A Quantitative Prognostic Method for Thickness Charts using Advective Tendencies

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Abstract

A method is presented for the use of upper winds to construct a chart for the horizontal distribution of advective tendencies in the layer 1000—500 mb. A 24-hour prognostic thicknesschart can then be constructed from these advective tendencies. The method has been tested in a few weather situations in Europe, especially the one of Jan. 30—Feb. 2, 1953.

In the light of recent developments in quantitative forecasting techniques it is of some interest to explore a little more in detail the simple graphical method that may be used in the daily forecasting with the present set up of an ordinary weather service. We shall here discuss a purely advective method by which we can obtain a quantitative forecast of the thickness pattern.

Such a prognostic chart for the thickness (relative topography), could be used together with the prognostic sea-level chart to construct a forecast for the absolute topography. It would also be useful in showing the new positions of fronts and possible new developments to be introduced on the prognostic sea-level chart.

The necessary analysis of the advective tendencies for the layer in question further shows, in a more distinct manner than the charts for fixed pressure levels with contour-lines and isotherms, the immediate magnitude of the advection, which is useful for any more detailed analysis of the mechanism of pressure changes.

The method by which the thickness changes in any particular layer may be computed, is derived in analogy with the tendency equation. Let $\triangle$ denote thickness (relative topography), R_d gas constant for dry air, p pressure, $\mathbf{v}$ horizontal wind, $T^\star$ virtual temperature and v_z vertical velocity. Thus we have

$$\left.\begin{aligned} \frac{\partial \triangle}{\partial t} &= R_d \int_p^{p_0} - \mathbf{v} \cdot \nabla_H \cdot T^\star \frac{\delta p}{p} + \\ &+ R_d \int_p^{p_0} \left(\frac{dT^\star}{dt} - v_z \frac{\partial T^\star}{\partial z} \right) \frac{\delta p}{p} \end{aligned}\right\} \qquad (1)$$

The last integral is called S.

In most cases we may neglect S, and equation (1) is then reduced to

$$\frac{\partial \triangle}{\partial t} = - R_d \int_p^{p_0} \mathbf{v} \cdot \nabla_H T^\star \frac{\delta p}{p} \qquad (2)$$

$\partial \triangle / \partial t$ represents the change in the amount of geopotential unit layers contained in the column of air between the pressure levels p_0 and

p, and from equation (2) we see that this change depends exclusively on horizontal advection of air. By neglecting S we have excluded the effects of vertical motion as well as non-adiabatic effects.

Assuming that the thermal wind relation is valid (1) may be transformed into (cf. ROSSBY, 1942)

$$\frac{\partial \triangle}{\partial t} = -4\,\boldsymbol{\Omega}\cdot\mathbf{A} \qquad (3)$$

where

$$\mathbf{A} = {}^1/_2 \int_{p_0}^{p} \mathbf{v} \times \delta\mathbf{v}$$

The integral has a simple geometrical interpretation and may be evaluated graphically from the hodograph for the layer between p and p_0.

For practical purposes we may assume that the triangle between $\mathbf{v}_1$ and $\mathbf{v}_2$ represents the area swept out by the velocity vector, and then equation (3) may be written.

$$\frac{\partial \triangle}{\partial t} = k \sin \varphi \cdot v_1 \cdot v_2 \sin \alpha \qquad (4)$$

where

$\partial\triangle/\partial t$ = the "advective tendency"
v_1 = wind velocity at level 1
v_2 = " " " " 2
k = a constant depending on the units. If we express v_1 and v_2 in knots and want to get in gpm/3 hours, the value of $k = 4.25 \cdot 10^{-2}$
φ = the latitud, counted positive in the northern hemisphere
α = the angle between the wind directions in levels 1 and 2 counted positive when the wind turns to the right with increasing height.

Some remarks on the construction of a 24 hour prognostic chart for the layer between 1000 and 500 mb.

Although the computation accounts for the layer 1000 – 500 mb, we cannot use the wind at the 1000 mb level to represent v_1, as it is too much influenced by friction. The best alternative is to take a wind value as close to the upper boundary of the friction layer as possible (950 mb), or to interpolate between two wind values, one within and one somewhat above this layer (e. g. the surface wind and the wind at 850 mb). v_2 is taken at 500 mb.

We assume that the contour lines of the 700 mb level give a reasonably good picture of the velocity field for the layer between 1000 and 500 mb. Arrows showing the 24-hour displacement according to the 700 mb velocity field in certain points are placed on the $\partial\triangle/\partial t$-chart with their mid-points in the points in question. We assume that the $\partial\triangle/\partial t$ pattern moves with the 700-mb wind without changing shape. The time integration may then be replaced by a space integration along the 24-hour displacement arrow. Since the advection tendencies are expressed in gpm/3 hours and we want to forecast the 24-hour change, each arrow is divided into eight parts and the advective tendencies at each point of the arrow (except the terminal point), are added to obtain an approximate value of the 24-hour thickness change at the terminal point (fig. 1).

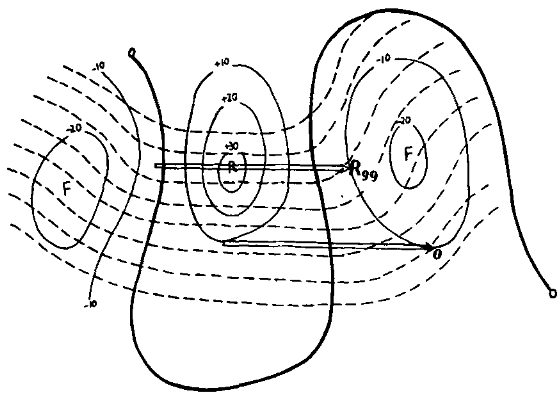

Fig. 1. Estimation of 24-hour thickness changes using the chart of 3-hour advective tendencies. Full lines represent lines for advective 3-hour tendencies. The broken lines represent isohypses of 700 mb. The arrows demonstrate the estimation of magnitude and position of a 24-hour maximum and the location of a point on a zero line.

Special care is taken to evaluate the motion of maxima and minima as well as zero lines. Before the final construction of this chart (prog $\triangle_{24}$ 1000 – 500 mb) charts of the past changes ($\triangle_{24}$ 1000 – 500 mb) should be studied. A series of such charts will show not only the successive displacement of areas of major changes but also variations of intensity.

The utilization of past changes has been done in analogy with the method described by SCHERHAG (1948), while the displacements of maximum, minimum, and zero lines are made in analogy with the method for construction of the sea-level pressure field by the aid of 3-hour sea-level pressure tendencies, introduced at the Swedish Weather Bureau by SIMILÄ.

The assumptions and approximations on which the prognostic method described here is based are:

(a) the last integral in equation (1) is neglected. This implies a lapse-rate close to the adiabatic or the absence of strong vertical wind components. Besides, we have disregarded all non-adiabatic processes. The assumption of no vertical motion is in same cases a too rough approximation. Since we know, however, that there is a close correlation between warm-air advection and upward motion and between cold-air advection and downward motion, the assumption essentially influences the magnitude of the 24-hour-maximum and minimum;
(b) the wind is geostrophic;
(c) the area of the hodograph computed by vertical integration is equal to the area between the 950 mb wind and the 500 mb wind;
(d) the geostrophic wind field in the 700 mb level gives a reasonably good picture of the velocity field in the layer between 1000 and 500 mb;
(e) a linear extrapolation scheme is used.

Test of the method

The prognostic method described above has been applied to some actual situations.

The resultant prognostic charts have been tested by computing a correlation coefficient between forecast and observed thickness changes. The tested area, containing 26 grid points, was the same as the area by LÖNNQVIST (1952). For comparison, a correlation coefficient was also computed for the ordinary prognostic thickness charts, constructed by pure extrapolation as discussed by LÖNNQVIST (1952).

Judging from the results of the checking, the proposed method can be regarded as giving surprisingly good results in view of the approximations we have done. The most important approximation is the assumption that the vertical motions can be neglected. This leads, as a rule, to too large absolute values of the computed $\partial\triangle/\partial t$. In spite of this we have not found that the prognostic 24-hour changes are too large. This may depend on the fact that the availabe observations used for the analysis of the $\partial\triangle/\partial t$-chart do not as a rule include absolute maximum or minimum values. As a consequense this means that the analysed $\partial\triangle/\partial t$-chart shows a smoothed horizontal field of "advective tendencies". Furthermore past changes have been used as a guide in the final construction of the prognostic thickness chart.

Table I. Correlation between predicted and observed thickness changes obtained by different methods

Date	Correlation coefficient: Ordinary method	Correlation coefficient: The "advective method"
22—23 Oct. 1950	0.45	0.68
14—15 Nov. 1950	0.18	0.63
1—2 Nov. 1951	0.52	0.80
30—31 Jan. 1953	0.68	0.92
31 Jan.—1 Feb. 1953	0.79	0.92
1—2 Feb. 1953	0.81	0.96

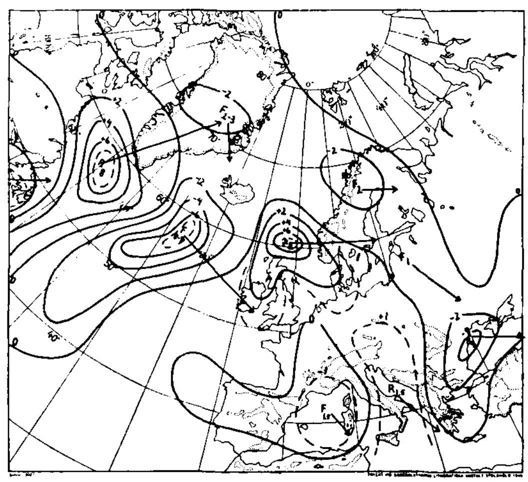

Fig. 2. Chart showing advective 3-hour tendencies of Jan. 30, 1953, 03 GMT. The lines are labelled in tens of gpm/3 hour. The arrows show the predicted direction of the displacement of each area of advection. The terminal point of each arrow shows the location of a 24-hour maximum or minimum, obtained by the movement of the area in question.

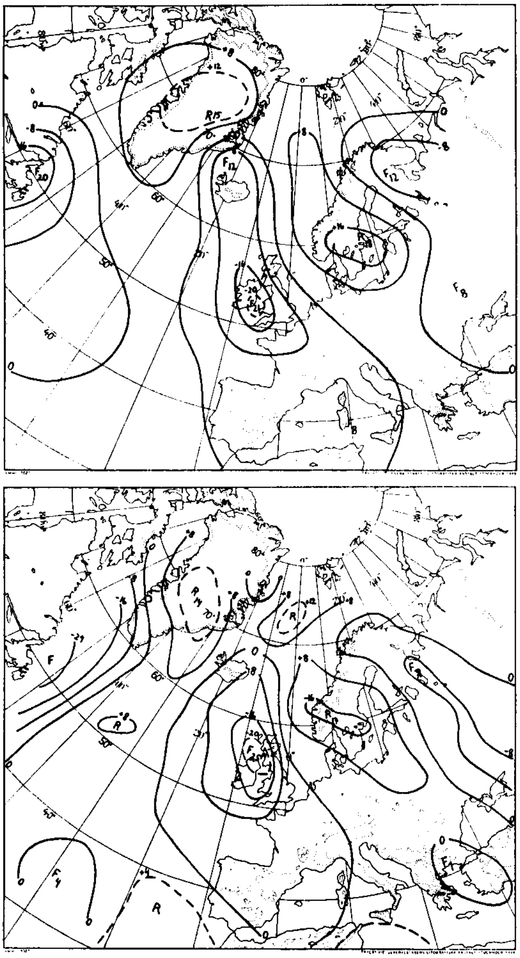

Fig. 3. 24-hour thickness changes 1000—500 mb, Jan. 30—Jan. 31, 1953, 03 GMT.
a) Predicted changes. b) Observed changes.
The lines are labelled in tens of gpm.

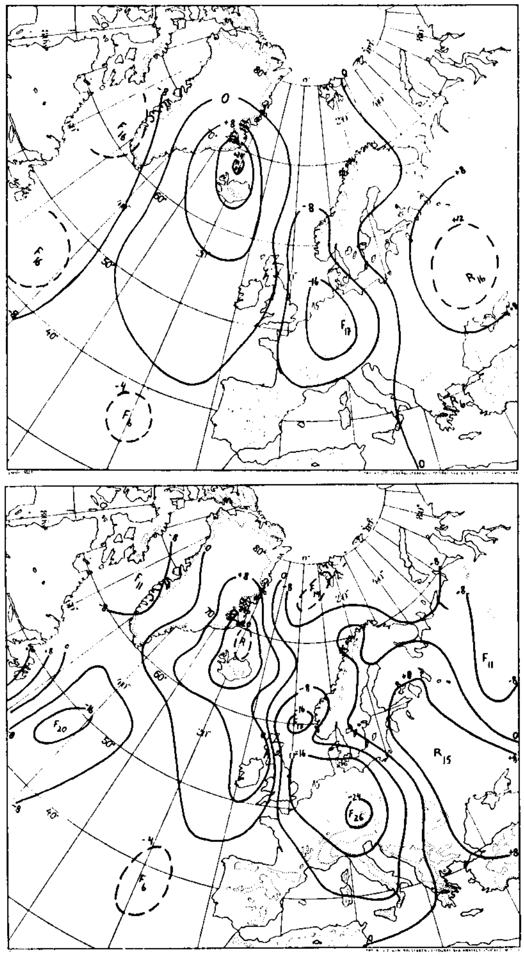

Fig. 4. 24-hour thickness changes 1000—500 mb, Jan. 31—Feb. 1, 1953, 03 GMT.
a) Predicted changes. b) Observed changes.

The author has tried to be as objective as possible when constructing the prognostic charts. However, in the three cases from 1953, his knowledge of the subsequent development may have influenced the results somewhat.

Application to the situation Jan. 30—Feb. 2, 1953

The weather situation over the Atlantic and Europe during the last week in January was characterized by a trough extending from the Lofoten Islands to southern Greenland and a high over France and the Bay of Biscay. In the south-westerly current south of Iceland and west of Scotland waves developed, which at first moved quite slowly north-east towards Scotland where they in most cases accelerated considerably and their amplitude increased. The resulting disturbances subsequently followed the WNW stream across southern Scandinavia to Poland where they gradually weakened.

Jan. 30, 1953

At 03 GMT a wave between Iceland and Scotland was moving ENE, i. e. parallel to the flow at about 700 mb. However, at the same time an intense cyclogenesis had occurred at

Newfoundland. In connection herewith a strong advection of warm air took place towards Greenland, and the cold air, which had long been stationary north of Iceland, began to flow south in the rear of the wave between Iceland and Scotland. The very strong advections of cold and warm air are clearly shown in fig. 2. This chart was taken as the base of a forecast for the thickness 1000 – 500 mb, until Jan. 31 03 GMT. The resulting forecast map shows quite clearly that the advection of cold air initiated south of Iceland is a factor of outstanding importance, and indicates a cyclogenesis (fig. 3 a) over the British Isles in the 500 mb level. Fig. 3 a indicates the following development in the upper troposphere: a rapid displacement eastwards (to the British Isles), and also an intensification, of the trough now extending SSW from Iceland. (cf. fig. 3 a and 3 b).

Jan. 31, 1953

The maps for sea-level and 700 mb at 03 GMT show an intense cyclone just north of Scotland; exceptionally high surface wind velocities were prevailing mainly over Scotland and Iceland. The strongest advection of cold air is now to be found over the British Isles, and the intensity of the advection of warm air towards southern Scandinavia has decreased. The strong advection of warm air which the day before had its centre south of Greenland has moved east to the sea between Greenland and Iceland, and has maintained its intensity. Displacing the area of strongest cold-air advection now over the British Isles, we find that the maximum 24-hour thickness fall will occur over southern Germany. The strong-warm air advection south west of Iceland will move north-eastwards. The resulting prog $\triangle_{24}$1000 – 500 mb (fig. 4 a) again shows a high correlation with $\triangle_{24}$ 1000 – 500 mb (fig. 4 b).

Feb. 1, 1953

The deep low has now its centre near Hamburg, and a full north-westerly gale prevails over the North Sea, the eastern parts of the British Isles, the Netherlands, and Belgium. The advection of warm air originally south of Greenland has now reached Iceland with slightly decreased intensity. As this flow of warm air continues in a north-easterly direction, it cuts off any further advection of cold air to the European cyclone, and at the same time as the low becomes thermally symmetric, it fills slowly. The high correlation between prog $\triangle_{24}$ 1000 – 500 mb and $\triangle_{24}$ 1000 – 500 mb is illustrated by fig. 5 a and fig. 5 b.

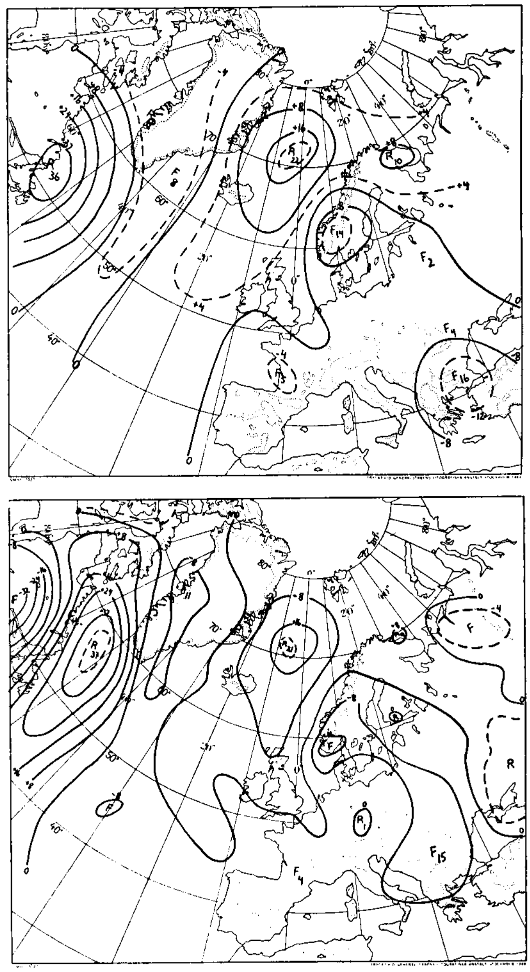

Fig. 5. 24-hour thickness changes 1000—500 mb, Feb. 1—Feb. 2, 1953, 03 GMT.
a) Predicted changes. b) Observed changes.

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