used to arrive at Fig. 1, we could rerun the model and come close to the behaviour of the real atmosphere as depicted in Fig. 3. When we make the assumption that the random forcing is brought about by large-scale eddies, then a comparison of Figs. 1 and 3 yields an estimate of the signal to noise ratio.

Atmospheric variability from month to month as such does not prove that eddies are important, because changes in the basic state could have taken place. However, shortly after the summer and winter solstices the basic state is virtually constant and in these periods of the year the comparison of $\rho(T^i, T^{i+1})$ for both "methods" is easiest. In the model without eddies ρ is very near to 1.0 in these periods, while the maximum in the real atmosphere seems to be about 0.30. So in terms of explained variance (EV) we know 100% and 9% of the spatial variance of next month's temperature field in the two cases respectively. In terms of explained variance we may write

$$\frac{EV_{signal}}{EV_{signal} + EV_{eddies}} \cong \frac{9}{100} \qquad (3)$$

and as a result $EV_{signal}/EV_{eddies} \cong 10\%$. As long as we do not know the influence of eddies on the mean atmosphere we cannot expect to be able to predict more than 9% of the spatial variance.

The order of magnitude of the signal to noise ratio, 10%, is consistent with an estimate according to Madden (1976). He estimated for many locations in the northern hemisphere the variability of monthly mean values of the surface pressure to be expected solely due to day-to-day fluctuations; this yields a natural variability. This natural variability can be compared with observed variability of monthly mean pressure. Because the observed variability is only a fraction larger than the natural variability, Madden concluded that the potential predictability of monthly mean surface pressure is very restricted. His computations discriminate between low and high latitudes; in low latitudes the predictability seems to be slightly better.

Our method yields a number representing the whole of the northern hemisphere. A place-dependent estimate cannot be made but an impression could have been obtained by considering correlations in time instead of pattern correlations in section 3, the diagnostic part. Per gridpoint we have time series of concurrent quantities in adjacent months, the record length being 28 or 29. In fact Namias (1959) computed temporal correlations for seasonally averaged 700 mbar heights. He found the correlation to be higher at low latitudes than more to the north; this is consistent with Madden's conclusion concerning latitude-dependent predictability.

It is easy to mention some weak points in our indirect method to find the signal to noise ration. The intention was to compare models with and without eddies, but otherwise the models should be equal. Obviously there are many more differences between the model of section 2 and the real atmosphere. Unlike the real atmosphere the model is linear, stationary and discretisized at two levels, the model is subject to boundary conditions that may be unrealistic and, last but not least, the basic state of the linear model does not depend on longitude nor does it include the mean meridional cells. Especially the simplification of the basic state might have influenced the estimate in (3). Correlation coefficients of nearly 1.0 will probably not be reached any more in a model linearized with respect to a more complex basic state; the more complex the basic state, the more difficult it is to find times of the year without relevant changes in the climatology. Moreover, the sensitivity of the model response may become larger for subtle changes in a realistic basic state. We guess that the value in the numerator of (3), 100%, will go down somewhat.

Apart from differences in the model, also the experiments performed with the model and the real atmosphere were not completely the same. The variance explained by the signal, 9% (denuminator of (3)), is derived from real atmospheric data, but unlike the model the real atmosphere has not been subject to absolutely persistent external forcing. There were changes in the external forcing from month to month, not only because external factors (SSTA) are not constant but also because the external forcing is determined in reality in an interactive way; external forcing depends on climatological ingredients and therefore on the time of the year. When we were able to experiment with a real atmosphere under constant external forcing, the variance explained by the signal (as meant in the denuminator of (3)) would certainly rise, but we guess by not more than a few per cent.

Summarizing we can state that a conservative (pessimistic) estimate of the signal to noise ration is about 10%. There are some reasons to believe that the real ratio is a little higher, maybe 15%.

5. Conclusions and discussion

In this paper we have tried to estimate the signal to noise ratio associated with the prediction of anomalies in the monthly mean tropospheric temperature field. The signal is defined as that part of the anomalies arising from external factors, whereas we look upon the effect of large-scale transient eddies on the monthly mean atmosphere as noise. In the absence of noise one would expect fairly constant monthly mean atmospheric anomalies, because the external anomalous forcing hardly changes from month to month. However, synoptic experience tells us that in reality the monthly mean atmosphere changes nearly at random, indicating a substantial noise level.

A comparison of atmospheres with and without the effect of eddies has been worked out quantitatively. The degree of month-to-month persistence in the eddy-free model (expressed in a pattern correlation coefficient) is high and shows a well-defined annual course. A similar annual course, but at a much lower level, can be detected by examining 29 years of observed northern hemisphere monthly anomaly patterns. From a comparison of the high level of persistence in the eddy-free model (close to 1.0) and the lower level in the real atmosphere ($0 < \rho < 0.3$) we deduce that the signal to noise ration should be about 10 to 15%.

The conclusion is that without any knowledge of the next month's eddy forcing we can potentially predict, on the average, 10 to 15% of the spatial variance of the northern hemisphere thickness (temperature) pattern. For this small amount of predictability we need a perfect model and perfect knowledge of the external forcing. As we have neither, even the level of 10-15% will not be reached by using present-day models.

The experiments with the stationary model show that, as far as atmospheric circulation is concerned, the lack of persistence in autumn and spring is not identical to a lack of predictability in these periods. We conclude that by taking into account the seasonal changes of the basic state a forecast of the atmospheric circulation can be made, the skill of this forecast being independent of the time of the year.

The predictability of the monthly mean atmospheric circulation seems to be limited. However, there are a number of circumstances that could improve the situation. (1) The signal to noise ratio of 10-15% represents a large part of the nortnern hemisphere, but at some locations in certain months the monthly mean atmosphere may be more predictable. (2) A limited or negligible predictability in atmospheric circulation parameters does not necessarily imply that the weather at the surface is equally unpredictable. Near the surface local contributions to persistence exist. With simple means (viz. damped persistence) 25% of the variance of the next month's air temperature can be predicted in the coastal area of the Netherlands (Van den Dool and Nap, 1981). (3) Possibly an atmospheric circulation parameter can be constructed that is more predictable than the ones depicted in Fig. 3, thickness, surface pressure and 500 mbar height. As an example we considered $Z_{500} - \alpha Z_{1000}$, with α varying from 0.95 in winter to 1.60 in summer. Hopefully such a new parameter is related to the weather experienced at the surface. (4) A limited predictability refers to an average skill, but possibly there are occasions, maybe extreme cases related to outspoken SSTA patterns, in which predictability is better. (5) The only real breakthrough in long-range weather prediction would be achieved by parameterizing the effect of large-scale eddies, but nobody knows whether this is possible. In this paper the effect of eddies is referred to as noise, but this is a practical rather than a theoretical point of view. We feel that it is not likely that anomalous eddy forcing is reproducibly linked to SSTA. If this were so, then the external plus eddy forcing should have to be much more persistent than it seems to be in the real atmosphere.

Most of the escapes offered in the foregoing list are wishful thinking. It is realistic to expect that we can predict only 10-15% of the next month's weather. At low latitudes (Madden, 1976) and close to the surface in maritime areas (local contributions to persistence) the predictability of some of the meteorological variables, mainly temperature, is higher.

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References

Adem, J., 1979: Low resolution thermodynamic grid models. Dynamics of Atmospheres and Oceans, 3, 433-451.

Craddock, J.M. and R. Ward, 1962: Some statistical relationships between the temperature anomalies in neighbouring months in Europe and Western Siberia. Meteorological Office London. Scientific Paper N. 12, p. 31.

Dool, H.M. van den, and J.L. Nap, 1981: An explanation of persistence in monthly mean temperatures in the Netherlands. Tellus, 33, in press.

Dool, H.M. van den, and J.D. Opsteegh, 1981: The planetary wave response of a linear two-layer primitive equation model to a localized heat source at mid-latitudes. Submitted to J. Atm. Sci.

Lorenz, E.N., 1973: On the existence of extended range predictability. J. Applied Met., 12, 543-546.

Madden, R.A., 1976: Estimates of the natural variability of tome-averaged sea-level pressure. Mon. Wea. Rev. 104, 942-952.

Namias, J., 1952: The annual course of month-to-month persistence of climatic anomalies. Bull. Amer. Met. Soc., 33, 279-285.

Namias, J., 1959: Persistence of mid-tropospheric circulations between adjacent months and seasons. Rossby Memorial Volume, p. 240-248. (Rockefeller Institute press and Oxford University press).

Namias, J., 1965: On the nature and cause of climatic fluctuations lasting from a month to a few years. W.M.O. Techn. Note N. 66, 46-62.

Nap, J.L., Dool, H.M. van den, and J. Oerlemans, 1981: A verification of monthly weather forecasts in the seventies. Mon. Wea. Rev., 109, ... (in preparation).

Oort, A.H., 1981: Global Atmospheric Circulation Statistics 1958-1973. NOAA Professional Paper, U.S. Government Printing Office, Washington D.C. (in preparation).

Opsteegh, J.D., and H.M. van den Dool, 1980: Seasonal differences in the stationary response of a linearized primitive equation model: prospects for long-range weather forecasting ? J. Atm. Sci., 37, 2169-2185.