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The automatic plotting of radiosonde data in isentropic form. By TAYLOR,B.F.

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The Automatic Plotting of Radiosonde Data in Isentropic Form

B.F. Taylor

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1. Introduction

The basic meteorological variables in upper-air messages are reported in terms of pressure as the vertical coordinate. This facilitates the preparation of isobaric charts at the standard pressure levels normally used in analysis and forecasting.

Some authorities (eg Danielson, 1961 and Ludlam, 1965) have advocated the use of an alternative vertical coordinate, namely potential temperature (θ), for the reason that unsaturated air remains, in adiabatic conditions, on a surface of constant potential temperature (which is also a surface of constant entropy, ie an isentropic surface). In contrast to this, air (in general) passes vertically through isobaric surfaces. Thus, where trajectories are to be studied or the vertical motion is of interest, isentropic analysis is to be preferred.

In the stratosphere several conditions favourable to the use of the isentropic technique are satisfied.

(1) Near adiabatic conditions exist in that clouds are absent and radiational cooling, typically $-1^{\circ}C\ day^{-1}$ according to Murgatroyd and Singleton (1961), is an order of magnitude lower than typical rates of adiabatic temperature change.

(2) The high static stability allows accurate determination of the height or pressure of specific isentropic surfaces from soundings.

It is therefore surprising that (to the best knowledge of the author) no one has previously described stratospheric flow in this way. Perhaps the reason for the lack of interest is that at the same time as high level data were becoming available the use of computers was increasing dramatically. With computer assistance the calculation of vertical velocities from grid-point values of isobaric height, temperature and wind data is simple. Nevertheless this approach, in treating the vertical component separately is inferior to the isentropic approach in so far as the production of a three dimensional picture of the air flow is concerned.

The principal disadvantage of the technique is the large amount of work involved in converting the reported (pressure level) data into isentropic form and subsequently plotting it for analysis. This conversion involves the determination of the pressure at which each sounding reaches the specified value of θ and the evaluation of wind and height at this pressure by interpolation against log p.

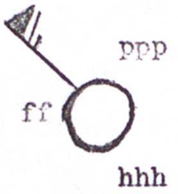
In this paper the use of a computer to perform the necessary interpolation and subsequently to plot the data is described.

2. The Program

A program, originally written by Met O 12, to retrieve from the synoptic data bank upper air observations at standard levels for stations within the octagon area and to plot these observations in chart form is maintained and serviced by Met O 19. Within this program subroutines 'LAND' and 'SHIPS' obtain the data for a specified level (for land and ship observations respectively) by calling the main retrieval subroutine 'LAR1ØM'. This basic program was copied and modified for isentropic plotting purposes by making fairly drastic changes to the two subroutines mentioned above; these were renamed 'LAN1' and SHP1'. The changes involved retrieving, for a given station, height, temperature, wind speed and wind direction at the six standard levels:-
100, 70, 50, 30, 20 and 10 mb as far as these were available, (the original program retrieved data for only one level in any single call to 'LAND').

Subsequent treatment of the data involved several interpolations in a manner exactly analagous to the procedure which would be adopted if the task were to be undertaken manually; but before any interpolation involving potential temperature was performed it was necessary to increase the vertical resolution because, although temperature may be assumed to vary linearly with height (or ln p) between standard levels, the variation of θ with height is strongly non-linear. Consequently, temperatures at 2 mb intervals were first obtained by linear interpolation of temperature against ln p between standard levels. These temperatures were converted to potential temperatures to provide a high resolution θ vs ln p profile which was then used to obtain the pressures (or ln (pressures)) at which standard values of θ occurred (again by linear interpolation). The 'standard' values of θ were all multiples of $50^{\circ}C$ found within the sounding, typically $\theta = 200^{\circ}C, 250^{\circ}C \ldots\ldots 550^{\circ}C$. Geopotential heights and wind components at the pressures corresponding to the standard values were similarly found.

The program was adapted to print out the interpolated data at the standard levels and to produce a plotted chart for any one level. The format of the plotted station circle is shown below.



where ppp is pressure in tenths of a millibar

hhh (in red) is height in geopotential decametres with the first digit truncated.

ff is wind speed in metres per second.

NB. Feathers on the wind arrow denote wind speed in knots not ms^{-1}.

Heights were not converted from geopotential to geometric units because there seemed little advantage to be gained by so doing. It follows that all vertical velocities inferred from these charts will be in units of geopotential height per unit time. In the following sections the term 'geopotential' will be dropped.

The use of 'significant point' data (part D of the message) in addition to standard (pressure) level data was considered but rejected on the basis that it is currently received from comparatively few foreign stations. However, if the program was ever to be adapted for tropospheric use, the inclusion of part B of the message would be vital because of the much greater variability of temperature with height found in the lower troposphere and near the tropopause.

3. Accuracy of Analysis

Because the various national radiosonde systems are known to produce systematically different values of pressure-heights, C.F.O. and Met O 19 apply standard corrections (the "Hawson corrections") to reported values before analysing isobaric charts. The question of the effect of radiosonde incompatability on isentropic data must therefore be considered. Most reported heights are too great (in comparison with UK radiosonde data); this implies that the temperatures up to the pressure-level concerned are correspondingly too high. The extraction of isentropic heights depends upon values of both isobaric height and temperature but in such a way that errors in these two produce a cancelling effect (a specific value of θ is encountered at a greater pressure in a warm sounding than in a cold sounding). A simple test indicated that for a station with a Hawson correction of −10 Dm at 100 mb (or −16 Dm at 25 km) the corresponding correction at the $\theta = 350^{\circ}C$ level (about 25 km) is typically −2 Dm. In view of this fact no systematic corrections were applied during the isentropic analysis.

Random errors on isobaric charts are dealt with in Met O 19 by a process of comparison between charts at different levels. Because isentropic charts for a single level were produced as and when required such a correction technique was not practicable. Consequently, random errors (typically about 10 Dm) were dealt with purely by subjective smoothing.

In effect this placed a limit on the levels for which isentropic analysis could be performed, a limit rather lower than the 10 mb level at which isobaric analysis is practised. In fact, it was not possible to use, in winter, an isentropic surface which exceeded the 20 mb level over a large section of the hemisphere because such a surface contained insufficient data to allow the subjective smoothing necessary for an accurate analysis. The limiting value of θ in mid winter was found to be $300^{\circ}C$.

4. Results

Production of the isentropic charts for periods during the winter half of the years 1974/75 and 1975/76 were undertaken using a level of $\theta = 350^{\circ}C$ (roughly 20 to 30 mb) in autumn and spring but reducing this to the level $\theta = 300^{\circ}C$ (20 to 40 mb) during the winter months. Fields of isentropic height and streamlines were drawn up. These fields change only slowly with time in comparison with tropospheric fields, and stratospheric trajectories over a period of a day or two do not differ significantly from streamlines. A single synoptic chart thus yields an accurate description of the air motions.

The principal qualitative finding was rather negative in the sense that the pattern of streamlines on an isentropic chart was generally similar to the pattern of contours on an isobaric chart at a roughly corresponding level. This indicates that changes in wind direction with height near the level considered are fairly small. In general, regions of high (low) contours on the isentropic charts were situated close to cold (warm) regions on isobaric charts. Thus, where a stationary warm centre was found on an isobaric chart, the isentropic analysis confirmed that this was maintained by adiabatic descent upwind and adiabatic ascent downwind of the warm area.

Fig 1 shows an example of an isentropic chart while fig 2 shows the isobaric chart for 30 mb at the same time. Because the pressure on the 300°C isentropic surface varies from 25 to 40 mb the two charts may only be used for a rough comparison; nevertheless such a comparison does serve to illustrate the various points made above.

Furthermore, the isentropic chart shows that the flow is controlled by a cyclonic circulation centred near Spitzbergen and an anticyclonic flow over the Gulf of Alaska. Bearing in mind that the fields are effectively stationary, it becomes clear that there is one principal area of ascent and one of descent. In the ascending limb of the circulation from Baffin Island to the Norwegian Sea the air climbs from 21 km to over 23.5 km in a little more than a day; the main descent occurs over Russia. Regions of nearly horizontal flow are found over Europe and over the Arctic Ocean.

Referring again to fig 2, the region of ascent described above may be identified with a zone of warm advection and the region of descent with a zone of cold advection. In so far as the fields are steady in time the two effects of adiabatic vertical motion and horizontal thermal advection are equal and opposite. The slow changes in the fields which are observed reflect any slight imbalance between these processes.

Quantitative results in the form of vertical velocity estimates over the area of analysis were produced for a few selected occasions. The estimates were made by drawing isotachs in addition to the streamlines and height contours already described. It was then a simple matter to calculate the vertical velocity w.

$$w = \underline{V}_h \cdot \nabla_h z_\theta + \frac{\partial z_\theta}{\partial t}$$

where z_θ is the height of the isentropic surface θ, $\underline{V}_h$ and ∇_h are the horizontal wind vector and horizontal gradient operator respectively.

Local rates of change of the isentropic height field may be as great as 0.5 km per 48 hours or about 0.3 cm s^{-1}. This is an order of magnitude lower than the values of $\underline{V}_h \cdot \nabla z_\theta$ found in significant regions of ascent or descent and may safely be ignored for most purposes.

Thus $\quad w \simeq \underline{V}_h \cdot \nabla z_\theta$

Using this technique it is a simple matter to calculate that, in fig 1 for instance, vertical velocities of 5 cm s^{-1} are reached in the region of ascent and −4 cm s^{-1} in the region of descent.

Results from vertical velocity analyses of this type at the time of the final warming of 1975 have been presented by Watson (1976).

5. Concluding Remarks

The ability to produce isentropic equivalents of the standard stratospheric charts quickly and easily in order to provide an alternative and three-dimensional representation of the air-flow is a valuable addition to the stratospheric analysis potential of Met O 19.

Using isentropic analyses it has been confirmed that the strong isobaric temperature gradients observed on standard charts are maintained by adiabatic vertical motions and the vertical components have been evaluated in certain cases (and discussed elsewhere).

The potential use of isentropic charts for trajectory analysis purposes in connection with the tracking of ozone or nuclear contaminants from a stratospheric source region remains to be exploited by other branches where this is of interest to them.

References

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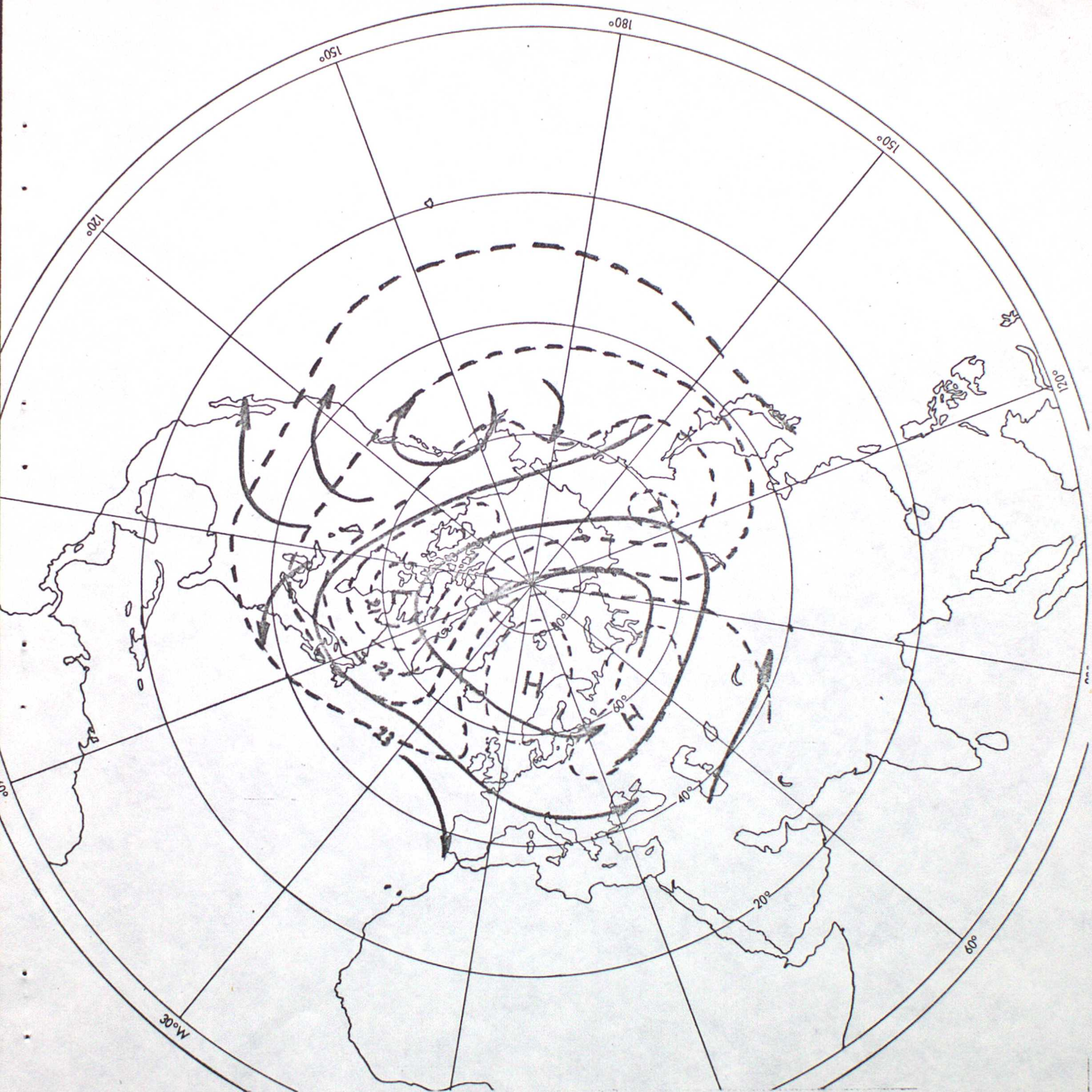

FIGURE 1 - ISENTROPIC ANALYSIS FOR THE SURFACE $\theta = 300^{\circ}C$
AT 00 GMT ON 18 MARCH 1976.

ereographic Projection

Solid lines represent stream-lines. Broken lines represent the height of the surface in geopotential kilometres.

FIGURE 2 - CHART FOR 30 MILLIBARS AT 00 GMT ON 18 MARCH 1976.

—— contour heights at intervals of 320 gpm

- - - isotherms at intervals of 10°C.