A detailed study of the horizontal and vertical distribution of ozone[1]

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(Manuscript received January 10, 1966)

ABSTRACT

The North American ozonesonde network has been used for a detailed study of the vertical and isentropic distribution of ozone mixing ratio during the period 1–5 May, 1963, when daily observations were made. By using isentropic trajectories and assuming that the ozone mixing ratio is constant it has been possible in effect to increase the network. The ozone distribution is studied with the aid of time cross sections, space cross sections and isentropic charts. Special emphasis is given to the lowest part of the stratosphere.

Introduction

The North American ozonesonde network which started 1 January, 1963 (HERING, 1964; HERING & BORDEN, 1964) has made it possible to start investigations on the detailed distribution of ozone in the vertical as well as in the horizontal. Before 1963 most studies had to be restricted to the distribution of total ozone DOBSON, 1930; DÜTSCH, 1962; LONDON, 1963, and others) or to the rather crude indication of the vertical distribution as received with the aid of Umkehr measurements (e.g. DÜTSCH, 1965). Studies using ozonesonde observations have been rather few and isolated, mainly dealing with the measurements taken at one single point (PAETZOLD, 1959; BERGGREN, 1965). Using a synoptic ozonesonde network it would be possible to gather valuable information of the horizontal and vertical distribution of ozone provided the network is dense enough in time and space. The North American network does not fulfil these requirements when it comes to detailed studies of the horizontal distribution of ozone over large areas. However, during special periods the density in time is increased substantially and by introducing special methods it is also possible to increase the spatial density. This has been done for a period in May, 1963, and the methods used and the results obtained so far will be discussed in this paper. The purpose of the paper is only to describe the methods used and the results of a study of a restricted period. Furthermore, the paper will only describe some facts about the distribution of ozone mixing ratio in the vertical and the horizontal directions. In a later paper the same information will be given for a more prolonged period and with better resolution in the vertical. Finally, at a later step of the investigation ozone will be used as a tracer in synoptic studies of, among other things, the wind and temperature distribution around the jet stream.

[1] The present study has been partly supported by the Swedish National Science Research Council through contract No. 2581-1 and 2581-2.

Material

The North American ozonesonde network consists of eleven stations (see Fig. 3*a*). Usually observations are taken once a week on Wednesdays. During the period 29 April to 10 May, 1963, however, daily observations were taken at most stations. Out of these observations those pertaining to the period 1–5 May, 1963, were chosen for the study.

The tabulated ozone data contain information about ozone partial pressure and potential temperature for every half minute. The ozone mixing ratio was calculated for each available station and was used as the principle ozone parameter in the study reported upon here.

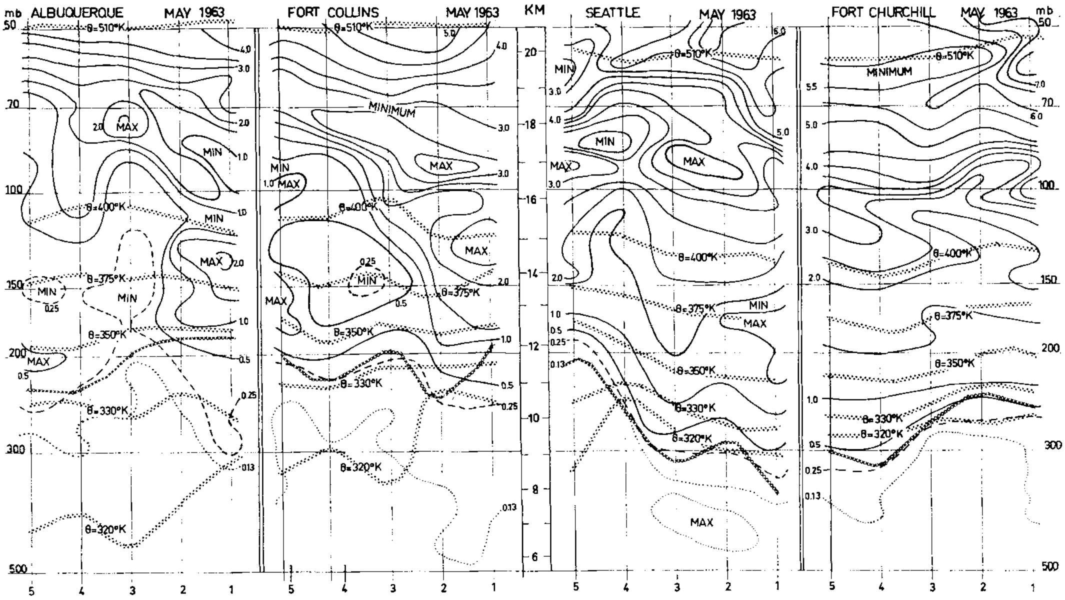

FIG. 1. Time cross sections for ozone mixing ratio (in $\mu g/g$, isolines for every 0.5 $\mu g/g$ with intermediate lines dashed (0.25 $\mu g/g$) or dotted (0.13 $\mu g/g$)). Crosses indicate the position of the conventional tropopause, dotted strips the position of the isentropic surfaces used in the present study.

In order to study the synoptic situation a number of isobaric charts were drawn twice daily between 500 mb and 30 mb. Furthermore, the following isentropic charts were plotted: 320, 330, 350, 375, 400, and 510°K. The isentropic data were calculated from the data published in the North American Data Tabulations, Part II and when necessary this material was complemented by teletype data. The machine programme is rather similar to the one discussed by BERGMAN (1962) and was written in ALGOL and run on the computer belonging to the Swedish Meteorological and Hydrological Institute.

The synoptic situation

On the 2nd of May, 1963, the synoptic situation in the upper troposphere and lower stratosphere over North America was characterized by a broad band of westerly winds over the southern part of the continent, while the circulation over the northern part was more meridional. Two days later the main features were the same and a nearly straight westerly jet stream could be observed from coast to coast near the U.S.-Canadian border (Fig. 3*d*). Comparing the circulation in the lowest part of the stratosphere with that around 50 mb, one notices (Fig. 3*l*) that the broad belt of westerlies has weakened considerably and in the southern parts been substituted by a cell of a subtropical high.

General remarks on the ozone distribution

Ozone time cross sections

In order to study the details of the distribution of the ozone mixing ratio, diagrams were plotted containing this quantity against time and a logarithmic pressure scale. In Fig. 1 are given diagrams for the following stations: Albuquerque, Fort Collins, Seattle, and Fort Churchill. All available soundings for the 1st through the 5th of May, 1963, are included. During the analysis data for the 30th of April and the 6th of May were also used.

It should be pointed out that all the ozone mixing ratio values used in the study have been smoothed with a fivepoint formula with the coefficients 1, 4, 6, 4, and 1. The original points are half a minute apart or 150–200 meters and thus the smoothing is performed over a layer the thickness of which is about 600–800 meters. The smoothing of the ozone values has of course the effect of somewhat obscuring the sudden changes that otherwise might be observed, e.g. at the tropopause level. Even when there is a very sharp discontinuity of the first order at the tropopause, it comes out as a gradually increasing value with the increase starting some 25 mb (at 300 mb) below the tropopause.

The study of the four diagrams reveals, among other things, the following:

Albuquerque. On the first three days of May the tropopause at Albuquerque was at or close to the 200 mb surface. However, as can be seen from Fig. 1, the vertical ozone distribution between 200 and 100 mb is quite different on the 3rd. The secondary maximum just above the 300 mb surface on the 1st coincides with a stable layer. On the temperature ascent curves for the 1st and 2nd we observe stable layers and increasing ozone mixing ratio well below the tropopause. On the 3rd these special features are not present and only very low ozone mixing ratio values are observed below the tropopause.

Above the tropopause the temperature distribution are quite similar on all three days. The ozone distributions are, however, not at all similar. We will return to a discussion of this in a later section.

Fort Collins. This diagram should be compared with that of Albuquerque as the two stations are not more than 700 km apart. It is obvious that many of the main features are the same, e.g. the change of ozone mixing ratio in the layer between 100 and 200 mb between the first and the second part of the period. However, the time of change in the layer between the 100- and 150-mb levels and the general absolute values of the ozone mixing ratio are different.

Seattle.[1] This diagram is different from the Albuquerque and Fort Collins ones, e.g. in the 100–200-mb layer on the 3rd and 4th. The rather low values at this level for the two southerly stations are not found at Seattle. On the 2nd, 3rd, and also—to a smaller degree—the 5th small secondary maxima were observed near the 400-mb surface in connection with marked stable layers.

Fort Churchill.[2] This diagram is somewhat simpler than the other three already discussed; the horizontal and vertical variations are smoother. It is interesting to note that on the 2nd the mixing ratio gradients at the tropopause is rather high. The temperature ascent curve shows a layer with a stability slightly higher than below and above at about 280 mb.

Ozone space cross section

Fig. 2 gives one example of an ozone cross section (for position of cross section line, see Fig. 3*c*), containing the ozone stations Thule, Fort Churchill, Fort Collins, and Albuquerque. The distance between Fort Churchill and Fort Collins is quite large and in order to get a somewhat firmer basis for the analysis of the ozone mixing ratio, observations from Seattle were taken into account by using the ozone time cross section in Fig. 1. Through successive approximations, points originating over Seattle in each of the six selected isentropic surfaces were found on the cross section line of Fig. 2 at the actual time of the section, i.e. 3 May, 12 GMT. For the computations the winds in the chosen isentropic surface were used. It is believed that these data, crude as they are, constitute additional pieces of information for the cross section analysis.

In the southern part of the section the typical multiple tropopause structure can be seen, one tropopause at about the 200-mb level and sloping markedly near the polar jet stream maximum and another about 100 mb petering out at about the latitude of the polar jet. A third tropopause can be found at about the 70-mb level with a very marked temperature inversion between the 100-mb and 70-mb levels at Rapid Falls (72662), Denver (72469) and Albuquerque (72365). The temperature sounding made at Fort Collins in connection with the ozone sounding supports the Denver values as it gives an inversion of about 12°C near the 90-mb level. The next station further north, Bismarck (72764), partly shows weak features of similar nature at these levels, whereas the station immediately to the south, El Paso (72270) does not at all indicate a similar struc-

[1] The ozone sounding for the 4th was very difficult to fit into the analyses. A comparison of the corresponding radiosounding and that of station 72793 Olympia revealed that the Seattle sounding on the average was 5° warmer than the Olympia one. As the later one fitted well into the isentropic analyses, the Seattle sounding was adjusted accordingly. With this correction the ozone analyses became reasonable.

[2] No data available for the 5th; isolines are interpolated between the 4th and the 6th.

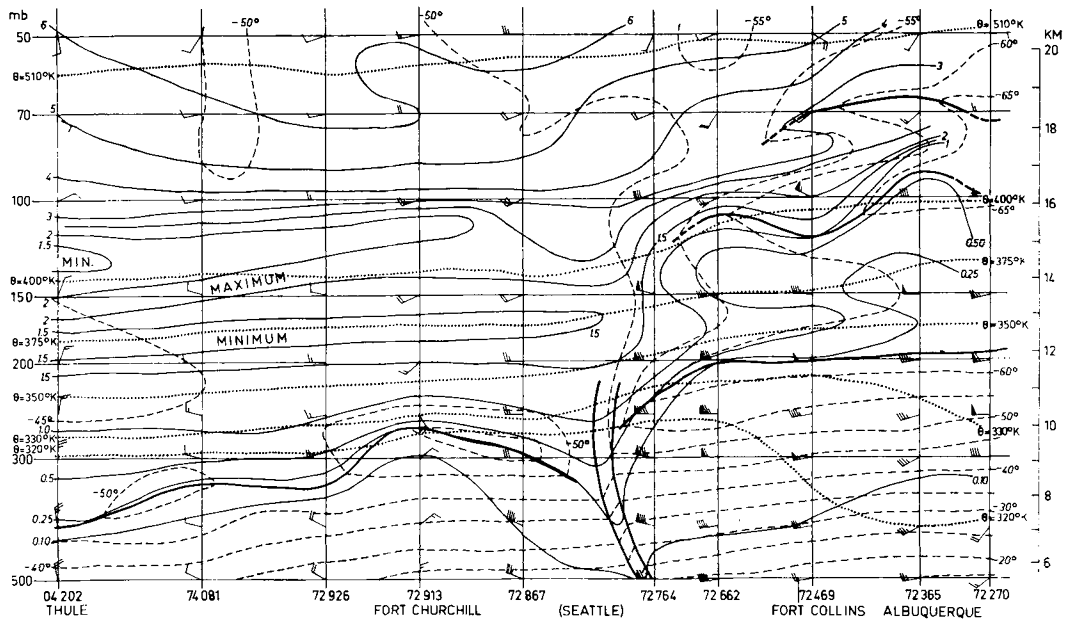

FIG. 2. Space cross section for 3 May, 1963, 1200 GMT, from Thule, Greenland, to El Paso, Arizona (position of line is given in Fig. 3c). The radiosonde stations used are given with WMO index numbers, the ozonesonde stations with names. Isotherms (dashed lines) for every 5°C; isentropes 320°, 330°, 350°, 375°, 400°, and 510°K (dotted lines); ozone mixing ratio (full lines) for every 0.5 μg/g up to 3 μg/g, then for every 1 μg/g, lines for 0.25 and 0.10 μg/g added; frontal boundaries and tropopauses heavy full lines; winds at standard isobaric levels (triangle 50 knots, full barb 10 knots, half a barb 5 knots).

ture. Thus, the region with very marked temperature changes in the vertical seems to be restricted to the area between Rapid Falls and Albuquerque in the cross section.

A striking feature of the temperature field are the very small variations in the horizontal as well as in the vertical north of the latitude of the polar front and above the tropopause.

The ozone distribution shows the following features:

(*a*) In the southern part of the section one notices a shallow layer with maximum values of ozone mixing ratio above the lowest tropopause. This feature is well born out by the Albuquerque as well as by the Fort Collins soundings (see also Fig. 1). On top of this layer there is a layer with minimum ozone at or somewhat above the level of maximum temperature. The stratospheric increase does not start until above the second tropopause. In connection with the third tropopause at about 70 mb the ozone mixing ratio has a maximum below this tropopause and where the temperature has a maximum, while the tropopause itself has relatively low values of ozone in combination with the minimum temperature.

(*b*) Going further north in the stratosphere the picture is dominated by very extensive maximum and minimum layers. A minimum layer with values less than 1.5 μg/g is observed at Fort Churchill (72913) as well as at Thule (04202) at or very close to the 375°K isentropic surface. The extension of this minimum layer goes well together with a value of 1.5 μg/g about halfway between the two stations The Pas (72867) and Bismarck at about 170 mb. This value was arrived at by a trajectory computation in the 375°K isentropic surface taking the point back to Seattle by using successive approximations. It is interesting to note that Seattle reported a minimum layer rather close to the 375°K isentropic level both on the 1st and the 2nd (cf. Fig. 1) with an ozone mixing value slightly less than 1.5 μg/g.

Another minimum layer can be observed at Fort Churchill and Thule at about 120–130 mb, where values less than 2 $\mu g/g$ were observed.

(*c*) The tropospheric values are less than 0.25 $\mu g/g$ and below the 300-mb level usually less than 0,10 $\mu g/g$, except near the polarfront and its associated jet stream.

(*d*) The downward dip of the ozone mixing ratio lines in connection with the polar front is based (1) on some interpolated values from the Seattle time cross section (Fig. 1), (2) on the general assumption of parallelism between the tropopause and the ozone mixing ratio lines as can be seen in those parts of the section where observed ozone values are available and also in other similar cross sections constructed by the authors but not shown here, (3) on the distribution of ozone in the frontal layer between 400 and 500 mb observed at Seattle on the 3rd at 12 GMT (cf. Fig. 1), (4) the distribution of ozone as given by ascent curves from the North American ozone sonde network, and (5) the general distribution of ozone mixing ratio in and at fronts as given by earlier publications (e.g. Briggs & Roach, 1963; Berggren, 1965).

The distribution of ozone mixing ratio in isentropic surfaces

The main purpose of the study has been to investigate the distribution of ozone in isentropic surfaces. With the aid of a number of isentropic surfaces it should be possible to get a reasonable picture of the quasihorizontal as well as the vertical distribution of ozone mixing ratio provided ozone observations are not too sparse. Unfortunately, the present network cannot be said to be sufficient for a direct analysis of ozone mixing ratio in isentropic surfaces. However, by introducing isentropic trajectories it is in effect possible to increase the density of the observations by a factor of two or three. This was done in the following manner.

It was decided to choose the ozone observations of the 3rd and 4th of May as basis for the study. On each of the isentropic charts for 320°, 330°, 350°, 375°, 400°, and 510°K the smoothed values of the mixing ratio were entered. These ozone values represented the basic observations. Additional information was taken from the observations taken the day before and after the actual day. Those values were transported to the two actual maps with the aid of isentropic trajectories, computed using maps 12 hours apart. In most cases actual winds were used and whenever gradient wind had to be used the resulting trajectories were checked with great care.

Using isentropic trajectories and ozone observations made not more than 24 hours before or after the actual time of the map (in a few cases 36 hours) it was then possible to arrive at a set of observation values, the density of which was close to three times denser than that belonging to the time of the map. In order to further increase the number of observations space cross sections were constructed containing not only wind, temperature, and potential temperature in the usual manner but also ozone mixing ratio (see Fig. 2 and corresponding text above). From these cross sections ozone mixing ratio values were taken at the isentropic levels for which maps were drawn. In this manner some additional information along a line was arrived at for the ozone mixing ratio maps.

Finally the number of observation points in the ozone mixing ratio maps was increased in the following manner. From the time cross sections with ozone mixing ratio isolines values were read off at 00 GMT on the 3rd, 4th, and 5th, and at the isentropic surfaces used. These observations were also transferred to the ozone mixing ratio maps discussed here with the aid of isentropic 12 hours trajectories.

The material on which the analysis of the ozone mixing ratio maps in Fig. 3 is based, consists obviously of observations of variable reliablity. During the analysis the emphasis has naturally been put on the ozone data from the actual map time. Then come those data from cross sections which are rather close to ozonesonde stations. Place number three in reliability was given to the data transferred by isentropic trajectories for 24 hours or less backwards or forwards in time. Least emphasis was put on the data which were first interpolated from time cross sections and then transferred to the map time by isentropic trajectories.

In order to achieve consistancy in the analysis the above described method was applied to ozone mixing ratio maps for every twelve hour from the 2nd at 1200 GMT to the 5th at 1200 GMT, inclusive. As most ozone observations were taken close to 1200 GMT, the corresponding maps were naturally the most im-

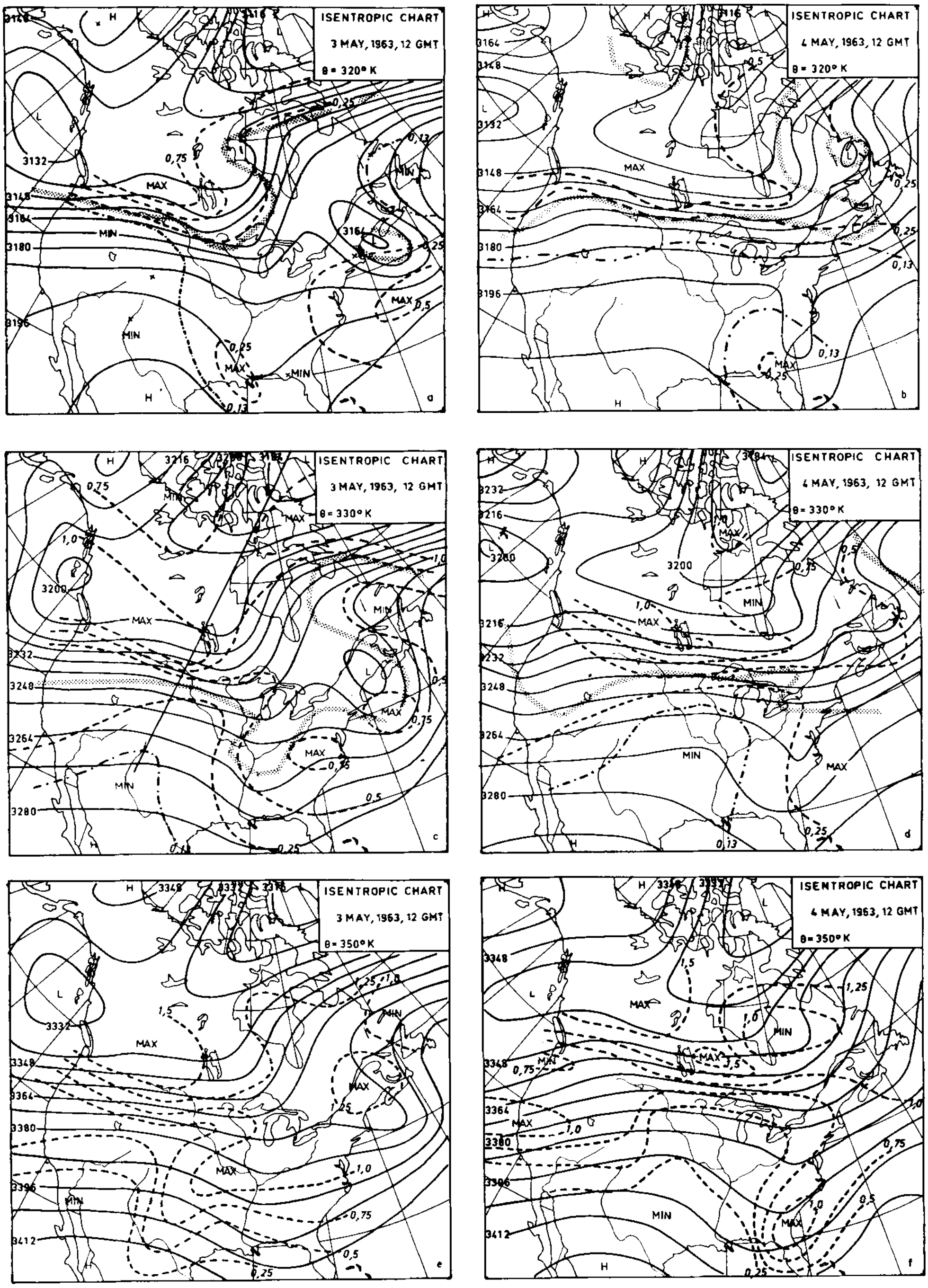
ISENTROPIC CHART
3 MAY, 1963, 12 GMT
θ = 320° K
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Fig. 3 *a–f*

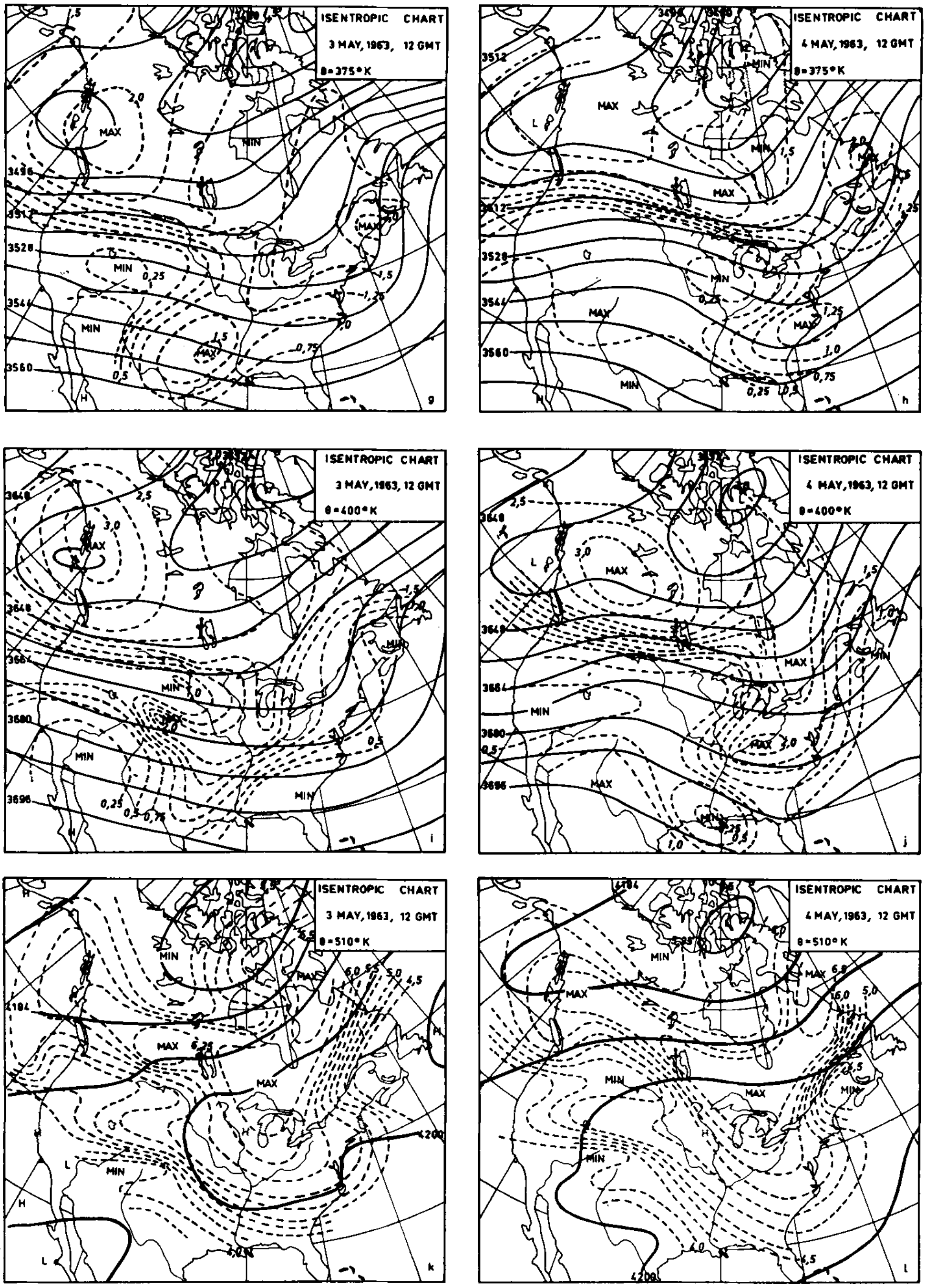

Fig. 3 *g–l*

FIG. 3 (*a–l*). Isentropic charts for 3 and 4 May, 1963, 1200 GMT; Montgomery stream function is given in full lines (interval in 800 MTS units, numbering given with last two digits omitted); ozone mixing ratio (dashed lines) for every 0.25 μg/g with lines for 0.13 μg/g added (dash-dotted); in *a* the crosses indicate the position of the nine ozonesonde stations used; in *c* the cross section line of Fig. 2 is given. In *a–d* are also indicated the intersections with the tropopause (dotted strips).

portant ones. To further the reliability of the analyses the 24 hours changes of the ozone mixing ratio were taken by graphical subtraction and these maps were checked for internal consistancy.

The isentropic charts in Fig. 3 give Montgomery stream function and the ozone mixing ratio. For the two lowest isentropic surfaces is also indicated which parts of the surface in question that are in the troposphere and which parts that are in the stratosphere. The latter analysis has the same basic weakness as that of any tropopause map, i.e. due to the ambiguity in the definition of the tropopause there are areas where the analysis is uncertain. The decision of whether or not a certain part of the isentropic surface was in the stratosphere or the troposphere was based on plotted ascent curves and numerous space and time cross sections. The difficulties arose as usual in connection with the jet stream. From Fig. 3 it is, however, quite clear that the analysis of the ozone mixing ratio and the troposphere-stratosphere analysis, *which were made independently*, go reasonably well together. On the 320°K charts the isoline for 0.25 μg/g runs quasi-parallel to the intersection line of the tropopause with two main exceptions. Over the easternmost part of USA and the adjacent sea area we notice on the 3rd high ozone values in the troposphere. However, the trajectories from the 2nd to the 3rd were quite difficult to compute as the point of origin was close to a low and thus the corresponding trajectories unreliable and furthermore the tropopause analysis was uncertain. The other apparent inconsistancy is found on the 4th over easternmost Canada. In this case the difficulties were twofold: (1) no ozone sounding was made at Goose Bay on the 4th and therefore an estimated value, interpolated from a time cross section, was used for that station and (2) the tropopause structure was quite complicated, resulting in a separate intersection between the tropopause and the 320°K isentropic surface.

Also at the 330°K isentropic charts some of the discrepancies are observed. They can, however, be explained by lack of ozone data. This is the case with the analysis over northwestern USA and southwestern Canada. It is possible, without violating any data, to draw the ozone isolines to run closer together and more parallel to the tropopause intersection. This would indicate on the chart for the 4th an eastward advection of low ozone mixing ratio over the easternmost Pacific. This is in good agreement with Fig. 1 from which we can notice that the ozone values for the 5th at Seattle are rather low in the 320°K and 330°K isentropic surfaces.

Other areas with apparent discrepancies are eastern USA and the adjacent sea areas. On the 3rd two maxima with ozone mixing ratio higher than 0.75 μg/g are indicated in this region, one well within and the other partly in the troposphere. However, over eastern USA the tropopause intersection is not too well defined and it is possible to draw this line more to the east. If we at the same time take the possible error in the trajectory computation into account, it can be stated with reasonable certainty that the ozone maximum is more likely in the stratosphere. Over the sea area it is of course possible to draw the tropopause intersection as well as the ozone isoline so as to place the ozone maximum entirely within the stratosphere.

On the 4th the analysis over western Atlantic can also be made so as to (1) give higher ozone values and (2) to place the maximum within the stratosphere.

Except for certain parts of the southernmost area given in Fig. 3*e* and *f* the 350°K isentropic surface is entirely within the stratosphere. However, in some areas it is in the lowest stratosphere and rather close to the so-called middle tropopause which can be found around the 200-mb surface (cf. Fig. 1*a*) (Albuquerque) and Fig. 2). North of 40° N the 350°K isentropic charts are quite similar to those for 320°K and 330°K as far as the isoline pattern is concerned. The similarities between the three sets of charts are specially striking in connection with the jet stream system over the northernmost part of western and central USA. The differences over southern USA consist mainly in the existence in the 350°K surface of more pronounced areas with high ozone values. The strong gradient just to the east of Albuquerque on the 3rd goes well together with the corresponding ozone time cross section in Fig. 1.

The trough in the streamline pattern over eastern USA moved rather slowly, whereas the wind speeds were much higher. This leads to the event that is normal for the levels in question, i.e. to have air particles move rather quickly through troughs and ridges. This also leads to the ozone distribution that can be seen in Fig. 3*e* and *f* where an ozone maximum on one occasion is coupled to a weak ridge and 24 hours later to a trough. Thus, the ozone concentration at a specific level cannot be too strongly correlated with the streamline pattern as far as smaller features are concerned.

The two 375°K isentropic charts show an ozone distribution rather similar to the ones in the 350°K surfaces, only that the numerical values in general are higher, corresponding to the higher elevation.

In the 400°K isentropic chart for the 3rd two new features appear, the first being a marked maximum and an equally marked minimum between 100° and 110° longitude. Comparing the positions of these extreme values with the run of the 400°K isentrope in Fig. 2 we notice that this line several times crosses the tropopause near 100 mb. The minimum in the 400°K isentropic chart over southwestern USA corresponds to the section around Albuquerque where the 400°K isentrope is within the troposphere. In the neighbourhood of Fort Collins and Denver (72469) the 400°K isentrope is well in the lowest stratosphere with corresponding increase of the ozone mixing ratio. Further north the isentrope once more penetrates into the troposphere with a resulting decrease in ozone.

The second noticable feature of the 400°K isentropic charts is found over eastern USA and Canada. The eastward movement of the jet maximum which on the 3rd was situated over western USA is followed by a corresponding adjustment of the ozone mixing ratio lines on the charts for the three lower isentropic surfaces. In the 400°K isentropic surface, however the jet maximum is still on the 4th lagging definitely behind the trough over eastern North America. At the same time an area with low ozone values moves from southwestern USA and eastwards. In connection with these two events one observes 24 hours changes of ozone mixing ratio that are quite different in different levels; this differential advection will be discussed in a later section.

The ozone distribution in the 510°K isentropic surface is characterized by (1) high numerical values as this level is close to the 50 mb surface, (2) strong gradients, and (3) rather small advective changes.

Ozone maxima in the lower stratosphere and in the troposphere

In the lower stratosphere one often notices more or less marked maxima in the vertical distribution of ozone and this has been discussed in the literature (e.g. Kroening & Ney, 1962; Breiland, 1964 and 1965). Breiland's papers are of special interest in connection with the present study as he has studied the same material, one paper dealing with ozone soundings from the 1st of May, and the other with data from 5th, 6th, and 7th of May. His conclusions are that marked variations in the vertical distribution of ozone up to about 70 mb are primarily associated with the origin and thermal structure of the air masses involved. An ozone minimum between a middle tropopause at about 200 mb and a tropical tropopause at about 100 mb is connected with a northward transport of tropical air with low ozone concentration. A maximum on the other hand is coupled with an intrusion of ozone-rich air of polar or middle-latitude origin. In this paper we have tried, with the aid of synoptic maps, to indicate in detail how air masses with varying ozone concentration are transported, provided the processes are dry-adiabatic, which is a reasonable assumption at the levels and time intervals discussed in this paper. The charts in Fig. 3 also give an indication of the extension and magnitude of the advection. One example will suffice: on the 3rd the ozone mixing ratio in the 375°K isentropic surface over Albuquerque (Fort Collins) is quite low, 0.22 μg/g (0.28 μg/g) after having been much higher 24 hours earlier, 0.85 μg/g (1.56 μg/g). The possible extent of the area with ozone mixing ratio less than 0.25 μg/g in the 375°K isentropic surface is given in Fig. 3*g* and *h* for the 3rd and the 4th. The eastward movement was quite regular with a marked decrease of ozone mixing ratio in the 375°K surface over Northeastern USA up to the 5th.

At the same time as advection of air with low ozone mixing ratio values occurred at 375°K isentropic surface and slightly lower, the advection in the 400°K surface was different with an increase of ozone mixing ratio from the 3rd to the 4th.

The 375°K and 400°K isentropic charts in Fig. 3 give thus an example of the creation of a weak ozone maximum in the lower stratosphere by differential advection. Similar examples can be found in other areas of the charts, e.g. over southern USA. It would be interesting to compare for ozone mixing ratio the observed advections as calculated from the isentropic charts in Fig. 3, the observed rates of change with time according to Fig. 1, the observed vertical gradients, and the vertical wind speeds as computed from the isentropic charts. This could be used to check all the involved analyses in order to provide a set of internally consistent parameters. The present density in time and space of the ozone sonde network does not, however, allow meaningful estimates in this regard.

The maximum in the vertical ozone distribution that is observed close to the 200mb surface and the 350°K isentropic surface (Fig. 2) from Bismarck (27764) and southward could be observed for several days (cf. Fig. 1*a* and *b*). This type of maximum is quite common at these levels over most of the area covered in Fig. 3. It is more common in winter and spring, although many striking examples can be found also in summer. Above the maximum layer there is a layer with ozone mixing ratio values close to those existing in the uppermost troposphere. This would imply either an intrusion of polar stratospheric air into tropical tropospheric air or a northward transport of tropical tropospheric air into polar stratospheric air or a combination of both processes. On the basis of the material for the May 1963 case and also from other studies and the published ozone soundings (Hering, 1964; Hering & Borden, 1964) it can be stated that the phenomenon is on a synoptic scale, at least of the magnitude of a major upper trough. Furthermore it is also clear that once formed these maxima and minima are quite persistent in time. It can be noted that during the first days of May, 1963, a westerly jet prevailed over most of the Pacific Ocean, penetrating into North America in northernmost USA. Thus, the air masses involved in building up the distribution of ozone and temperature in the southern part of the cross section in Fig. 2, have quite a long time been moving from west to east. Any "interleafing" process, creating the observed maxima and minima, must most likely have occurred long before the air masses invaded western North America.

Finally a few words about ozone maxima in the troposphere and the hypothesis that air in tropospheric frontal layers frequently comes from the stratosphere (Reed & Danielsen, 1959). In Figs. 1 and 2 we notice tropospheric maxima that are more or less marked. It seems reasonable to relate these maxima with fronts and this has been done by several authors (e.g. Briggs & Roach, 1963; Berggren, 1965). It is, however, striking that these maxima never reach high values below, say, the 300-mb surface. In most cases the numerical values are not more than 0.25–0.30 μg/g. This would indicate one of two possibilities: (1) the air in the frontal layer between 500 and 300 mb comes from the uppermost parts of the troposphere or the lowest parts of the stratosphere, (2) the air comes from higher levels in the stratosphere, but during the downward movement quite strong mixing takes place. The observed values of water vapour mixing ratio in tropospheric frontal layers sometimes do confirm very strong subsidence at least partially originating well above the tropopause and this would support the idea of quite strong mixing of the air in the frontal layer with the surrounding air. On the other hand it has been the authors' experience that the ozone mixing ratio values observed at a station agree quite well with those transported from another station with the aid of isentropic trajectories. It is, however, possible that the mixing processes are much more dominating near a jet stream system and the related frontal layer, and it would perhaps be necessary to take into account also diabatic effects. The present network of ozone sounding stations does not permit a detailed study of the problem.

Ozone and aviation

In later years the interest of possible ozone concentrations has been increasing in connection with aviation. First and foremost it is of course the ozone problem in relation to supersonic transport that has caused the greatest interest as the operating altitude of a supersonic aircraft is such that high ozone concentration can invariably be expected. The high concentration of ozone in the ambient air has several effects on the aircraft and its crew and passengers. Some material, as rubber, is greatly influenced by ozone. If the ozone concentration in the cabin air is too high, it has certain effects on the respiratory organs. For supersonic transport the latter problem will not arise as these aircraft must be equipped with ozone destroying devices and thus the ozone concentration can be controlled to any required level. However, the question arises whether or not present day jet aircraft operate at levels where at times the ozone concentration is so high that enough ozone escapes into the cabin, causing difficulties to some passengers specially sensitive to ozone. In order to study this question we need information on three different parameters: (1) the ozone concentration in the ambient air, (2) the efficiency of the ozone destruction by, among other things, the heating system, and (3) the critical value of ozone concentration with respect to respiratory difficulties.

The ozone material collected in connection with the present study give some indication on (1). Information regarding (2) is difficult to get, but the data available so far seem to indicate that 10 to 25 per cent will escape into the cabin (BRABETS, 1963). Regarding (3) finally it is more difficult to find good estimates on the critical value. However, according to JAFFE and ESTES (1963) this value should be at least 0.3 μg/g. If we assume that, on the average, 20 per cent of the ambient ozone can find its way into the cabin, that means that a value of at least 1.5 μg/g is required for the ozone mixing ratio in the ambient air to be critical. The cruising altitude of present day jet aircraft is somewhere between 10,000 and 12,000 meters, i.e. between 250 and 200 mb. From Fig. 1 it is clear that an ozone mixing ratio of the ambient air greater than 1.5 μg/g was observed quite frequently during the investigated period for the levels indicated above. However, estimating the possible effects of ozone on an aircraft and its crew and passengers, one must also take into account the time of exposure to values greater than the critical ones. During the period investigated there were large areas where the ozone mixing ratio between the 250- and 200-mb surfaces was greater than the critical value. This means that a rather long flight continuously can be made in air with a critical ozone concentration. Further studies are needed of (*a*) the amount of ozone that escapes into the cabin, (*b*) the critical values of ozone mixing ratio with respect to the comfort of crew and passengers in a present day jet aircraft and (*c*) the interrelationship between high ozone values at a specific altitude and the meteorological situation.

Acknowledgment

The authors want to express their gratitude to the Director General of the Swedish Meteorological and Hydrological Institute, Dr. Alf Nyberg, and the Director of the Institute for Meteorology and Geophysics of the Free University Berlin, Professor Richard Scherhag for the interest shown in the present study. Thanks are also due to Dr. Wayne S. Hering AFCRL, USA, for supplying all the necessary ozone data. Mrs. N. Greesnis, SMHI, and Mrs. R. Lerch, FUB, plotted most of the working charts and prepared the drawings.

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ДЕТАЛЬНОЕ ИЗУЧЕНИЕ ГОРИЗОНТАЛЬНОГО И ВЕРТИКАЛЬНОГО РАСПАДЕНИЯ ОЗОНА

Результаты, полученные с озоновых зондов на североамериканской сети станций, были использованы для детального изучения распределения отношения смеси озона по вертикали и на изэнтропических поверхностях за период с 1 по 5 мая 1963 г. Используя изэнтропические траектории и предполагая отношение смеси озона постоянным, оказывается возможным увеличить сеть данных об озоне. Распределение озона изучается с помощью временных и пространственных разрезов и изэнтропических карт. Специальное внимание уделяется нижней части стратосферы.