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SHORT CONTRIBUTION

On the objective analysis of atmospheric fronts

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ABSTRACT

Based on the dynamic boundary condition, a criterion is proposed for objectively determining the position of atmospheric fronts. An example of the use of this criterion is presented and discussed.

1. Introduction

In numerical weather analysis and forecasting the variables are mostly considered to be continuous functions of space and time. Only occasionally have attempts been made to determine in an objective way the position of frontal discontinuities (Renard and Clarke, 1965; Mudrick, 1974; Shapiro and Bleck, 1976; Price, 1977). The criteria used in these studies were based on the minimum value of the relative vorticity, on the wet-bulb potential temperature, and/or some other technique. In spite of some promising results achieved in these attempts, fronts on numerically produced charts are at present drawn according to subjective estimates of forecasters, mostly following the axes of troughs in the pressure or geopotential fields.

In view of the great practical importance of frontal surfaces, continuation of efforts to arrive at satisfactory methods for objective determination of the position of fronts appears worthwhile (Kirk, 1966). A possible approach will be presented in the following sections.

2. Criterion for the determination of the existence of a front

The well-known Margules' formula for a sloping discontinuity surface (see e.g. Palmén and Newton, 1969), here called the dynamic boundary condition, may be expressed in the pressure coordinate system as

$$\operatorname{tg} \alpha \bigg|_p = -\left. \frac{\bar{T}\left(\dfrac{\partial \phi}{\partial n} - \dfrac{\partial \phi'}{\partial n}\right)}{T - T'} \right|_p \tag{1}$$

Here primed and unprimed quantities distinguish properties in the cold and the warm air mass, respectively, and n is a normal to the frontal line, directed towards the cold air mass. $\bar{T}$ denotes the mean value of the cold and warm air mass temperatures.

A standard analysis of the dynamic boundary condition, in a hydrostatic system, shows that the front must be associated with a trough in the geopotential or pressure surfaces. Another important characteristic of a frontal surface is that it represents a discontinuity in the temperature field.

We want here to define a criterion for the determination of the location of fronts which will be based on these two characteristics of frontal surfaces. In addition, we want this criterion to be applicable to data given at points of a square grid, on constant pressure surfaces.

For that purpose, we shall assume that the front is zonally extended between two adjacent grid points, j and $j + 1$ (j increases towards north), and between two adjacent constant pressure surfaces. Furthermore, we shall assume that there is a cold air mass towards north and a warm one towards

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south. Equation (1), written using the simplest finite difference approximation, then takes the form

$$\operatorname{tg} \propto \Big|_p = -\frac{1}{4d}(\bar{\phi}_{j+2} - \bar{\phi}_{j+1} - \bar{\phi}_j + \bar{\phi}_{j-1})_p \times \left(\frac{h_{j+1} + h_j}{h_{j+1} - h_j}\right)$$

or

$$\operatorname{tg} \propto \Big|_p = -\frac{\bar{h}_{j+1/2}}{2d} \frac{\Delta_2 \bar{\phi}_{j+1/2}}{\Delta h_{j+1/2}}\Big|_p$$

Here d denotes the grid distance, $\bar{\phi}$ average height of the two geopotential surfaces, h the thickness of the layer between the two surfaces.

We now need a procedure which can be used for an objective localization of fronts in numerical forecasting models. The condition for the existence of the trough can then be formulated as the requirement for the maximum of the average geopotential height of these two surfaces. Since the frontal line is predestinated to pass between two grid points, for symmetry we again calculate the second derivative by a four-point formula, rather than by the standard three-point formula. At the same time it may be expected that the difference between thickness values in two adjacent points, separated by a frontal surface, has a maximum.

It follows that the frontal boundary surface between two adjacent points in the grid possibly should be considered to exist if a trough in the geopotential field $\bar{\phi}$ is present and if the sum $|\Delta_z \bar{\phi}| + |\Delta h| = \mathscr{F}$, reaches a maximum. In other words, the frontal boundary surface will be expected to exist when the following conditions are fulfilled:

$$\Delta_2 \bar{\phi}_{i+1/2}, \Delta_2 \bar{\phi}_{j+1/2} > 0$$
$$(\Delta \mathscr{F}_i)(\Delta \mathscr{F}_{i+i}), (\Delta \mathscr{F}_j)(\Delta \mathscr{F}_{j+1}) < 0 \quad \text{and}$$
$$\Delta_2^* \mathscr{F}_{i+1/2}, \ \Delta_2^* \mathscr{F}_{j+1/2} < 0. \tag{2}$$

3. Application of the criteria

To evaluate the applicability of these criteria for objective determination of fronts, they were employed on 30 different synoptic situations. As a testing period the first half of February 1971 was selected. During this period several pronounced cold and warm air mass outbreaks were observed. The area for the tests was bounded by 40° and 60° N latitudes and 0° and 30° E longitudes. The horizontal resolution of the grid was 1° latitude 1.5° longitude, and for the vertical resolution the standard isobaric surfaces 1000, 850, 700, 500 and 300 mb were used.

An example of front positions obtained by applying our method to the thickness 850/1000 mb, is shown in Fig. 1. The subjective analysis of the German Weather Service is also shown. It is seen that according to the objective analysis the front extending along the meridian 25° E is obtained as a single system. The same front in the subjective analysis is, however, not continuous. Furthermore, the subjectively analysed front lying over the Balkan peninsula shows a shape and location different from those of the two fronts obtained by the objective analysis. Also, by the objective method a front was found extending zonally north of the Pyrinees and the Alps. In the subjective analysis this front was not identified. Careful examination of the surface data, shown in Fig. 1, gives the impression that the fronts obtained by the objective analysis in this case were more realistic than those obtained by the subjective analysis. The results from the remaining 29 cases were also encouraging.

4. Conclusion

We have seen that the discontinuities in the atmosphere can be identified in an objective manner. The method is too simple to reliably identify all atmospheric fronts, since fronts are very complex phenomena. However, combined with methods commonly used, our method will hopefully contribute to a more precise analysis of atmospheric fronts. Besides, our method could quantitatively express the intensity and space development of fronts and other discontinuities which are essential for weather analysis and forecasting.

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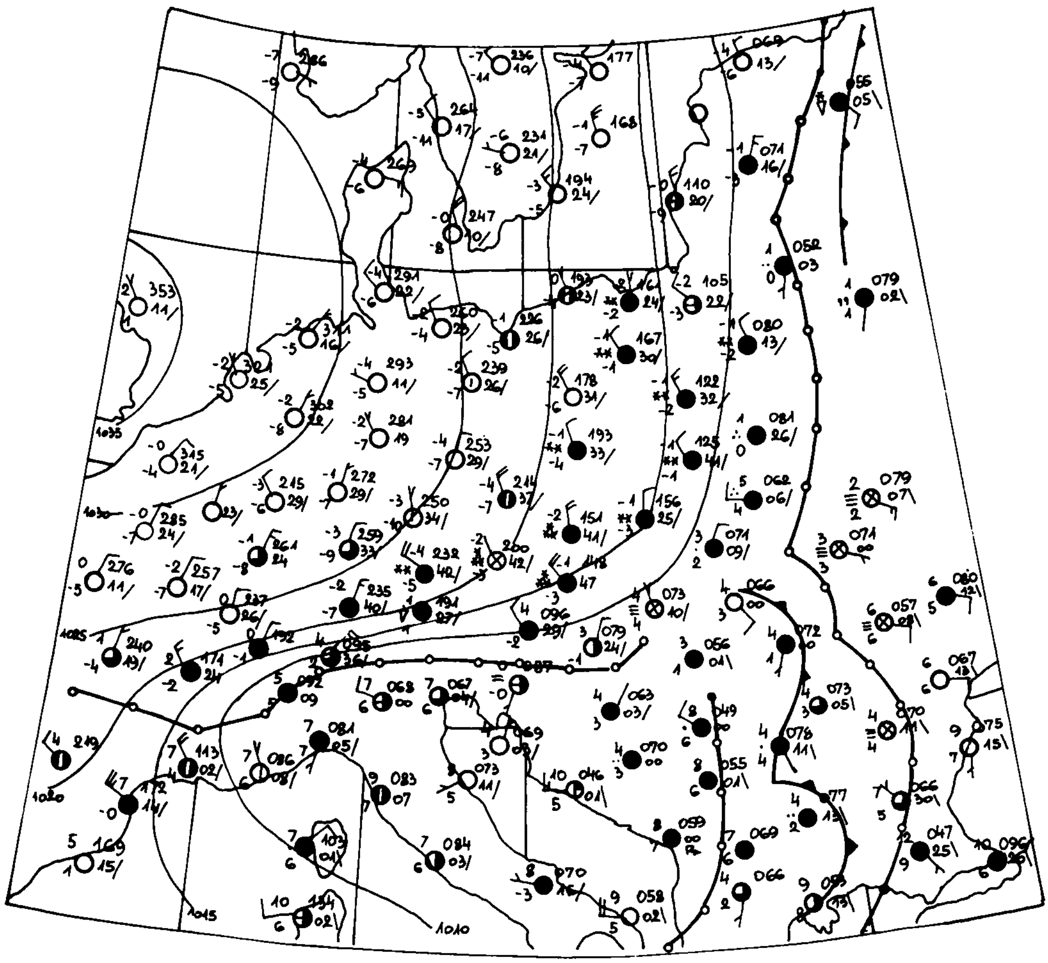

Fig. 1. Surface chart, 00 GMT, February 2, 1971, with fronts obtained by objective method (O–O–O) and by subjective analysis (▼–▼–▼–▼), taken from Täglicher Wetterberichte. Circles along the objectively obtained fronts denote grid points at which the criterion (2) was found to be fulfilled.

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