Forecasting winter precipitation over north India 3-7 days ahead—The synoptic approach

P. S. PANT

Meteorological Office, Poona

ABSTRACT. A brief review of some important synoptic methods of Medium Range Forecasting is presented and the line of approach adopted in the present investigation is indicated.

An examination of the mean charts for the winter seasons of the six-year period (1956-61) has revealed the large scale pressure systems which have an influence on winter precipitation over north India for periods of 5-days or more. Some of the interesting and useful relations found between pressure pattern and the corresponding precipitation are presented. The influence of the large scale pressure systems on the fast moving daily disturbances is examined.

1. Introduction

Forecasts of weather issued for a period of about a week are known as "Medium Range or Extended Range" forecasts, range here referring to period of validity. Such forecasts are of utmost importance to agriculture, where many things depend upon weather elements, particularly precipitation and temperature. These are also required in connection with issue of flood warnings and various other kinds of civil and military planning.

There are at present about a dozen countries which prepare medium range weather forecasts (CAe-III/Doc 16 dated 16-6-1961). Among these, Thailand is the only tropical country. But the forecasts issued in this country seem to be intended only for restricted circulation among interested persons and institutions and not for general use. Technical details regarding methods of preparation and verification of these forecasts are not available. Forecasts issued by most of the countries are qualitative and results of verification of these are not readily available. Only USSR issues quantitative forecasts of wind direction and speed, temperature maxima and minima as well as time limits (in days) for weather periods.

Organised research into this problem of medium range forecasting has been going on for about two decades in many countries, which are now regularly issuing such forecasts. The importance of medium range weather forecasts for an agricultural country like India needs no emphasis. Investigation of this problem of great practical utility was started in the India Meteorological Department in 1957.

The basis for any medium range forecasting method is the existence of large scale pressure systems which have an evolution of their own extending over periods of about a week or longer, during which they extend their influence on the day-to-day weather. These systems and the periods during which they have a natural evolution are referred to in different terms in different countries. The concept of "Grosswetter" introduced by Baur (1951), the long waves in the westerlies which play an important role in the American methods of forecasting and the "macro-homogeneous synoptic processes" of the Russian methods, all belong to the category of such large scale pressure systems. The initial effort everywhere was directed towards discovering these large scale pressure systems which affect weather over the respective regions.

A medium range forecaster employs tools different from those of the short range forecaster. The composite chart showing the day-to-day positions and intensities of some important pressure systems is one such tool.

Such charts give a perspective of longer period changes taking place in the important systems. These are made use of by the Russian forecasters. Whereas the American forecasters use the mean charts for periods of 5-days. From a series of such charts, long period changes of the important pressure systems are derived. Although this technique of averaging has come in for criticism from the Russian school of meteorologists and is not well understood by many others the mean charts so obtained have been found to be very useful in practice. The averaging process subordinates the minor short term processes which, though extremely important to short range forecaster, may contribute very little to broad scale development. Thus the main purpose of averaging is to portray those major planetary waves and related sea-level centres of action, whose evolution dominates the circulation and weather over periods of about a week. Longer period circulation anomalies are reflected in the 5-day mean maps by pure persistence of a similar flow pattern. Apart from considering the means over periods of five-days, their deviations from the normal (anomalies) are also studied. For, ultimately one is required to forecast the anomalies in the pressure pattern and the associated weather.

Before embarking upon any particular method of medium range forecasting, it is necessary to critically review the existing methods.

2. Review of synoptic methods of Medium Range Forecasting

There are two main methods of Medium Range Forecasting — (i) Synoptic and (ii) Statistical. The statistical procedures are not generally based on the preparation and analysis of synoptic charts and are not discussed in this paper. Only the synoptic methods are reviewed here.

The synoptic methods can again be classified into three main categories. All those empirical methods which try to find similarities in weather charts and their sequence and mechanically use this fact for prognostication, both of pressure pattern and weather, come under the first category. In these, no attempt is made to understand the physical processes of evolution of pressure systems and weather. The Typing and Analogue methods come under this group. The second category consists of methods in which physical reasoning plays an important role, but in which empiricism and statistics are also used to some extent. The Mean Circulation methods employed in the U.S. Weather Bureau and the method of medium range forecasting developed in the U.S.S.R. come under this category. The numerical methods of forecasting now being tried in the Extended Forecast Section of the U.S. Weather Bureau constitute the third category. A brief description of all the above mentioned synoptic methods is given below.

Typing methods

The typing methods consist of classifying past observed weather maps into typical situations and thereby providing a rapid means of selecting cases similar to the present weather map. The success that can be achieved with these methods will depend upon (a) correctly identifying the type and (b) ability to forecast its evolution into succeeding types. In this connection the concept of "Grosswetter" (Broad Weather Situation) introduced by Baur is of importance. The significance of "Grosswetter" lies in its controlling influence on weather over a period of a week or more. This concept is still being used in Germany in their medium range forecasting methods (Hess et al. 1956 and Hoffmann 1957). These methods have also been tried in U.S.A. Krick (1942) and Elliot (1951) are two of the workers in this field. They have classified the weather maps into certain types and worked out correlations between the various types so as to enable the forecaster to predict the evolution of one type from another. One of the serious drawbacks of these methods is that they are all based on surface data, since proper air data were not available at that time for a long enough period.

Analogue Methods

The analogue method is based on the premise that if two identical weather situations are found, then their further evolution will be similar. If the proper analogue is found in the old records, a forecast for a given period can be made by reading the 'weather' directly from the subsequent series of observed maps. However, similarity of weather maps does not ensure that their later evolutions will also be similar unless their past history is comparable. A good agreement between two charts in all these respects is very difficult to get in practice. In this connection, the following quotations from Air Weather Service Tech. Report No.105/93 is relevant. "As yet there has been developed for the extended period forecast, no method of selecting analogue the success of which is not highly dependent on the judgement and experience of the forecaster". In spite of the above mentioned disadvantages, analogues can still be useful to infer the actual weather that could be expected from a pressure pattern prognosis obtained by other methods. This analogue technique is being tried out in the Meteorological Office, London in their experiments for issue of forecasts of weather for a period of one month (Craddock 1958).

Mean Circulation Method

The mean circulation methods were evolved by Namias and his collaborators. By means of physical reasoning and statistical procedures, this method seeks to forecast features of the atmospheric circulation which are represented by the pressure pattern at one or more levels. For a detailed discussion of these methods, reference may be made to Namias (1947), Namias and Clapp (1951) and Jay (1960).

The four steps involved in the preparation of extended range forecasts by this method are—(i) Assessing the initial state of the general circulation, (ii) predicting the mean circulation, (iii) interpreting the prognostic flow pattern in terms of weather expected

during the period, and (iv) forecasting the sequence of events within the period.

The initial state of the atmosphere is ascertained from a number of indices describing the flow in the sub-tropical, temperate and polar belts. Large scale changes in circulation are associated with changes in these indices. A judicious combination of statistical relations, physical reasoning and qualitative appraisal of various parameters, are used in order to forecast the indices and the corresponding wind profiles. Further, regions of 'confluence' and 'blocking' are located and their influence on the strength of the middle latitudes westerlies and hence on the index cycle is assessed.

The forecasted 5-day mean 700 mb contour pattern is arrived at by making use of (i) physical methods and (ii) trend and kinematic methods. The physical methods consist of applying the Rossby Wave formula (Rossby 1939) with some modifications for assessing the future positions of troughs and ridges. Constant Absolute Vorticity (C.A.V.) trajectories prepared as suggested by Rossby (1942) are also utilised to derive the directions of movement of trough and ridge systems and changes in amplitude of waves. It is also possible, at times to infer from them the temperature advections, onset of confluence and the development of troughs, ridges and cut-off lows and highs. In order to infer about temperature advection and the consequent weakening and strengthening of systems, the temperature anomaly at 700-mb level and the 1000-700 mb thickness relating to the daily as well as the mean charts are also studied.

As additional tools, statistical relations have been developed for arriving at a 5-day mean chart centred on the day on which forecast is to be issued. This is referred to as the 'trend chart' and is made up of observed values for 3 days and statistically derived values for 2 days. The 2-day tendencies centred on the middle day of the latest observed 5-day mean chart and of the 'trend chart' are also derived. Petterssen's

equations which are commonly used for daily charts are applied both to the 'trend' as well as the latest observed charts and the future positions of pressure systems are arrived at. After examining the forecast 5-day mean charts obtained on the basis of kinematical methods and physical methods, the final prognostic 5-day mean 700-mb chart is prepared. (Kinematic methods based on Petterssen's equation were given up in 1957, for the displacements computed were found to be invalidated by the change taking place in the flow pattern and the tendency field during the forecast period).

In the forecasting procedure, temperature and precipitation anomalies are assumed to be byproducts of the contour prognosis. Various statistical relations and model charts connecting anomalies in the 700-mb contours and anomalies in the surface temperature and precipitation are made use of for preparing the actual weather forecast. All these relations have generally been found to be more successful in forecasting temperature anomalies than in predicting precipitation anomalies. Making use of all the available forecast techniques, both short and medium range, daily prognostic chart for the forecast period are also prepared. This is a very difficult step and there are serious limitations to the techniques adopted. But these daily charts can be expected to broadly indicate the trends within the forecast period.

Method of natural synoptic periods

A brief account of the method of medium range forecasting evolved by Khrabrov (1959) of the U.S.S.R. essentially based on the findings of Mul'tanovskii and his school is given below.

This method has its origin in the classical concept of Mul'tanovskii that there are 'Natural Synoptic periods during which an orienting process develops in a definite manner with the sign of the field being preserved in the area of the natural region.' Such synoptic periods are generally associated with one 'macro-homogeneous synoptic process'. An important feature of circulation which is used to distinguish between different macro-synoptic processes is the 'high altitude planetary frontal zone' (h.p.f.z.). The latter is identified as the region of maximum pressure gradient or the line joining points of maximum wind at a level. A synoptic process during which the h.p.f.z. undergoes a well defined evolution (a cycle of undulatory change of position) is termed a 'macro-homogeneous synoptic process'. Thus in this method, the position of the h.p.f.z. is treated as the most important characteristic of circulation in middle latitudes. The h.p.f.z. is found to reflect the basic features of synoptic processes such as, regions of maximum warm and cold advection, principal cyclogenetic and anticyclogenetic regions, the major upper-level pressure formations and their shift, the measure of zonality or meridionality of synoptic processes, the number of long waves in the northern hemisphere and such other features of circulation. The different evolutions of the h.p.f.z. during a macro-homogeneous synoptic process have been typed and their relation to the wavelength of the h.p.f.z. is established. Assuming that the change of position of h.p.f.z. is connected with the formation of centres of vorticity and their movement, the author has indicated a qualitative method of assessing these changes based on the principle of conservation of absolute vorticity.

Making use of the trend, both in the vorticity changes as well as changes in position of the h.p.f.z. during the first two days of the macro-synoptic process, the future positions of the pressure system and the evolution of the h.p.f.z. are inferred. Further, typical trajectories of pressure formations connected with a particular h.p.f.z. position are also utilised. Thus the character of the circulation conditions during the forthcoming homogeneous synoptic process are arrived at.

In order to forecast weather elements, the mean changes of the concerned elements (air

temperature, cloudiness and precipitation) in different quadrants of a pressure system during the shift of the system from one region to another along the typical trajectory are utilised. Analogues are also used for this purpose.

On a comparison of the mean circulation method and the method of natural synoptic periods described above, it becomes clear that though the nomenclature used in the two methods may be different, there is much in common. For, the concepts of 'undulatory changes of the h. p. f. z.' and that of the 'Index cycle' are very much the same. Both methods make use of the principle of conservation of absolute vorticity and the formula for wavelength derived therefrom. The methods of typing and analogues find equally important place in both the methods. Fundamentally, both methods associate medium-range changes in the middle latitude westerlies with particular types of changes of day-to-day circulation and weather.

Numerical Methods

With the growing stress on objectivity in weather analysis and forecasting and the development of numerical methods for prognostication, these dynamical and numerical methods are being increasingly used in the extended range forecasting practices of the U.S. Weather Bureau for obtaining the prognostic 5-day mean contour pattern. Namias and his collaborators (1958) have given a detailed description of these methods and a critical appraisal of results achieved.

The 'Trend method' essentially consists of the preparation of the 5-day mean 500-mb chart centred on the day on which the forecast is being issued. This is obtained by averaging the observed height values for 3 days (including the forecast day) and the predicted contour height values for the next two days obtained from short range numerical prognosis based on the barotropic model. The 2-day height tendencies centred on the middle day of this 5-day period are also automatically computed by the machines which do the numerical computations and are printed

on these 'trend charts'. From the current mean charts and the corresponding tendencies on it, kinematical computations of long wave motion and development are carried out and the 5-day mean chart centred 4 days in advance of the 'trend chart' can be obtained. The charts so obtained will at best indicate the broad-scale slower evolving trends. But this method fails very badly in regions where the trends themselves change considerably.

The 'Summation method' of prognostication uses daily numerical prognoses made upto 96 hrs, though it is known that the prognosis for periods of longer than 48 hours obtained by employing the barotropic model deviates far from the actual. The 5-day mean pattern centred two days after the day of the forecast is obtained by averaging the chart for the forecast day and the prognostic chart for the next 4 days. The two-fold purpose of the summation chart is (*i*) to provide a mean chart centred 2 days in advance so that comparison of this with earlier charts and the 'trend chart' may provide further inferences regarding evolution of mean pattern and (*ii*) to obtain estimates of 5-day mean temperature anomalies.

The "Basic current method" essentially involves treating the 5-day mean chart as a daily chart and obtaining the prognosis on the basis of the barotropic model. This was done mainly because earlier application of concepts of conservation of absolute vorticity and wave formula derived in relation to daily synoptic charts were found to work well for mean charts as well. Attempts are now being made to take into consideration (*i*) departure of the observed mean pattern from the normal pattern and (*ii*) the local peculiarities of orography etc in the numerical prediction procedures. The methods utilised for arriving at the forecasted weather elements from the prognostic pressure pattern are the same as those described under the mean circulation method. The results of verification of medium range weather forecasts obtained by

applying the Dynamical numerical methods show that "the level of skill of predictions is higher than ever before."

3. The synoptic approach to medium range forecasting of winter precipitation over north India

The first step towards evolving any technique of forecasting weather 3 to 7 days ahead over a region is to locate the dominant pressure systems or "Grosswetter" which have an influence on weather over the region for periods of about a week. In almost all methods of medium range forecasting the upper level pressure pattern is prognosticated first and from that the prognostic sea-level chart is derived. This procedure is followed because independent prognostication of sea-level charts is more difficult than that of the upper level charts. Results of preliminary examination of 5-day mean charts for India and neighbourhood (Rai Sircar and Lal 1960) has revealed that the mean patterns at 700-mb level undergo some orderly development and movement, whereas the mean surface patterns are more complicated. Therefore attention is initially directed to the five-day mean 700-mb contour patterns and their association with five-day total precipitation patterns.

Charts utilised and method of preparation

The following charts for the winter season (December, January and February) of the years 1956-1961, were examined in this study.

(i) Extended charts showing 5-day mean 700-mb contour height,

(ii) Five-day total precipitation (cm) charts, and

(iii) Charts showing the deviation of the 5-day total precipitation from normal.

For the preparation of the mean 700-mb charts, contour height values at the four corners and centre of five-degree squares over the Indian region were obtained from the 00 and 12 GMT daily working charts prepared in the Weather Central, Poona and their 5-day averages worked out. For the region not covered by the Weather Central

charts, mean data were directly obtained at the four corners and centre of ten-degree squares from the ozalid copies of 5-day mean hemispheric charts prepared and kindly supplied by the U.S. Weather Bureau.

The 5-day total precipitation charts are prepared with rainfall data for 210 stations over Indo-Pakistan region, which are chosen such that different rainfall regimes are properly represented. For preparing charts showing the deviation of the total precipitation from normal, the rainfall during each one of the standard pentads for the past 30 years at each station is arranged separately in the decreasing order of magnitude. The top one-third of the values are considered as above normal, the last one-third as below normal (or sub-normal) and the rest as normal. Thus the lower limit of the above normal values and the upper limit of the below normal values are obtained for all the standard pentads and for different stations. Such limits are now available for about 150 stations. These limits for intermediate pentads are obtained by graphical interpolation. By comparison of any particular 5-day total precipitation of a station with the corresponding limits, the former is classified as Above normal (A), Normal (N) or Sub-normal (S). These charts show the abnormalities in rainfall pattern and it is our aim to understand and forecast these abnormalities.

Normal 700 mb contour chart for winter

A good orientation to the problem can be obtained by studying the normal 700-mb contour pattern in winter over India and neighbourhood. The normal chart for January prepared on the basis of averages worked out with all available data up to the end of 1960 based on 12 GMT ascents at all the Indian radiosonde stations and also the averages for a few stations outside India obtained from the monthly climatic data of the world for five to six years and from other sources is presented in Fig. 1. The charts published by the London Meteorological Office (1960) and the mean charts published

by the Academia Sinica, Peking (1957) have also been consulted. The important features of this chart are — (i) Two semi-permanent troughs, one near the Caspian Sea and another relatively weak one near about 90°E and (ii) the subtropical high pressure belt. Throughout the winter period, the region of highest pressure at 700-mb level over the Indian region lies over the Peninsula and it decreases in strength from December to February. It is reasonable to expect that variations in position and strength of these semi-permanent features may have an influence on the weather over the region. Keeping these normal features in mind, the charts for winter season of the years 1956-61 have been examined and some of the interesting relations observed are presented here.

The purpose of presenting these results is more to stress on the line of approach to the problem of medium-range forecasting than on the particular relations noticed. The results obtained are based on an examination of charts for a period of six years and data for many more years will be required to prove the statistical validity of these. But so long as the relations observed have a physical basis and are not beyond reasonable expectation, it is desirable to take cognisance of them. These have, of course, to be kept under constant review as more and more analysed data and charts become available.

4. Discussion of results

The important synoptic feature of winter weather over north India is the 'Western Disturbance' which usually appears as a trough in the westerlies at levels above 1·0 km and as closed circulation at lower levels. The structure and characteristics of these disturbances and their influence on Indian weather have been studied by many. Pisharoty and Desai (1956) and Mooley (1957) have summarised all the available information about these western disturbances. One of the features of these disturbances which is not still understood is that some of these intensify as they reach the Indo-Pakistan area and cause considerable precipitation, over wide
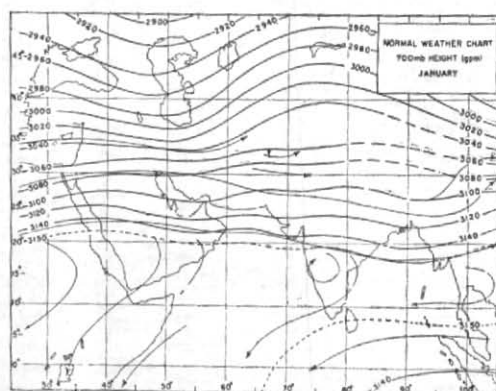

Fig. 1

regions, whereas others do not develop well marked circulations and cause only a little precipitation in the extreme north of the country. The answer to this and many other questions may lie in the influence of larger scale pressure systems on the day-to-day disturbances.

Five-day mean troughs at 700-mb level

It is recognised that the western disturbances have their origin in the middle latitude troughs in the westerlies and the importance of the interaction between middle latitude troughs and the low latitude systems has been stressed by Riehl (1954). It can, therefore, be expected that the troughs observed on the mean 700-mb contour charts will have considerable influence on weather over the region. For the purpose of this study, troughs are objectively defined as lines connecting adjacent points of minimum latitude reached by each contour in westerly flow or alternatively as lines joining adjacent points at each latitudes circle where minimum height values are reached.

An examination of the 5-day mean 700-mb contour charts and the corresponding precipitation charts reveals that above normal rainfall over large parts of north India occurs usually in association with a mean trough over the Indo-Pakistan region, though there are some differences in the extent and
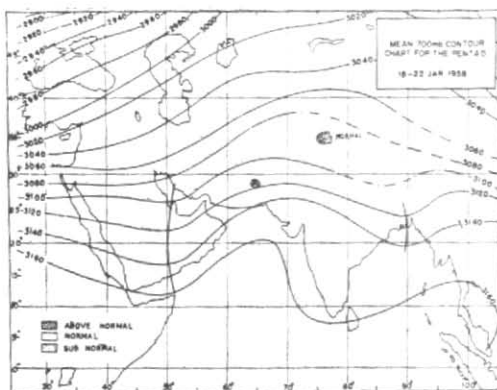
Fig. 2

Fig. 3

amount of rainfall caused by different troughs. This feature indicates that the 5-day mean troughs, which are identified with long-wave troughs in the westerlies (Namias 1944) do have an influence on winter precipitation over north India and points the need for a detailed study of the characteristics of these troughs.

In Figs. 2 and 3 are presented two five-day mean 700-mb contour charts on which regions of 'above normal', 'normal' and 'below normal' rainfall are also shown separately. These are for two occasions, one with the mean trough to the west of India and another with the trough near about 70°E. It is seen from the figures that in the former case there was no 'above normal' rainfall over India, whereas with the mean trough around 70°E large parts of north India experienced 'above normal' rainfall.

One of the prominent source regions of 5-day mean troughs at 700 mb is the Caspian Sea area (50°-60°E) where troughs are seen on 20-30 per cent of the occasions in winter (Klein and Winston 1958). But only a few of these move eastwards and affect the Indo-Pakistan region. The orography of Iran, Afghanistan and Western Pakistan seems to considerably weaken and at times even obliterate the southern part of these troughs. Thus only on about 10 per cent of the occasions is a mean trough located over the Indo-Pakistan region. Apart from these troughs
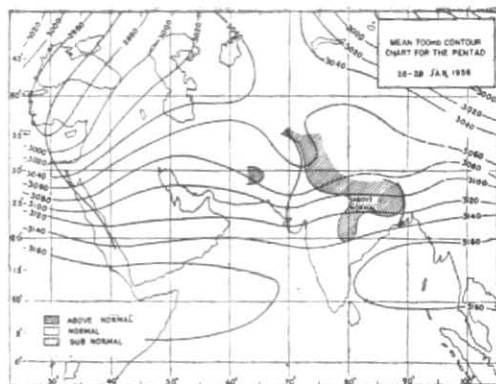
which move from the west, there are a few which form *in-situ* over the region. Lack of sufficient upper air data to the west of India, especially over Iran, is still a serious handicap in identifying and following the troughs. Added to this, the troughs are very weak over the region and the height differences across the mean trough may at times be only of the order of a few g.p.m. But these have been identified and traced taking the additional help of the 5-day mean hemispheric charts prepared by the U.S. Weather Bureau and the daily charts published by Japan (500 mb) and U.A.R. and from considerations of continuity. Some of the difficulties experienced in tracing these troughs could be overcome if the movement of these troughs could be connected with changes in any other synoptic feature over the country which could be studied with the available upper air data. It has actually been shown later that the movement of these troughs is closely related to the changes in strength of the high over the Peninsula.

Effect of the mean trough on the Western Disturbances

An examination of the daily synoptic charts for winter reveals that all western disturbances that affect India are not equally active, both in terms of circulation as well as in the amount and spread of precipitation that they cause. The fact that 'above normal' rainfall over large parts of north India is
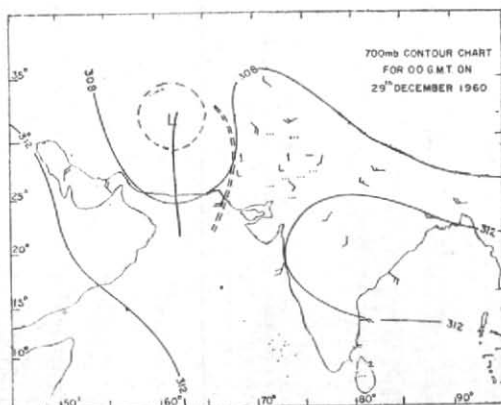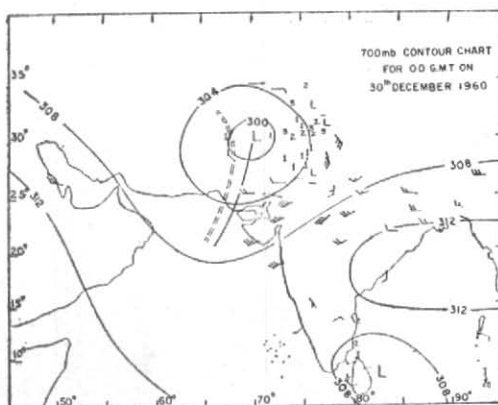
Fig. 4

Fig. 5

usually associated with a 5-day mean trough over the region leads one to conjecture that the activity of the individual western disturbances may in some way depend upon these mean troughs. This aspect has been examined and a very interesting and useful result has been arrived at.

The daily troughs at 700-mb level (associated with western disturbances) are usually found to be very active and cause significant 'above normal' rainfall both over the hills and the plains, when they are very near or in the same position as the five-day mean trough at the same level. This is generally in accord with what should be expected. For, when a trough of low pressure moves into a region where the pressure has, in the mean, been low relative to its surroundings, the trough can be expected to get accentuated. Thus the cognisance of the mean troughs and their influence on the daily pressure systems will be of help in short range forecasting, especially to infer the short period changes in intensity of the daily disturbances. This will particularly hold good in all cases of slow moving mean troughs. The speed of the mean troughs is generally about a fifth of that of the daily troughs (Namias 1944).

In Figs. 4 and 5 are shown the 700-mb contour charts for 00 GMT of 29 December 1960 when the daily trough (thick continuous line) is behind the mean trough (double dashed line) and for 00 GMT of 30 December 1960, when the daily trough has just crossed over the eastern side of the mean trough. The precipitation (cm) reported is also shown on these charts. They clearly show that the daily trough became accentuated and active when it moved close to the mean trough. In Fig. 6, is presented the 700-mb chart for 21 January 1958, where another daily trough which is also around 70°E but not associated with a mean trough is shown. This caused very little precipitation. Thus the presence or absence of a mean trough over the region seems to make a significant difference to the activity of the western disturbances. It is this kind of influence that the large scale pressure patterns are expected to have. The fact that maximum spread (southwards and eastwards) of the above normal rainfall occurs in association with a five-day mean trough suggests that the mean trough may have considerable influence on the track of the western disturbance. This aspect remains to be examined.

Sub-tropical High Pressure Cell

Apart from the region of westerlies to the north of 20°N, the important pressure system over the Indian region is the high pressure cell over the Peninsula. While discussing
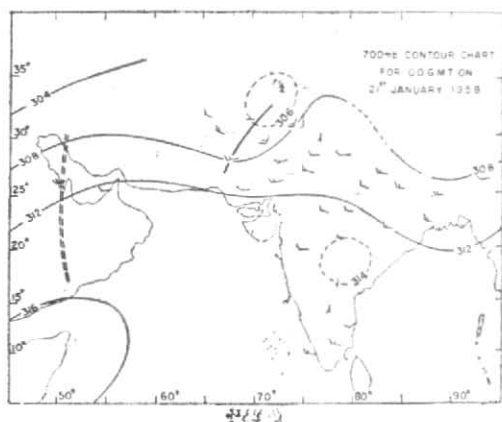
Fig. 6

Fig. 7

the effect of pressure systems on weather, very little attention is usually paid to the 'Highs'. Wexler (1951) has drawn pointed attention to the need for a study of the influence of the high pressure belt on weather in the tropics. Considering from another point of view, it is quite likely that large scale changes in circulation pattern over the tropics in general and over India in particular could probably be linked up with changes in position and strength of the subtropical High, just as large scale changes in circulation in middle latitudes are associated with changes in the strength of the westerlies.

As a 5-day mean trough approaches the Indo-Pakistan area from the west, the high over the Peninsula gradually weakens and is weakest (much below normal) when the trough is right over the region. Generally, the continuous weakening of the high is a precursor of the approach of a mean trough. But there are also a few instances of considerable weakening of the high even when a mean trough could not be located over the region.

Another interesting observation made is that almost all instances when the 5-day total precipitation (or 'above normal' rainfall) has maximum spread over north India occur when the high over the Peninsula is weakest (below normal strength). In Fig. 7
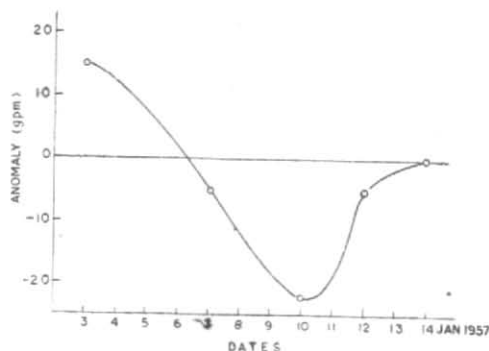
is presented the 5-day mean 700-mb contour anomaly at the grid point 17·5°N/77·5°E (taken as representative of the high pressure cell over the Peninsula at 700-mb level) for the pentads 1—5 January to 12—16 January 1957. The contour anomaly corresponding to each pentad is plotted against the middle date of that pentad (the anomaly for 8 to 12 January 1957 is plotted against 10 January 1957). During this period, a 5-day mean trough approached the region from the Caspian Sea area. It is interesting to note that 'above normal' rainfall over north India had the maximum spread (Fig. 8) during the pentad 8—12 January 1957 when the high over the Peninsula was weakest (—22 gpm). Thus an examination of the changes in the strength of the high will be of help in foreshadowing the advance of a 5-day mean trough over the region and also give an indication about the spread of rainfall over north India. This highlights the need for a study of the changes in the strength and position of the high pressure cell over the Peninsula and for evolving methods of prognosticating these changes.

Semi-permanent trough near 90°E

A weak but more or less semi-permanent trough near 90°E (Fig. 1) is present on about 30 to 40 per cent of the occasions on the 5-day mean 700-mb contour charts during
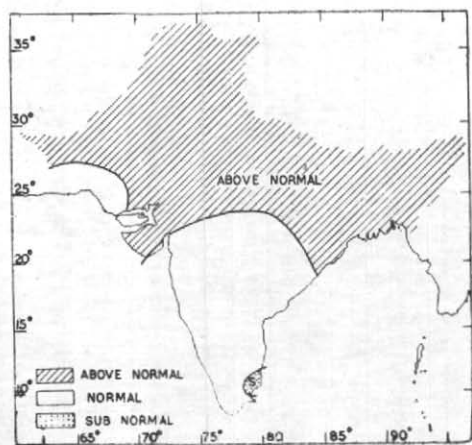
Fig. 8. Precipitation chart for the pentad
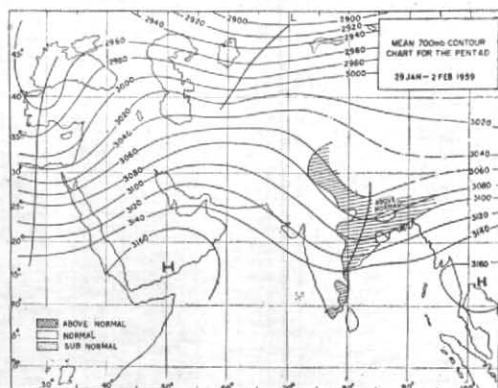8-12 January 1957

Fig. 9

winter. As a 5-day mean trough approaches India from the west, this trough shifts westwards and when the mean trough is right over the country, this trough in the east becomes less prominent and occasionally even vanishes. But when the eastward moving mean trough approaches 80°—85°E the two troughs seem to merge and form an accentuated trough which on occasions extends as far south as 15°N.

The relation between the semi-permanent trough near 90°E and weather over India is not apparent. But on occasions when there is an accentuated mean trough extending upto 15°N 'above normal' rainfall is found to extend almost all along the east coast of India (Fig. 9).

5. Summary

(i) This investigation has revealed that the three important pressure systems which seem to have considerable influence on winter precipitation over north India, are— (a) The 5-day mean trough in the westerlies at 700-mb level, (b) the high pressure cell over the Peninsula and (c) the weak semi-permanent trough near 90°E. All these three systems are interrelated. Depending on the relative importance of one or more of these systems, it may be possible to type the different synoptic situations during winter.

(ii) The fact that 'above normal' rainfall over large parts of north India is usually associated with a mean trough at 700-mb level over the Indo-Pakistan region, indicates the influence of the long waves on winter weather over north India.

(iii) The observations that (a) the high over the Peninsula gradually begins to weaken prior to the arrival of a mean trough over the country and (b) that the maximum spread of above normal rainfall over north India occurs when the high is weakest, are of importance both for short as well as medium range forecasting.

(iv) The tendency of the western disturbances to intensify as they approach the mean trough is of considerable importance for predicting the changes in intensity of the daily pressure system during a 5-day period.

It is clear that in order to achieve considerable success in prognosticating winter precipitation over north India 3 to 7 days ahead, it is necessary to forecast the development and movement of the 5-day mean troughs at 700-mb level and the changes in the high over the Peninsula. Some of the methods used for prognostication of the mean troughs in higher latitudes can be tried,

taking into consideration the special features of orography in and around India. But before doing so it is necessary that the characteristics of the mean troughs like preferred regions of their formation and dissipation, frequency of their occurrence, their rates of movement etc, are critically examined. These aspects of the mean troughs are now under study and will be presented in a forthcoming paper.

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