The Use of Normals in Numerical Forecasting

by R. S. SCORER

Imperial College, London

(Manuscript received July 18, 1953)

Abstract

If there exists, in the spectrum of fluctuations of weather, a period of relatively low amplitude, and if a set of normal values of the right kind can be defined, then dynamical equations for the behaviour of the atmosphere can be used for the numerical prediction of charts meaned over the period of low amplitude.

1. Introduction

The complete equations of motion for the atmosphere are too complicated to solve by existing methods and the data are not available for making even a rough estimate of many of the terms, such as those involving friction, convection by clouds, and so on. The question posed, therefore, is whether normal values can be used as substitutes for any of these. The belief that they can be of value is based on the ability of forecasters to use their experience in forecasting: that experience is condensed and classified in the forecaster's memory as it takes place, and there is some hope that if the classification could be made available to a machine it might improve upon numerical forecasts which are based on equations which are known to omit many important influences.

This discussion is in very general terms because it is believed that the principle stated may find application on many scales. It was suggested by the work of CLAPP (1953) who used normal values in the barotropic vorticity equation applied to 5-day mean charts, and it seemed worthwhile to state a general principle of which Clapp had discussed a particular example.

2. The definition of a normal

The idea of a normal value is based on the supposition that the atmosphere behaves habitually in a particular way. If there were in no sense a repitition of its behaviour no normals could be defined. If there is some sort of repitition a normal can be defined as the average of a specified large number of occasions. We can speak of "annual rainfall" because, although it varies from year to year, rainfall amounts are repeated within not very wide limits in many parts of the world from year to year. We can speak of the normal temperature for a time of year in places where the annual variation exceeds considerably the short period fluctuations. The concept of normal temperature is not generally useful except as a reference value because the diurnal variations and variations due to the passage of weather systems are large enough to render the normal useless as a forecast for a particular time in the future. But if these short period fluctuations are sufficiently short we can take a mean value for a period long enough to contain several such fluctuations and yet short enough to represent a time of year, and we may say with some confidence that the mean value for such a period in the future will aproximate closely to the average over many years.

Unfortunately instances are easily found in the records of fluctuations of almost any period we care to name. Exceptional seasons are frequently experienced, but if one could evolve a forecasting method that could be applied at times that are not so exceptional it would be of great value. Clapp chose the period of 5 days. One could argue that this is short enough for seasonal variations to be imperceptible and long enough to contain several of the smaller disturbances which dominate the weather: but the precise length of the period is not relevant to the present argument. The important issue is whether an interval, such as 5 days, could be chosen at all which was at a minimum in the spectrum of fluctuations, there being large annual fluctuations and large fluctuations of much shorter period, but no important ones of period close to the interval chosen. Undoubtedly no interval could be found to satisfy this condition always everywhere, but if an interval were once chosen the occasions when it failed could mostly be recognised.

For the sake of argument we may suppose that 5 days is the interval chosen. This done the normal values of all the quantities whose means we shall require would not simply be calculated for a time of year. It would be necessary to define certain weather types and calculate normals for each weather type. We might, for example, calculate the normal value of a term in an equation for seasons colder than usual, or for particular common blocking situations. In principle, instead of lumping all occasions together we would classify them and have normal values for each class: then, when we require to use a normal, we decide that the occasion on which it is to be used falls in one particular class, and we use the corresponding value.

The same procedure might be applied to the coefficient of vertical transport (of water vapour for instance). For a given site experiments might have found a relationship between the wind speed and the transfer coefficient, the relationship depending perhaps upon the lapse-rate of temperature. In using such a coefficient we assume that we are dealing with a large number of the small eddies and only a fraction of a large eddy such as a cyclone: in fact we are working in a region of the spectrum of fluctuations where the amplitude is low. Having measured the lapse-rate and wind speed on a particular occasion we could then apply the coefficient for purposes of prediction. To use a coefficient which depends upon conditions is obviously better than to use a universal one, and in the same way we could, by classification of weather types obtain a normal value more appropriate than an 'all time' normal. The transfer coefficient is completely analogous to any normal value that is any use, and it is only prudent to improve our normals in the same way.

3. The use of normals

In using a transfer coefficient we simply measure on some occasions the quantities it relates and assume its value to be the same when one of the quantities is unknown. Thus, in order to calculate the transfer of heat into the atmosphere by convection it is not necessary to measure the transfer directly if it can be included in an equation in which everything else can be measured. We might, for instance measure the changes in vorticity and deduce the vertical velocity and changes in temperature that result, and compare them with the observed changes, ascribing the rest to convection. Indeed we need not ascribe the rest to anything in particular but simply to everything we cannot measure; and on another occasion when there was one more unknown, we could use the normal value obtained from several similar situations to evaluate the unknown.

To be more specific, let us suppose that we have established an equation

$$Q = A + B + C + \dots \qquad (1)$$

Q being the unknown—the quantity to be forecast—while A, B, C, ... are measurable, in theory at least, directly or indirectly.

The instruments making the measurements —barometers, tharmometers, etc.—usually take mean values over a period of perhaps a minute, and from these ordinary charts are obtained. But if we have decided to use 5 day mean charts in order to use normals at all then we must use the equation in the form

$$\bar{Q} = \bar{A} + \bar{B} + \bar{C} + \ldots \quad (2)$$

the bar denoting a 5 day mean value.

The same equation applies to the normal values (however they have been defined), and using suffix N to denote them we have

$$Q_N = A_N + B_N + C_N + \ldots \quad (3)$$

The quantities A etc. may be complicated functions of the observations. If r and s are observed quantities we might have

$$A = r \cdot s \quad (4)$$

whence

$$\bar{A} = \overline{r \cdot s} = \bar{r} \cdot \bar{s} + X \quad (5)$$

in which X may be complicated expression involving the departures of r and s from their means $\bar{r}$ and $\bar{s}$. The familiar Reynold's stresses are examples of terms like X.

Since X is a term representing the effect of fluctuations we assume that it is the same in every case in which many fluctuations are involved and so

$$A_N = r_N \cdot s_N + X \quad (6)$$

and then $\bar{Q} = \bar{A} + \ldots$

$$= (\bar{r} \cdot \bar{s} - r_N \cdot s_N + A_N) + \ldots$$
$$= (\bar{r} \cdot \bar{s} - r_N \cdot s_N) + \ldots + Q_N \quad (7)$$

and so $\bar{Q}$ is known from observations such as $\bar{r}$ and $\bar{s}$ and the normal values

Provided that the terms B, C, etc. do not represent processes which operate largely by means of periodicities nearly equal to the interval over which we have meaned the charts they can, if desired, be treated in the same way as the term X. They may therefore be either long term radiation effects or short term dynamical ones, but we may merely assume that they bring about the same relationship to the measurable quantities and our single unknown as they do between the normal values.

Thus as a first approximation we have $\bar{Q} = Q_N$, i.e. our first forecast is that the quantity will assume its normal value. When we can measure current values of r and s we have

$$\bar{Q} = \bar{r} \cdot \bar{s} - r_N \cdot s_N + Q_N \quad (8)$$

and if at a later stage we can measure B then

$$\bar{Q} = \bar{r} \cdot \bar{s} - r_N \cdot s_N + \bar{B} - B_N + Q_N \quad (9)$$

and so on.

There is nothing new in this general principle, but it is now seen in the light of mean values and normals as applied to a turbelent atmosphere.

Clapp's application was simply to use the vorticity equation and obtain.

$$\frac{g}{f} \Delta^2 \frac{\partial \bar{z}}{\partial t} = (-\bar{v} \cdot \Delta\, \bar{\eta}) - (-v_N \cdot \Delta\, \eta_N) \quad (10)$$

(in the usual notation) assuming $\partial z_N / \partial t$ to be zero. The second term on the right hand side is a first attempt to introduce an estimate of all that was left out in the barotropic vorticity equation, and there is good reason to suppose that if suitable intervals for the mean charts can be chosen, and if normals can be appropriately defined, better approximations can gradually be obtained as it becomes possible to estimate the current values of more terms in the full equation. The limits to this procedure are set by the nature or the spectrum of the actual fluctuations – whether or not it possesses any band of periods of low relative amplitude.

The second question raised is 'what is the appropriate equation to use?' If the forecast is to be considerably better than using an unmodified normal value the equation must contain an expression of what is peculiar to the current situation. The equation must, therefore, deal with the pressure distribution for this is the most important single field that controls weather developments. The reasons which have led workers to handle the pressure field through the equation for the advection of vorticity will govern equally our present choice. It is, in consequence, a reasonable procedure to apply the method here suggested to any equation which experience has shown can be handled usefully; and in the case of numerical forecasting Clapp's choice of the barotropic vorticity equation would be the one to choose on the basis of the experience of other workers, such as Charney and Fjørtoft, in recent years.

The method must be tried because it is a fundamental one. Its success is not to be taken as a judgment upon whether it is appropriate to apply it but as an indication of whether the task is hopeless or not; for if it proves to be of no value it means that the spectrum of atmospheric fluctuations is unbroken in the region where we have tried it and no method can than work better than the simplest— to give the normal as the forecast.

REFERENCE

CLAPP, P. F., 1953: Application of Barotorpic Tendency Equation to Medium-Range Forecasting. *Tellus* **5**, No. 1. p. 80.