NORSK POLARINSTITUTT
SKRIFTER NR. 155

DEN NORSKE ANTARKTISEKSPEDISJONEN, 1956-60
SCIENTIFIC RESULTS NO. 11

BJØRN GEIRR HARSSON

The 2nd tropopause,
a statistical and physical study

NORSK POLARINSTITUTT
OSLO 1971

DET KONGELIGE DEPARTEMENT FOR INDUSTRI OG HÅNDVERK

NORSK POLARINSTITUTT

Middelthuns gate 29, Oslo 3, *Norway*

SALG AV BØKER

Bøkene selges gjennom bokhandlere, eller bestilles direkte fra:

SALE OF BOOKS

The books are sold through bookshops, or may be ordered directly from:

UNIVERSITETSFORLAGET

Postboks 307	*16 Pall Mall*	*P.O. Box 142*
Blindern, Oslo 3	*London SW 1*	*Boston, Mass. 02113*
Norway	*England*	*USA*

Publikasjonsliste, som også omfatter land- og sjøkart, kan sendes på anmodning.

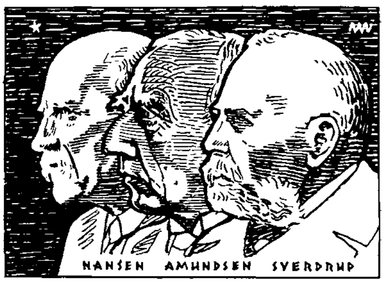
List of publication, including maps and charts, may be sent on request.

NORSK POLARINSTITUTT
SKRIFTER NR. 155

DEN NORSKE ANTARKTISEKSPEDISJONEN, 1956–60
SCIENTIFIC RESULTS NO. 11

BJØRN GEIRR HARSSON

The 2nd tropopause,
a statistical and physical study



NORSK POLARINSTITUTT
OSLO 1971

Manuscript received January 1971

Printed August 1971

Contents

Summary

Some comments are made on the definition of the 2nd tropopause. An estimate of the observational errors shows that the observed changes of the lapse rate associated with the 2nd tropopause are real.

Data from seven radiosonde stations are used, two in Antarctica, three in Norway, and two in the Atlantic Ocean. More than 4200 ascents in the course of five winters have been investigated. At all stations the 2nd tropopause is found to occur more frequently during the day than during the night. For five stations this difference is statistically significant. The material available does not show an interrelation between the presence of the 2nd tropopause at noon and at midnight.

For the layers between the standard pressure surfaces, 12 hourly mean vertical velocities are calculated for Norway Station (Antarctica) in the course of three winter-months. A relation is found between the vertical velocity in the layer where the 2nd tropopause occurs and that of the layer below. The mean vertical velocity is divided into two components: one depending on the local temperature change, and the other depending on advection. A relation is found between the latter component and the occurrence of the 2nd tropopause. Such a relation, if it exists, is less marked for the local component.

A computation indicates that absorption of short-wave radiation by ozone may give so great temperature changes that a 2nd tropopause may be formed. Ozonesonde data are studied in order to detect a possible connection between ozone concentration and the occurrence of the 2nd tropopause. Although the material for such a study is limited, it appears that during daytime there is a clear connection between the ozone concentration and the occurrence of a 2nd tropopause. During night-time, on the other hand, there seems to be no such connection.

Acknowledgements

I am grateful to Mr. J. NORDØ, Norwegian Meteorological Institute, for helpful discussions, which have formed much of the basis of the statistical part of the present work. My thanks are also due to Professor E. HESSTVEDT, University of Oslo, for his encouragement and for information about the properties of the ozone in the upper atmosphere. Last but not least I want to thank Mr. V. HISDAL, Norsk Polarinstitutt, for his kind interest in my work as well as for valuable criticisms, and for rewriting the manuscript for publication.

Table 1

Frequency distribution of the radiosonde ascents at Norway Station

GMT:	Jan. 00	Jan. 12	Feb. 00	Feb. 12	March 00	March 12	April 00	April 12	May 00	May 12	June 00	June 12
1957												
1958	29	31	28	28	29	30	29	29	30	31	30	30
1959	26	26	25	24	27	31	28	26	29	29	28	28
Total	55	57	53	52	56	61	57	55	59	60	58	58
00 and 12 GMT	112		105		117		112		119		116	

GMT:	July 00	July 12	Aug. 00	Aug. 12	Sept. 00	Sept. 12	Oct. 00	Oct. 12	Nov. 00	Nov. 12	Dec. 00	Dec. 12	Total 00	Total 12	Total 00 and 12
1957	29	30	31	31	30	30	30	31	30	30	24	30	174	182	356
1958	30	30	31	31	30	30	29	28	30	30	30	31	355	359	714
1959	28	30	28	28	29	30	30	31	30	30	30	31	338	344	682
Total	87	90	90	90	89	90	89	90	90	90	84	92	867	885	
00 and 12 GMT	177		180		179		179		180		176		1752		

1. Introduction

Norway Station (70°30′S, 02°32′W) was established in January 1957 as the Norwegian main-base in Antarctica during the International Geophysical Year 1957–1958. However, the work at the station continued until January 1960. In the meteorological sector ordinary surface observations were carried out every 3rd hour, and generally radiosonde ascents were made at 12 and 24 GMT every day. In addition, the different radiation components as well as the temperature and wind profiles in the lowest decameters were observed.

Radiosonde data from before 1 August 1957 are not used because of varying quality.

Table 1 gives the frequency distribution of ascents, specified for year, month and hour, while Fig. 1 shows the number of ascents which has passed the different pressure levels during the observation period.

It may be mentioned in this connection that it has not been necessary to differ between local- time and GMT-time at Norway Station.

In Fig. 2 are represented four ascents revealing typical 2nd tropopauses.

2. Historical notes

Since the term "tropopause" was introduced in 1902 as a designation of the boundary between the troposphere and the stratosphere, several theories have been put forward in order to explain this characteristic division of the atmosphere, discovered by Teisserence de Bort only a few years earlier. Some authors have stressed the importance of radiative processes, while others have tried to put forward an explanation on a thermodynamic basis.

Bjerknes and Palmén (1937) analysed some cases with a fairly complicated temperature structure in the layers about the tropopause. It appeared that the tropopause height might change rapidly with time (about 1 km in 12 hours). When in the tropopause layer several

Fig. 1. *Number of ascents which has passed the uppermost pressure levels.*

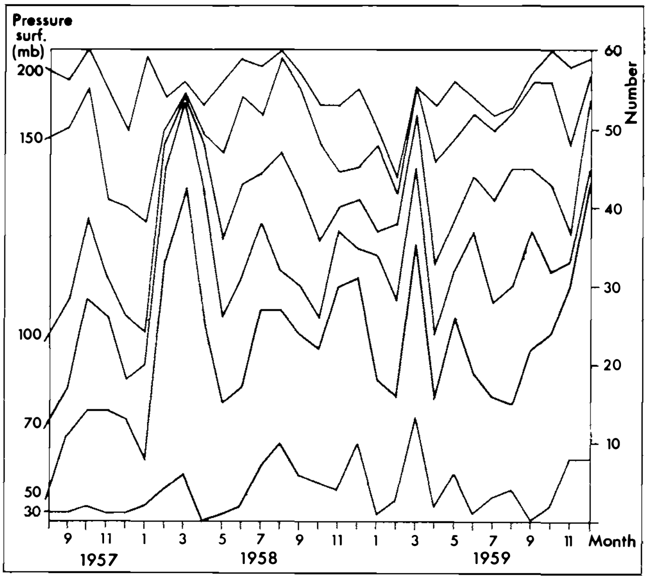
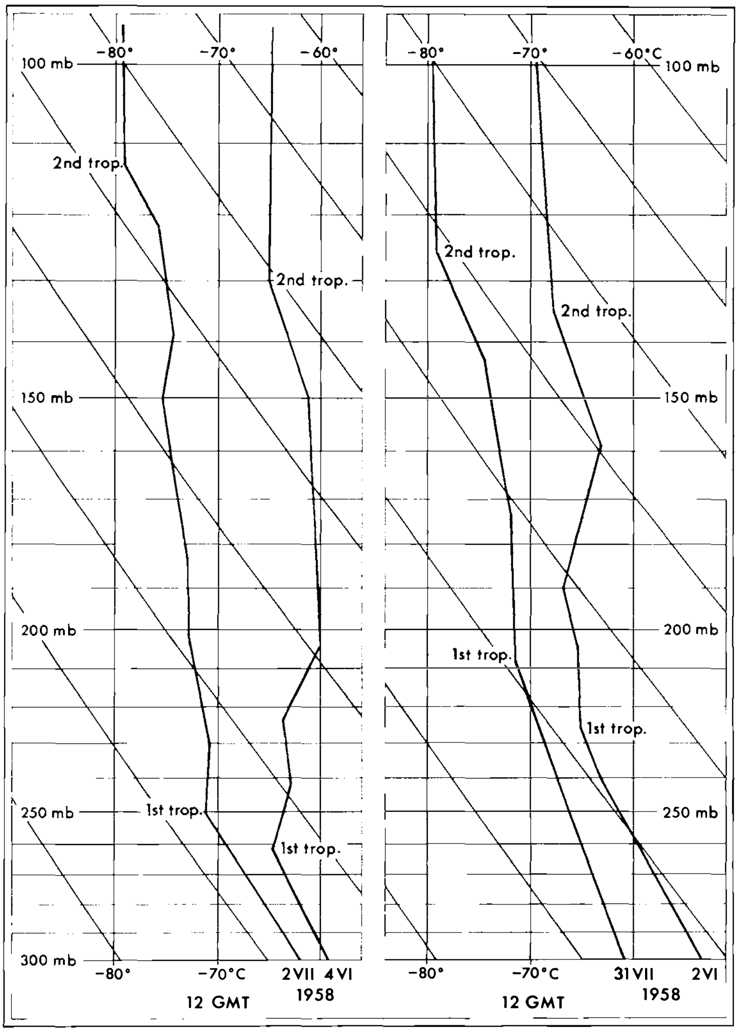


Fig. 2. *Four ascents showing typical 2nd tropopauses.*



successive changes in lapse rate were observed, they used the term "multiple tropopause" (double, triple, and so on). They also put forward a theory assuming a folding of the tropopause in connection with atmospheric fronts. A global tropopause model was introduced by PALMÉN and NAGLER (1948). In each hemisphere the tropopause was divided into three discontinuous, quasi-zonal fields, the discontinuities being associated with jet streams.

In his discussion of the radiosonde data from Maudheim, Antarctica, SCHUMACHER (1962) mentions the occurrence of "secondary tropopauses", without entering into a further analysis of its possible causes. ASTAPENKO (1960) uses the expression "multiple tropopause" of the same phenomenon, and he maintains that it is observed most frequently during the spring and during the autumn. This applies to some further specified Antarctic stations, and he suggests that the transition from a summer- to a winter-type of tropopause (or vice versa) is a deciding factor in this connection.

3. Definition

In synoptic analysis as well as in statistical investigations of the tropopause, the tropopause-definition has been a problem. Up to 1957 national criteria were used to find the tropopauses. Nevertheless, most nations seemed to apply the requirement that the lapse rate should be less than 2°C/km at the tropopause level. Other possible criteria, mentioned by COURT (1942), is the level of lowest temperature, or the level where the lapse rate starts to decrease. Judging by the literature, however, neither of these criteria seems to have been used to any great extent. During and after the second world war the radiosonde technique improved considerably, and a more exact definition was needed. In 1957 WMO sanctioned the following formulation (WEBB 1966):

1. The "first tropopause" is defined as the lowest level at which the lapse rate decreases to 2°C per kilometer or less, provided also the average lapse rate between this level and all higher levels within 2 kilometers does not exceed 2°C per kilometer.
2. If, above the first tropopause, the average lapse rate at any level and at all higher levels within one kilometer exceeds 3°C per kilometer, then a "second tropopause" is defined by the same criteria as the first tropopause. This tropopause may be either within or above the one kilometer layer.

In the present case the tropopause was determined in agreement with the WMO-definition. No upper limit was set. However, no tropopause was found higher than the 50 mb level. In an instruction published by The Norwegian Meteorological Institute (November 1961) it was decided that Norwegian radiosonde stations should never report a tropopause higher than the 90 mb level. This decision should be maintained until international agreement was achieved.

Even with these criteria and restrictions, however, it may often be difficult to decide whether a significant point above the ordinary tropopause should be indicated as a 2nd tropopause or not. It seems clear that the lapse rates given in the definition give rather arbitrary positions of the tropopauses. This applies especially to the winter season, when the transition from tropospheric to stratospheric air masses is least significant. If other lapse rates had been chosen, the tropopause might occur at other levels, and the number of 2nd tropopauses (3rd tropopauses and 4th tropopauses . . .) would be different.

In the present work a 2nd tropopause is considered as the result of disturbances in the lower part of the stratosphere, and the definition of the 2nd tropopause involves certain requirements as to the size of these disturbances.

4. Observation errors

Vaisala radiosondes of the type RS 11 were used during the whole observation period. The signals were recorded by means of a manual receiver. The observation errors might be due to imperfections in the following sources:

1. radiosonde instruments,
2. reception of radio signals,
3. calibration diagrams.

An analysis of these sources of error, on the basis of results and methods published by FINK (1960), HARRISON (1962), RAPP (1952), VAISALA (1953), and the "Vaisala News" (1960), leads to the following conclusions for the interval 250–50 mb:

a. As far as the lapse rate is concerned, an estimated "uncertainty" is found to be about $\pm 0.3°C$ for the two temperatures establishing the lapse rate.
b. The "uncertainty" of the temperature at an arbitrary level (between 250 mb and 50 mb) is about $\pm 0.5°C$, varying slightly during the day.
c. The "uncertainty" in pressure is about ± 2 mb.
d. The recordings of the humidity is less interesting because of a considerable instrument lag (about 15 min.).

It should be stressed that the changes in lapse rate that occur in connection with the registration of the 2nd tropopause (and possibly a 3rd and 4th tropopause etc.) cannot be attributed to observation uncertainties, but have to be considered as real.

The 1752 ascents from Norway Station were checked to see if the definition of the 2nd tropopause was satisfied. For the other radiosonde-stations used for comparison, the data were taken from journals, and it has not been possible to make a corresponding control. On the other hand, it is not likely that such a control would have brought about changes that would noticeably influence the conclusions in the statistical part of this work. On the basis of the data from Norway Station, it should be expected that displacements and omissions of the 2nd tropopause would occur unsystematically and rather seldom for the other stations too.

5. Statistical investigations

a. The difference between day- and night-frequencies at Norway Station

From Fig. 3 it appears that the number of observed 2nd tropopauses varies during the year, and a marked maximum occurs in the winter-months June–August. The diagram shows, moreover, that the 2nd tropopauses were observed more often during the day than during the night. An attempt to test if this difference is significant is based on the following suppositions:

1. On the basis of a radiosonde ascent it is always possible to decide whether a 2nd tropopause is present or not.
2. The result obtained from one ascent is independent of the result of the preceding one. (This point will be discussed later on.)

The following null hypothesis is put forward:

H_0: $p_t = q_t$ for every t,

where $t = 1,2,3,\ldots, N$ indicates the dates taken into account, p_t is the probability

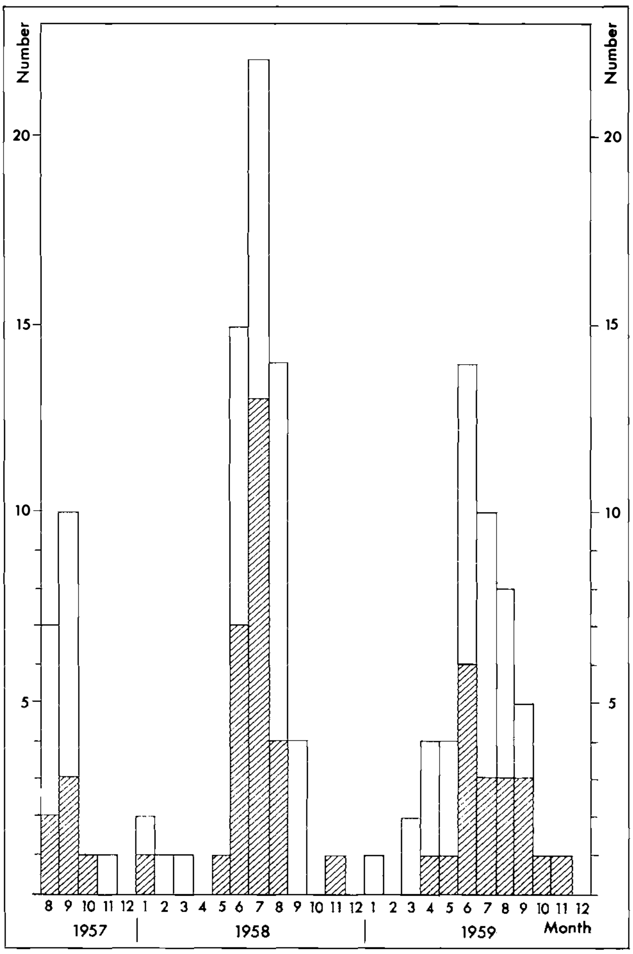


Fig. 3. *Number of observed 2nd tropopauses for each month. Line histograms: noon. Shaded histograms: midnight.*

of a 2nd tropopause for a noon-ascent on date t, and q_t is the corresponding probability for a midnight-ascent on date t.

The alternative to H_0 is assumed to be:

H: $p_t > q_t$ for one or more values of t.

The stochastic variables are:

X: the number of 2nd tropopauses in n noon-ascents.
Y: the number of 2nd tropopauses in m midnight-ascents.

We may either compare an ascent made at 12 GMT with one made at 24 GMT on date t, or we may say that the date t starts with the ascent made at 00 GMT and compare this with the ascent carried out at 12 GMT. Both methods will be used, starting with the comparison 12 GMT versus 24 GMT. For the sake of simplicity we choose $n = m = N$. In order that a date shall be included in N it is necessary that:

1. Two ascents have been made on that date, one at noon and one at midnight.
2. Both ascents have passed the 100 mb level. If a 2nd tropopause occurs lower than the 100 mb level in one ascent, this date is included in N if also the other ascent has passed the level at which the 2nd tropopause occurred.

Since the occurrence of 2nd tropopauses seems to be in particular a winter phenomenon, only the winter months April–September are considered.

On an arbitrary date t we have:

$$X_t = \begin{cases} 1 & \text{if a 2nd tropopause is present at 12 GMT,} \\ 0 & \text{if this is not the case,} \end{cases}$$

$$Y_t = \begin{cases} 1 & \text{if a 2nd tropopause is present at 24 GMT,} \\ 0 & \text{if this is not the case.} \end{cases}$$

The expectation and variance of X_t and Y_t are:

$EX_t = p_t$, var $X_t = EX_t^2 - (EX_t)^2 = p_t(1-p_t)$,
$EY_t = q_t$, var $Y_t = q_t(1-q_t)$.

For the difference we have:

$$X_t - Y_t = \begin{cases} 1 \\ -1 \\ 0 \end{cases}$$

where:

$Pr(X_t - Y_t = 1) = Pr\,(X_t = 1) \cdot Pr\,(Y_t = 0) = p_t(1-q_t)$, and correspondingly:
$Pr(X_t - Y_t = -1) = q_t(1-p_t)$

H_0 is rejected if Z_N, defined by

$$Z_N = \sum_{t=1}^{N} (X_t - Y_t) \qquad (1)$$

is greater than a chosen constant ε where ε indicates the significance level. The expectation of Z_N is:

$$EZ_N = \sum_{t=1}^{N} E(X_t - Y_t) = \sum_{t=1}^{N} (EX_t - EY_t) = \sum_{t=1}^{N} (p_t - q_t) \tag{2}$$

and the variance:

$$\text{var } Z_N = \sum_{t=1}^{N} \text{var } (X_t - Y_t) = \sum_{t=1}^{N} \text{var } X_t + \sum_{t=1}^{N} \text{var } Y_t \tag{3}$$

$$\text{var } Z_N = \sum_{t=1}^{N} [p_t(1-p_t) + q_t(1-q_t)] \tag{4}$$

The quantity:

$$W = \frac{Z_N - EZ_N}{\sqrt{\text{var } Z_N}} = \frac{Z_N - \sum_{t=1}^{N} (p_t - q_t)}{\sqrt{\sum_{t=1}^{N} [p_t(1-p_t) + q_t(1-q_t)]}} \tag{5}$$

is approximately normally distributed, N(0.1).

If H_0 is correct, i.e. $p_t = q_t$, Eq. (5) is reduced to:

$$W = \frac{Z_N}{\sqrt{2 \sum_{t=1}^{N} [p_t(1-p_t)]}} \tag{6}$$

The probability of rejecting H_0 is given by

$$\begin{aligned} Pr(Z_N > k_\varepsilon) &= Pr\left(\frac{Z_N}{\sqrt{2 \sum_{t=1}^{N} [p_t(1-p_t)]}} > \frac{k_\varepsilon}{\sqrt{2 \sum_{t=1}^{N} [p_t(1-p_t)]}} \right) \\ &= 1 - Pr\left(\frac{Z_N}{\sqrt{2 \sum_{t=1}^{N} [p_t(1-p_t)]}} \leq \frac{k_\varepsilon}{\sqrt{2 \sum_{t=1}^{N} [p_t(1-p_t)]}} \right) \\ &= 1 - G\left(\frac{k_\varepsilon}{\sqrt{2 \sum_{t=1}^{N} [p_t(1-p_t)]}} \right) = \varepsilon \end{aligned} \tag{7}$$

where G is the cumulative probability function of the normal distribution.

If $u_{1-\varepsilon}$ is the $(1-\varepsilon)$-quantile, we have:

$$k_\varepsilon = u_{1-\varepsilon} \sqrt{2 \sum_{t=1}^{N} [p_t(1-p_t)]} \tag{8}$$

Instead of trying to estimate p_t, we choose the value of p_t that makes $p_t(1-p_t)$

a maximum, i.e. $p_t = \frac{1}{2}$. The corresponding k_ε is bound to be equal or greater than the k_ε computed from the true value of p_t. With $p_t = \frac{1}{2}$ we have:

$$k_\varepsilon = u_{1-\varepsilon} \sqrt{\frac{N}{2}} \tag{9}$$

From Table 1A (in the Appendix) we find $N = 169$. Choosing $\varepsilon = 5\%$ this gives: $k_5 = 15.1$.

From Table 1A we further obtain:

$Z_{169} = 19$.

Consequently, $Z_N > k_5$ and H_0 is rejected. This means that $p_t > q_t$ for an arbitrary date t, or in other words: Radiosonde data from Norway Station indicate that the 2nd tropopause is more frequent at noon than at midnight. As will be evident, $k_5 = 15.1$ is the maximum value of k_5 for $N = 169$. If p_t had been estimated from the relative frequencies in the different months, $p_t(1 - p_t)$ would have varied between $\frac{1}{4}$ and $\frac{1}{8}$. The median value, $\frac{1}{5}$, would have given $k_5 = 13.6$, which gives an even stronger basis for rejecting H_0.

On p. 10 we assumed the result from one ascent to be independent of that of the preceding one. If this is not the case, Eq. (3) should be written:

$$\text{var } Z_N = \sum_{t=1}^{N} \text{var } X_t + \sum_{t=1}^{N} \text{var } Y_t - 2 \sum_{t=1}^{N} \text{cov } (X_t, Y_t) \tag{10}$$

Theoretically $\sum_{t=1}^{N} \text{cov } (X_t, Y_t)$ may be positive, zero or negative. However, the possibility of a negative value may be disregarded, since this would mean a tendency of two succeeding ascents to give opposite results, a tendency which would be most improbable from a physical point of view, and which there is no indication of in our observation material. Denoting the covariance term C, therefore, Eq. (8) may be written:

$$k_\varepsilon = u_{1-\varepsilon} \sqrt{2 \sum_{t=1}^{N} [p_t(1 - p_t)] - C} \tag{11}$$

where $C > 0$. Thus, the assumption of independence gives a stricter test than would the assumption of interdependence.

Hitherto, we have compared a day-ascent with the following night-ascent. It is natural to complete this investigation by making a corresponding comparison between a day-ascent and the preceding night-ascent. This latter comparison gives the following values:

$Z_{180} = 22$, $\qquad k_5 = 15.7 \ (N = 180)$

We still find $Z_N > k_5$ and the conclusion is unchanged: the 2nd tropopause is more frequent at noon than at midnight.

b. Diurnal frequency differences for other stations

In the following we will try to ascertain whether the results found for Norway Station is of a more general character. For this purpose we studied radiosonde data from Halley Bay (75°31′S, 26°36′W) for 1958, published by MAC DOWALL and BURTON (1962), and data from some Norwegian radiosonde stations and from two weather ships. For Halley Bay we found, as for Norway Station, a maximum occurrence of the 2nd tropopause in midwinter. Both ways of grouping the material, viz. 12 versus 24 GMT and 00 versus 12 GMT, gave $Z_N > k_5$, and consequently the conclusion is the same as for Norway Station. For the following stations: Bodø (67°17′N, 14°25′E), Ørland (63°42′N, 09°37′E), Gardermoen (60°12′N, 11°05′E), and the Weather Ships A (62°N, 32°W) and M (66°N, 02°E), the upper air data used here were those available at the Meteorological Institute in Oslo.

For each station the two daily ascents from between 445 and 913 days during the winter half-year (September–March) were considered. Tables 2 and 3 show the result of a comparison, as far as the 2nd tropopause is concerned, between the day- and the night-ascents. Applying our statistical test on these values, we obtain the result represented in Tables 2 and 3. The magnitude of k_ε is calculated for

Table 2

Significance test of the difference between the frequency of 2nd tropopauses at noon and at the following midnight. (The symbols are explained in the text.)

	Number of months	Z_N	N	k_ε for different significance levels 5%	2.5%	1%	$\frac{Z_N}{k_5}$	$Z_N - k_5$
Norway Station	12	19	169	15.1	18.0	21.4	1.26	3.9
Halley Bay	7	18	109	12.2	14.5	17.2	1.47	5.8
Weather Ship A	17	6	445	24.6	29.2	34.8	0.24	−18.6
Weather Ship M	40	40	900	35.0	41.6	49.4	1.14	5.0
Bodø	35	39	781	32.6	38.7	46.0	1.20	6.4
Ørland	35	41	875	34.5	40.9	48.7	1.19	6.5
Gardermoen	35	9	913	35.2	41.8	49.7	0.25	−26.2
Total	181	172	4192					

Table 3

Significance test of the difference between the frequency of 2nd tropopauses at midnight and at the following noon. (The symbols are explained in the text.)

	Number of months	Z_N	N	k_ε for different significance levels 5%	2.5%	1%	$\frac{Z_N}{k_5}$	$Z_N - k_5$
Norway Station	12	22	180	15.7	18.6	22.1	1.40	6.3
Halley Bay	7	16	117	12.6	15.0	17.8	1.27	3.4
Weather Ship A	17	12	445	24.6	29.2	34.8	0.49	−12.6
Weather Ship M	40	25	906	35.1	41.7	49.6	0.71	−11.1
Bodø	35	46	789	32.8	38.9	46.2	1.40	13.2
Ørland	35	38	879	34.6	41.0	48.9	1.10	3.4
Gardermoen	35	6	912	35.2	41.8	49.7	0.17	−29.2
Total	181	165	4228					

$\varepsilon = 5\%$, $\varepsilon = 2.5\%$, and $\varepsilon = 1\%$. We notice that $Z_N > 0$ for all stations, and for both ways of grouping the material. For the stations in the northern hemisphere, $Z_N > k_\varepsilon$ for Bodø and Ørland only. For Weather Ship M $Z_N > k_\varepsilon$ for 12 versus 24 GMT, while $Z_N < k_\varepsilon$ for 00 versus 12 GMT.

Even if the frequency differences are not significant in all cases, the fact that Z_N is positive for every station in the two tables strongly indicates that the 2nd tropopause is more frequent at noon than at midnight. If this result had been purely accidental, and a positive and a negative value of Z_N were equally probable, i. e.

$$\Pr(Z_N > 0) = \tfrac{1}{2},$$

the probability that $Z_N > 0$ for all seven stations in Tables 2 and 3, provided they are mutually independent, would not be greater than

$$(\tfrac{1}{2})^7 \text{ or } 0.78\%.$$

As is shown by Fig. 4 for the stations in the Northern hemisphere, the quantity Z_N/k_ε tends to increase with latitude. However, it is premature to say if this is a general feature. It should be worth while to investigate this point further by means of a greater observation material. As to the weather ships, the importance of differences in local time is for the present unclear. The two ships are located one to three hours after (west of) the land stations.

c. The connection between day- and night-observations

As pointed out in Section 5a it was, from a statistical point of view, not necessary to know whether a dependence between the occurrence of the 2nd tropopause in two following ascents did actually exist. Without taking any standpoint towards the physical part of the problem, the least favourable basis for the statistical test was chosen. However, if we want to elucidate the causal connection behind the earlier found difference between day- and night-frequencies, it may be of interest to investigate the question of dependency a bit further. Information on this point may give an idea of the duration of the conditions leading to the formation of a 2nd tropopause. We consider the n_m dates of each winter-month satisfying the criteria on p. 11. The index m indicates the month, but for practical reasons it is dropped in the following. For each date we may have:

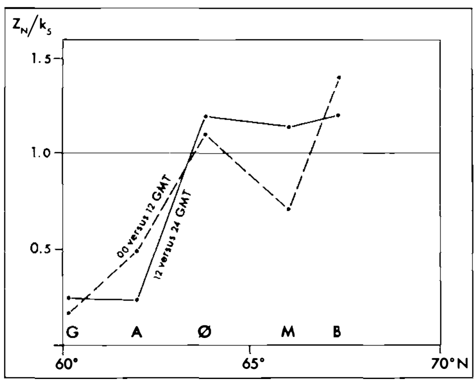


Fig. 4. *Variation of Z_N/k_5 with latitude.*
G: Gardermoen, A: Weather Ship A,
Ø: Ørland, M: Weather Ship M, B: Bodø.

AD_1: the 2nd tropopause is observed at noon, *or:*
AD_2: the 2nd tropopause is not observed at noon, *and:*
AN_1: the 2nd tropopause is observed at midnight, *or:*
AN_2: the 2nd tropopause is not observed at midnight.

For each date we get one of the four possible combinations [AD_i and AN_j], where $i=1$ or 2 and $j=1$ or 2. The probability of each of the four combinations is assumed to be the same for all n dates in the month. For the individual stations and months the frequencies can be set out in a table of the form:

Day	AD_1	AD_2	Total
Night			
AN_1	X_{11}	X_{12}	$X_{1\cdot}$
AN_2	X_{21}	X_{22}	$X_{2\cdot}$
Total	$X_{\cdot 1}$	$X_{\cdot 2}$	n

These data are given in Tables 1A to 7A (see Appendix), where:

X_{11} corresponds to	the number of	dates where	$X_t=Y_t=1$		$(Z_t=0)$
X_{12}	—	—	$X_t=0$ and $Y_t=1$		$(Z_t=-1)$
X_{21}	—	—	$X_t=1$ and $Y_t=0$		$(Z_t=1)$
X_{22}	—	—	$X_t=Y_t=0$		$(Z_t=0)$

Here X_{ij} is the observed quantity, while we do not know the probability p_{ij} of the corresponding event. When investigating the question of a possible dependency between AD_i and AN_j (the same date), our null hypothesis is:

$p_{ij}=p_{i\cdot}\, p_{\cdot j}$ for all i and j.

As estimators for $p_{i\cdot}$ and $p_{\cdot j}$ we use:

$$\hat{p}_{i\cdot}=\frac{1}{n}X_{i\cdot}=\frac{1}{n}\sum_{j=1}^{2}X_{ij} \tag{12}$$

$$\hat{p}_{\cdot j}=\frac{1}{n}X_{\cdot j}=\frac{1}{n}\sum_{i=1}^{2}X_{ij} \tag{13}$$

On the assumption that the null hypothesis is correct, the number of combinations [AD_i and AN_j] would be:

$$n\hat{p}_{ij}=n\frac{X_{i\cdot}}{n}\frac{X_{\cdot j}}{n}=\frac{1}{n}X_{i\cdot}\,X_{\cdot j} \tag{14}$$

and the quantity:

$$Q=\sum_{i,j}\frac{(X_{ij}-n\,\hat{p}_{ij})^2}{n\,\hat{p}_{ij}} \tag{15}$$

will approximately follow a chi-squared distribution with $[R-(s+t)]$ degrees of freedom, where:

$$R = \sum_{m=1}^{s} r_m, \quad r_m = i_{max} \cdot j_{max}$$

s = number of seasons

$t = s + i_{max} + j_{max} - 3$

Using Eq. (14) we get:

$$Q = \sum_{i,j} \frac{\left(X_{ij} - \frac{1}{n} X_{i.}\, X_{.j}\right)^2}{\frac{1}{n} X_{i.}\, X_{.j}} = n \sum_{i,j} \frac{X^2_{ij}}{X_{i.} X_{.j}} - n \quad (16)$$

The null hypothesis is rejected if $Q > c_{0.95}$, where $c_{0.95}$ is the 0.95-quantile in the chi-squared distribution with $[R-(s+t)]$ degrees of freedom. Because the number of seasons is not the same for all stations, the number of degrees of freedom will vary. For some stations there is even a change in the number of degrees of freedom from month to month due to a varying number of missing observations. Table 4 gives corresponding values of the number of seasons, the number of degrees of freedom and the 0.95-quantile.

Table 5 shows that of the 48 Q-values computed we find three cases only (Halley Bay in August and October, Weather Ship A in January) where $Q > c_{0.95}$.

Table 4

Corresponding values of the number of seasons, the number of degrees of freedom, and the 0.95-quantile of the chi-squared distribution

Number of seasons	Number of deg. of freed.	0.95-quantile
6	11	19.68
5	9	16.92
4	7	14.07
3	5	11.07
2	3	7.81
1	1	3.84

Table 5

The quotient $Q/C_{0.95}$ for individual stations and months. (Number of months in parenthesis.)

	Norway Station	Halley Bay	Weather Ship A	Weather Ship M	Bodø	Ørland	Gardermoen
Jan.			1.18 (1)	0.01 (6)	0.19 (5)	0.01 (5)	0.64 (5)
Feb.			0.26 (1)	0.20 (6)	0.01 (5)	0.19 (5)	0.16 (5)
March			0.50 (1)	0.19 (5)	0.65 (5)	0.02 (5)	0.05 (5)
April	0.07 (1)	0.58 (1)					
May	0.12 (1)	0.02 (1)					
June	0.04 (2)	0.09 (1)					
July	0.28 (2)	0.05 (1)					
Aug.	0.42 (3)	1.10 (1)					
Sept.	0.12 (3)	0.26 (1)	0.90 (3)	0.01 (5)	0.27 (5)	0.03 (5)	0.05 (5)
Oct.		1.74 (1)	0.26 (3)	0.58 (6)	0.01 (5)	0.14 (5)	0.37 (5)
Nov.			0.05 (4)	0.49 (6)	0.17 (5)	0.01 (5)	0.44 (5)
Dec.			0.28 (4)	0.06 (6)	0.01 (5)	0.22 (5)	0.05 (5)

It should be noted that in these three cases the value of Q is based on observations from one season only. Halley Bay (all months) and Weather Ship A (January–March) are the stations from which we have had the smallest amounts of data, and accordingly we here find the greatest fluctuations of Q. For all the other stations where a much greater amount of data has been available, Q is smaller, in most cases much smaller than $c_{0.95}$. Hence the following conclusion seems valid: Our test gives no basis for maintaining that a connection exists between a 2nd tropopause at noon and a 2nd tropopause occurring at midnight. This may possibly mean that the conditions leading to the formation of a 2nd tropopause are of a rather short duration, in most cases less than 12 hours.

d. Variations from season to season

We consider all N dates satisfying the requirements to the observation data mentioned on p. 11. If n_k is the number of dates in season k, we have:

$$N = \sum_{k=1}^{w} n_k$$

where w is the total number of seasons. For each date only one of the following events can occur:

$B_1 = AD_1$ and AN_1 $\quad$ $B_3 = AD_1$ and AN_2

$B_2 = AD_2$ and AN_1 $\quad$ $B_4 = AD_2$ and AN_2

AD_i and AN_j are defined as in Section 5 c. For every date in the season k, the probability of each of the four possible events is: p_{1k}, p_{2k}, p_{3k} and p_{4k}, while the corresponding number of observed events is denoted:

Y_{1k}, Y_{2k}, Y_{3k} and Y_{4k}

We will try to test whether the probability of B_1, B_2, B_3 and B_4 is constant from season to season, which gives the null-hypothesis:

p_{1k}, p_{2k}, p_{3k} and p_{4k} are independent of k.

The estimated number of B_i in season k (assuming the null-hypothesis to be correct) is

$$n_k \frac{Y_{i.}}{N}$$

while Y_{ik} (tabulated in the Appendix) is the corresponding observed number.

The quantity:

$$V = \sum_{i,k} \frac{\left(Y_{ik} - n_k \frac{Y_{i.}}{N}\right)^2}{n_k \frac{Y_{i.}}{N}} \tag{17}$$

has an approximate chi-squared distribution with $(v-1)(w-1)$ degrees of freedom, where $v = 4$ is the number of possible events (B_i). The level of significance is chosen as in Section 5c, and the null hypothesis is rejected if $V > c_{0.95}$.

Table 6

Significance test of the change from season to season of the frequency of 2nd tropopauses. (The symbols are explained in the text.)

	Number of seasons	Number of deg. of freed.	V	$c_{0.95}$	$V-c_{0.95}$	$\frac{V}{c_{0.95}}$
Norway Station	2	3	2.91	7.81	–4.91	0.37
Weather Ship M	5	12	36.08	21.03	15.05	1.72
Bodø	5	12	28.27	21.03	7.24	1.34
Ørland	5	12	26.58	21.03	5.55	1.26
Gardermoen	5	12	38.35	21.03	17.32	1.82

The results are given in Table 6. For all stations but Norway Station $V > c_{0.95}$. The conclusion is therefore that the probability of B_1, B_2, B_3 and B_4 changed significantly from season to season. As the data for Norway Station include two seasons only, it is difficult to have any definite opinion as to the deviating result for this station. A future investigation on this point, based on a greater amount of data, should be of interest.

6. Discussion of different meteorological factors

We now turn to the question of a possible connection between the 2nd tropopause and various other atmospheric parameters: vertical air motion, the change of wind with height, stratospheric clouds, and potential temperature. The following investigations are confined to Norway Station, since this was the only station for which adequate data were available on punched cards.

a. Vertical velocity

The computation of the vertical velocity (w) was based on an equation developed from the first law of thermodynamics by JENSEN (1961). After some simplifying assumptions (i. a. adiabatic motion) we have:

$$w = -\frac{\frac{\partial T}{\partial t} + \mathbf{v} \cdot \nabla_p T}{\frac{g}{c_p} + \frac{\partial T}{\partial z}} \tag{18}$$

where $\mathbf{v}$ is the wind vector, and $\nabla_p T$ is the temperature gradient along an isobaric surface.

To make this expression more applicable for the computation of vertical velocities it is necessary to introduce finite differences. In this connection we have to consider the term $\mathbf{v} \cdot \nabla_p T$ more closely. By assuming geostrophic wind conditions we find by means of the thermal wind equation and integrated hydrostatic equation:

$$\mathbf{v}_m \cdot \nabla_p T_m = \frac{f\,T_m}{g\,\Delta z}\mathbf{k} \cdot (\mathbf{v}_m \times \mathbf{v}_t) \tag{19}$$

Here f is the coriolis parameter ($2\,\Omega \sin \varphi$), subscript m indicates a mean value (in space) and t the thermal wind. Furthermore, indicating the lower and upper level of the layer for which w is to be computed by the subcripts 1 and 2 respectively, the vector product $\mathbf{v}_1 \times \mathbf{v}_2$ may with good approximation be introduced instead of $\mathbf{v}_m \times \mathbf{v}_t$:

$$\mathbf{k} \cdot (\mathbf{v}_m \times \mathbf{v}_t) = |\mathbf{v}_1| \cdot |\mathbf{v}_2| \sin \Delta\alpha \tag{20}$$

where $\Delta\alpha$ is the difference between the wind directions at the upper and lower limit of the layer considered. Eq. (19) may then be written:

$$\mathbf{v}_m \cdot \nabla_p T_m = -\frac{f\,T_m}{g\Delta z} |\mathbf{v}_1| \cdot |\mathbf{v}_2| \sin \Delta\alpha \tag{21}$$

The minus-sign is due to the fact that in meteorology the direction of the positive rotation of the wind vector is opposite to that applied in vector analysis. The final expression for w is:

$$w = -\frac{\left[\frac{T_1+T_2}{2}\right]_{t=0} - \left[\frac{T_1+T_2}{2}\right]_{t=-12}}{\left\{\frac{g}{c_p} + \frac{1}{2}\left(\left[\frac{T_2-T_1}{\Delta h}\right]_{t=0} + \left[\frac{T_2-T_1}{\Delta h}\right]_{t=-12}\right)\right\}\Delta t} + \tag{22}$$

$$\frac{\frac{f}{g}\left(\frac{\left[v_1 v_2 \frac{\sin \Delta\delta}{\Delta h}\right]_{t=0} + \left[v_1 v_2 \frac{\sin \Delta\delta}{\Delta h}\right]_{t=-12}}{2}\right)\left(\frac{[T_1+T_2]_{t=0} + [T_1+T_2]_{t=-12}}{4}\right)}{\frac{g}{c_p} + \frac{\left[\frac{T_2-T_1}{\Delta h}\right]_{t=0} + \left[\frac{T_2-T_1}{\Delta h}\right]_{t=-12}}{2}}$$

where Δh is the thickness of the layer, and Δt is the time interval, which is here the time between two ordinary ascents, i.e. 12 hours. This expression gives a 12-hourly mean value of w. The first term on the right side of the equation represents effects due to local temperature changes, while the second term represents advective effects. In the following these quantities are indicated by w1 and w2, so that:

$$w = w1 + w2.$$

The values of w1 and w2 are calculated on an IBM 1620[II] electronic computer. For practical reasons we had to confine ourselves to the months of June, July, and August 1958.

It goes without saying that the calculated w values may deviate from the true 12-hourly mean vertical velocities because of the approximations made in deriving Eq. (21). Such deviations may also be caused by instrumental and observational errors.

It is difficult to determine the size of the difference between calculated and true values of w. Rough estimates seem to show, however, that uncertainties of the observed meteorological quantities are likely to be dominating. These estimates are based on Eq. (22) applied on the levels near the tropopause. By taking into account the uncertainties in the radiosonde observations, discussed earlier, the estimated uncertainty in w is about $\pm$ 0.5 cm/s (provided the wind conditions are not too extreme). The estimated uncertainty of w1 is about $\pm$ 0.2 cm/s and of w2 somewhat less than $\pm$ 0.5 cm/s. A more thorough and detailed study of the factors of uncertainty involved in the calculation of w would be very complicated, and would scarcely be worth while in the present case.

In the Figures 5a to d are represented the two vertical velocity components for the layers 400–300 mb, 200–150 mb, 150–100 mb, and 100–70 mb. To try to find the typical difference between situations with and without a 2nd tropopause, we have chosen our data according to the following requirements:

1. If, for a certain ascent, a 2nd tropopause is not found, the radiosonde must for this and the previous ascent have recorded temperature and wind at least up to the 100 mb level. This in order to make possible the calculation of the vertical velocity for all layers considered. (In the case of Fig. 5d the radiosonde must have passed 70 mb.)
2. If a 2nd tropopause is found, the immediately preceding and succeeding vertical velocities are disregarded. The succeeding velocities are not cut out if in the next ascent there is observed more than one tropopause as well.

Because of the hours at which the radiosonde ascents took place, it is not possible to calculate vertical velocities that may be considered as pure day- or night-values. As is indicated in the figures, we have distinguished between velocities based on data from a night ascent and the following day ascent (ND-values for short) and velocities based on a day ascent and the following night ascent (DN-values).

From Fig. 5a, which represents w1 and w2 in the 400–300 mb layer, we see that w2 is the largest of the two components. The most conspicuous feature, however, is the fact that the largest values of w2 (numerically) are all associated with ascents where 2nd tropopauses are observed. It appears that the components calculated on the basis of ascents where no 2nd tropopause is discernible are gathered within a relatively small circle around origo. There is one exception from this general feature, viz. the point $w1 = 3.3$ cm/s, $w2 = -4.8$ cm/s, which dates from 27 August, 12 and 24 GMT. A closer investigation of this case reveals that the temperature curve at 24 GMT makes a marked turn at 219 mb as well as at the 154 mb level. The first one of these changes of the temperature gradient satisfies the definition of the tropopause, while the second one is not sufficiently significant to be considered as a 2nd tropopause. The 12 GMT ascent shows a tropopause at the 200 mb level, followed by a steady temperature fall of about 3°C up to the 100 mb level. For both ascents the lapse rate between 400 mb and 300 mb is very nearly adiabatic, which means small denominators in Eq. (22), and consequently large values of w1 and w2. However, as they have opposite signs, w itself is comparatively small.

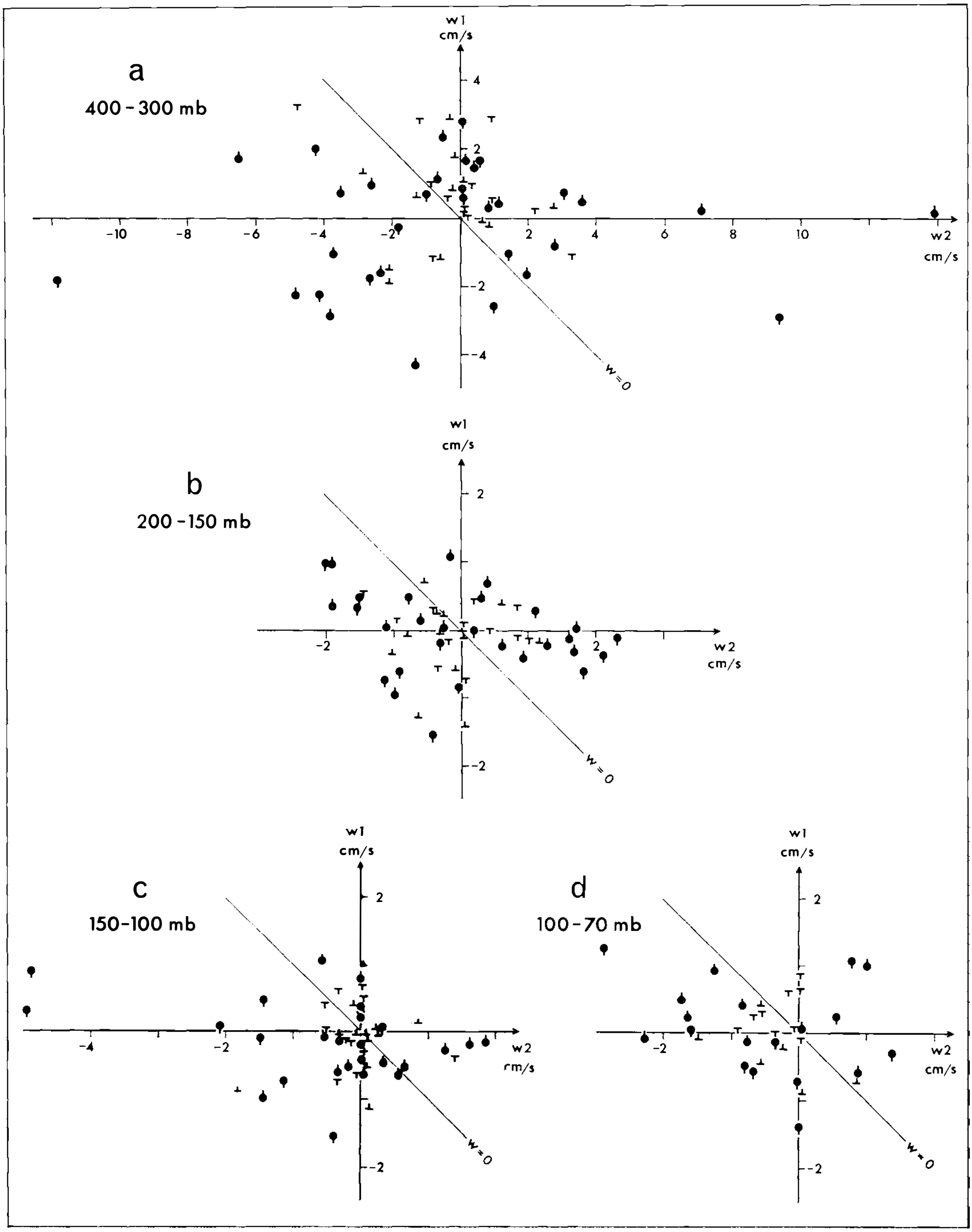


Fig. 5. *The vertical velocity components (w1 and w2) for different pressure layers. Dots: the 2nd tropopause is found on one or both of the two ascents which form the basis of the velocity computations; horizontal lines: the 2nd tropopause is found on neither of these two ascents. A vertical line upwards: the velocity is based on a night ascent and the following day ascent (ND-value); vertical line downwards: the velocity is based on a day ascent and the following night ascent (DN-value).*

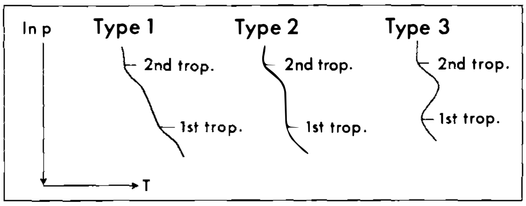


Fig. 6. *Three main types of 2nd tropopauses.*

The distribution of ND- and DN-values seems not to show any significant features.

The features revealed by Fig. 5a are more or less clearly in evidence in Fig. 5b to d as well. Concerning the magnitudes of the vertical velocities, however, they are generally much larger in the layer 400—300 mb than in the layers higher up. One reason for this is that the ordinary tropopause for the months considered is usually found between 275 mb and 150 mb. Accordingly, among the layers studied here, the greatest lapse rates occur in the 400—300 mb layer. This means, as mentioned above, relatively small denominators in the expressions for w1 and w2. Even if the enumerators are not large, w1 and w2 may be so.

An attempt at classifying the 2nd tropopauses in the three main types indicated in Fig. 6 did not lead to any clear tendencies concerning the distribution of the points in Figs. 5a to d.

Fig. 7 represents the components of the vertical velocity in the layers (limited by standard pressure surfaces) where the 2nd tropopause is observed. The distribution on the different layers of the 24 2nd tropopauses is as follows:

Layer (mb)	200—150	150—100	100—70	70—50	Total
Number of 2nd trop.	4	11	7	2	24

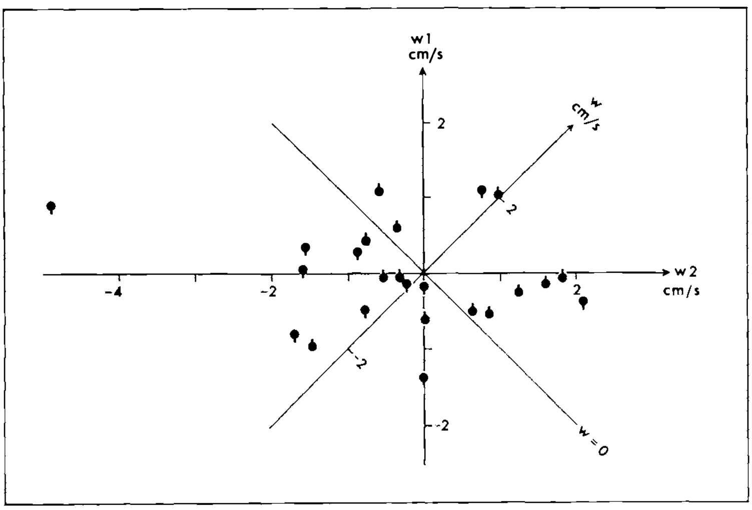


Fig. 7. *The vertical velocity components (w1 and w2) in the layers where the 2nd tropopause is observed. The vertical lines have the same meaning as in Fig. 5.*

Table 7
Frequency distribution of the vertical velocity components for different types of 2nd tropopauses.

Type	Frequency of |w1| > |w2|	Frequency of |w1| < |w2|	Total
3	4	4	8
2	1	9	10
1	2	4	6
Total	7	17	24

The values of w1 lie within $\pm$ 1.4 cm/s, and those of w2 within $\pm$ 2.1 cm/s. The only exception is formed by the time interval 12 June 12 GMT to 24 GMT, where $w2 = -4.9$ cm/s ($w1 = 0.9$ cm/s). From the ascent at the latter hour the 2nd tropopause is found at 117 mb, without any marked wind shear in the layer 150–100 mb. The ascent at 12 GMT, however, reveals a considerable wind shear in this layer, the wind speed decreasing from 120 knots at the lower level to 50 knots at the upper level. Furthermore, it appears from Fig. 7 that $|w2|>|w1|$ in 17 out of the 24 cases.

By classifying the 2nd tropopauses according to the three main types indicated previously (Fig. 6), we obtain the frequency distribution given in Table 7. We see that when $|w1|>|w2|$ in the layer where the 2nd tropopause is observed, type 3 is relatively most frequent, while for $|w1|<|w2|$ type 2 is the most frequent one. The relative frequency of type 1 is nearly equal in the two cases.

Figs. 8a and b show for different layers and different intervals of $|w2|$ the number of cases with and without a 2nd tropopause. It appears that for all layers the number of situations without a 2nd tropopause is dominating when $|w2|$ is small. From the interval 1.0–1.4 cm/s and upwards situations with a 2nd tropopause are most frequent. This indicates that the 2nd tropopause most often forms in situations where $|w2|$ is relatively large for one or several layers from about the layer of the ordinary tropopause and further upwards.

A corresponding investigation of $|w1|$, using intervals of 0.25 cm/s, did not

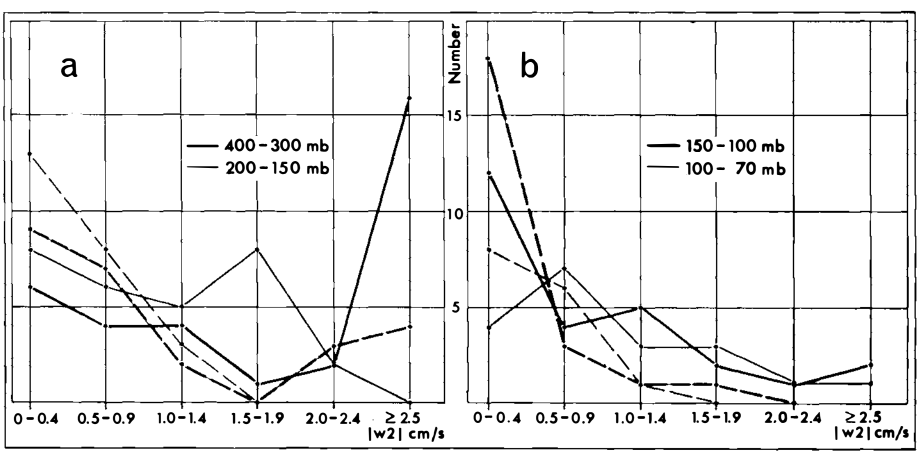


Fig. 8. *Number of cases with a 2nd tropopause (solid lines) and without a 2nd tropopause (broken lines) for different intervals of w2 and for different pressure layers.*

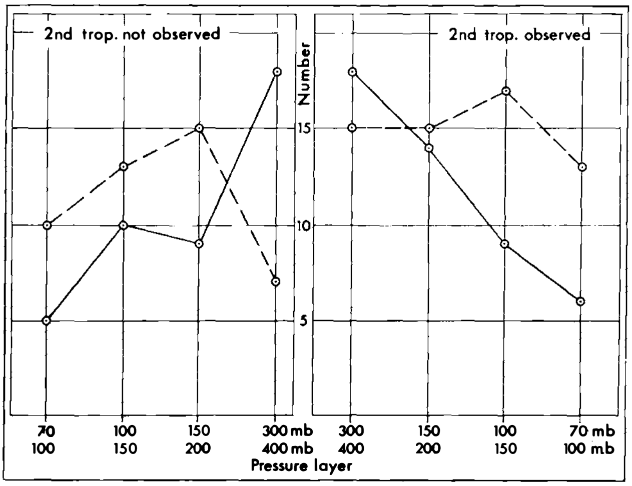


Fig. 9. *Number of cases of positive (solid line) and negative (broken line) vertical velocities (w) for different pressure layers and for situations with a 2nd tropopause (diagram to the right) and without a 2nd tropopause (diagram to the left).*

give the same systematic picture, suggesting that the magnitude of |w1| is of small importance for the formation of the 2nd tropopause.

Fig. 9 shows the frequencies of positive and negative values of w for situations with and without a 2nd tropopause respectively. We find the same tendency in both cases. The number of positive w is largest in the lowest layer considered, while for the higher layers the number of negative w is largest.

Fig. 10 gives a picture of how the 2nd tropopauses are distributed with height. At the same time it shows the distribution of the vertical velocity in the layer

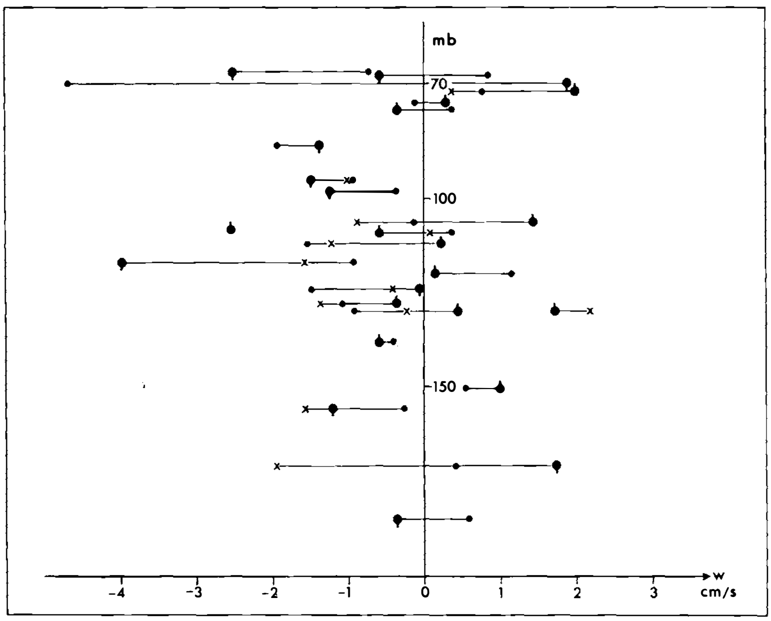


Fig. 10. *Large dots: the vertical velocity (w) in the layer where the 2nd tropopause is observed (the vertical lines have the same meaning as in Fig. 5). Small dots: the vertical velocity in the layer below. Crosses: the vertical velocity in the layer above.*

where the 2nd tropopause is observed, as well as in the layer immediately below and immediately above the 2nd tropopause layer. The vertical velocities (w) of these three layers are in the following indicated by the subscripts t (for tropopause), b (for below), and a (for above).

It has been possible to calculate w_a in 12 (out of 24) cases only, which makes it difficult to draw conclusions concerning this part of the material. The main impression of Fig. 10, however, is that w_a and w_b generally is situated on the same side of w_t. As to w_b we find that in 20 out of 24 cases:

$w_t \geq w_b$ (equality in one case) when $w_t > 0$,
$w_t \leq w_b$ (equality in one case) when $w_t < 0$.

For three out of the remaining four cases w_t is found in the interval $+0.16$ to -0.35 cm/s (120 – 124 – 128 mb), and is thus smaller than the uncertainty limit indicated previously. It may therefore be questioned if they really are exceptions from the general features pointed out above. Concerning the fourth exception, the value of w is dominated by w1 ($w1 = -1.36$ cm/s, $w2 = 0$ cm/s) and the 2nd tropopause is situated at 86 mb. The connection we have found between w_t and w_b may possibly reflect a general property of the layers above the tropopause. To examine this possibility more closely, we have considered all cases where the vertical velocity is computed up to the 150–100 mb layer. However, situations with a 2nd tropopause in this layer are cut out, and only cases for which $w_t \geq 0.50$ cm/s are taken into account. In this special investigation w_t and w_b refer to the layers 150–100 mb and 200–150 mb respectively. A comparison between this material and a corresponding "2nd tropopause material" is shown in Table 8. From this comparison it seems to appear quite clearly that the connection between w_t and w_b pointed out above is characteristic for situations where a 2nd tropopause occurs.

b. Diurnal temperature variations and the ozone content

Although the advection term in the expression of the vertical velocity seems, as a rule, to be of greatest importance in connection with the 2nd tropopause, the local term may well, according to its sign, act to strengthen or weaken the connection between the advection term and the 2nd tropopause. Evidently this possi-

Table 8

A comparison of the vertical velocity (w_t) in the 2nd tropopause layer (first line and in the 150–100 mb layer when no 2nd tropopause is observed (second line) with the vertical velocity in the the layer below (w_b).

	$w_t > 0.5$ cm/s Expr. $w_t \geq w_b$ is		$w_t < -0.5$ cm/s Expr. $w_t \leq w_b$ is		Total	
	right	wrong	right	wrong	right	wrong
w_t means the vert. vel. in the 2nd trop. layer	6	0	9	1	15	1
w_t means the vert. vel. in the 150–100 mb layer (provided no 2nd trop. occurs in this layer)	5	7	11	10	16	17

bility should be studied in the light of the result obtained previously, that the 2nd tropopause occurs more frequently at noon than at midnight, in other words, that the conditions seem to be most favourable for the formation of the 2nd tropopause during daytime.

When deducing Eq. (22), all processes were presumed adiabatic. If diurnal changes of the thermal energy added to or subtracted from the air masses are of importance, it is difficult to say anything about the quantitative influence on w. By presuming that the transferred thermal energy mainly causes a temperature change, it is possible to draw some qualitative conclusions. Provided diurnal variations of the transferred thermal energy do not influence the $\mathbf{v} \cdot \nabla_p T$ – estimate noticeably, such variations cannot have any notable influence on the enumerator of the w2 term either, since this quantity is mainly dependent on the wind velocity and its change with height. The enumerator of the w1 term, however, may be subject to a diurnal change, as it depends on the temperature and its variation with time. The denominators of w1 and w2 are always positive as long as we keep above the ordinary tropopause. In the stratosphere the w2 term is more often negative than positive, which is due to the fact that at these altitudes the wind tends to turn in an anticlockwise direction with height. This feature is independent of whether the 2nd tropopause is present or not.

The contribution of $\frac{\partial T}{\partial t}$ to w1 may be due to:

1. heat transfer into or out of the system considered, or
2. processes within the system.

It is the sum of these two effects that gives rise to the difference between the temperatures of two succeeding radiosonde ascents. Over an extensive snowfield during the polar night, which is the situation we consider, a diurnal course of the long-wave radiation flux may be assumed to be negligible. On the other hand, as shown by Fig. 11, the solar radiation in the layers considered (10–20 km) varies substantially in the course of the day. This should give a positive contribution to $\frac{\partial T}{\partial t}$ from night to day, which means a negative contribution to w. On the other hand, a quantity $\frac{\partial T}{\partial t}$ that is not due to heat supply from without should be expected to be, on an average, as frequently positive as negative. It seems clear, therefore, that during winter time w1 and w2 should more often be of the same sign (negative) than of opposite signs when we consider the time interval from midnight to noon. Correspondingly, if we consider the time interval from noon to midnight, the signs will be opposite in the majority of the cases. Provided the formation of the 2nd tropopause is dependent on both w1 and w2, this result may explain why the 2nd tropopause is more frequent at noon than at midnight.

Studying Tables 2 and 3 it appears that if, on an average, five to ten 2nd tropopauses per winter may be attributed to the radiative heat effect pointed out above, this would be sufficient to make the test on p. 10 give a significant difference between the frequency of the 2nd tropopauses observed at noon and those observed at midnight.

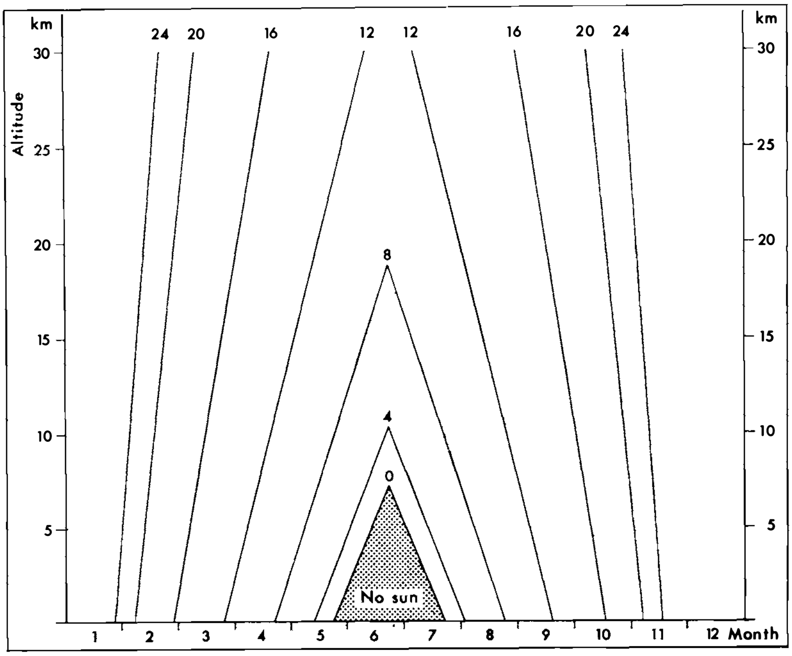


Fig. 11. *Duration of sunshine (in hours) at Norway Station for different times of the year and for different altitudes.*

The heat effect may possible be due to the absorption by ozone of solar radiation. If we assume that all the energy released during this absorption process is used to heat the air, we may put:

$$J_3 \cdot n(0_3) \cdot \Delta E = c_p \cdot \frac{\Delta T}{\Delta t} \cdot \rho \qquad (23)$$

where:

J_3 is the dissociation coefficient of ozone, equal to $7 \cdot 10^{-4}$ s^{-1} during the winter season and at a height of 15 km at 60° lat. (HESSTVEDT, personal communication),

$n(0_3)$ is the concentration of ozone, equal to $7 \cdot 10^{12}$ cm^{-3} for the same season and at approximately the same height and latitude as for J_3 (HERING and BORDEN 1965),

ΔE is the energy released during the absorption, about 1 eV (GREEN and WYATT 1965),

Δt is the time interval from the hour the first solar rays hit the part of the atmosphere considered till the 12 GMT ascent, i.e. from 3 to 8 hours (cf. Fig. 11), ρ and c_p have the same meaning as before.

This would give a temperature increase from the midnight ascent to the noon ascent of between

$\Delta T = 0.06°C$ and $\Delta T = 0.13°C$ (at about 100 mb).

These values represent extreme means of ΔT during the winter season. Assuming a reasonable dispersion of the values, i.a. because of the fact that the quantities specified above may take values deviating somewhat from those given here, it seems likely that ΔT in some cases may be as large as 0.3–0.5°C. A temperature increase of this magnitude would be of importance for w1.

As to the variation of the ozone content, reference may be made to a work by TØNSBERG and LANGLO (1944) dealing with observations made in Tromsø (69°42′N). They find that the day to day variations in some cases exceed the difference between the largest and smallest monthly mean value. Furthermore, calculations made by means of the Umkehr method show that the change in the total quantity of ozone mainly occurs at a height of 10–20 km (200–50 mb). MACDOWALL (1960) finds that during the winter of 1958 the maximum change of ozone with height at Halley Bay occurred at a mean height of 14.5 km. During the same season the maximum concentration of ozone was found to occur between 16 and 17 km. At Norway Station (about 950 km north-east of Halley Bay) the mean height of the 2nd tropopause in 1958 was 14.9 km in June, 14.5 km in July, and 13.8 km in August.

HERING and BORDEN (1964–65) have for a series of stations and of radiosonde ascents given corresponding values of temperature and ozone concentration from the surface up to about 5 mb. Of the stations considered in their paper, Fairbanks (64°48′N, 147°54′W) is the one that is best suited as a basis of comparison in the present case. Some characteristic features revealed by the data from this station may be mentioned. Frequently there is a rather large variation of the ozone concentration with height. The noon ascents often show a remarkably good correspondence between the variations of temperature and ozone concentration with height. This does not apply, however, to the midnight ascents. The most marked minima of the ozone content during the day ascents in Fairbanks are connected with vertical temperature changes that indicate a 2nd tropopause (or a 3rd or 4th tropopause).

The facts pointed out above do not of course "prove" that the absorption of solar radiation by ozone is the reason for the temperature changes associated with the 2nd tropopause. They indicate, however, that the ozone content may be of importance for the formation of the 2nd tropopause during daytime, and further research on this point should be of interest.

On the basis of our data it is difficult to form any definite opinion concerning the relationship between the influence on the 2nd tropopause of the ozone effect and the effect of the vertical velocities discussed previously.

c. Other factors

The potential temperature for the levels between 850 mb and 50 mb was studied for several shorter periods during the winter season 1958. However, it was difficult to find traces of a connection between this element and the formation of the 2nd tropopause. The same applies to an investigation of the horizontal wind velocity. Possibly, the time interval of 12 hours between the ascents is too long for investigations of this kind.

The frequency of stratospheric clouds was approximately the same in situations where a 2nd tropopause occurred as in situations where it did not occur.

An attempt at studying the synoptic situation in connection with the 2nd tropopause was based on the weather maps published by the South African Weather Bureau. It was not possible, however, to reach any conclusive results. Obviously, the stations in the area considered are too widely spaced to allow a detailed analysis.

Authors's address:

Norges geografiske oppmåling
Oslo 1 - Norway

References

ASTAPENKO, P. D., 1960: *Atmospheric prosesses in the high latitudes of the Southern Hemisphere.* Moskva. (Scient. Translations, Jerusalem 1964.)

BJERKNES, J., and E. PALMÉN, 1937: Investigations of selected European Cyclons by means of Serial Ascents. *Geof. Publ.* **12** (2). Oslo.

COURT, A., 1942: Tropopause Disappearance During the Antarctic Winter. *Bull. Am. Met. Soc.* **23** (5). Boston.

FINK, C., 1960: Über die Korrektion der Temperaturumkehrpunkte eines Radiosondenaufsteiges. *Met. Rundschau.* **13** (4). Berlin.

GREEN, A. E. S., and P. J. WYATT, 1965: *Atomic and space physics.* Addison–Wesley Pub. Co. Mass.

HARRISON, D. N., 1962: Errors of the Meteorological Office radiosonde, Mark 2B. *Met. Office Scient. Paper* No. 15. London.

HERING, W. S., and T. R. BORDEN, 1964–65: Ozonesonde observations over North Amerika. **1-3**. *U. S. Air Force. Cambridge Res. Lab., Mass. Environmental Res. Papers.*

JENSEN, C. E., 1961: Energy transformation and vertical flux prosesses over the Northern Hemisphere. *Journ. Geoph. Res.* **66** (4). Washington.

MACDOWALL, J., 1960: Some observations at Halley Bay in seismology, glaciology and meteorology. In: A discussion of the Royal Soc. exp. to Halley Bay, Antarctica, during the I. G. Y. *Proc. Royal Soc. A.* **256**. London.

MACDOWALL, J., and J. M. C. BURTON, 1962: Upper-air meteorological observations. *The Royal Soc. I.G.Y. Ant. Exp., Halley Bay, 1955–59.* (Ed. by D. BRUNT.) **3**. London.

PALMÉN, E., and K. M. NAGLER, 1948: An analysis of the wind and temperature distribution in a free atmosphere over N. America in a case of approximately westerly flow. *Journ. Met.* **5** (2). Boston.

RAPP, R. 1952: The effect of variability and instrumental error on measurements in the free atmosphere. *New York University Met. Papers.* **2** (1).

SCHUMACHER, N. J., 1962: The tropopause. *Norw.-Brit.-Swed. Ant. Exp., 1949–52. Scient. Results.* 1 (1B). Norsk Polarinst. Oslo.

TØNSBERG, E., and K. LANGLO, 1944: Investigations on atmospheric ozone at Nordlysobservatoriet, Tromsø. *Geof. Publ.* **8** (12). Oslo.

VAISALA, V., 1953: The lag coefficient of hygroscopic hygrometers, supplementary report. *Helsinki Univ. Met. Inst. Mitteilungen* No. 74.

Vaisala News (6) 1960. Helsinki.

WEBB, W. L., 1966: Structure of the stratosphere and mesosphere. *Intern. Geoph. Series.* **9**. Academic Press. New York.

Appendix A

Table 1A[1]

Norway Station. Day-ascent: 12 GMT. Night-ascent: 24 GMT (on the same date)

Day		$X_t=1$				$X_t=0$				Total
Night	Month	1957	58	59	Total	1957	58	59	Total	
	4		x	0	0		x	1	1	1
	5		x	0	0		x	1	1	1
$Y_t=1$	6		1	2	3		4	3	7	10
	7		5	1	6		4	2	6	12
	8	2	2	1	5	0	0	1	1	6
	9	1	0	1	2	1	0	2	3	5
	Total	3	8	5	16	1	8	10	19	35
	4		x	2	2		x	10	10	12
	5		x	3	3		x	6	6	9
	6		4	6	10		7	9	16	26
$Y_t=0$	7		2	2	4		5	8	13	17
	8	2	8	3	13	1	10	12	23	36
	9	2	3	1	6	1	15	12	28	34
	Total	4	17	17	38	2	37	57	96	134
	4				2				11	13
	5				3				7	10
	6				13				23	36
Total	7				10				19	29
	8				18				24	42
	9				8				31	39
	Total				54				115	169

[1] The contents of Tables 1A to 7B are explained on p. 11.

Table 2A

Halley Bay. Day-ascent: 12 GMT. Night-ascent: 24 GMT (on the same date)

Day		$X_t=1$	$X_t=0$	Total
Night	Month	1958	1958	Total
$Y_t=1$	4	3	0	3
	5	4	2	6
	6	11	2	13
	7	8	4	12
	8	7	1	8
	9	2	2	4
	10	2	1	3
	Total	37	12	49
$Y_t=0$	4	7	6	13
	5	6	4	10
	6	2	0	2
	7	1	1	2
	8	4	6	10
	9	7	2	9
	10	3	11	14
	Total	30	30	60
Total	4	10	6	16
	5	10	6	16
	6	13	2	15
	7	9	5	14
	8	11	7	18
	9	9	4	13
	10	5	12	17
	Total	67	42	109

Table 3A

"A"-Ship 62°N-32°W. Day-ascent: 12GMT. Night-ascent: 24GMT (on the same date)

Day		$X_t=1$					$X_t=0$					Total
Night	Month	1960	62	64	66	Total	1960	62	64	66	Total	
$Y_t=1$	9	3		0	0	3	2		3	1	6	9
	10	1		3	1	5	2		6	0	8	13
	11	2	10	6	3	21	7	8	8	2	25	46
	12	6	0	5	6	17	8	2	1	5	16	33
	1		3			3		1			1	4
	2		1			1		3			3	4
	3		1			1		2			2	3
	Total	12	15	14	10	51	19	16	18	8	61	112
$Y_t=0$	9	1		1	1	3	17		26	26	69	72
	10	2		6	5	13	25		13	22	60	73
	11	4	3	8	7	22	11	7	6	13	37	59
	12	6	2	11	0	19	6	12	9	16	43	62
	1		4			4		15			15	19
	2		4			4		18			18	22
	3		2			2		24			24	26
	Total	13	15	26	13	67	59	76	54	77	266	333
Total	9					6					75	81
	10					18					68	86
	11					43					62	105
	12					36					59	95
	1					7					16	23
	2					5					21	26
	3					3					26	29
	Total					118					327	445

Table 4A

"M"-Ship 66°N-02°E. Day-ascent: 12GMT. Night-ascent: 24GMT (on the same date)

Day		$X_t=1$								$X_t=0$								Total
Night	Month	1958	59	60	61	62	63	64	Total	1958	59	60	61	62	63	64	Total	
$Y_t=1$	9	0	x		2	0	0	0	2	3	x		1	1	3	0	8	10
	10	1	0		7	2	0	0	10	3	2		2	1	1	3	12	22
	11	0	2		5	2	3	0	12	1	3		3	2	4	3	16	28
	12	0	1		2	0	2	1	6	1	1		5	1	2	5	15	21
	1	0	0	1	1	0	0		2	2	0	2	2	5	1		12	14
	2	0	0	2	1	1	1		5	1	0	3	2	1	2		9	14
	3	x	1	1	1	0	0		3	x	5	3	3	0	1		12	15
	Total	1	4	4	19	5	6	1	40	11	11	8	18	11	14	11	84	124
$Y_t=0$	9	3	x		5	5	2	3	18	21	x		18	18	17	22	96	114
	10	5	1		5	5	2	1	19	9	24		14	18	20	25	110	129
	11	1	3		5	1	2	4	16	15	9		12	23	7	19	85	101
	12	3	3		5	2	1	4	18	18	16		8	16	13	15	86	104
	1	2	2	5	6	4	3		22	21	14	15	17	12	16		95	117
	2	0	1	5	4	4	1		15	11	16	14	13	20	11		85	100
	3	x	1	7	4	2	2		16	x	17	20	20	22	16		95	111
	Total	14	11	17	34	23	13	12	124	95	96	49	102	129	100	81	652	776
Total	9								20								104	124
	10								29								122	151
	11								28								101	129
	12								24								101	125
	1								24								107	131
	2								20								94	114
	3								19								107	126
	Total								164								736	900

Table 5A

Bodø. Day-ascent: 12 GMT. Night-ascent: 24 GMT (on the same date)

Day		$X_t=1$						$X_t=0$						Total
Night	Month	1959	60	61	62	63	Total	1959	60	61	62	63	Total	
$Y_t=1$	9	1	0	3	0	0	4	3	1	3	0	2	9	13
	10	0	0	0	3	1	4	1	2	3	4	3	13	17
	11	0	4	1	1	0	6	2	0	2	7	1	12	18
	12	1	3	2	1	0	7	3	6	5	2	2	18	25
	1	3	0	0	5	4	12	3	3	4	7	0	17	29
	2	0	2	0	1	4	7	4	3	6	1	4	18	25
	3	0	4	1	0	0	5	0	2	0	0	0	2	7
	Total	5	13	7	11	9	45	16	17	23	21	12	89	134
$Y_t=0$	9	2	4	0	2	3	11	22	22	19	25	10	98	109
	10	1	2	5	9	2	19	15	26	16	9	4	70	89
	11	2	2	5	1	3	13	19	12	15	20	3	69	82
	12	2	5	5	4	5	21	14	12	10	17	2	55	76
	1	2	5	6	7	3	23	19	17	15	6	15	72	95
	2	1	6	9	1	4	21	19	11	6	21	9	66	87
	3	3	7	4	4	2	20	27	12	19	22	9	89	109
	Total	13	31	34	28	22	128	135	112	100	120	52	519	647
Total	9						15						107	122
	10						23						83	106
	11						19						81	100
	12						28						73	101
	1						35						89	124
	2						28						84	112
	3						25						91	116
	Total						173						608	781

Table 6A

Ørland. Day-ascent: 12 GMT. Night-ascent: 24 GMT (on the same date)

Day		$X_t=1$						$X_t=0$						Total
Night	Month	1961	62	63	64	65	Total	1961	62	63	64	65	Total	
$Y_t=1$	9	1	0	0	0	0	1	2	2	0	2	1	7	8
	10	0	3	0	0	1	4	4	6	2	1	1	14	18
	11	1	0	0	2	0	3	1	3	1	5	0	10	13
	12	0	2	1	0	0	3	0	0	2	1	2	5	8
	1	0	0	1	0	0	1	2	2	3	0	1	8	9
	2	5	0	1	[illegible]	0	6	4	1	2	2	1	10	16
	3	0	0	0	0	0	0	1	0	1	1	0	3	3
	Total	7	5	3	2	1	18	14	14	11	12	6	57	75
$Y_t=0$	9	2	2	4	1	0	9	21	23	19	26	29	118	127
	10	2	4	0	1	5	12	23	15	19	27	24	108	120
	11	5	4	3	4	4	20	14	16	19	15	17	81	101
	12	4	2	1	4	2	13	20	11	11	24	24	90	103
	1	3	0	8	1	2	14	21	14	13	30	20	98	112
	2	5	2	9	2	0	18	9	16	13	20	23	81	99
	3	4	1	3	2	2	12	26	29	22	21	28	126	138
	Total	25	15	28	15	15	98	134	124	116	163	165	702	800
Total	9						10						125	135
	10						16						122	138
	11						23						91	114
	12						16						95	111
	1						15						106	121
	2						24						91	115
	3						12						129	141
	Total						116						759	875

Table 7A

Gardermoen: Day-ascent: 12 GMT. Night-ascent: 24 GMT (on the same date)

Day		$X_t=1$						$X_t=0$						Total
Night	Month	1961	62	63	64	65	Total	1961	62	63	64	65	Total	
$Y_t=1$	9	1	0	1	1	0	3	3	3	4	5	1	16	19
	10	5	2	3	1	1	12	5	4	3	4	2	18	30
	11	3	1	0	6	0	10	1	4	4	5	1	15	25
	12	3	0	1	2	2	8	5	5	4	3	3	20	28
	1	1	1	4	3	2	11	3	1	1	4	4	13	24
	2	1	0	4	1	1	7	4	1	3	2	1	11	18
	3	0	0	0	1	1	2	2	2	1	2	5	12	14
	Total	14	4	13	15	7	53	23	20	20	25	17	105	158
$Y_t=0$	9	2	0	1	4	3	10	17	25	19	14	25	100	110
	10	2	4	4	5	6	21	15	21	17	19	21	93	114
	11	4	2	2	7	1	16	15	22	17	10	23	87	103
	12	2	3	4	5	5	19	12	18	11	14	19	74	93
	1	6	2	4	2	2	16	18	20	16	11	22	87	103
	2	5	1	2	10	5	23	16	24	15	12	19	86	109
	3	0	1	1	4	3	9	26	26	22	19	21	114	123
	Total	21	13	18	37	25	114	119	156	117	99	150	641	755
Total	9						13						116	129
	10						33						111	144
	11						26						102	128
	12						27						94	121
	1						27						100	127
	2						30						97	127
	3						11						126	137
	Total						167						746	913

Table 1B

Norway Station. Night-ascent: 00 GMT. Day-ascent: 12 GMT (on the same date)

Day		$X_t=1$				$X_t=0$				Total
Night	Month	1957	58	59	Total	1957	58	59	Total	
$Y_t=1$	4		x	0	0		x	0	0	0
	5		x	0	0		x	0	0	0
	6		0	3	3		5	1	6	9
	7		6	0	6		5	2	7	13
	8	0	2	1	3	2	0	2	4	7
	9	1	0	0	1	1	0	2	3	4
	Total	1	8	4	13	3	10	7	20	33
$Y_t=0$	4		x	1	1		x	10	10	11
	5		x	2	2		x	8	8	10
	6		6	4	10		7	10	17	27
	7		2	5	7		5	9	14	21
	8	2	8	4	14	1	9	13	23	37
	9	2	4	2	8	3	15	15	33	41
	Total	4	20	18	42	4	36	65	105	147
Total	4				1				10	11
	5				2				8	10
	6				13				23	36
	7				13				21	34
	8				17				27	44
	9				9				36	45
	Total				55				125	180

Table 2B

Halley Bay. Night-ascent: 00 GMT. Day-ascent: 12 GMT (on the same date)

Day / Night	Month	$X_t=1$ 1958	$X_t=0$ 1958	Total
$Y_t=1$	4	2	0	2
	5	5	2	7
	6	7	4	11
	7	10	6	16
	8	5	0	5
	9	5	1	6
	10	4	0	4
	Total	38	13	51
$Y_t=0$	4	7	9	16
	5	6	3	9
	6	4	0	4
	7	0	0	0
	8	4	8	12
	9	6	3	9
	10	2	14	16
	Total	29	37	66
Total	4	9	9	18
	5	11	5	16
	6	11	4	15
	7	10	6	16
	8	9	8	17
	9	11	4	15
	10	6	14	20
	Total	67	50	117

Table 3B

"A"-Ship 62°N-32°W. Night-ascent: 00 GMT. Day-ascent: 12 GMT (on the same date)

Day		$X_t=1$					$X_t=0$					Total
Night	Month	1960	62	64	66	Total	1960	62	64	66	Total	
$Y_t=1$	9	2		0	1	3	3		2	0	5	8
	10	0		4	0	4	3		6	1	10	14
	11	3	6	8	4	21	5	11	6	1	23	44
	12	11	0	5	3	19	3	2	2	6	13	32
	1		2			2		3			3	5
	2		3			3		1			1	4
	3		0			0		3			3	3
	Total	16	11	17	8	52	14	20	16	8	58	110
$Y_t=0$	9	3		1	0	4	15		27	26	68	72
	10	3		5	6	14	24		13	21	58	72
	11	3	7	7	5	22	12	4	6	17	39	61
	12	2	3	12	3	20	9	15	8	13	45	65
	1		5			5		13			13	18
	2		2			2		19			19	21
	3		3			3		23			23	26
	Total	11	20	25	14	70	60	74	54	77	265	335
Total	9					7					73	80
	10					18					68	86
	11					43					62	105
	12					39					58	97
	1					7					16	23
	2					5					20	25
	3					3					26	29
	Total					122					323	445

Table 4B

"M"-Ship 66° N-02° E. Night-ascent: 00 GMT. Day-ascent: 12 GMT (on the same date)

Day → / Night ↓	Month	$X_t=1$ 1958	59	60	61	62	63	64	Total	$X_t=0$ 1958	59	60	61	62	63	64	Total	Total
$Y_t=1$	9	1	x		2	1	1	0	5	2	x		0	0	2	0	4	9
	10	1	1		3	1	0	0	6	4	1		6	2	1	2	16	22
	11	1	2		4	1	3	2	13	2	3		5	3	5	2	20	33
	12	0	2		4	1	0	1	8	1	2		5	0	3	6	17	25
	1	1	0	3	1	2	0		7	1	2	0	4	3	2		12	19
	2	0	0	2	1	0	2		5	2	0	3	2	1	2		10	15
	3	x	1	0	1	0	0		2	x	4	4	3	0	1		12	14
	Total	4	6	5	16	6	6	3	46	12	12	7	25	9	16	10	91	137
$Y_t=0$	9	2	x		6	4	1	3	16	19	x		17	19	18	24	97	113
	10	5	0		6	6	2	1	20	10	25		12	17	21	26	111	131
	11	0	2		6	2	2	2	14	14	11		8	22	9	21	85	99
	12	3	2		3	1	4	4	17	16	15		7	17	10	15	80	97
	1	1	2	4	7	1	3		18	19	13	14	14	16	17		93	111
	2	0	1	5	4	5	0		15	11	15	14	13	21	16		90	105
	3	x	1	7	4	2	2		16	x	19	19	20	23	16		97	113
	Total	11	8	16	36	21	14	10	116	89	98	47	91	135	107	86	653	769
Total	9								21								101	122
	10								26								127	153
	11								27								105	132
	12								25								97	122
	1								25								105	130
	2								20								100	120
	3								18								109	127
	Total								162								744	906

Table 5B

Bodø. Night-ascent: 00 GMT. Day-ascent: 12 GMT (on the same date)

Day → / Night ↓	Month	$X_t=1$ 1959	60	61	62	63	Total	$X_t=0$ 1959	60	61	62	63	Total	Total
$Y_t=1$	9	1	0	2	0	0	3	2	1	3	0	3	9	12
	10	0	1	1	3	0	5	2	1	3	2	4	12	17
	11	0	3	2	1	0	6	2	0	2	6	1	11	17
	12	2	5	3	0	1	11	3	4	4	4	2	17	28
	1	2	0	1	4	3	10	4	3	3	5	2	17	27
	2	0	3	2	1	3	9	5	2	3	2	4	16	25
	3	0	3	0	0	0	3	0	3	1	0	0	4	7
	Total	5	15	11	9	7	47	18	14	19	19	16	86	133
$Y_t=0$	9	3	5	2	2	2	14	22	19	18	26	13	98	112
	10	2	1	3	9	2	17	12	26	18	11	7	74	91
	11	2	3	4	1	3	13	20	12	14	20	4	70	83
	12	2	4	7	5	5	23	15	14	9	15	1	54	77
	1	3	5	6	8	4	26	18	15	14	9	12	68	94
	2	1	4	6	1	5	17	19	13	10	20	8	70	87
	3	3	7	5	4	3	22	27	13	18	22	10	90	112
	Total	16	29	33	30	24	132	133	112	101	123	55	524	656
Total	9						17						107	124
	10						22						86	108
	11						19						81	100
	12						34						71	105
	1						36						85	121
	2						26						86	112
	3						25						94	119
	Total						179						610	789

Table 6B

Ørland. Night-ascent: 00 GMT. Day-ascent: 12 GMT (on the same date)

Day		$X_t=1$						$X_t=0$						Total
Night	Month	1961	62	63	64	65	Total	1961	62	63	64	65	Total	
$Y_t=1$	9	1	1	0	0	0	2	3	1	0	2	1	7	9
	10	1	2	0	0	2	5	3	7	2	1	0	13	18
	11	0	2	0	2	0	4	2	2	2	5	0	11	15
	12	0	1	0	0	0	1	0	1	2	1	2	6	7
	1	0	0	2	0	0	2	1	2	2	0	0	5	7
	2	3	1	2	1	0	7	8	0	1	1	1	11	18
	3	0	0	0	0	0	0	1	0	1	1	0	3	3
	Total	5	7	4	3	2	21	18	13	10	11	4	56	77
$Y_t=0$	9	2	1	4	1	0	8	20	23	18	25	29	115	123
	10	1	4	0	1	4	10	24	15	19	27	25	110	120
	11	4	3	4	4	4	19	15	17	17	15	21	85	104
	12	5	3	2	5	2	17	20	11	12	23	25	91	108
	1	3	0	7	1	2	13	22	13	14	30	20	99	112
	2	6	1	8	1	0	16	5	18	14	21	23	81	97
	3	4	1	3	1	2	11	26	29	22	22	28	127	138
	Total	25	13	28	14	14	94	132	126	116	163	171	708	802
Total	9						10						122	132
	10						15						123	138
	11						23						96	119
	12						18						97	115
	1						15						104	119
	2						23						92	115
	3						11						130	141
	Total						115						764	879

Table 7B

Gardermoen. Night-ascent: 00 GMT. Day-ascent: 12 GMT (on the same date)

Day		$X_t=1$						$X_t=0$						Total
Night	Month	1961	62	63	64	65	Total	1961	62	63	63	65	Total	
$Y_t=1$	9	3	0	0	4	0	7	1	3	4	2	1	11	18
	10	3	5	2	2	0	12	7	1	4	3	2	17	29
	11	0	1	1	5	1	8	3	3	4	0	1	17	25
	12	3	1	2	1	3	10	4	5	5	4	2	20	30
	1	0	0	2	2	2	6	3	1	4	6	3	17	23
	2	0	0	3	3	2	8	6	2	4	1	1	14	22
	3	0	0	0	1	2	3	2	2	2	2	3	11	14
	Total	9	7	10	18	10	54	26	17	27	24	13	107	161
$Y_t=0$	9	1	0	2	2	3	8	20	25	18	18	24	105	113
	10	4	2	5	5	6	22	13	23	17	19	22	94	116
	11	5	2	1	7	0	15	14	23	18	9	23	87	102
	12	3	2	3	6	4	18	15	18	10	14	19	76	94
	1	7	3	6	3	1	20	16	21	11	10	24	82	102
	2	6	1	4	8	4	23	14	22	13	12	18	79	102
	3	0	0	1	4	2	7	26	27	21	18	23	115	122
	Total	26	10	22	35	20	113	118	159	108	100	153	638	751
Total	9						15						116	131
	10						34						111	145
	11						23						104	127
	12						28						96	124
	1						26						99	125
	2						31						93	124
	3						10						126	136
	Total						167						745	912

Norsk Polarinstitutt Skrifter Nr. 155. Bjørn Geirr Harsson: The 2nd tropopause, a statistical and physical study

A.W. BRØGGERS BOKTRYKKERI A/S - OSLO