The Threefold Structure of the Atmosphere and the Characteristics of the Tropopause

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Abstract

All available soundings for January 1, 1956 have been studied with respect to their tropospheric and stratospheric temperature structure and with emphasis on the height and form of the tropopause. It was found that the latitudinal influence on the total vertical structure of the soundings was not dominating, but rather the location of soundings with respect to the two main westwind maxima (polarfront jet and subtropical jet) of the westerlies seemed to be important. A selection of soundings according to this principle (north of polarfront jet, between the two jets, south of subtropical jet) made it possible to distinguish between different types of soundings. This fundamental difference is discussed and will form the basis for future studies of world wide circulation changes. Furthermore the distribution of tropopause height and temperature has been mapped and studied on a hemispheric scale. Each of the above mentioned types possesses a typical vertical temperature structure and a characteristic tropopause heigth. Two rapid changes in tropopause height (tropopause breaklines) connected with the main westwind belts separate areas possessing an almost uniform tropopause level. Inside each of these areas a remarkable quasi-barotropic state of the upper tropospheric layers is shown.

Similar discussion has been devoted to the nature of soundings inside or close to the jets or the breaks in tropopause height. Here the soundings have a more complicated vertical structure and their interpretation becomes difficult.

Introduction

Until the present time synoptic and theoretical work in meteorology has been more or less restricted to the study of atmospheric conditions up to the 300 mb surface (about 9 km). This is especially true for the daily routine synoptic work. Although numerous studies have included the stratospheric conditions, these studies are mainly restricted to certain areas. Worldwide hemispheric investigations for stratospheric levels are extremely rare in meteorology. This is partly due to the fact that complete hemispheric data for levels above 300 mb are not available, and also because the contribution of stratospheric developments to that at lower levels has not generally been considered very important.

There are certain important features in the upper atmosphere (upper part of the troposphere and the stratosphere), which should be closely studied. We find at these levels the polarfront jet connected with the polarfront and the subtropical jet located mainly at about 30° lat. and at a height of about 200 mb. These two jets are the main windmaxima of the broad westerlies. While the polarfront jet has been studied rather thoroughly and its hemispheric existence has been shown, the subtropical jet has not been investigated enough. It is not shown yet, that the subtropical jet is a continuous belt around the hemisphere, however, climatological studies and certain vertical cross-sections in different meridional planes suggest its more or less continuous existence around the earth.

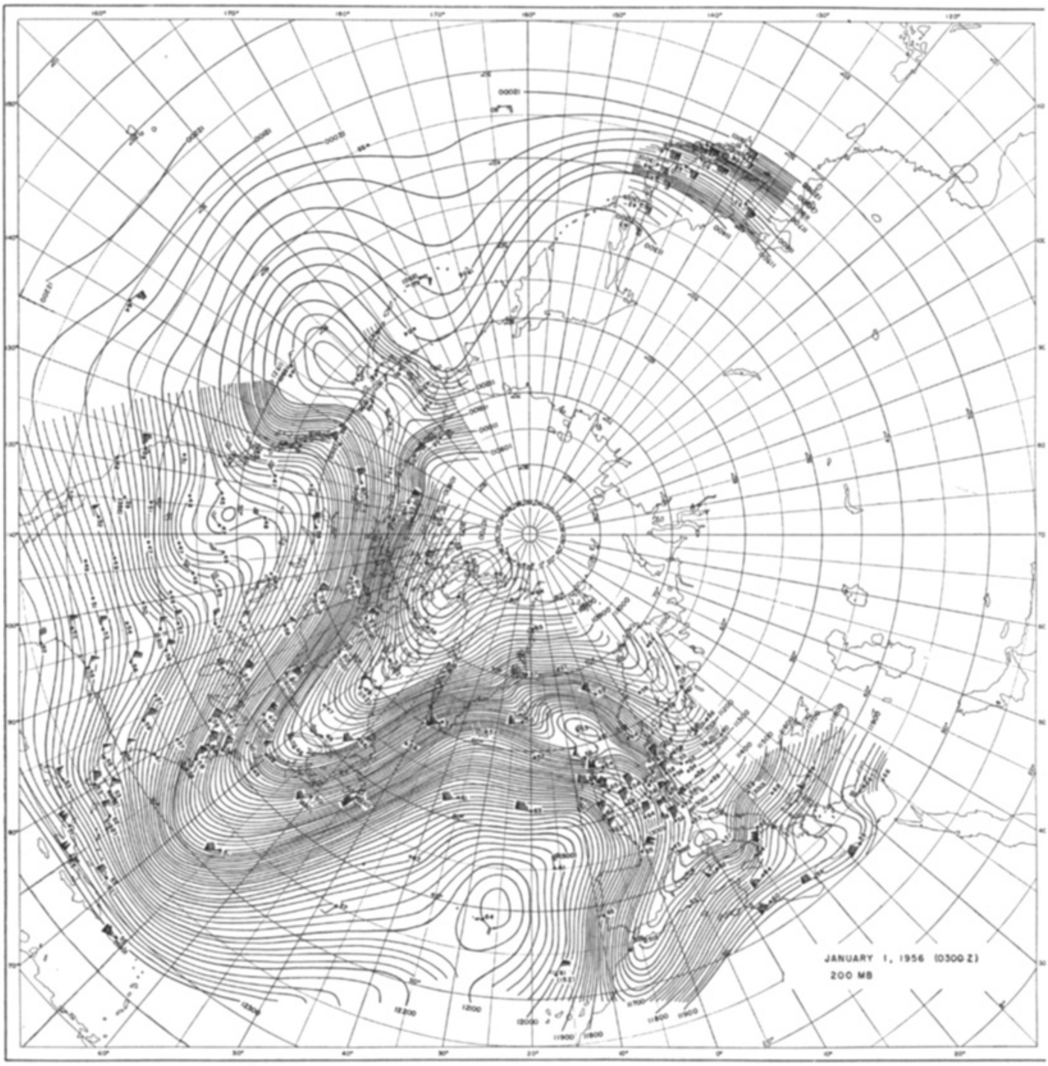


Fig. 1. 200 mb contour map of January 1, 1956 (0300 Z) (Thick contours for every 100 dyn. m., thin contours for every 20 dyn. m.; Temperatures in C° and minus sign omitted. Windspeed in kts.)

Another very important feature of the higher atmosphere is the variation of the tropopause height. The temperature field in the stratosphere has not either been studied enough.

The purpose of this paper is to investigate the behaviour of the atmosphere from the tropopause level upward. Special emphasis will be given to the variation of the tropopause height in vertical and in latitudinal direction. This is being done for a period beginning 1 January 1956. All available soundings of the northern hemisphere have been plotted and studied thoroughly. This period was selected as hemispheric maps from the surface up to the 300 mb level showed certain periodic and pronounced changes of the world-wide patterns. This paper deals only with January 1, 1956. During the preparation of the material, it was found that the Russian and Chinese radiosondes did not extend above 300 mb, so that no, or only little information was available in these areas. The analysis covers therefore the Pacific Ocean, North America, the Atlantic Ocean and Europe.

1. General synoptic situation on January 1, 1956

It is clear that the 200 mb level is most suitable for identifying the subtropical jet, as the highest wind speed of this phenomenon occurs close to this level. The polarfront jet can also be noticed in this level as the wind velocity remains still strong and the gradient of the contour lines shows a well marked concentration at the 200 mb level (upper polarfront). A further advantage is the well known reverse of the meridional temperature gradient, so that the temperature field is also a guide in distinguishing the two separate wind belts. This will be shown in detail later. As an exampel Fig. 1 gives the situation on January 1, 1956 (0300 z). This analysis clearly shows a strong meandering circulation pattern. Particularly strong troughs can be noticed just off the American East Coast, over Europe and over the Japanese Islands. A weaker trough appears south of Alaska. The wind values over the North American Continent together with the gradient of the contour lines show the upper polarfront jet running across Northern Canada and going around the trough at the East Coast of America. At the same time, the high wind velocities over the Southern United States and the Caribbean Islands show the subtropical jet quite well. Over the Atlantic the polarfront jet seems to run from New Foundland to the southern part of Greenland, to the north of Iceland and into the middle of Europe.

The subtropical jet in this area continues from the Caribbean Islands towards the northeast, crosses the northern part of the Atlantic Ocean and enters England. Over France the two jets nearly join, running southwest to the African West Coast and show up again over North Africa.

Fig. 1 also shows the reversed temperature gradient at 200 mb. North of the upper polarfront relatively high temperatures appear on the chart (sometimes higher than -50° C). This indicates that in the area surrounded by the upper polarfront the tropopause is below the 200 mb level and the temperatures belong to the polar stratosphere. South of the upper polarfront temperatures between -50 and -60° C appear, where the tropopause is still below the 200 mb surface. Going further south the temperatures become relatively low, indicating that the tropopause intersects the 200 mb level and slopes upward to higher altitudes. Still further south the temperatures rise slightly and refer now to the higher troposphere. This can best be seen over the Atlantic area where the subtropical jet runs exceptionally far north. In this area temperatures lower than -60° C are observed, indicating that most of the Atlantic is covered by a rather cold air of subtropical origin with the tropopause above 200 mb. Here the temperatures belong to the higher part of the troposphere.

This discussion indicates a threefold structure of the tropopause height which will be discussed in the following.

2. The tropopause map of January 1, 1956

To study this threefold structure in tropopause height, it was decided to prepare separate hemispheric tropopause maps. For this purpose about 200 soundings were plotted and checked for every day and for a period of seven days. The height of the tropopause was computed for each individual sounding. For most of the soundings it was easy to select the tropopause level by applying the standard method. (Either a noticable change of tropospheric lapse rate to an isothermal layer or to an increase of temperature with height.) Sometimes it was difficult, however, to find a well defined tropopause. This was almost always true for soundings, which met either the polarfront jet or the subtropical jet close to their wind maxima. In case of soundings running through the polarfront jet no distinct tropopause could be found. In the case of soundings going through the subtropical jet, two different breaks in lapse rate appeared, suggesting a double structure of the tropopause. Both of these cases will be discussed later.

Fig. 2 shows the tropopause map of January 1, 1956 (0300 z). In this map the two separate west wind belts stand out clearly in the gradient of the contour lines of the tropopause level. Two different bands picturing the break in the tropopause height connected with the existence of the polarfront—and the subtropical wind maxima can be seen all around the hemisphere. This double break in tropopause separates, in a clear manner, three differ-

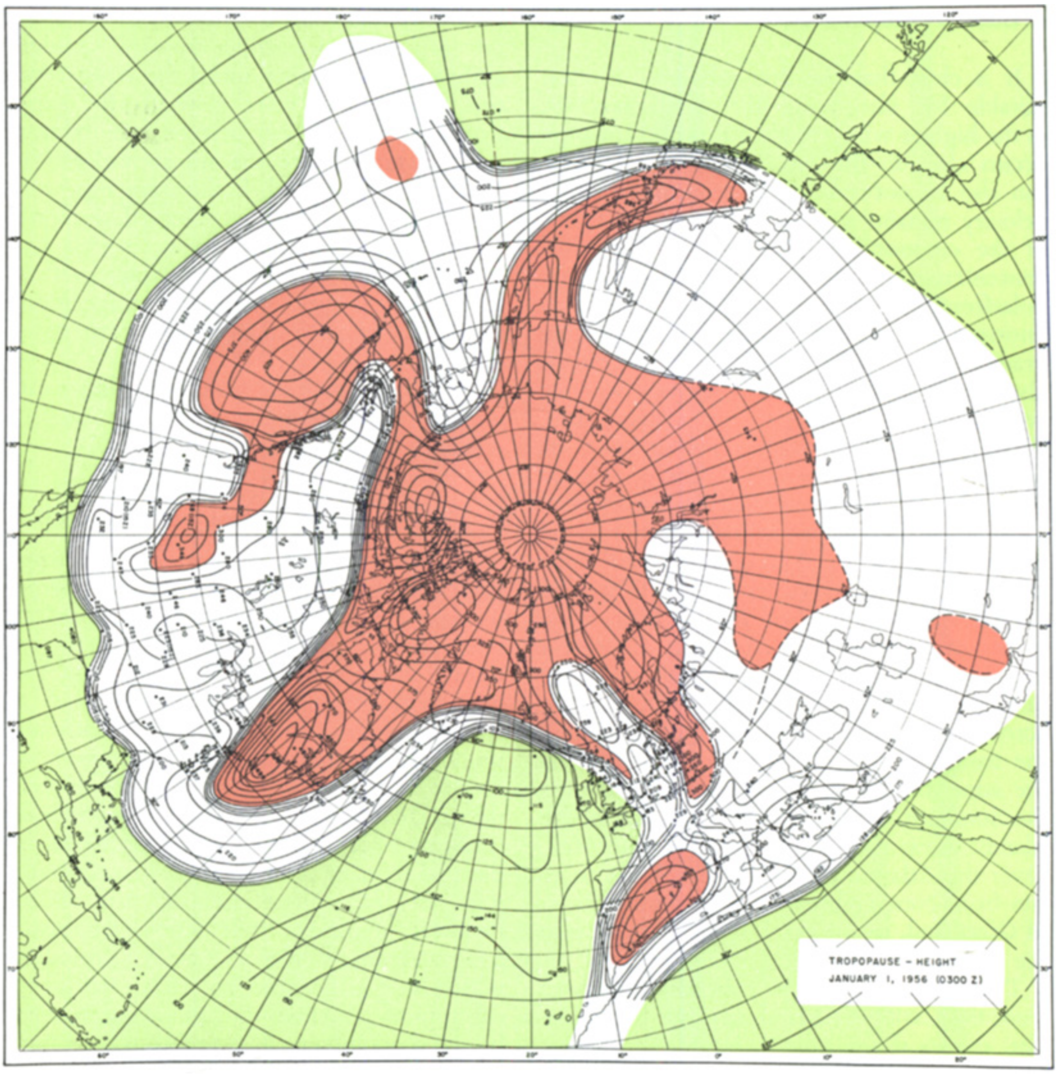


Fig. 2. Hemispheric map of tropopause height (in mb) of January 1, 1956 (0300 Z). Breaklines of tropopause height are shown by concentrations of isolines. Dashed lines over Asia give approximate continuation of the breaklines of tropopause height.

ent areas with different characteristic tropopause heights.

South of the subtropical break line the height of the tropopause is mostly around 100 mb or even higher. Only in those parts where this southern breakline goes far towards the north (in this map over the Atlantic Ocean) does the height of the tropopause drop down to about 175 mb, which can still be considered an exceptionally high tropopause at these latitudes according to synoptic experience.

In the area between the two breaklines the tropopause height stays around 250 mb. It is rather astonishing that the height of the tropopause does not vary by more than 50 mb inspite of the fact that the stations are located in widely differing latitudes. This can best be seen over the Northern American Continent where the two break lines are far apart.

In the area north of the polar break line, the tropopause heights range between 300 and 400 mb and in certain locations even as

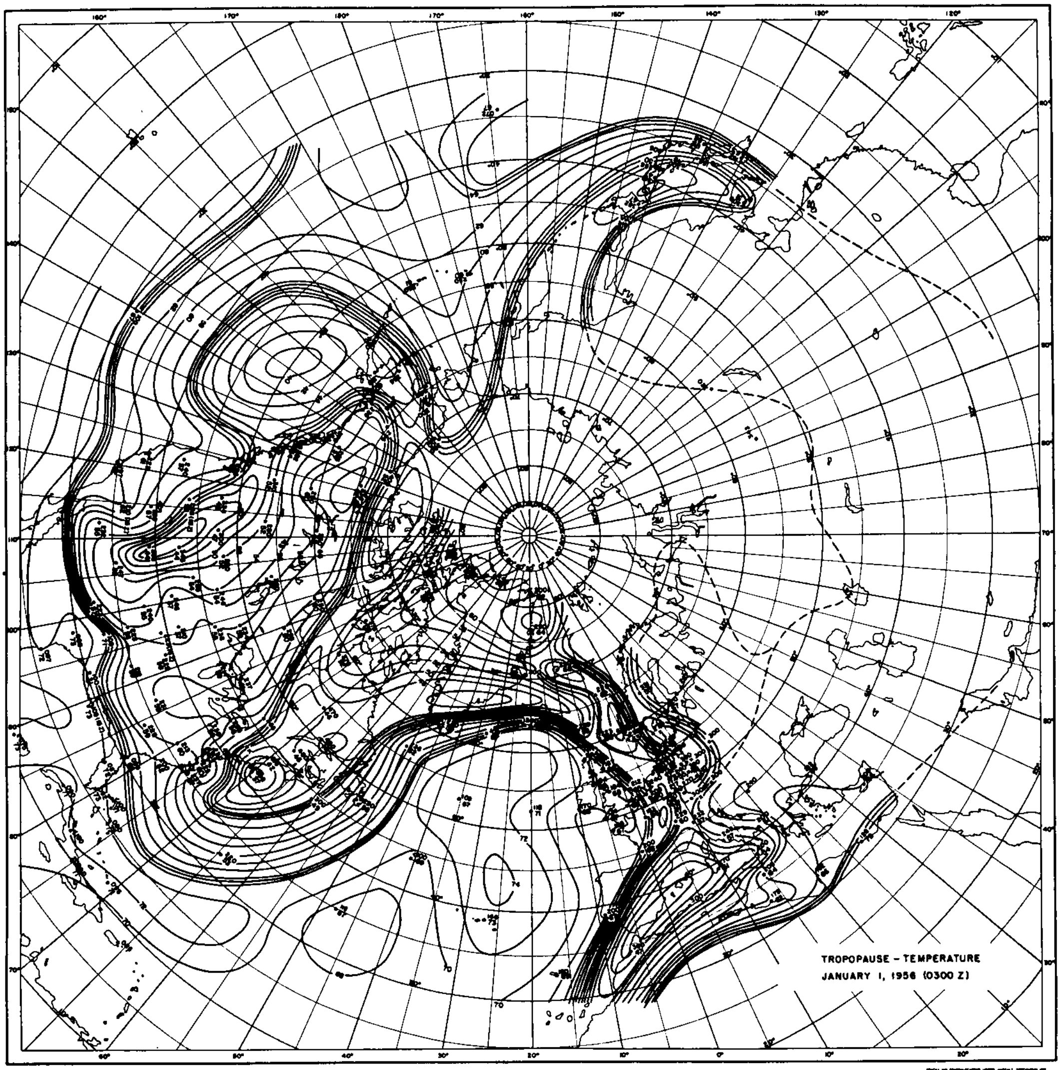


Fig. 3. Hemispheric map of tropopause temperature of January 1, 1956 (0300 Z). (For each station tropopause height in mb (three figures) and tropopause temperatures in C° (two figures) are plotted. Minus sign for temperatures omitted.) Note the striking similarity with Fig. 2.

low as 500 mb. This low tropopause height not only shows above cold polar vortices, but can also be found above cold polar outbreaks in relatively low latitudes; see e.g. the troughs off the East Coast of America, to the south of Alaska, over Northern Japan or even the weak trough east of the Rocky Mountains.

The tropopause map has the advantage to show in a clear manner the distribution of cold and warm tropospheric air masses, together with the location of both jets. One can say that the tropopause map gives an immediate three-dimensional picture of the state of the atmosphere. In this connection one should pay attention to a remarkable feature of this map, namely the location of the subtropical breakline over the Atlantic Ocean. Here the subtropical jet has been displaced far towards the north. The discussion of this feature will be left for a separate paper.

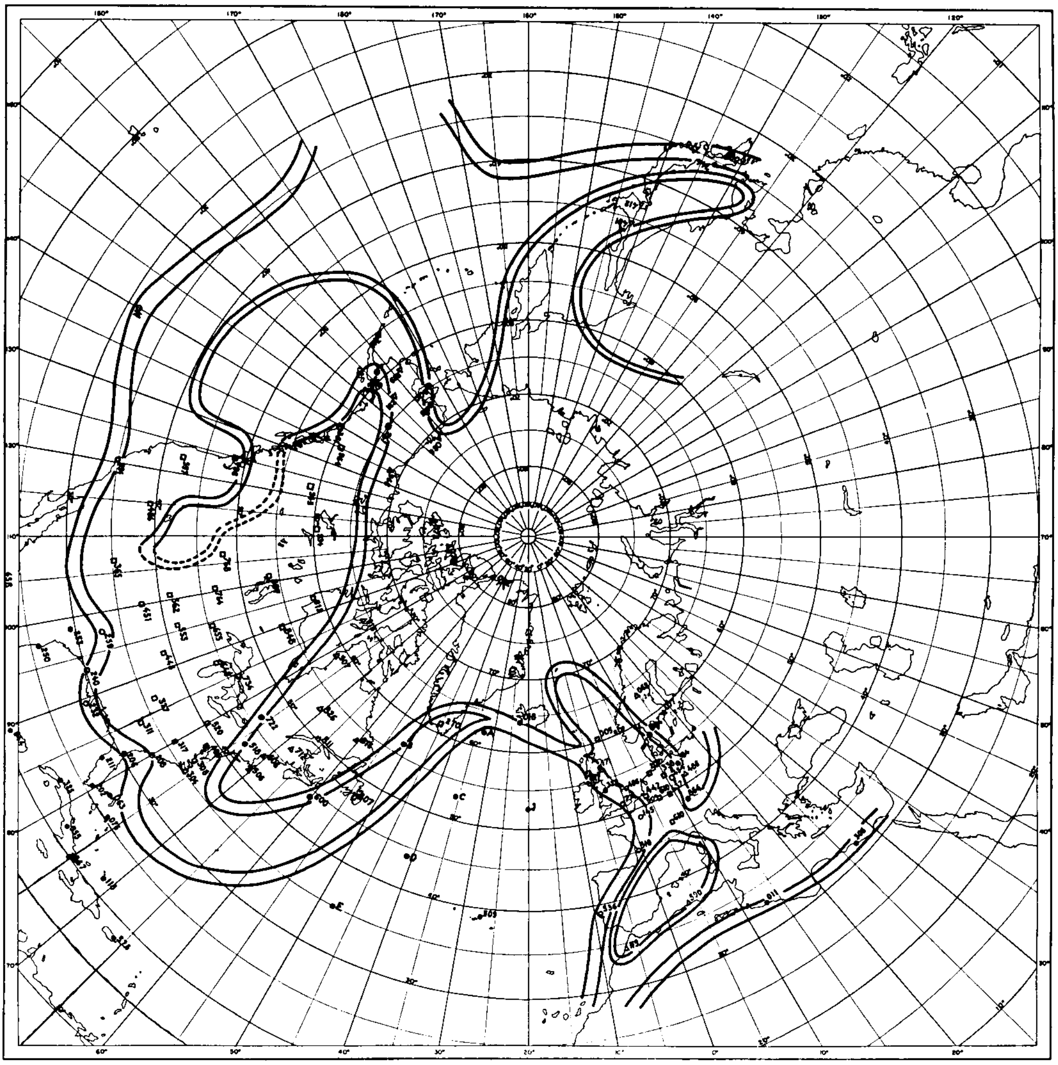


Fig. 4. The distribution of stations selected with respect to the tropopause breaklines. (The triangles (△) = stations north of the polar breakline, squares (□) = stations between the two breaklines, full circles (●) = stations south of the subtropical breakline. Circles with a cross (⊕) = stations inside polar breaklines, circles (○) = stations inside the subtropical breakline.)

3. The tropopause temperature map of January 1, 1956

Fig. 3 shows a similar analysis of the tropopause temperature. In comparing the pattern of this temperature field with the pattern of the tropopause height presented in Fig. 2, we notice a marked similarity. The breaklines in tropopause height and strong concentrations in the distribution of the tropopause temperature agree closly in location. The tropopause temperatures south of the southern breakline remain almost constant between −67 and −74° C. The same is true for the middle area between the two break lines where the tropopause temperature ranges between −56 and −60° C. North of the northern breakline the tropopause temperatures are mostly higher than −50° C and in deep depressions of tropopause height (e.g. at the American East Coast) may be as high as −37° C. This kind of temperature analysis offers a rather clear distinction between three very different parts of the northern hemisphere which are separated by the main wind belts or, what is the same, by the breaklines in tropopause height or by strong bands with rapid change in the tropopause temperature. With the exception of the very northern latitudes (75 to 90° N) the close relation between tropopause height and tropopause temperature seems to be almost perfectly fulfilled in the sense that an increase of height goes parallel with a decrease in temperature or vice versa (compensation principle).

4. The presentation of different groups of soundings

The threefold structure in the tropopause heigth mentioned above will now be shown by presenting different series of soundings selected according to their location with respect to both breaklines. Fig. 4 shows the distribution of the stations selected. The stations are divided into five groups:

a) Stations north of the polar breakline (polar group of soundings)

b) Stations between the two breaklines (middle group of soundings)

c) Stations south of the subtropical breakline (subtropical group of soundings)

d) Stations close to or in the polar breakline (soundings through polarfront jet)

e) Stations close to or in the subtropical breakline (soundings through subtropical jet)

a) *Polar group of soundings*

The polar soundings and their mean are shown in *Fig. 5*. In these soundings the tropopause usually is formed below the 300 mb level. The tropopause height is more changeable than for the two types b and c discussed later. In some cases (near the center of polar vortices and inside deep troughs) the tropopause is lower than 400 mb, sometimes even below 500 mb (see e.g. No. 3, 15 and 16, Mould Bay, Portland and Nantucket). In the lowest layers of the troposphere a nearly isothermal structure or strong surface inversion is found. The higher tropospheric layers possess a nearly uniform lapse rate and in the stratosphere an almost constant temperature with height or even a slight decrease (above 200 mb) is observed. The total structure (troposphere plus stratosphere) is similar in almost all the soundings. This typical form of the polar soundings is best seen in the mean sounding on the right side of Fig. 5. *Table I* presents vertical lapse rates of the mean polar sounding.

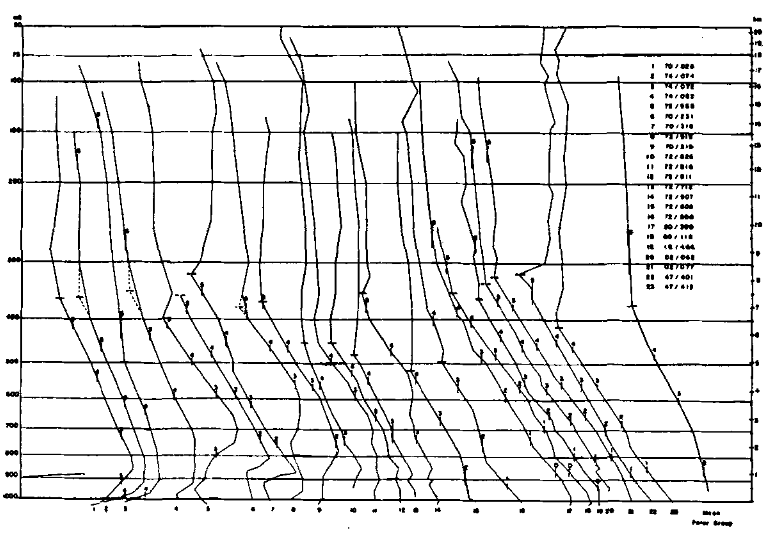


Fig. 5. The vertical temperature structure of soundings north of the polar breakline (polar group). Note the location of the tropopause below 300 mb. The — 10°, — 20°, — 30° C a.s.o. are indicated by 1, 2, 3 resp. Mean temperature distribution of these soundings is given on the right side.

Table I (hundredth of °C/100 m)

layer (mb)														
from	940	920	900	880	860	840	820	800	780	760	740	720		940
to	920	900	880	860	840	820	800	780	760	740	720	700		700
	22	26	14	22	18	18	24	22	24	35	38	39	Mean	25

layer (mb)														
from	700	680	660	640	620	600	580	560	540	520	500	480		
to	680	660	640	620	600	580	560	540	520	500	480	460		
	41	61	65	55	67	59	81	71	78	70	58	58		
from	460	440	420	400	380									700
to	440	420	400	380	360									360
	40	55	54	35	39								Mean	61

layer (mb)															
from	360	340	320	300	280	260	240	220	200	180	160	140	120		360
to	340	320	300	280	260	240	220	200	180	160	140	120	100		100
	00	05	10	05	08	04	08	02	01	08	10	01	00	Mean	05

From Table I one may see that the lower polar troposphere up to 700 mb is rather stable (mean lapse rate − 0.25° C/100 m) while the upper troposphere tends towards a more unstable stratification (mean lapse rate − 0.6° C/100 m, sometimes − 0.7 to − 0.8). The total mean tropospheric lapse rate is − 0.46°/100 m. In the polar stratosphere almost isothermal conditions are present (mean lapse rate − 0.046°/100 m). The mean tropopause height is 370 mb (approx. 8 km) and the tropopause temperature is − 49° C.

b) *Middle group of soundings*

Fig. 6 a, b shows all the soundings from stations situated between the two breaklines together with their mean. These soundings in general look rather different in their vertical structure from the ones mentioned above. The lowest parts of these soundings, approximately up to 850 mb, vary considerably from one sounding to another. Often strong surface inversions are observed which partly are low level polarfront intersections. The higher tropospheric layers up to the tropopause show a surprisingly uniform vertical temperature distribution. The tropopause is found at about 240 mb and in no case seems to be above 200 or below 300 mb. At the tropopause the nearly constant vertical lapse rate of the higher troposphere changes to a more or less constant temperature with height in the stratosphere. However in the higher stratospheric layers (from 150 mb upwards) the temperatures are mostly − 60° C and lower. In this group of soundings only those somewhat closer to the subtropical breakline show a small inversion just above the main tropopause. Here also slight indications of an additional rather high tropopause above 100 mb

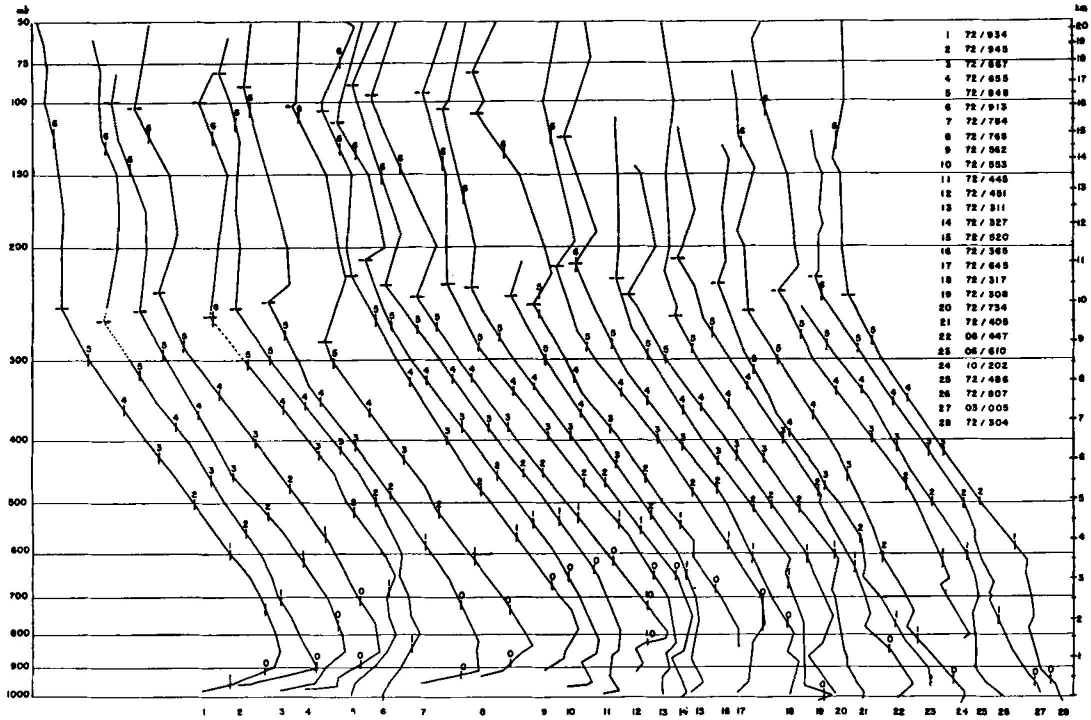
Table II (hundredth of °C/100 m)

layer (mb)											
from	980	960	940	920	900	880	860	840	840		980
to	960	940	920	900	880	860	840	820	800		860
	00	00	00	00	00	00	00	12	16	Mean	14

layer (mb)													
from	800	780	760	740	720	700	680	660	640	620	600		800
to	780	760	740	720	700	680	660	640	620	600	580		580
	19	40	40	40	55	75	76	40	70	48	52	Mean	52

layer (mb)																			
from	580	560	540	520	500	480	460	440	420	400	380	360	340	320	300	280	260		580
to	560	540	520	500	480	460	440	420	400	380	360	340	320	300	280	260	240		240
	72	78	70	73	69	63	73	80	86	83	73	85	75	76	61	62	40	Mean	72

layer (mb)												
from	240	220	200	180	160	140	120	100	80	60		240
to	220	200	180	160	140	120	100	80	60	50		50
	+ 18	+ 11	00	15	24	19	16	01	+ 06	+ 03	Mean	12



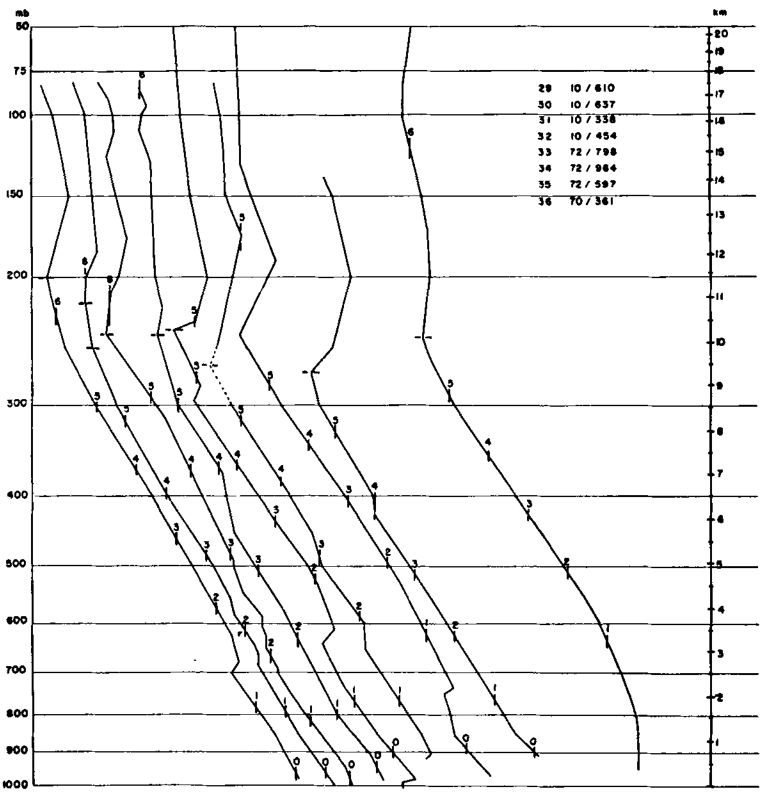


Fig. 6. The vertical temperature structure of soundings between the two tropopause breaklines (middle group). Note the location of the main tropopause between 200 and 300 mb. The —10°, —20°, —30° C a.s.o. are indicated by 1, 2, 3 resp. Mean temperature distribution of these soundings is given on the right side.

can be noticed (e.g. No. 7, 9, 10, 11, 12, 16; Bismark, North Platte, Omaha, Columbia, Dodge City, Albuquerque).

Table II presents vertical lapse rates for different height intervals of the mean sounding of this group.

The lowest layers show rather variable conditions and the mean lapse rate of −0.14° C/100 m is only a result of the averaging process. Above 800 mb the lapse rate of the mean middle sounding increases with height up to about 340 mb and decreases slightly until the tropopause is reached (240 mb). A total mean lapse rate of the troposphere is −0.64°/100 m. The tropopause temperature is −56° C. Even in the mean sounding a slight inversion appears above the tropopause and from 170 mb upwards the temperature decreases only very little with height (−0.12° C/100 m) up to 90 mb, where a secondary tropopause level can be found. From there on the temperature remains nearly constant.

c) *Subtropical group of soundings*

Fig. 7 shows all the soundings from stations south of the subtropical jet, together with their mean sounding. These soundings possess again a rather similar vertical temperature structure. Even in the lower layers the differences in temperature are rather small. The 0° C level is around 620 mb (approx. 4.0 km). The tropopause appears in all soundings at rather high altitudes (near the 100 mb level). The vertical lapse rate seems to be quite uniform in the whole troposphere and at the tropopause level temperatures of −70° C or lower are observed. A sharp break in lapse rate appears at the tropopause and from there on the temperature increases with height up to 50 mb. At 50 mb the observed temperatures are mostly around −60° C. There seems to be no indication of a constant temperature with height in the stratosphere, at least not in the layer between 100 and 50 mb. Above 50 mb the observational evidence is rather poor, therefore nothing conclusive can be said about it. A study of the mean sounding shows the above described structure in a clear manner. Table III presents vertical lapse rates for different layers of this mean sounding.

In the lower troposphere (1,000—600 mb) where the temperature varies more from sounding to sounding, the mean vertical lapse rate is −0.46° C/100 m and from there on a rather constant lapse rate of −0.73° C/100 m extends upwards to 250 mb. At this level the lapse rate changes a little and the mean value from 250 mb to the tropopause is about the same as in the lowest layer (−0.41° C/100 m). In the subtropical stratosphere the mean

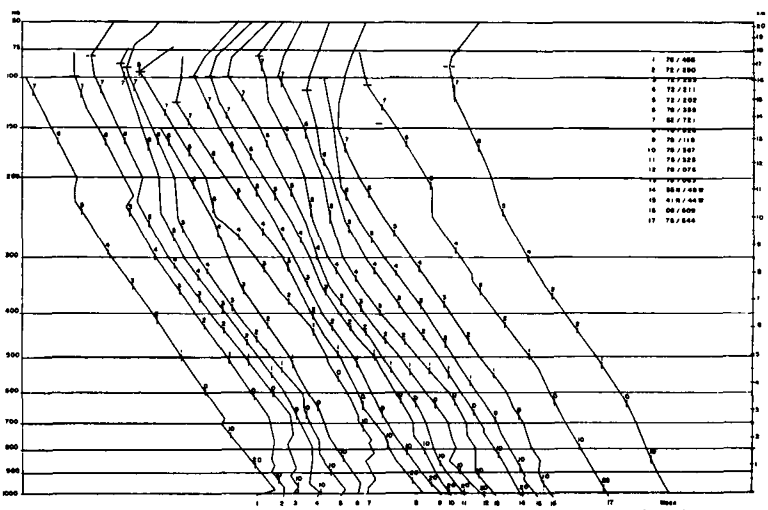


Fig. 7. The vertical temperature structure of soundings south of the subtropical breakline (subtropical group). Note the high level tropopause (above 150 mb). Location of —10°, —20°, —30° C a.s.o. are indicated by 1, 2, 3 resp. Mean temperature distribution of these soundings is given on the right side.

Table III (hundreth of °C/100 m)

layer (mb) from	980	960	940	920	900	880	860	840	820	800	780	760	740	720
to	960	940	920	000	880	860	840	820	800	780	760	740	720	700
	32	48	40	50	50	44	50	30	40	30	41	50	32	55

layer (mb) from	700	680	660	640	620	600	980
to	680	660	640	620	600	580	580
	43	48	56	52	56	72	Mean 46

layer (mb) from	580	560	540	520	500	480	460	440	420	400	380	360	340	320	300	280	260	580
to	560	540	520	500	480	460	440	420	400	380	360	340	320	300	280	260	240	240
	57	72	73	67	87	66	100	71	81	76	69	72	73	58	82	58	73	Mean 73

layer (mb) from	240	220	200	180	160	140	120	240
to	220	200	180	160	140	120	100	100
	47	39	41	60	46	44	10	Mean 41

layer (mb) from	100	90	80	70	60	100
to	80	80	70	60	50	50
	17 + 13 + 50 + 33 + 30					Mean 27

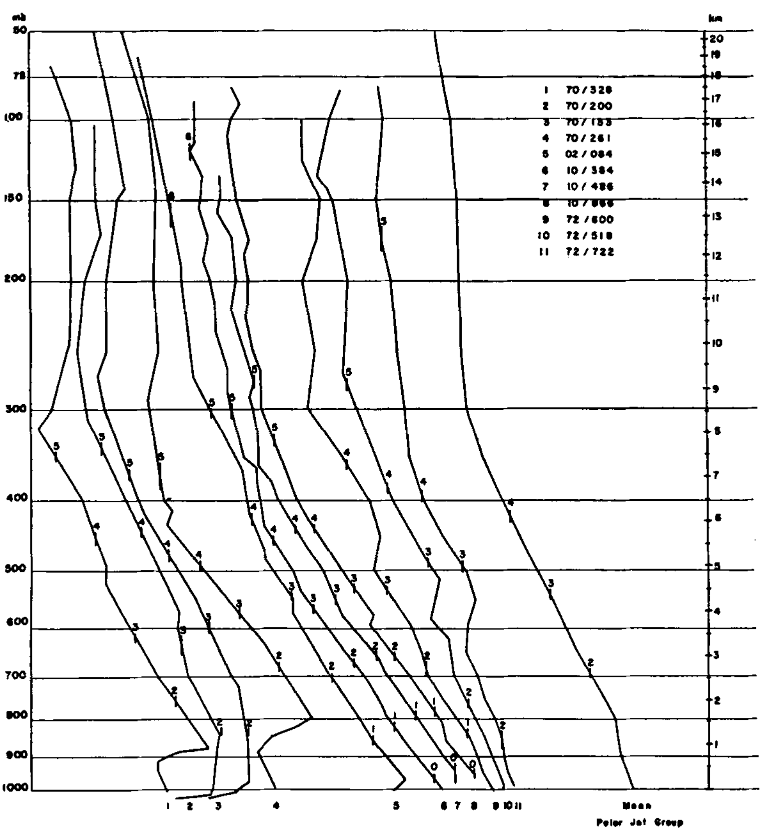


Fig. 8. The vertical temperature structure of soundings inside the polar breakline. The tropopause is not well defined and the temperature continues to decrease upward. The mean of these soundings is presented on the right side of the figure. The — 10°, — 20°, — 30° C a.s.o. are indicated by 1, 2, 3.

vertical increase of temperature with height was computed to be +0.27° C/100 m. The mean tropopause is a little above 100 mb surface (exactly at 90 mb) and the tropopause temperature is −72° C.

In the area south of the subtropical breakline a typical sounding shows therefore a more or less uniform temperature decrease in the whole troposphere, which extends upwards to higher altitudes (near to 100 mb). From there on a noticeable increase of temperature with height is observed. The tropopause level is in most cases well defined. It must be clearly understood that soundings farther south would show the tradewind inversion. In addition the tropopause would show up in still higher altitudes (between 90 and 60 mb) and the tropopause temperature would still decrease (in the equatorial region even as low as −80° C, see e.g. No. 7, Khartoum).

d) *Polar jet group of soundings*

In soundings which intersect the wind maximum connected with the polarfront (Fig. 8) no clear tropopause is observed. The temperature decreases mostly with height both in tropo- as well as in stratosphere. This can be seen in the soundings of Berlin, Munich, Dresden and Albany (No. 6, 8, 7 and 10). In some of these soundings slight tropopause indications may be seen. The form of these soundings and the breaks in lapse rat, depend very much on the exact location of the sounding with respect to the polar jet and on the steepness of the upper polarfront. One has to be rather careful not to mix the tropopause with breaks in lapse rate appearing when the sounding passes the polarfront layer. The mean sounding also shows the continuous temperature decrease with height. A broad layer with a slight change in lapse rate separates the troposphere from the stratosphere.

e) *Subtropical jet group of soundings*

In Fig. 9 soundings through the subtropical jet are presented. In these soundings it is also difficult to select a single tropopause. But contrary to the case of polar jet soundings, two different tropopause levels are generally present. From these, the lower one is formed around 200 mb level or a little above, while the higher one shows up at about 100 mb. This twofold tropopause structure can clearly be seen in the mean sounding. Immediately after passing the lower tropopause, a frontlike temperature inversion can be noticed in most cases. This lower tropopause seems to be closely related to the level of highest wind speed of the subtropical jet. Above this inversion the temperature falls off again sharply

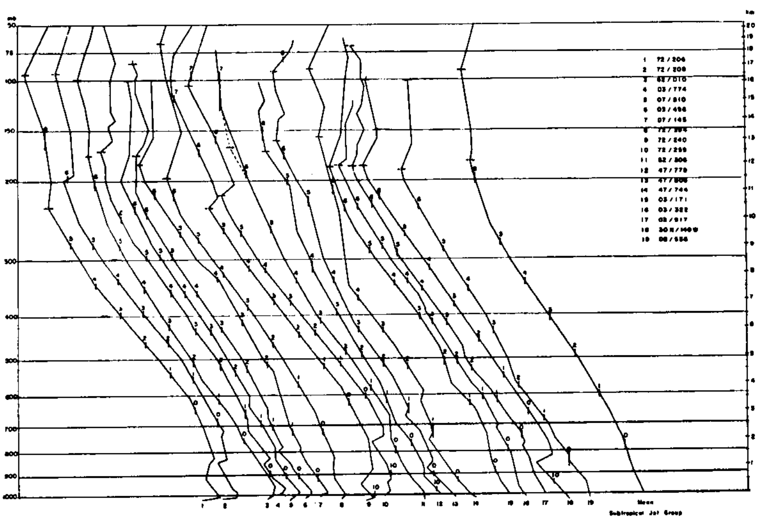


Fig. 9. The vertical temperature structure of soundings inside the subtropical breakline. Note the double tropopause level. The —10, —20, —30° C a.s.o. are indicated by 1, 2, 3. The mean of these soundings is given on the right side of the figure.

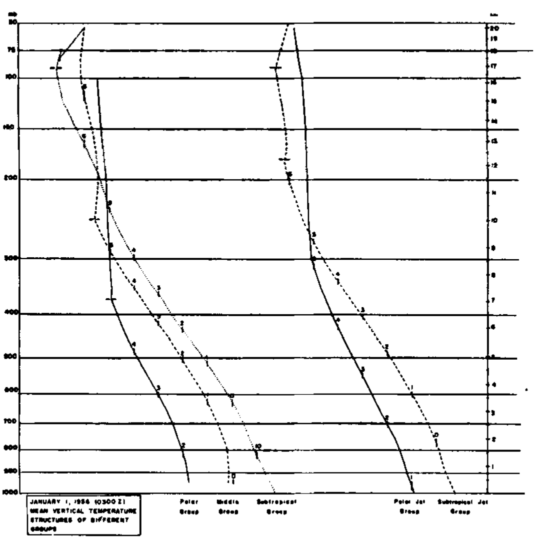


Fig. 10. Mean vertical temperature distribution fo the five different groups. The —10, —20, —30° C a.s.o. are indicated by 1, 2, 3.

and at the higher tropopause this decrease changes abruptly to an increase with height. Here also it depends critically on the exact location of the sounding with respect to the subtropical jet maximum whether the lower or the higher tropopause is dominating.

5. Comparison of the mean soundings

Fig. 10 presents the five mean soundings side by side. From this picture it is rather obvious that besides the strong baroclinicity in the troposphere between polar and middle soundings concentrated mainly in the polarfront zone an equally important baroclinicity is present in the stratosphere between middle and subtropical group, except that the horizontal temperature gradient is reversed. However, the stratospheric differences in temperature between polar and middle group are rather small. For a circulation type such as that of January 1, 1956, where the subtropical jet

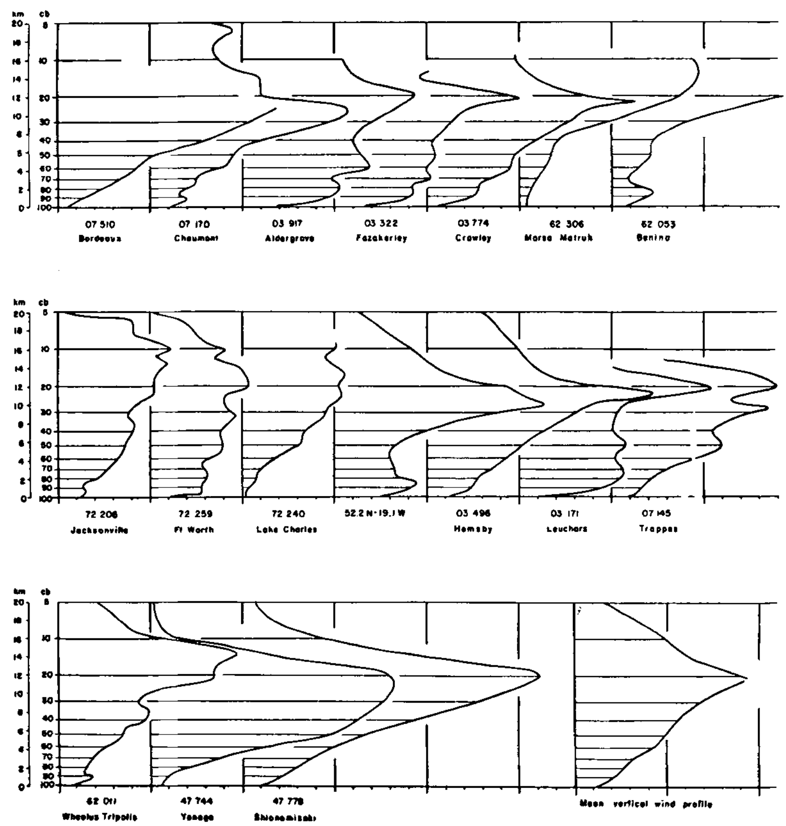


Fig. 11. Vertical wind profiles of January 1, 1956, from stations close to the subtropical tropopause breakline. The mean vertical wind profile is presented on the right side of the lowest row. Each small interval on the abscissa indicates 10 kts and the main vertical lines intervals of 50 kts.

remains mainly near latitude circle 30° N and the polar jet is mostly far apart the two baroclinic zones are also well separated. When the subtropical system moves northward, as e.g. over the Atlantic Ocean, then the tropospheric and the stratospheric baroclinicity are nearly superimposed. In this case the middle part disappears and the whole baroclinicity exists between subtropical and polar group in tropo- and stratosphere, but in the stratosphere in the reversed sense.

6. Vertical wind profiles of subtropical jet region

In the foregoing discussion it has been mentioned that the obvious breaks in tropopause height are closely related to the main wind belts. To show this more clearly the vertical wind profiles of stations close to, or in, the southern breakline of the tropopause (group e) are presented in Fig. 11. From these vertical profiles it is rather evident that the subtropical breakline in tropopause height is closely related to the subtropical jet, which in all of these profiles appears around the 200 mb level. In some of these examples a broad wind maximum can be noticed (Jacksonville, Ft. Worth and Lake Charles), that is when the sounding did not hit the jet center. There are also some examples of extremely sharp wind maxima in the vertical, indicating that the sounding met the center (e.g. Crawley, Liverpool (Fazakerley), Hemsby, Shionomisaki a.o.). The vertical wind profiles of Liverpool and Crawley are rather beautiful examples of a well defined jet restricted to a layer of a small vertical extent of about 50 mb (1.5 km). There exists a strong vertical wind shear above and below the jet center.

By making a mean profile from these 20 stations, the phenomenon of the subtropical jet in its hemispheric extent is well shown. That this jet phenomenon is not connected with the polarfront can be seen from the temperature distributions presented in Fig. 9.

It was not possible to present a similar wind profile for the polar breakline of tropopause height, as stations over Canada did not have good enough wind information and over the Atlantic the two jet belts were so close together that both phenomena showed up in vertical profiles.

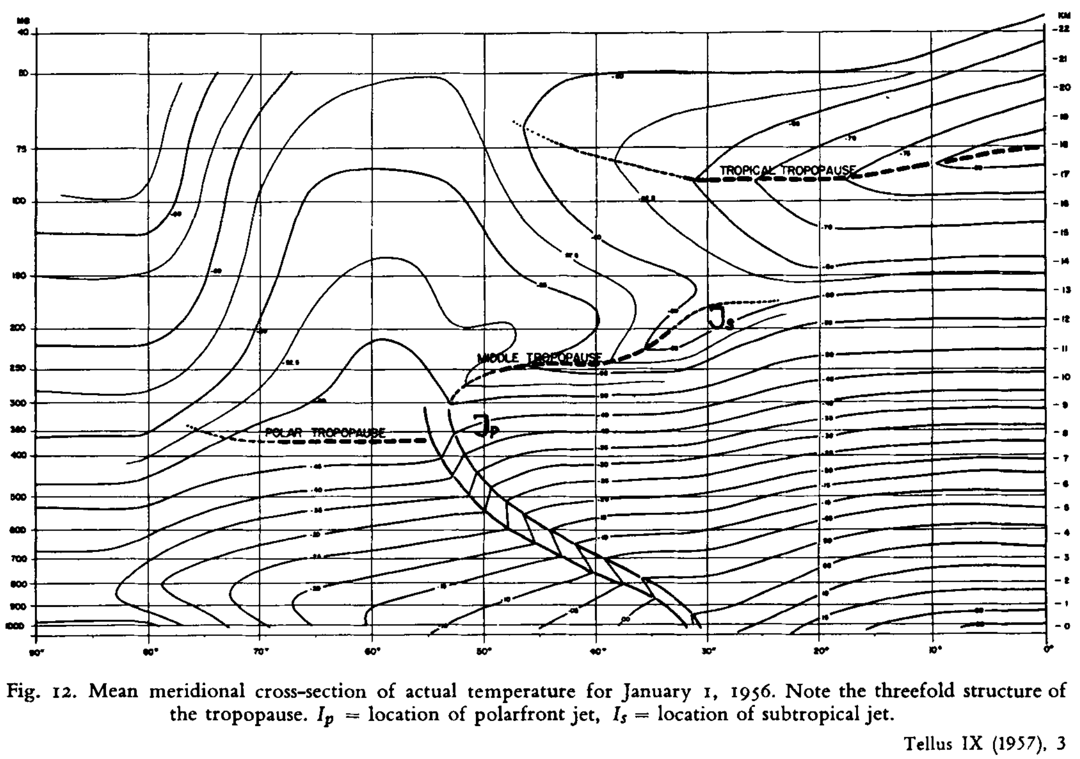


Fig. 12. Mean meridional cross-section of actual temperature for January 1, 1956. Note the threefold structure of the tropopause. I_p = location of polarfront jet, I_s = location of subtropical jet.

7. Summary of the foregoing discussion and presentation of a mean meridional cross-section

In Fig. 12 a mean meridional cross-section based on the mean values of temperature obtained above is presented. The purpose of this figure is to give the reader a general picture of the important features of the temperature field of the atmosphere in meridional direction. The threefold structure of the tropopause can easily be seen.

The foregoing discussion summarized in Fig. 12 divides the atmosphere from the polar to the tropical region into three widely differing parts represented by their mean soundings. Each part has its own typical vertical temperature structure in troposphere and stratosphere together with a characteristic tropopause height.

The polar and the middle part are separated in the troposphere by the polarfront, which extends upwards to about 300 mb. There exist a definite break in the tropopause height related to the polarfront jet (polar breakline in tropopause height; mostly between 250 and 350 mb). As mentioned before the strongest baroclinicity of the troposphere is concentrated in the inclined polar frontal zone. The tropospheric meridional temperature structure of the middle part can be considered almost barotropic. This is true especially for the upper troposphere.

The middle and the subtropical, tropical part resp., are not separated by any frontal surface in the troposphere. However, there exists a small baroclinicity between the almost quasibarotropic stratification of the middle and subtropical troposphere. This is indicated by the inclination of the isotherms in Fig. 12 around lat. 25—30° N. On top of this weak baroclinic zone another break in the tropopause is present (subtropical breakline in tropopause height; mostly between 240 and 100 mb). The vertical extent of this breakline is much larger than that of the polar breakline. The middle tropopause seems to continue southward and increases its height to about 180 mb. The subtropical jet is located in the mean just beneath this continued part of the middle tropopause. This is why the soundings through the subtropical jet indicated in all cases a lower tropopause as well as the higher subtropical one. The subtropical tropopause has an average height of about 90 mb and seems to rise towards the equator. A close study of the middle soundings indicates that the subtropical tropopause continues also towards north, increases in height and gradually disappears.

So far we have not mentioned anything about the temperature field in the stratosphere. A study of the Fig. 12 shows that the stratospheric temperature difference between the polar and the middle part is not very pronounced. However, this difference becomes quite noticeable between the stratosphere of the middle part and the upper subtropical troposphere. In ordinary cases when the two main westwind maxima are separated by the middle part the stratospheric meridional temperature gradient is not very pronounced. But whenever the subtropical system is displaced northward and the middle part disappears the total meridional temperature difference of the stratosphere concentrates in a frontlike zone above the polarfront but with an opposite inclination.

From this discussion we may now easily understand why a hemispheric presentation of tropopause height as well as tropopause temperature makes it possible to visualise the characteristic features of the three dimensional structure of the atmosphere. The study of the atmospheric field of temperature by means of certain isobaric levels can lead to serious misinterpretations. It is also rather difficult to draw any conclusion in this way.

In this discussion we have so far excluded the area from about 80 to 90° N (inner polar cap). This region is affected by different factors such as advection in different layers and from different directions or radiational influences. Here no representative mean state can be found. This does not mean that we underestimate the importance of this part of the atmosphere.

Fig. 13 presents the meridional distribution of potential temperature of the section shown in Fig. 12. In the troposphere north of the polarfront the isentropic surfaces rise towards the pole with an almost constant inclination. The concentration of these surfaces starting at the surface around lat. 65° and continuing towards the pole up to a height of about 650 mb is an indication of the so called arctic front. The strongest concentration can be seen inside

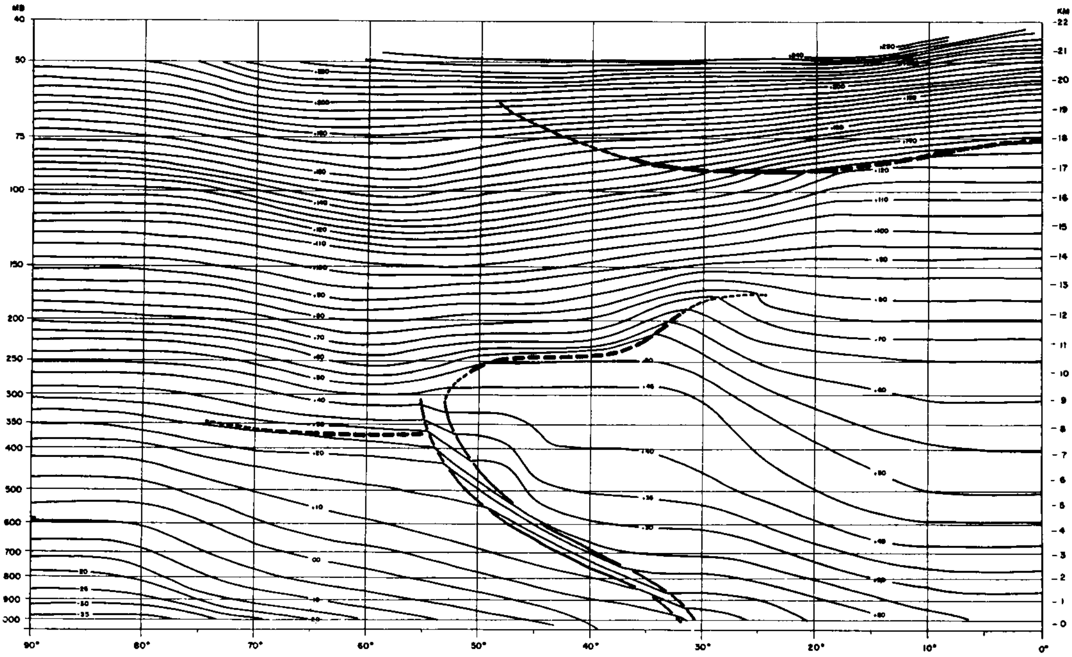


Fig. 13. Mean meridional cross-section of potential temperature for January 1, 1956.

the boundaries of the polarfront. The sharp slope of the isentropes immediately south of the polar jet (about lat. 45°) seems to be closely related to the existence of the jet. Between 45 and 30° N the isentropic levels are almost horizontal. This is an indication of the quasibarotropic state of the middle part of the atmosphere described before. From 30° southward to about 20° N a further downward slope of the isentropes indicates the difference between middle and subtropical air. Further south the atmosphere is again quasi barotropic. Here the concentration of the isentropes especially in the upper troposphere has a close relation to the existence of subtropical jet near 200 mb.

In the upper troposphere of the tropical region between the equator and 20° N the stratification is again barotropic. Above the tropical tropopause (tropical stratosphere) and in the middle stratosphere (from about 20° N) the isentropes slope downwards until about 65° N. From there on towards the pole they incline upwards. In the space where the middle tropopause rises and gradually disappears (northern side of subtropical jet) a frontlike concentration of the isentropes can be seen. Whenever the subtropical jet moves far northward and comes close to the polar jet,

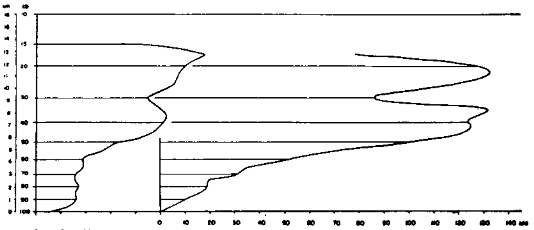


Fig. 14. Examples of complicated double jet structure in the vertical wind profiles of Keflavik (Iceland) and Narsarssuak (Greenland).

this stratospheric frontal slope becomes more pronounced and may be interpreted as a stratospheric continuation of the polarfront. In such cases the two jet maxima approach and nearly superimpose, resulting in a double wind maximum in the vertical wind fields. Fig. 14 shows an example of such a double jet over southern Greenland and Iceland, where the two jets are close to each other (see also Figs. 2 and 3).

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