The Trough-and-Ridge diagram

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Abstract.

A discussion is given concerning the construction and interpretation of a diagram which shows longitude and intensity of troughs and ridges at the 500 mb level in middle latitudes as a function of time.

1. Troughs and ridges as characteristic features of upper air charts

As synoptic-aerological observation material, during the 1930's, became sufficiently copious to permit the regular construction of upper air charts, it was soon found that these charts were not of such complex character as the surface maps often are. Many of the minor singularities of surface maps (and surface weather) are due to local orographic effects, and it is evident that such irregularities can not extend to any great height. Besides, several (though not all) minor irregularities of non-orographic character were not found to exist — in some cases one might say: were found not to exist — in the upper air.

Another characteristic feature of the upper air charts is the preponderance of a northward slope of the isobaric surfaces in middle latitudes. The predominance of the westerly winds which is observed near the surface in both hemispheres between latitudes 35 and 65°, is still more pronounced in the middle and upper troposphere and the lower stratosphere. The great cyclonic and anticyclonic systems of the surface layers are not smoothed out on the 500 mb charts, with the exception of some anticyclones in which the air is extremely cold; but in many cases, the cyclones appear as troughs open to the north and the anticyclones as ridges open to the south.

The complex nature of surface charts is a great hindrance to any systematical classification of these charts and to any other effort towards a rational prognostic method. As far as upper air charts — and more specially the 500 mb charts — are concerned, the significant variable factors are not quite so numerous: the location and the velocity of the strongest westerly flow; the longitude, orientation, and intensity of troughs and ridges; the location, shape, and intensity of cut-off vortices. In the present paper, we are mainly concerned with the troughs and ridges: their position (in terms of longitude), their intensity and intensity variations, and their displacements. For our purpose, it is, within certain limits, justified to treat the cut-off vortices as over-developments, so to say, of troughs and ridges.

The troughs appearing on 500 mb charts are of many different types. Some of them are the insignificant attendants of moderately developed warm-sector cyclones. Others are minor troughs existing in the greater part of the troposphere but of slight intensity in all levels. Troughs of moderate intensity are often accompanied by well-developed wave cyclones in the first phase of occlusion, or of a cyclone which is already filling; others are associated with troughs in the lower troposphere and if so, they are in most cases of a non-frontal character (so called "polar troughs"). The major troughs, normally existing to a number of 2—6 in the northern hemisphere, are always cold troughs; very often the amplitude of the isotherms is even greater than that of the contour lines.

Minor and moderate troughs move, with only few exceptions, eastwards; in such cases where the upper trough is associated with a cyclone or a trough near the earth's surface the velocity of the upper system is approximately the same as that of the system at the surface, though minor differences sometimes may occur. The propagation of polar troughs is generally rather slow; evidently, the air moves into such troughs from the west and leaves them again towards the east.

The major troughs of the upper air are nearly always slow-moving as compared with wave cyclones; in some cases, they are even stationary or have a sligth retrograde movement.

The life-history of an individual trough is not always simple and clear cut. The ideal case, as it might be called, of the growth of a minor trough into a major one and the subsequent continuous decline and disappearance, is not often seen; in most cases, we see on our charts rather complicated processes of amalgamation and partition. It should be pointed out, however, that many major troughs and some troughs of moderate development may be followed without difficulty throughout several days or even weeks.

As for the ridges, we find an almost equally great number of variations in type and life-history. Ridges of maximum development are in most cases almost stationary or even slightly retrograde; normally they exist for a week or more, thus exerting a "blocking effect" upon wave trains approaching from the west.

2. Construction of trough-and-ridge diagrams

The existence of a trough at a certain longitude within the belt of latitude which we are considering, comes out very clearly if we plot the mean height of the 500 mb level within that latitudinal belt as a function of longitude. Major and minor troughs, troughs with steep or weak "slopes" to the east and west, symmetrical and asymmetrical troughs are easily discriminated by this graphical representation.

If we want to follow the movement of a certain trough or ridge during several days, a different method of representing the observed facts must be used. We may simply plot the longitude of the trough (as found by the method described above or by any analogous techniques) as a function of time.

These two simple ways of illustrating characteristic features of troughs and ridges may be combined in a graph showing the mean height of e. g. the 500 mb level between fixed latitudes as a function of longitude and time. Such diagrams have been constructed for the period October, 1945, to April, 1946.

The material on which the diagrams were based is the series of Historical Weather Maps published by the Headquarters of the U. S. (Headquarters, Air Weather Service: Northern Hemisphere Historical Weather Maps). From these maps the height of the 500 mb surface was taken at the intersection points between every fifth degree of longitude and the parallels of 35, 40, 45, 50, 55, and 60° N. The choice of parallels is to some extent arbitrary. Although the annual geographical variation of the belt of maximum zonal wind might be taken as a reason to choose different latitudes for different months, it was considered more advantageous to use the same belt for the whole period covered by the investigation. The lower limit, 35°, is in the northern border region of the subtropical belt with high pressure and a rather small slope of the isobaric surfaces; the upper limit, 60°, is generally to the north of the belt in which the zonal wind in the 500 mb level has its maximum intensity. Besides that, the aerological material north of 60° during the period concerned was too scarce to secure a sufficiently correct analysis; in fact, the analysis over the greater part of Asia and the Pacific ocean is rather tentative even for the belt between 35 and 60° N.

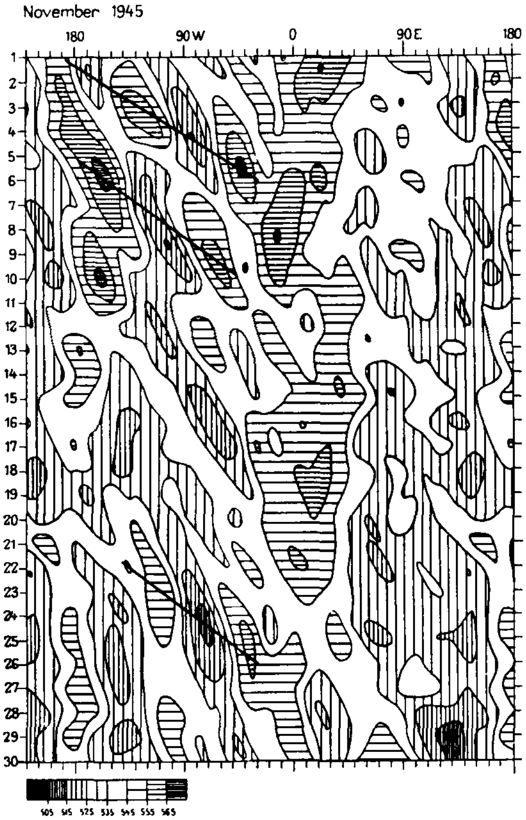
Taking the average of the six values obtained from each map to represent every 5th degree of longitude between latitudes 35 and 60° N (or, as one might rather say, between $32^1/_2$ and $62^1/_2$° N), we get a sufficiently good approximation to the actual mean value for this part of the meridional circle, provided, of course, that the maps themselves are satisfactory. By computing such average values for every fifth degree of *longitude*, we are sure to get a rather detailed picture of the profile along the zonal belt. The time interval between two consecutive maps, 24 hours, is, however, rather too long. With an interval of 12 hours instead of that, the identification of minor troughs and ridges should probably be less ambiguous.

As far as the regions with relatively ample observation material are concerned, there is no reason to smooth the average values plotted in the diagram, neither before plotting them nor in drawing the isolines. It was thought that little should be gained and some unwished subjectivity introduced by smoothing the more doubtful values between appr. 60° E and 150° W, hence, for the analysis, all values were taken to be correct. That means, of course, that as far as this longitude interval is concerned little or no confidence could be taken in minor irregularities occurring in the analyzed diagrams.

The ideal way of representing the material would be to fold the diagram around a cylindre, the time scale being parallel to the axis. To reduce the disadvantages of a discontinuity along a certain meridional circle, the strip between 120 and 180° E has been placed left and right in the diagram.

3. Analysis of the trough-and-ridge diagram for Nov. 1945.

The diagram for Nov. 1945 (Fig. 1) shows at a glance that an almost stationary major ridge prevailed throughout the month near longitude 0°. To the west of this blocking ridge, several troughs and ridges are moving east during the month. Some of the troughs seem to penetrate into the stationary ridge but this is always rebuilt very soon. The phase velocities of troughs and ridges are given by the orientations of the "bottom line" of the troughs and the "peak line" of the ridges. They can be measured directly in terms of degrees longitude per 24 hours; for the interval between 180° W and the stationary ridge they vary between 5 and 15° long. per day. No systematical difference is found between the velocities of major and minor troughs in this part of the diagram. To the east of the stationary ridge, conditions seem to be complex and ill-defined but the main feature may be said to be an almost stationary trough, situated at appr. 140° E during the greater part of the month.



Pig. 1. Geopotential (given in dynamical decametres) of the 500 mb level as a function of longitude and time. The values on which the diagram is based are average values of geopotentials at 6 different points on the same meridian (at latitudes 35, 40, 45, 50, 55 and 60° N respectively). Areas of high geopotential values (i. e. ridges) are shown by horizontal hatching, areas of low values (troughs) by vertical hatching. The slanting straight lines indicate a succession of maximum development of troughs and ridges which is of the general character required by the dispersion theory of atmospheric waves (see text).

It is by no means easy, even in this diagram where zonal inequalities have been eliminated, to count the number of troughs and ridges at any given time. But if we look upon the month as a whole, we get the impression that only two major troughs are present, one near the east coast of Asia, another (which is more variable in position and intensity) near the east coast of North America. The ridges are one over western Europe or the eastern Atlantic, and one (fluctuating rather much) over the Pacific.

Looking more closely upon the conditions of the western hemisphere as shown by the diagram, we will find a remarkable rhytm in the intensity of troughs and ridges: An intensity maximum of a trough is in several cases followed after one to three days by a maximum of the ridge nearest ahead of (to the east of) the trough. Good examples of this phenomenon are found, above all, during the first ten days of the month. Although there are some cases where the rule quoted above does not hold good, it would seem that the phenomenon is a real one and not a matter of chance. In fact, it is essentially in agreement with the theory of dispersion introduced in meteorology by Rossby (1945). According to this theory, we should have (at 45° N, which is nearly in the midst of the latitudinal belt with which we are concerned)

$$c = U - \frac{L^2}{360}, \qquad c_G = U + \frac{L^2}{360},$$

where c is the phase velocity, c_G the group velocity, U the velocity of the basic current, and L the wave length. (The unit of length used here is the length of 1 degree of longitude at the latitude concerned, i. e. $111 \cdot \frac{\sqrt{2}}{2}$ km, and the time unit is 24 hours.) In these formulas, the value of U is most difficult to fix. By inserting empirical values (taken from the figures)

$c = 10°$ long./day, $c_G = 28°$ long./day, $L = 65°$ long., we get from the first equation

$$U = 22° \text{ long./day} \sim 70 \text{ km/t}$$

and from the second

$$U = 16° \text{ long./day} \sim 50 \text{ km/t.}$$

These values of U are quite reasonable and not too different from one another. It should be remembered that the elementary barotropic theory is based on the assumption that the perturbations (the additional velocities) are very small as compared with the velocity of the basic zonal current. This assumption, which means a serious limitation to the application of the theory, is in the present case definitely not in good agreement with the observed facts. One might, however, conclude that the dispersion phenomenon resulting in a group velocity different from (greater than) the phase velocity is not confined to such cases where the perturbation amplitudes are small.

4. Brief description of diagrams for other months

(Oct. 1945, Dec. 1945—April 1946).

Space does not permit us to publish the other diagrams of the type of fig. 1 which have been constructed but we shall give a short description of their main features and a figure showing the "wave profile" of each month as a whole (Fig. 2).

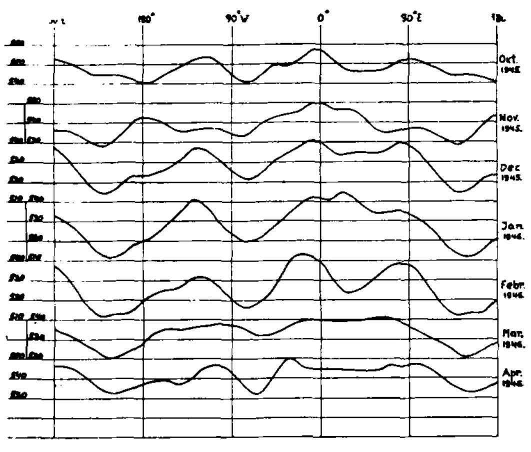


Fig. 2. Monthly mean profiles of the 500 mb level in middle latitudes (32,5—62,5° N).

The number of major troughs is generally 2 or 3. The most permanent feature of the whole period was a trough near 140° E, i. e. in the vicinity of Japan, from the end of October, 1945 to the beginning of April, 1946. It should be stressed, however, that over most of Asia and the Pacific the material is very sparse. Another trough, which was well-developed most of the time but showed greater variations in position and intensity, was situated generally between 90 and 50° W, i. e. near the east coast of North America. A third trough was indicated during much of the time at some longitude between 0 and 90° E (Europe and western Asia); during the month of February, 1946, this was a major trough of almost the same intensity as the two mentioned above.

As for the ridges, the variability appears to be somewhat greater. The longitudes at which they occurred most frequently are: 0—30° W (eastern Atlantic); 100—130° W (western part of North America); 70—90° E (western part of Central Asia).

The major troughs and ridges (mean troughs as termed by NAMIAS and CLAPP (1944)) were, without any noticeable exeption stationary or slow-moving, their displacement usually being less than 5° long. per day. Some cases of a very slow retrogression of a trough or a ridge may be found.

In several cases, individual troughs are seen moving east within the general area of a major trough. The phase velocity of these individual or "daily" troughs, some of which are quite deep, usually amounts to appr. 10° long. per day. There are a few examples, also, of individual highs (ridges) moving east within the general area of ridge with a speed of 5—10° long. per day. In some other cases, troughs or ridges are seen breaking through an area of slight deviations, and in such cases the speed may amount to as much as 15° long. per day even for the ridges.

A few examples of the dispersion phenomenon may be found in any of the months. Some of these examples are rather speculative, but the best ones (occurring in Oct. 1945 and Febr. 1946) are almost as striking as those in early Nov. 1945. The group velocities are remarkably uniform, 25—35° long. per day.

5. Comparison with normal conditions.

By the courtesy of Mr. Namias, I have had the opportunity to compare the results outlined above with a series of unpublished charts showing the mean height of the 500 mb level (one chart for each month). These charts indicate, as well as those published by SCHERHAG (1948), that the existence of two main troughs, which seems to be a normal feature, may be interpreted as a reflection of the fact that the central polar low of the upper atmosphere is not of a circular but rather of an elliptical shape. The longitudinal distance between the troughs is not exactly 180° but this is in agreement with the position of the axis of the low: the mean maps indicate that this axis does not go through the north pole itself.

The existence of a third trough is also indicated on some of the mean maps, the contour lines having a more or less triangular shape. As for the positions and intensity of the main troughs and ridges, there are some significant differences between our diagrams and the normal charts. Judging from the well-known great anomalies of surface pressure which occur in middle and high latitudes, notably in winter, and from the positive correlation between pressure and tropospheric mean temperature which is known to exist for at least some areas where large pressure deviations are frequent (Europe and Eastern Atlantic), there can be no doubt that the anomalies of the upper air currents of individual months as compared with the normal conditions for that month are of great significance. The prediction of such anomalies may be called a basic problem of long-range weather forecasting.

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