On Temperature Frequency Distribution in the Free Atmosphere and a Proposed Model for Frontal Analysis

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Abstract

The possibility of tracing baroclinic fields in the lower stratosphere by means of temperature frequency distributions in the main isobaric surfaces is discussed. The existence of a stratospheric front is indicated by the diagrams.

In the study of the temperature frequency distribution in the main isobaric surfaces of the troposphere there is the opportunity to trace baroclinic fields. Starting with the sloping baroclinic field connected with frontal layers, the importance of which BERGERON and SWOBODA pointed out already 1924, we may pursue the following reasoning.

Let us begin with the simplest case, that of the whole temperature difference between two air masses being concentrated in the frontal layer (see fig. 1). If this front is oscillating over a station, the temperature in a certain isobaric surface will be constant within the warm air as well as within the cold air. In the frontal layer, however, the station will show rapidly changing temperature. The temperature distribution in an isobaric surface will therefore have two maxima, corresponding to the temperatures of the warm and cold air respectively. The temperatures between these two maxima will be less frequent. In the real atmosphere with its baroclinity also outside the frontal layer, the above-mentioned picture will be less distinctive, but will certainly keep its main features.

In the case of a sloping large-scale front in the atmosphere the warmer air is always situated above the front. This means that if a station has warm air in, say, the 700 mb surface, it must be in the warm air in the 500 mb surface, too. This gives the same temperature frequencies for the two surfaces. In addition to these cases, however, we have cold air at the lower surface and warm air at the upper surface in all the cases, when the front is situated between these two isobaric surfaces. Thus, with increasing height the frequency of warm air will increase at the expense of the frequency of the cold air.

According to MCINTYRE (1950, p. 102) the reasoning in the above paragraphs gives the necessary and sufficient conditions for the existence of a sloping baroclinic layer in the atmosphere. This cannot be quite true, because the case of a horizontal inversion swinging up and down above a station would give the same characteristic temperature frequency distribution. From an empirical study

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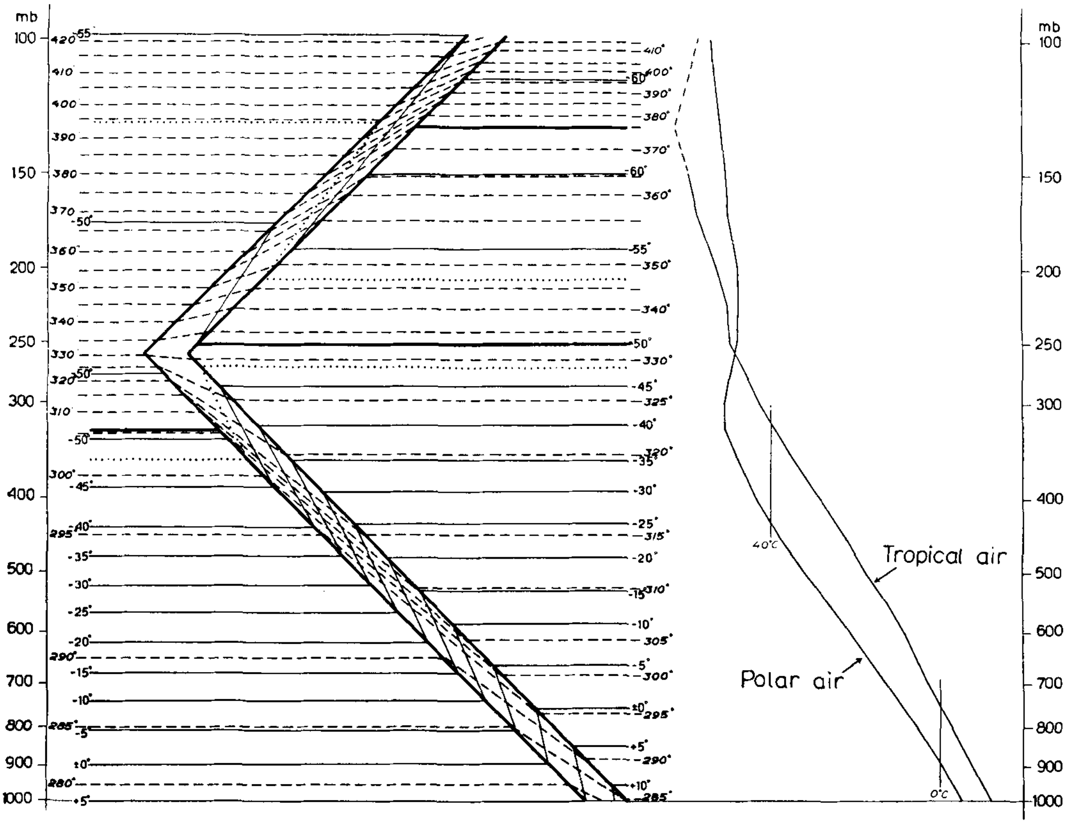

Fig. 1. Schematic vertical cross section based on two mean soundings (representative for western Europe and the eastern part of the middle Atlantic in November). Isotherms are given as thin solid (C°, intermediate values are given by dotted lines), isentropes as thin dashed lines (°K), and frontal boundaries and tropopauses as heavy lines. The inclination of the front is 1/100. (After BERGGREN, 1952 b, fig. 22.)

of several stations at different latitudes and their relative frequencies of, say, Tropical air one can, however, state that the baroclinic layer must be sloping. From synoptic experience and from theory it is obvious.

The discussion of the temperature distribution in isobaric surfaces can also be applied to the nearly vertical baroclinic field in the middle and upper troposphere connected with the jet stream. This baroclinic field appears as the strong baroclinity in the warm air immediately above the frontal layer (see *e. g.* BERGGREN, 1952 a, fig. 6).

Up to this point a review of the above-mentioned paper by MCINTYRE (1950)has been given. When the present author's attention was drawn to this paper, he was investigating some problems connected with the frontal analysis in the upper troposphere and the lower stratosphere. In two papers (1952a and 1952b) I have tried to show that the tropospheric Polar front in many cases may be prolonged into the stratosphere. Fig. 1 in the present paper gives a schematic vertical cross section through such a front. If this idea is correct it ought to be possible to apply McIntyre's reasoning to the frequency distributions above the 300 mb level.

As a first example the British radiosonde station Lerwick on the Shetland Islands has been chosen. In order to compare the two papers, the period used in this study is the same as that used by McIntyre. From the *Upper Air Section* of the *Daily Weather Report of the Meteorological Office*, London, five winter months were chosen, *viz.* January, February,

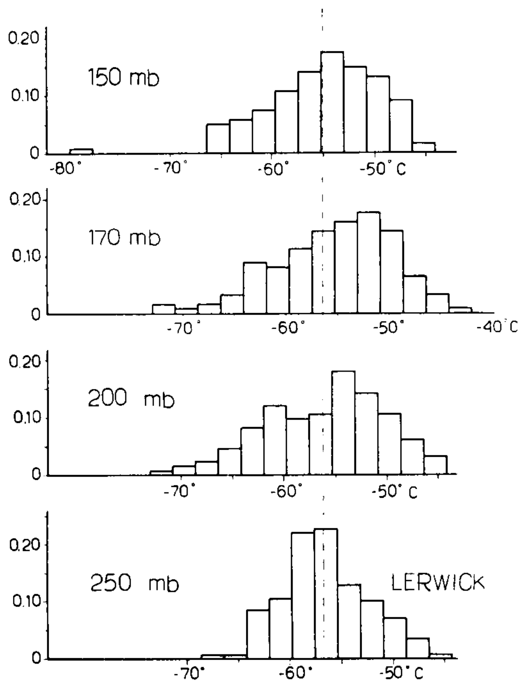

Fig. 2. Winter temperature frequency polygons for Lerwick (60° N, 01° W). The dashed line gives the mean values for the different levels.

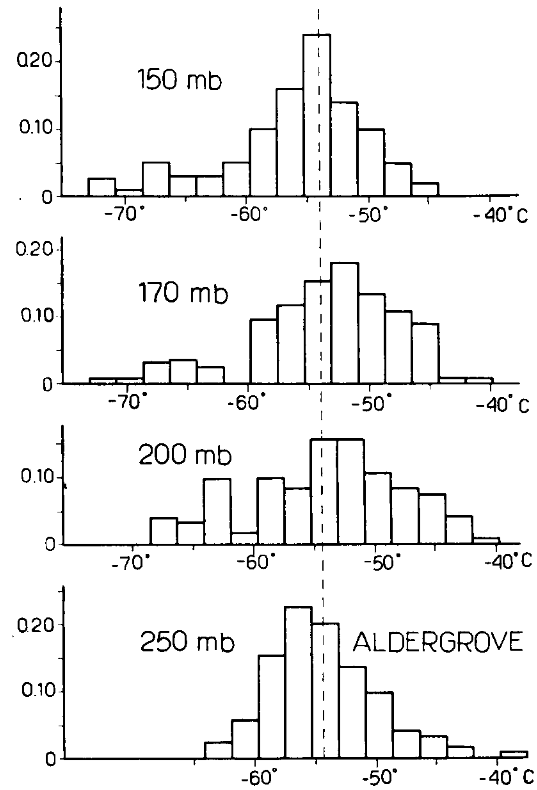

Fig. 3. Winter temperature frequency polygons for Aldergrove (55°N, 06°W). The dashed line gives the mean values for the different levels.

and December 1947, January and February 1948. Furthermore only the 00 GCT or 06 GCT soundings have been used. In McIntyre's paper it is not clearly pointed out, whether the investigation is restricted to the night or early morning soundings or not. In our case, however, we prefer to do so since we are studying stratospheric conditions, and in that case the radiation error may cause trouble.

The frequencies in the 700, 500, 400 and 300 mb surfaces are given in McIntyre's paper as fig. 7. In our fig. 2 the temperature frequency distribution of the 250, 200, 170, and 150 mb levels are shown. The 250 mb distribution agrees with the 300 mb distribution given by McIntyre, who relates the fact that this curve is nearly Gaussian to the observed fact that at about the 250 mb level there are almost barotropic conditions along a meridian. In my papers mentioned above I have pointed out that the temperatures of the Tropical and Polar air are about the same at this level. *The fact that the frequency distribution for the 250 and 300 mb levels shows a marked single maximum, does not imply that we have only one air mass at this level.* The maxima of the two distributions become so pronounced because *the Polar and Tropical air acquire about the same temperatures at these levels.*

If we continue to the 200 mb level (see fig. 2) we get the double maxima once more. We are now well in the stratosphere as far as the Polar air is concerned but near the tropopause level in the Tropical air. The 200 mb surface is well above the level where the front changes its character from warm front to cold front or vice versa (see fig. 1).

The Polar air maximum at —54° C and the Tropical air maximum at —61° C are easily detectable. If the reasoning in the first paragraphs is applied to this case, and if the front model given in fig. 1 is right, then the frequency distributions of the 170 mb and the 150 mb surfaces must show an increase of the Polar air peak at the expense of the Tropical air peak. Fig. 2 shows that this is really the case. (A discussion of the reality of the double maxima will be given below.)

Before going further I must strongly emphasize that it is not my intention to postulate that this high-tropospheric and low-stratospheric front, seperating tropospheric Tropical air and stratospheric Polar air, always can be found. A short discussion of the applicability of the proposed model is given in the above-mentioned paper (Berggren, 1952b).

The frequency diagrams for the British radiosonde station Aldergrove in northern Ireland were also constructed. In fact, they give the same picture as the one from Lerwick, and they are reproduced as fig. 3 without any special remark. Especially interesting are the extreme low temperatures down to —70° C or even lower, attained in the Lerwick frequency diagram for 150 mb, but the discussion of this item must be considered outside the scope of this paper.

In order to be able to compare the results with those of McIntyre's I have tried to choose the same period and the same stations as he did. But unfortunately the North American radiosonde material for the winter months of 1947 and 1948 were not available here. For this reason five other winter months have been chosen. The data from December 1948 and January 1951 have been taken from *Daily Upper Air Bulletin*, the winter months of January, February, and December 1949 from *Daily Series Synoptic Weather Maps.*

In fig. 4 the temperature frequency diagrams for the 700, 500, 300, 200, and 150 mb surfaces for the radiosonde station Tatoosh Island in northwestern USA are given.

Before going further we must compare the mean values for the winter months in question. These are given in table I. The frequency diagrams given by McIntyre for Tatoosh Island have two maxima in the 700 mb diagram, corresponding to —2,5° C and

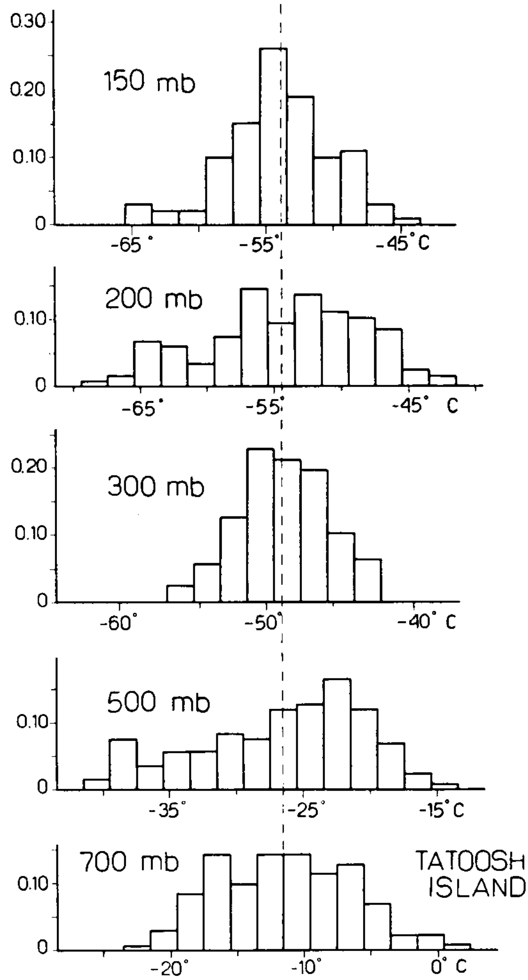

Fig. 4. Winter temperature frequency polygons for Tatoosh Island (48°N, 124°W). The dashed line gives the mean values for the different levels.

Table I. The mean temperatures (°C) of different isobaric surfaces and for selected months for Tatoosh Island (48° N, 125° W). (From *Monthly Weather Review* and *Climatological Data*.)

	jan.—47	feb.—47	dec.—47	jan.—48	feb.—48	dec.—48	jan.—49	feb.—49	dec.—49	jan.—51
700 mb	— 9.2	— 5.1	— 8.6	— 7.2	—10.9	—10.3	—12.0	—12.8	—10.2	—11.9
500 mb	—23.9	—21.0	—24.0	—22.6	—26.6	—24.9	—26.9	—28.8	—25.4	—26.6
300 mb	—47.2	—46.7	—47.5	—46.8	—48.7	—48.1	—49.9	—49.9	—47.7	—50.1
200 mb	—56.0	—61.3	—55.3	—53.9	—51.1	—55.9	—55.0	—54.4	—53.4	—54.6
100 mb	—	—	—	—59.8	—51.9	—54.5	—52.9	—53.3	—	—56.0

—14,5° C, respectively. As can be seen from our fig. 4 we have three peaks for the same level, the warmest of which is situated at —6,5° C. This discrepancy can be explained if we look at table I. The winter months chosen by McIntyre are definitely warmer than the ones chosen by us. This difference of the mean temperatures is brought about by the lower frequency of warm Tropical air as well as by higher frequency of rather cold Polar air.

The other two maxima correspond to old Polar air and fresh Polar air. The latter of these two air masses has come down more directly from the cold air reservoir in the north, being recently transformed Arctic air.

This lack of warm Tropical air seems to have almost disappeared at the 500 mb level, where we get a maximum at —22,5° C, compared with McIntyre's at —21,5° C. The higher frequency of cold Polar air in our case is clearly seen in fig. 4, which has an extra maximum at —36,5° C, whereas McIntyre has only one cold maximum at — 31,5° C.

Anyhow there is no question about the existence in both cases of a strong baroclinic field. The warm air maximum in fig. 4 has increased compared to the distribution at 700 mb at the expense of the cold air maxima.

The single maximum distribution of the 300 mb surface temperatures is established for both periods. In our case the temperature corresponding to maximum frequency is about 3° C colder than in the other case, and the distributions have a rather different shape.

If we now continue higher up in the atmosphere, we once more get the three maxima at the 200 mb level. If there were a sloping baroclinic field above this station between the 200 and 150 mb surfaces, then the maximum corresponding to the warm (Polar) air should increase at the expense of the colder peak. As can be seen from fig. 4, this is indicated in the upper diagram. The question whether the maximum corresponding to Tropical air is real or not will be discussed below. There a discussion of the validity of the three maxima in fig. 4 also will be given.

We have thus come to the conclusion that for this North American station as well as for the British stations there exists a sloping baroclinic field in the stratosphere.

As to a station situated far to the south on the North American continent one would expect that the sloping baroclinic field seldom exists. As an example McIntyre has chosen Santa Maria in California. The frequency distribution of this station (see his fig. 2) shows a very marked peak corresponding to Tropical air. The few cases with Polar air form a tail to the left in the frequency diagram, more distinct at the 700 mb level than at 500 mb level as is to be expected.

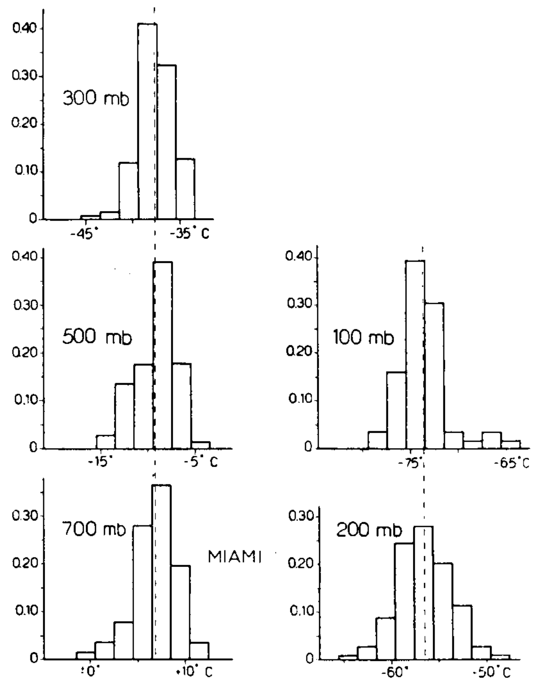

Fig. 5. Winter temperature frequency polygons for Miami (26°N, 80°W). The dashed line gives the mean values for the different levels.

The present author has chosen the station Miami in Florida (see fig. 5), instead of Santa Maria in southern California. This change has been done because of the fact that here the Polar air very seldom reaches above the 700 mb surface and the Tropical air thus dominates the frequency distribution. The one-maximum curve must be found at all levels if the reasoning of the first paragraphs is right. Fig. 5 gives the frequency distributions with very marked peaks and the disturbances come out only as a few lower values in the 700, 500 and 300 mb diagrams. Higher up in the 200 and 100 mb surfaces these disturbing values are naturally higher than the temperature corresponding to the maximum frequency.

When studying the temperature frequency distribution in the main isobaric surfaces for a single station, it is generally very difficult to decide whether the different maxima are real or not. The double maxima of the diagram for 170 mb in fig. 2 and the triple maxima of the diagram for 200 mb in fig. 4, for instance, may be the result of this special sampling. The populations from which these samples are drawn might just as well be normally distributed. When assuming that this is the case and investigating the deviation of the sample distributions by standard statistical methods (χ^2-methods at the 5 % level) one obtains no definite results. In some cases the hypothesis of normal distribution must be rejected, in others not. Furthermore it may be so that the population is not normally distributed.

Instead of making a loose assumption about the distribution and investigating the existence of a significant deviation the present author prefers to use an indirect proof. In McIntyre's paper as well as in this paper quite a lot of examples are given and in all cases there are at least indications of the phenomena on which the whole reasoning in these papers are based. The probability that this is a false result of the ramdom sampling must be considered small.

My conclusion is thus that the (sloping) baroclinic field in the troposphere is shown (and indirectly proved) by McIntyre's figures, and the corresponding field in the lower stratosphere by my figures.

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