TARTU ÜLIKOOLI METEOROLOOGIA OBSERVATOORIUMI
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SCIENTIFIC PAPERS
OF THE METEOROLOGICAL OBSERVATORY OF THE UNIVERSITY OF TARTU
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CHANGE OF CLIMATE IN THE NORTHERN HEMISPHERE

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An attempt is made in this paper to analyze the variations of climate in the Northern Hemisphere. For this purpose we have used the temperature observations of meteorological stations whose period of observation extends at least from 45 to 50 years beginning with 1860—1870. In Table 1 are given the names of the observation points with their geographic coordinates and length of their period of observation.

In order to give a better survey the distribution of the meteorological stations is shown in Fig. 1.

The variations of temperature have been deduced from the average monthly temperatures given in the Meteorological Year Books. It must be noted that the average monthly temperatures of the North American Meteorological Stations have been calculated from the daily max. and min. temperatures. The whole period of the observations of each station is divided into two halves and the average temperature for each month has been reckoned for each half-period separately. On the basis of the abovementioned average temperatures for both half-periods we are able to determine the variation of the monthly mean temperature for the whole period with its mean error, which has been reckoned by means of the term

$$\varepsilon = \sqrt{\frac{\sum_{i=1}^{n} e_i^2 + \sum_{j=n+1}^{2n} e_j^2}{n\,(n-1)}}$$

where e_i denotes the deviations of the monthly mean temperatures from the average for the first half period, e_j — the corresponding deviations from the average temperature of the second half period, and n — the length of the half period in years. Table 2 gives the determined variations of temperature (Δt) with their mean error (ε) for January.

The temperature variations for the North American Stations have been determined separately from the average

Table 1.

Name	Latitude	Longitude	Years	Name	Latitude	Longitude	Years
Tartu	58° 23′ N	26° 43′ E	1866—1930	Bogoslovsk	59° 45′ N	60° 01′ E	1871—1930
Helsingfors	60° 10′ N	24° 57′ E	1881—1934	Barnaoul	53° 20′ N	83° 48′ E	1871—1930
Oulu	65° 01′ N	25° 28′ E	1881—1933	Touroukhansk	65° 55′ N	87° 38′ E	1878—1930
Haparanda	65° 50′ N	24° 09′ E	1873—1932	Verkhoiansk	67° 33′ N	133° 24′ E	1884—1920
Stockholm	59° 21′ N	18° 04′ E	1873—1932	Thorshavn	62° 02′ N	6° 45′ W	1874—1924
Vardö	70° 22′ N	31° 06′ E	1868—1934	Grimsey	66° 33′ N	17° 58′ W	1875—1934
Bergen	60° 24′ N	5° 19′ E	1861—1934	Stykkisholm	65° 05′ N	22° 46′ W	1874—1934
Copenhagen	55° 41′ N	12° 33′ E	1874—1933	Ivigtut	61° 12′ N	48° 10′ W	1875—1932
Königsberg	54° 44′ N	20° 34′ E	1870—1932	Jacobshavn	69° 13′ N	51° 02′ W	1874—1932
Hamburg	53° 38′ N	10° 00′ E	1876—1932	Upernivik	72° 47′ N	56° 07′ W	1874—1932
Munich	48° 09′ N	11° 34′ E	1879—1933	Toronto	43° 40′ N	79° 24′ W	1841—1930
Aberdeen	57° 10′ N	2° 06′ W	1869—1934	Buffalo	42° 53′ N	78° 50′ W	1885—1934
Valentia	51° 56′ N	10° 15′ W	1869—1934	Detroit	42° 21′ N	83° 03′ W	1885—1934
San Fernando	3 °28′ N	6° 12′ W	1870—1932	Chicago	41° 47′ N	87° 35′ W	1885—1934
Ponta Delgada . . .	37° 44′ N	25° 40′ W	1867—1934	Savannah	32° 04′ N	81° 08′ W	1885—1934
Vienna	48° 15′ N	16° 22′ E	1864—1929	New Orleans	29° 57′ N	90° 04′ W	1885—1934
Graz	47° 04′ N	15° 28′ E	1886—1929	Bismarck	46° 47′ N	100° 38′ W	1885—1934
Budapest	47° 31′ N	19° 01′ E	1870—1933	Portland	45° 32′ N	122° 41′ W	1885—1934
Milan	45° 27′ N	9° 15′ E	1851—1933	San Francisco . . .	37° 48′ N	122° 26′ W	1885—1934
Prague	50° 05′ N	14° 25′ E	1865—1932	San Diego	32° 43′ N	117° 10′ W	1885—1934
Warsaw	52° 13′ N	21° 02′ E	1870—1931	Bombay	18° 54′ N	72° 49′ E	1847—1933
Moscow	55° 50′ N	37° 33′ E	1879—1930	Batavia	6° 11′ S	106° 50′ E	1866—1930
Sverdlovsk	56° 50′ N	60° 38′ E	1871—1930				

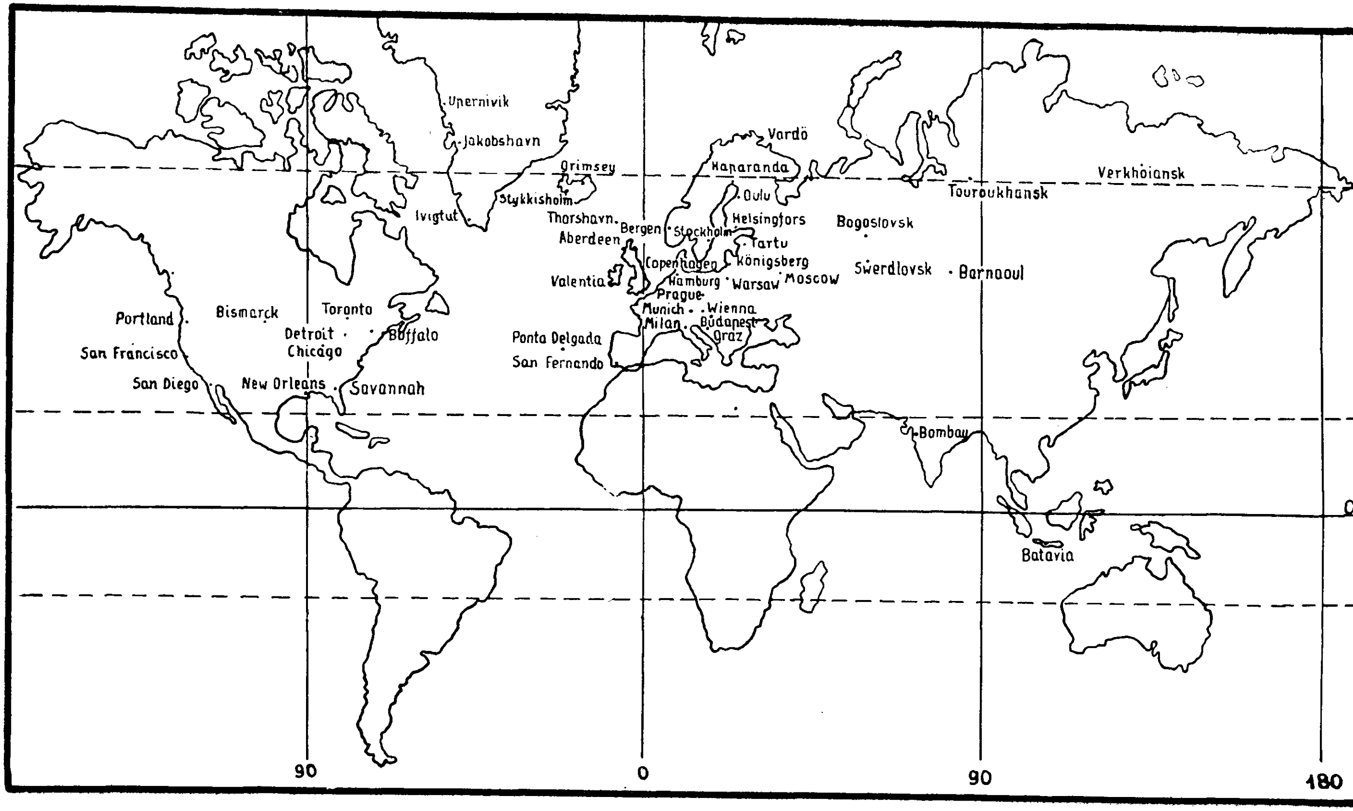

Fig. 1. Distribution of Meteorological Stations.

Table 2.

Name	Δt	ε	Name	Δt	ε
Tartu	0.7	0.5	Bogoslovsk . . .	0.7	0.7
Helsingfors . . .	0.6	0.7	Barnaoul	2.7	0.6
Oulu	0.3		Touroukhansk . .	4.0	0.6
Haparanda . . .	1.6	0.9	Verkhoiansk . .	4.2	1.0
Stockholm	1.2	0.6	Thorshavn . . .	0.1	
Vardö	1.4	0.5	Grimsey	0.9	0.7
Bergen	2.5	0.5	Stykkisholm . . .	1.5	0.6
Copenhagen . . .	1.9	0.5	Ivigtut	1.4	0.7
Königsberg . . .	1.3	0.7	Jacobshavn . . .	1.6	1.3
Hamburg	2.6	0.6	Upernivik	1.7	1.3
Munich	4.4	0.7	Toronto	-0.1	
Aberdeen	1.2	0.3	Buffalo	0.8	0.8
Valentia	0.7	0.3	Detroit	1.1	0.8
San Fernando . .	0.1		Chicago	2.6	1.0
Ponta Delgada . .	0.5	0.2	Savannah	2.3	0.6
Vienna	3.4	0.6	New Orleans . . .	2.0	0.6
Graz	3.1	0.7	Bismarck	3.6	1.4
Budapest	3.5	0.6	Portland	1.2	0.6
Milan	2.6	0.4	San Francisco . .	—0.2	0.4
Prague	2.0	0.6	San Diego	0.2	0.4
Warsaw	2.3	0.7	Bombay	0.4	0.2
Moscow	2.1	1.0	Batavia	0.9	0.1
Sverdlovsk . . .	2.6	0.8			

max. and min. temperatures. In Table 2 as well as in the following tables we find the arithmetical means of the variations determined from the average max. and min. temperatures.

The variations of temperatures for January given in Table 2 are graphically represented in Fig. 2. The regions where the rise in temperature surpasses its double mean error are marked with thin lines, whereas the dots denote the regions where the fall of temperature surpasses its double mean error. The regions where the variation of temperature surpasses its fourfold mean error are marked with thick lines or corresponding thick dots. As seen from the map a considerable rise in temperature is observed in West Europe and North-East Asia. The British Islands, Spain, the Azores, Iceland, Greenland, the

Western Coast of North America as well as the West Indies show but a slight rise in temperature.

Temperature variations can also be determined by means of frequency-curves [1]). The calculation of temperature frequencies being very troublesome the latter have only been reckoned for January for Hamburg (Fig. 3) and Vienna (Fig. 4).

In compiling the distribution of temperature the three daily observations have equally been taken into consideration. One degree C. was taken as a unit for the division of tempe-

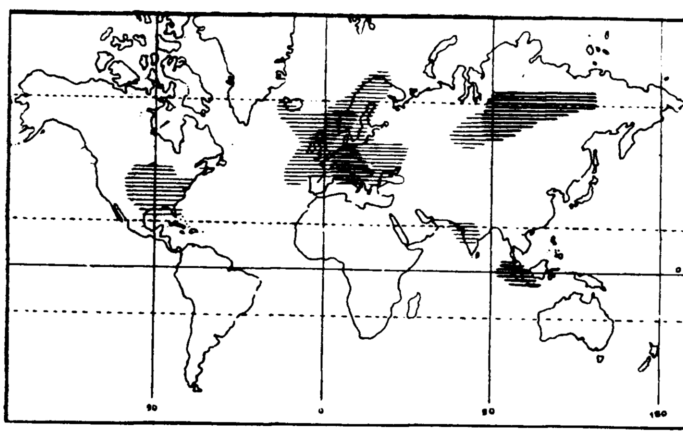

Fig. 2. Variations of Temperatures for January.

ratures into groups. In determining the climatic changes the frequencies of air temperature have been composed for both the abovementioned half-periods and expressed in a percentage of the whole number of observations for each period. Both temperature distributions are graphically represented by broken lines. The solid line denotes the frequency for the first half-period, the dotted line — for the second. The mean error of frequency for the first half-period has been calculated by means of the formula

$$\sigma = 100 \sqrt{\frac{pq}{S}}$$

where S denotes the whole number of observations, p — the probability that an observation belongs to the i group, q —

[1]) K. Kirde, Meteorological Elements characterized by Frequency-Curves. Scientific Papers of the Meteorological Observatory of the University of Tartu № 1.

the reverse probability ($q = 1 - p$). In order to obtain a clearer survey of the difference in the distribution of temperatures in both half-periods a four σ broad dotted stripe has been drawn in the figures. We see that the line of frequencies

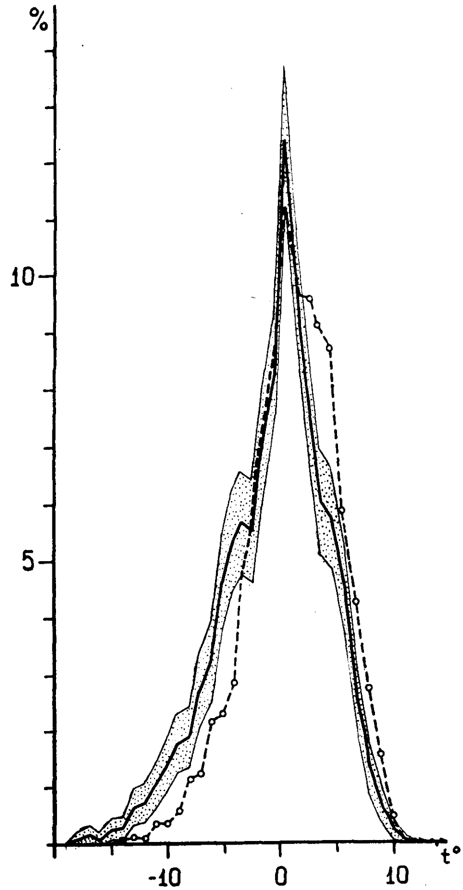

Fig. 3. Frequency of Temperatures for Hamburg in January.

for the second period lies several times beyond the four σ stripe.

These outlying parts are marked by circles in the graphs. We know from the theory of probabilities that 95 % of all the cases must keep within the limits of the four σ and only 5 % of all the cases may lie outside provided that the outward conditions remain unaltered during each trial. As seen from Fig. 3 the distribution of temperature for Hamburg is divided into 33 different groups. The frequencies of the second period can lie outside the four σ but twice. In reality we see

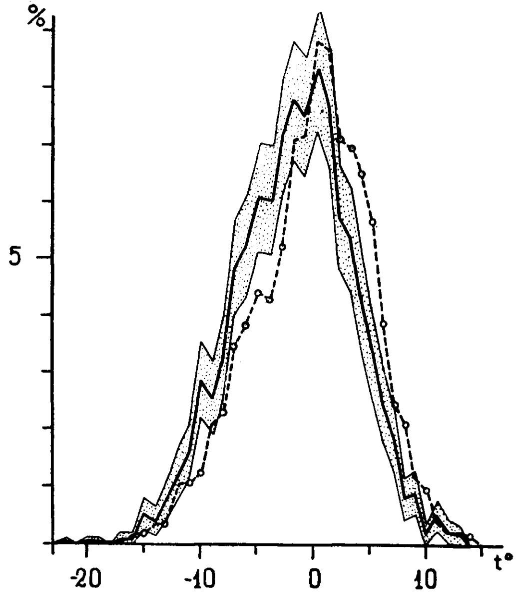

Fig. 4. Frequency of Temperatures for Vienna in January.

that the frequencies of temperature for the second half-period lie 19 times outside the limits of the four σ.

By means of Pearson's term

$$P = \frac{\int_{\chi}^{\infty} e^{-1/2\,\chi^2}\,\chi^{n-1}\,d\chi}{\int_{0}^{\infty} e^{-1/2\,\chi^2}\,\chi^{n-1}\,d\chi}$$

we can easily find the possibility that such a difference in the distribution of temperatures for both half-periods has taken place accidentally without any extraneous influence. In the above term e is the basis of the natural logarithms, n — the number of groups less one,

$$\chi = \Sigma \frac{d^2}{\mu}$$

where d is the difference between the frequencies for each group and μ the frequency for the corresponding group of the first period. We obtain for the required probability for Hamburg:

$$P = 6.10^{-71}$$

which means that such a difference can take place accidentally only once in a period of 5.10^{71} years. For Vienna the corresponding probability $P = 3.10^{-58}$ and the number of years — 10^{59}.

The variations of temperature for the other months have been calculated in the same way. Table 3 gives the variations of temperature for February.

We see in Fig. 5 a considerable rise of temperature in Iceland, Middle North America, and Java. A fall of temperature is observed in Thorshavn, Ireland, Spain, Eastern

Table 3.

Name	Δt	ε	Name	Δt	ε
Tartu	0.3	0.7	Bogoslovsk . . .	1.1	0.9
Helsingfors . . .	0.6	0.8	Barnaoul	2.4	0.8
Oulu	0.8	1.0	Touroukhansk . .	−1.1	0.7
Haparanda . . .	1.9	1.0	Verkhoiansk . . .	0.0	
Stockholm	2.2	0.7	Thorshavn	−0.6	0.3
Vardö	0.9	0.5	Grimsey	2.8	0.6
Bergen	1.5	0.4	Stykkisholm . . .	2.4	0.6
Copenhagen . . .	1.1	0.5	Ivigtut	0.8	0.9
Königsberg . . .	0.4		Jacobshavn . . .	2.7	1.5
Hamburg	0.4		Upernivik	2.8	1.2
Munich	0.9	0.8	Toronto	−0.6	0.4
Aberdeen	0.7	0.4	Buffalo	0.8	0.8
Valentia	−0.8	0.4	Detroit	2.3	0.8
San Fernando . .	−0.3		Chicago	4.7	0.8
Ponta Delgada . .	0.0		Savannah	2.0	0.6
Vienna	1.2	0.7	New Orleans . .	2.4	0.8
Graz	1.3	0.7	Bismarck	7.2	1.0
Budapest	2.4	0.6	Portland	1.6	0.6
Milan	0.7	0.5	San Francisco . .	1.4	0.4
Prague	0.1		San Diego	0.5	0.4
Warsaw	1.3	0.8	Bombay	−0.6	0.2
Moscow	−2.5	0.9	Batavia	0.7	0.1
Sverdlovsk . . .	−0.2	0.8			

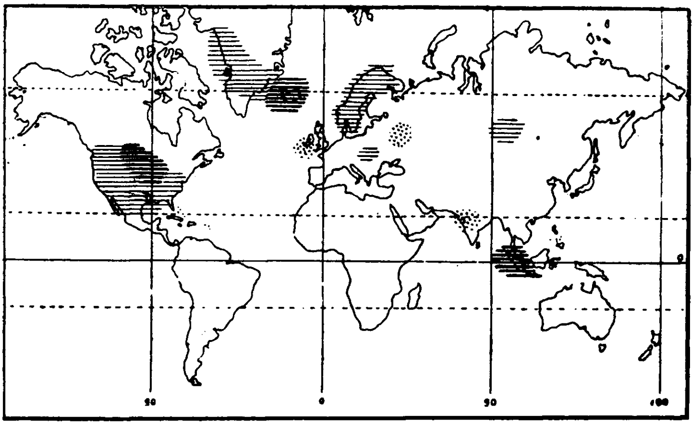

Fig. 5. Variations of Temperatures in February.

Europe, and India. The fall in the average temperature surpasses its fourfold mean error only in Moscow.

The frequency curve of temperature for February has been composed for Stockholm (see Fig. 6).

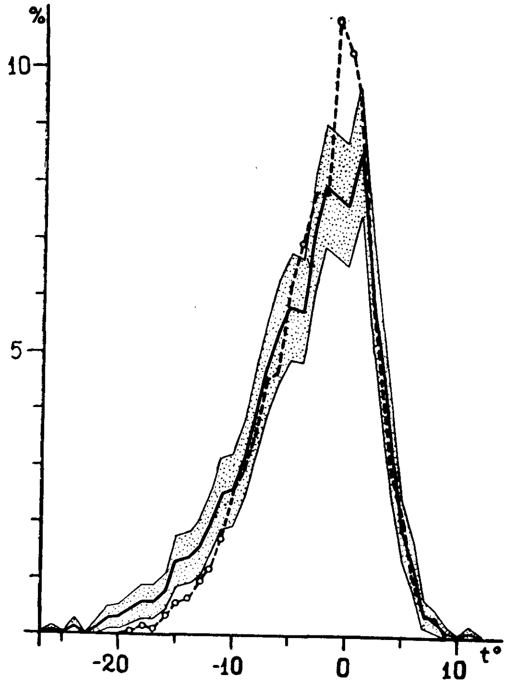

Fig. 6. Frequency of Temperatures for Stockholm in February.

The calculation shows that such a fall in low temperatures can occur accidentally only once in a period of 4.10^{22} years.

As regards the variations of temperature in March, we see from Fig. 7 (Table 4) that a rise of temperature took place in North America (except the Eastern Coast), in Greenland, Iceland, Europe (except the British Islands), and in Java. The greatest rise is observed in Greenland where it surpasses its mean error 6 times. A considerable fall of temperature (—4.7°) was observed only in Siberia.

Table 4.

Name	Δt	ε	Name	Δt	ε
Tartu	1.2	0.5	Bogoslovsk . . .	0.0	
Helsingfors . . .	1.8	0.7	Barnaoul	0.0	
Oulu	2.0	0.7	Touroukhansk . .	—4.7	0.6
Haparanda	3.7	0.7	Verkhoiansk . . .	3.7	1.2
Stockholm	2.2	0.6	Thorshavn	0.3	
Vardö	1.2	0.4	Grimsey	4.3	0.7
Bergen	2.1	0.4	Stykkisholm . . .	3.2	0.6
Copenhagen . . .	1.5	0.2	Ivigtut	1.4	0.8
Königsberg . . .	2.0	0.6	Jacobshavn . . .	6.2	1.2
Hamburg	1.6	0.5	Upernivik	5.1	1.1
Munich	1.9	0.6	Toronto	2.0	0.6
Aberdeen	0.6	0.4	Buffalo	0.1	
Valentia	—0.1		Detroit	1.2	0.8
San Fernando . .	0.0		Chicago	2.1	0.8
Ponta Delgada . .	—0.4	0.2	Savannah	—0.8	0.6
Vienna	2.2	0.5	New Orleans . . .	—0.8	0.6
Graz	2.1	0.5	Bismarck	5.4	1.2
Budapest	2.8	0.5	Portland	1.4	0.6
Milan	1.6	0.3	San Francisco . .	2.6	0.4
Prague	2.2	0.5	San Diego	1.6	0.4
Warsaw	2.0	0.6	Bombay	—0.3	0.2
Moscow	1.4	0.7	Batavia	0.6	0.1
Sverdlovsk . . .	0.3	0.7			

The frequency curve (Fig. 8) represents the variations of temperature at Jacobshavn, where a marked warming has been registered.

The reckoning of the corresponding probability ($P = 10^{-54}$) gives for the accidental occurrence of such warming a period of 3.10^{55} years.

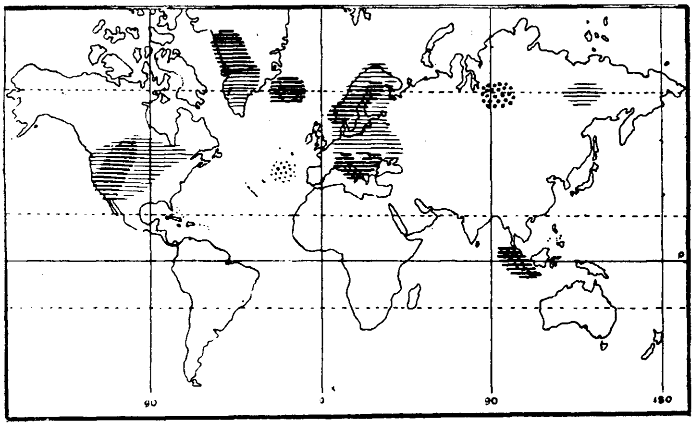

Fig. 7. Variations of Temperatures in March.

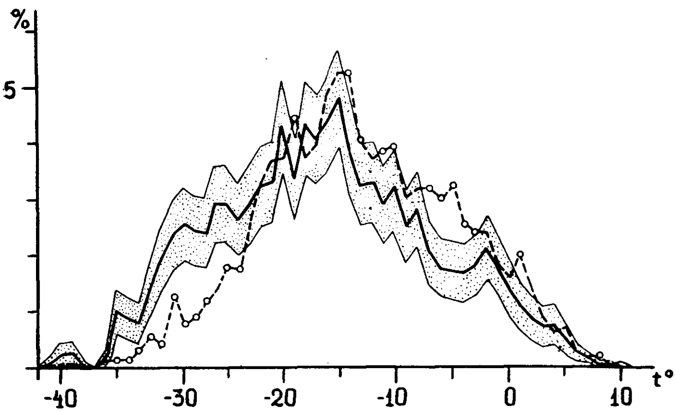

Fig. 8. Frequency of Temperatures for Jacobshavn in March.

The data of the variations of temperature in April differ considerably from those in March (Table 5).

Table 5.

Name	Δt	ε	Name	Δt	ε
Tartu	1.2	0.4	Bogoslovsk . . .	3.7	0.6
Helsingfors . . .	1.2	0.4	Barnaoul	1.4	0.7
Oulu	—0.3		Touroukhansk . .	2.1	0.3
Haparanda	2.0	0.4	Verkhoiansk . . .	2.4	1.1

Name	Δt	ε	Name	Δt	ε
Stockholm	1.2	0.4	Thorshavn	—1.6	0.3
Vardö	0.4	0.4	Grimsey	1.4	0.5
Bergen	0.4		Stykkisholm . . .	0.6	0.5
Copenhagen . . .	1.2	0.3	Ivigtut	0.5	
Königsberg . . .	1.7	0.5	Jacobshavn . . .	3.1	1.0
Hamburg	0.3		Upernivik	2.1	0.8
Munich	0.5	0.4	Toronto	2.4	0.4
Aberdeen	—0.4		Buffalo	—0.6	0.6
Valentia	—1.5	0.2	Detroit	0.4	
San Fernando . .	0.0		Chicago	2.0	0.6
Ponta Delgada . .	—1.5	0.2	Savannah	1.3	0.4
Vienna	—0.2		New Orleans . . .	0.8	0.4
Graz	1.0	0.4	Bismarck	0.7	0.8
Budapest	—0.1		Portland	1.2	0.6
Milan	0.2		San Francisco . .	1.3	0.4
Prague	0.4	0.4	San Diego	1.0	0.4
Warsaw	1.1	0.5	Bombay	0.4	0.2
Moscow	2.5	0.6	Batavia	0.7	0.1
Sverdlovsk . . .	3.7	0.8			

Vast regions of a rise in temperature spread over North-East Europe, North Asia, Java, and Greenland (Fig. 9). The region of decrease takes the form of a stripe stretching from the Azores across the British Islands to the Faroe Isles. In West Europe we observe only a slight warming. The frequency curve of

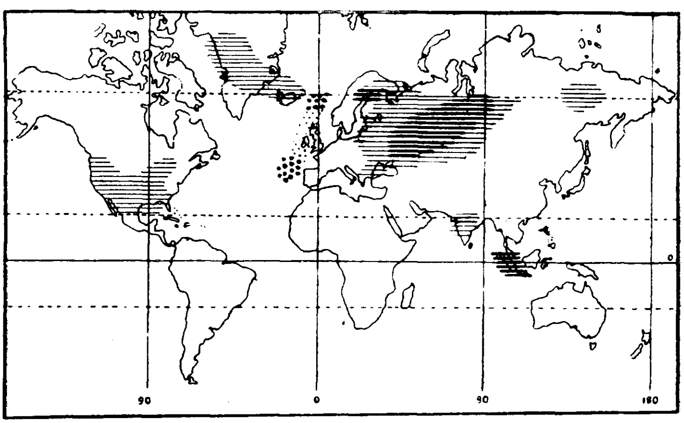

Fig. 9. Variations of Temperatures for April.

Haparanda (Fig. 10) shows a rise of high — and a decrease of low temperatures.

The probability of such a variation is only 2.10^{-24} which shows that the accidental occurrence of such a variation is possible only once in a period of 10^{25} years.

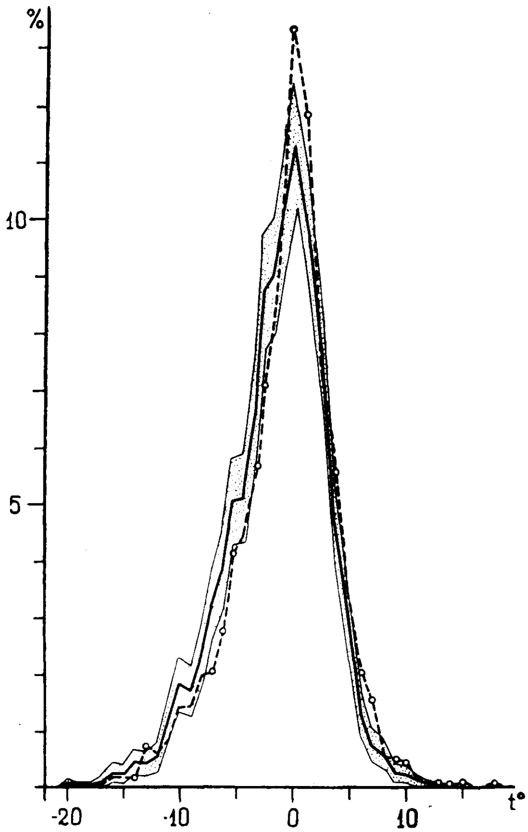

Fig. 10. Frequency of Temperatures for Haparanda in April.

Table 6 and the corresponding Fig. 11 show that the region of the warming in May lies in Middle Europe, where in many places it surpasses its fourfold mean error.

Other regions where the temperature has risen are found in North America, Greenland, and Java. A slight cooling has taken place in the Azores, Faroe Isles, and in East Europe. The variation of temperature on the basis of the frequency curve is given for Hamburg in Fig. 12, which shows a slight diminution of the low — and a rise of the high temperatures.

Table 6.

Name	Δt	ε	Name	Δt	ε
Tartu	1.8	0.4	Bogoslovsk . . .	—0.4	
Helsingfors . . .	0.2		Barnaoul	0.7	0.5
Oulu	—0.6	0.5	Touroukhansk . .	1.2	0.3
Haparanda . . .	1.3	0.4	Verkhoiansk . . .	—0.1	
Stockholm	1.2	0.4	Thorshavn . . .	—1.4	0.3
Vardö	0.6	0.4	Grimsey	1.2	0.4
Bergen	0.4		Stykkisholm . . .	0.6	0.4
Copenhagen . . .	1.7	0.3	Ivigtut	1.4	0.4
Königsberg . . .	3.3	0.5	Jacobshavn . . .	2.5	0.5
Hamburg	2.2	0.4	Upernivik	2.6	0.5
Munich	3.0	0.5	Toronto	2.3	0.4
Aberdeen	0.8	0.2	Buffalo	—0.3	0.4
Valentia	0.0		Detroit	0.4	0.6
San Fernando . .	0.6	0.2	Chicago	2.3	0.6
Ponta Delgada . .	—0.9	0.2	Savannah	—0.4	0.4
Vienna	1.3	0.4	New Orleans . .	0.3	0.4
Graz	1.6	0.5	Bismarck	1.0	0.8
Budapest	2.2	0.4	Portland	1.1	0.6
Milan	1.7	0.3	San Francisco . .	1.3	0.4
Prague	3.0	0.4	San Diego	0.7	0.4
Warsaw	2.5	0.5	Bombay	0.2	
Moscow	—2.0	0.7	Batavia	0.6	0.1
Sverdlovsk . . .	—1.6	0.6			

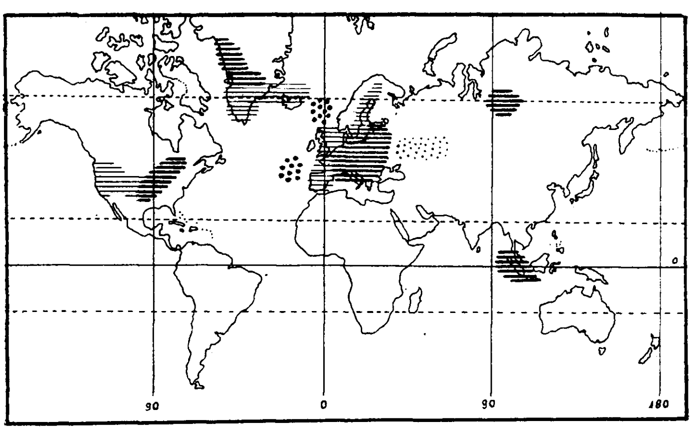

Fig. 11. Variations of Temperatures for May.

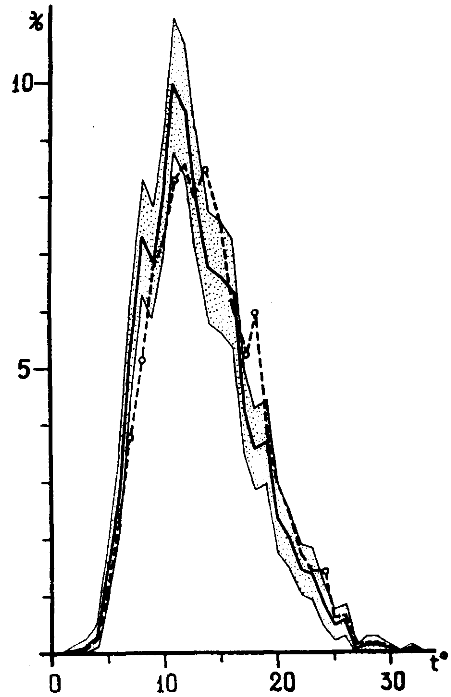

Fig. 12. Frequency of Temperatures for Hamburg in May.

Such a change of temperature can occur without any extraneous influences according to the above-mentioned probability ($P = 3.10^{-16}$) only once in 10^{17} years.

The data of the variations of temperatures in June (see Table 7) differ from those of the preceding month.

Besides the regions where the rise of temperature surpasses its fourfold mean error, there are also some places with an equally intensive diminution of temperature.

Such a cooling is observed in the Azores, Faroe Isles, South Finland, and Estonia. (Fig. 13). The regions with an increase of temperature like that of the preceding month spread over North America, Greenland, Siberia, and Java. Only in Portland, Touroukhansk, and Java (Batavia) does the increase of temperature exceed its fourfold mean error.

The frequency curves for June are given for Tartu (Fig. 14) and Hamburg (Fig. 15).

Table 7.

Name	Δt	ε	Name	Δt	ε
Tartu	—1.7	0.2	Bogoslovsk	1.4	0.4
Helsingfors	—1.8	0.4	Barnaoul	0.1	
Oulu	—1.5	0.5	Touroukhansk	2.0	0.4
Haparanda	—0.3	0.4	Verkhoiansk	2.4	0.9
Stockholm	—1.2	0.4	Thorshavn	—1.0	0.2
Vardö	0.4		Grimsey	1.0	0.4
Bergen	—1.2	0.4	Stykkisholm	0.8	0.3
Copenhagen	—0.3	0.3	Ivigtut	0.6	0.4
Königsberg	1.4	0.4	Jacobshavn	0.7	0.4
Hamburg	—0.6	0.4	Upernivik	0.9	0.4
Munich	0.2		Toronto	2.6	0.3
Aberdeen	—0.4	0.3	Buffalo	—1.2	0.4
Valentia	—0.9	0.2	Detroit	0.4	0.6
San Fernando	0.0		Chicago	1.4	0.6
Ponta Delgada	—1.5	0.2	Savannah	0.1	0.3
Vienna	0.4		New Orleans	0.8	0.2
Graz	0.3		Bismarck	1.7	0.8
Budapest	1.0	0.4	Portland	1.8	0.4
Milan	0.8	0.3	San Francisco	1.4	0.4
Prague	0.4	0.4	San Diego	0.6	0.2
Warsaw	—1.5	0.4	Bombay	0.6	0.1
Moscow	—0.8	0.5	Batavia	0.9	0.1
Sverdlovsk	1.4	0.4			

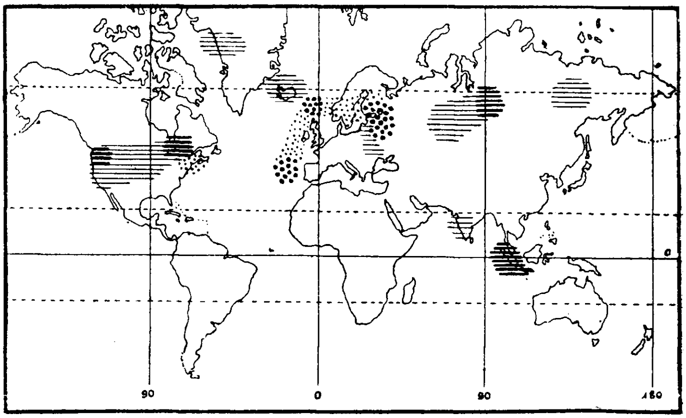

Fig. 13. Variations of Temperatures for June.

Both figures show a considerable increase of the low — and a decrease of the high temperatures.

The lengths of the periods for the accidental occurrence of such changes according to the above mentioned probabilities:

$$\begin{array}{ll} \text{Tartu} & P = 7.10^{-26} \\ \text{Hamburg} & P = 10^{-20} \end{array} \quad \text{and}$$

are 4.10^{26} years for Tartu, and 3.10^{21} years for Hamburg.

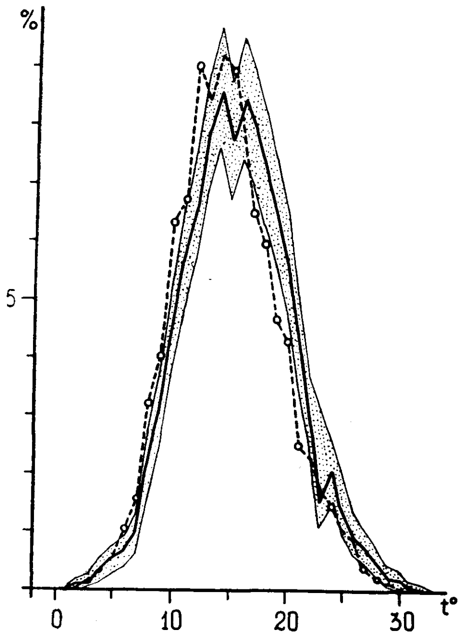

Fig. 14. Frequency of Temperatures for Tartu in June.

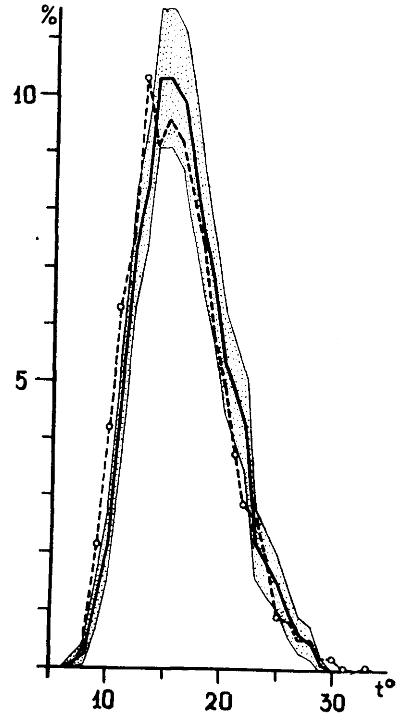

Fig. 15. Frequency of Temperatures for Hamburg in June.

The picture of the variations of temperature for July is similar to that for June (Table 8).

Here also we see some regions with an intensive cooling surpassing its mean error at least four times, but besides the Azores, we must also point out Warsaw and Moscow (Fig. 16). Among the stations with an augmentation of temperature

Table 8.

Name	Δt	ε	Name	Δt	ε
Tartu	—0.1		Bogoslovsk . . .	—0.6	0.5
Helsingfors . . .	1.6	0.5	Barnaoul	—1.0	0.4
Oulu	1.3	0.5	Touroukhansk . .	0.4	
Haparanda . . .	1.6	0.4	Verkhoiansk . . .	2.2	0.8
Stockholm	—0.4	0.4	Thorshavn	—0.5	0.2
Vardö	1.0	0.3	Grimsey	1.2	0.5
Bergen	—0.3		Stykkisholm . . .	0.6	0.2
Copenhagen . . .	1.0	0.3	Ivigtut	0.2	
Königsberg . . .	2.2	0.4	Jacobshavn . . .	0.1	
Hamburg	1.2	0.3	Upernivik	0.6	0.3
Munich	0.2		Toronto	2.0	0.3
Aberdeen	—0.2		Buffalo	—0.4	0.4
Valentia	—0.1		Detroit	1.0	0.4
San Fernando . .	0.0		Chicago	1.7	0.4
Ponta Delgada . .	—1.7	0.2	Savannah	0.2	0.3
Vienna	0.2		New Orleans . .	1.0	0.2
Graz	0.5	0.3	Bismarck	1.4	0.6
Budapest	0.8	0.3	Portland	0.9	0.4
Milan	0.1		San Francisco . .	1.6	0.4
Prague	0.7	0.4	San Diego	1.0	0.4
Warsaw	—1.1	0.3	Bombay	0.5	0.1
Moscow	—2.5	0.5	Batavia	1.2	0.1
Sverdlovsk . . .	—1.0	0.5			

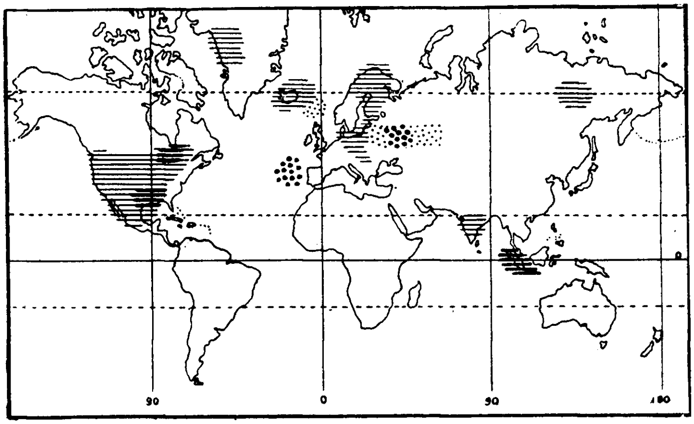

Fig. 16. Variations of Temperatures for July.

Table 9.

Name	Δt	ε	Name	Δt	ε
Tartu	—0.5	0.3	Bogoslovsk . . .	—0.1	
Helsingfors . . .	1.0	0.4	Barnaoul	0.0	
Oulu	0.1		Touroukhansk . .	1.3	0.3
Haparanda . . .	0.6	0.3	Verkhoiansk . . .	3.0	0.6
Stockholm	0.0		Thorshavn . . .	—0.7	0.2
Vardö	0.4		Grimsey	0.5	0.4
Bergen	—0.4		Stykkisholm . . .	0.8	0.3
Copenhagen . . .	0.6	0.3	Ivigtut	1.2	0.2
Königsberg . . .	1.9	0.3	Jacobshavn . . .	1.7	0.3
Hamburg	0.3		Upernivik	2.3	0.4
Munich	0.6	0.3	Toronto	0.9	0.2
Aberdeen	0.2		Buffalo	—0.2	0.6
Valentia	0.0		Detroit	0.8	0.4
San Fernando . .	0.7	0.2	Chicago	0.8	0.4
Ponta Delgada . .	—1.3	0.1	Savannah	0.4	0.4
Vienna	0.7	0.4	New Orleans . .	1.0	0.2
Graz	0.0		Bismarck	0.4	
Budapest	0.9	0.4	Portland	1.6	0.4
Milan	1.0	0.3	San Francisco . .	1.2	0.4
Prague	0.7	0.3	San Diego	—0.2	0.3
Warsaw	—1.2	0.3	Bombay	0.4	0.1
Moscow	—1.0	0.5	Batavia	0.9	0.1
Sverdlovsk . . .	—0.7	0.4			

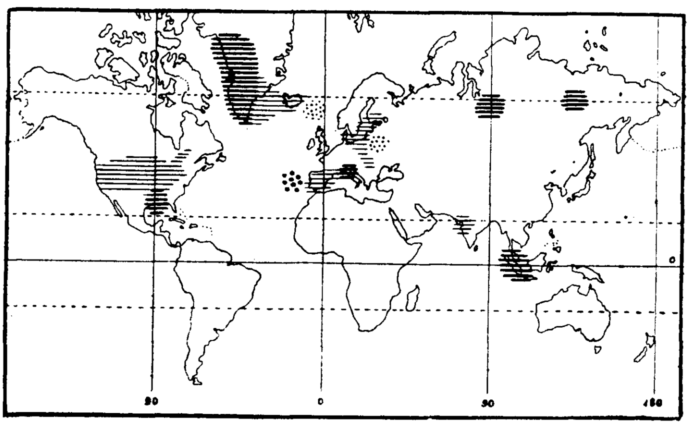

Fig. 17. Variations of Temperatures for August.

only Batavia shows an increase surpassing its fourfold mean error. A slight warming is observed in North America, Iceland, Finland, and Middle Europe.

Table 9 and the corresponding chart for August (Fig. 17) show an intensive warming at a large number of stations, such as Greenland, North America, Siberia, and Java.

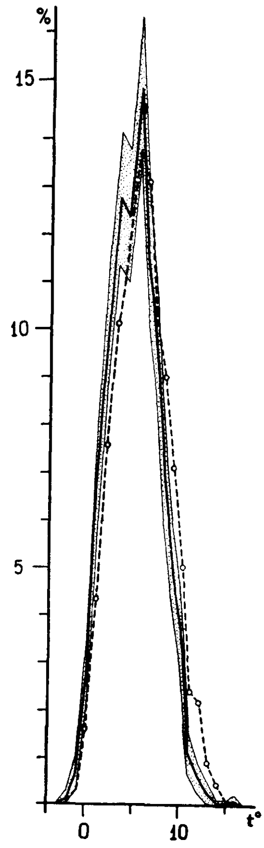

Fig. 18. Frequency of Temperatures for Upernivik in August.

Among the stations which show a fall of temperature, Moscow alone is characterised by a comparatively small mean error. The frequency curve for Upernivik in Greenland (Fig. 18) shows a marked increase of temperature in almost all groups. On the basis of the reckoned probability

$$P = 3.10^{-76}$$

this may happen only once in 10^{77} years.

The data for September are almost identical with those for August (see Table 10).

Table 10.

Name	Δt	ε	Name	Δt	ε
Tartu	—0.2	0.2	Bogoslovsk	0.5	0.5
Helsingfors	0.2		Barnaoul	—0.7	0.3
Oulu	0.1		Touroukhansk	2.6	0.3
Haparanda	0.0		Verkhoiansk	—0.2	
Stockholm	—0.8	0.2	Thorshavn	—0.4	0.2
Vardö	0.7	0.3	Grimsey	—0.6	0.4
Bergen	—0.4		Stykkisholm	—0.4	0.3
Copenhagen	0.0		Ivigtut	1.0	0.3
Königsberg	1.3	0.3	Jacobshavn	1.4	0.5
Hamburg	—0.1		Upernivik	1.9	0.3
Munich	0.4		Toronto	2.2	0.4
Aberdeen	—0.2		Buffalo	0.3	0.4
Valentia	—0.1		Detroit	1.0	0.4
San Fernando	0.9	0.6	Chicago	1.8	0.4
Porta Delgada	—1.0	0.2	Savannah	1.7	0.4
Vienna	—0.5	0.4	New Orleans	1.8	0.3
Graz	—0.5	0.4	Bismarck	—0.7	0.6
Budapest	0.5	0.4	Portland	0.6	0.3
Milan	1.3	0.3	San Francisco	1.2	0.4
Prague	—0.2		San Diego	—0.4	0.4
Warsaw	—0.8	0.4	Bombay	0.4	0.1
Moscow	0.6	0.4	Batavia	0.9	0.1
Sverdlovsk	0.3				

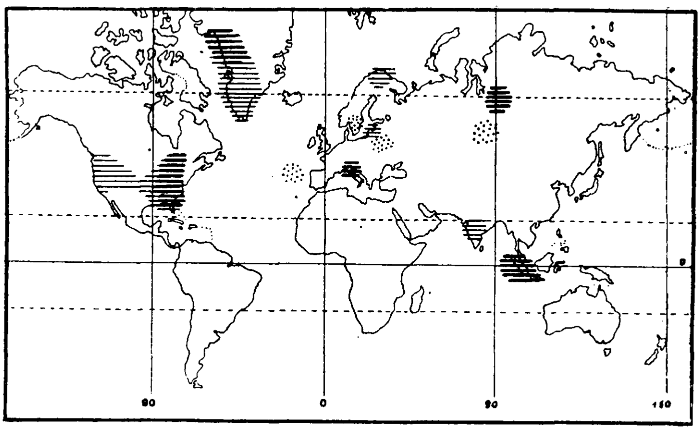

Fig. 19. Variations of Temperatures for September.

In North America, Greenland, Java, and Milan a considerable rise of temperature has taken place, whereas a decrease has been observed only in the Azores and Stockholm (Fig. 19).

A slight cooling is also seen in Iceland, the British Isles, and the Faroe Isles. In Upernivik (Greenland) the augmentation

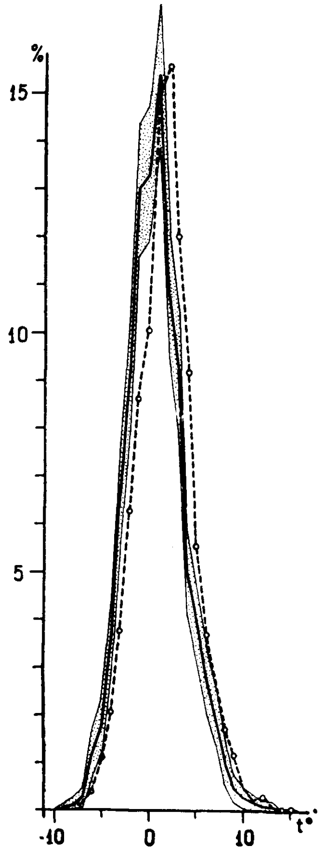

Fig. 20. Frequency of Temperatures for Upernivik in September.

of temperature is as strongly marked in September as it was in August (see Fig. 20).

The reckoning gives for the mentioned probability

$$P = 10^{-68}$$

and for the occurrence of this change, when the outlying conditions remain without alteration, a period of 2.10^{69} years.

Table 11.

Name	Δt	ε	Name	Δt	ε
Tartu	0.2	0.4	Bogoslovsk . . .	—0.5	0.7
Helsingfors . . .	—0.2		Barnaoul	—0.4	0.6
Oulu	—0.1		Touroukhansk . .	2.3	0.4
Haparanda . . .	—0.2		Verkhoiansk . . .	2.3	1.1
Stockholm	0.6	0.4	Thorshavn	0.6	0.4
Vardö	0.0		Grimsey	0.1	
Bergen	0.9	0.3	Stykkisholm . . .	0.4	0.4
Copenhagen . . .	0.9	0.3	Ivigtut	0.5	0.4
Königsberg . . .	1.4	0.4	Jacobshavn . . .	0.1	
Hamburg	0.7	0.4	Upernivik	0.1	
Munich	2.2	0.4	Toronto	2.8	0.4
Aberdeen	1.1	0.3	Buffalo	1.1	0.4
Valentia	—0.9	0.4	Detroit	2.4	0.6
San Fernando . .	1.0	0.3	Chicago	2.8	0.6
Ponta Delgada . .	—0.5	0.2	Savannah . . .	2.2	0.4
Vienna	—0.1		New Orleans . . .	2.7	0.4
Graz	0.9	0.5	Bismarck	0.7	0.8
Budapest	1.2	0.4	Portland	0.7	0.4
Milan	0.5	0.3	San Francisco . .	1.2	0.4
Prague	0.9	0 4	San Diego	0.2	0.3
Warsaw	0.3		Bombay	0.7	0.1
Moscow	—0.5	0.6	Batavia	0.6	0.1
Sverdlovsk . . .	—0.7	0.8			

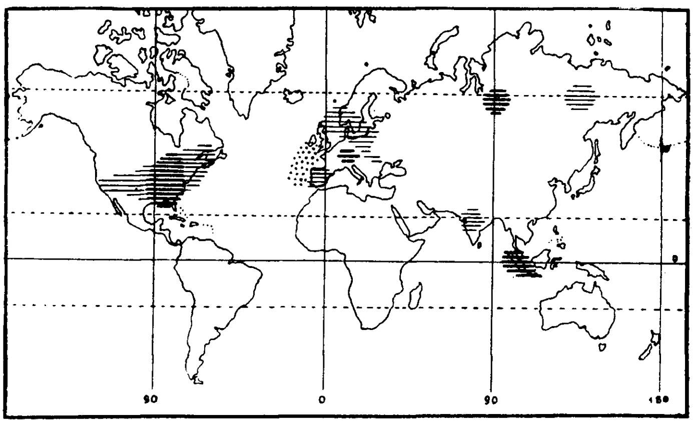

Fig. 21. Variations of Temperatures for October.

The variations of temperature in October differ from those of September and August by the fact that Greenland shows only a slight rise of temperature (Table 11).

Only the stations of the Eastern part of North America, Siberia, and Java are characterised by a rise surpassing its fourfold mean error.

The region of cooling spreads over the Azores and British Isles, but the decrease of temperature surpasses only its double

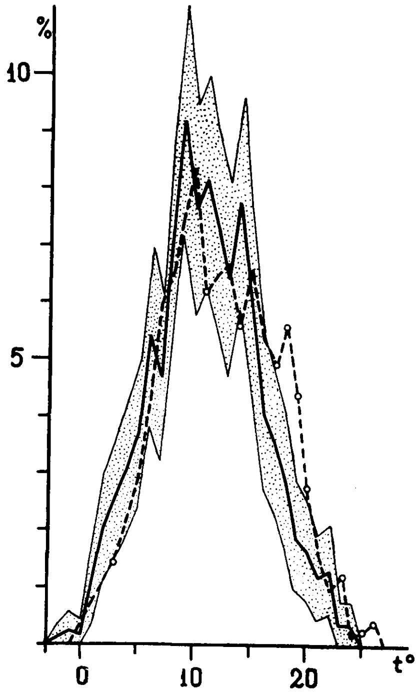

Fig. 22. Frequency of Temperatures for Munich in October.

mean error. The frequency curve of Munich (Fig. 22) shows a slight increase of high temperatures. Such a change can occur according to the reckoned probability

$$P = 2.10^{-14}$$

only once in a period of 10^{15} years.

There is no great difference between the variations of temperature in October and November (Table 12), except for a more marked warming in Greenland.

Table 12.

Name	Δt	ε	Name	Δt	ε
Tartu	1.6	0.4	Bogoslovsk . . .	2.2	0.9
Helsingfors . . .	0.2		Barnaoul	2.6	0.9
Oulu	0.4		Touroukhansk . .	3.0	0.5
Haparanda	1.4	0.8	Verkhoiansk . . .	3.2	1.1
Stockholm	0.4	0.5	Thorshavn	—0.6	0.4
Vardö	1.4	0.4	Grimsey	0.7	0.4
Bergen	1.2	0.4	Stykkisholm . . .	0.6	0.3
Copenhagen . . .	1.0	0.4	Ivigtut	1.1	0.5
Königsberg . . .	0.4		Jacobshavn . . .	1.3	0.7
Hamburg	—0.1		Upernivik	2.3	0.7
Munich	1.1	0.4	Toronto	1.8	0.4
Aberdeen	0.4		Buffalo	0.8	0.4
Valentia	—0.5	0.3	Detroit	0.9	0.6
San Fernando . .	0.2		Chicago	1.9	0.6
Ponta Delgada . .	—0.7	0.2	Savannah	0.1	0.4
Vienna	1.2	0.5	New Orleans . . .	0.6	0.6
Graz	0.3		Bismarck	2.6	1.2
Budapest	1.6	0.5	Portland	0.6	0.4
Milan	1.8	0.3	San Francisco . .	0.9	0.4
Prague	0.0		San Diego	0.8	0.4
Warsaw	0.1		Bombay	0.7	0.2
Moscow	1.0	0.7	Batavia	0.6	0.1
Sverdlovsk . . .	2.2	0.8			

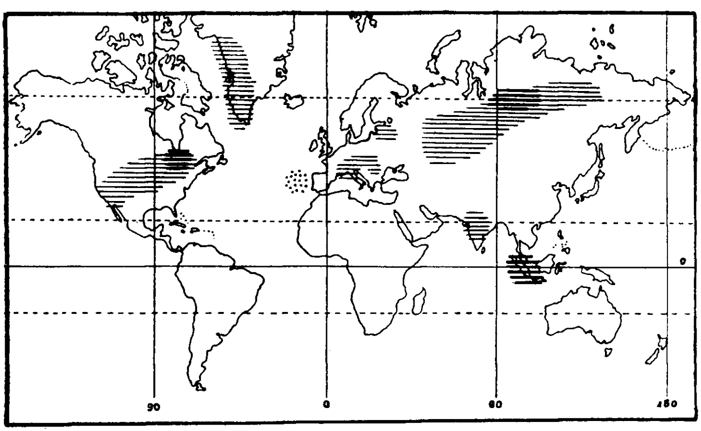

Fig. 23. Variations of Temperatures for November.

The regions showing a considerable rise of temperature lie in North America, Siberia, and Java (see Fig. 23).

The frequency curve of Upernivik (Fig. 24) again presents a strong warming, which on the basis of the corresponding probability

$$P = 8.10^{-59}$$

can accidentally take place only once in 4.10^{59} years.

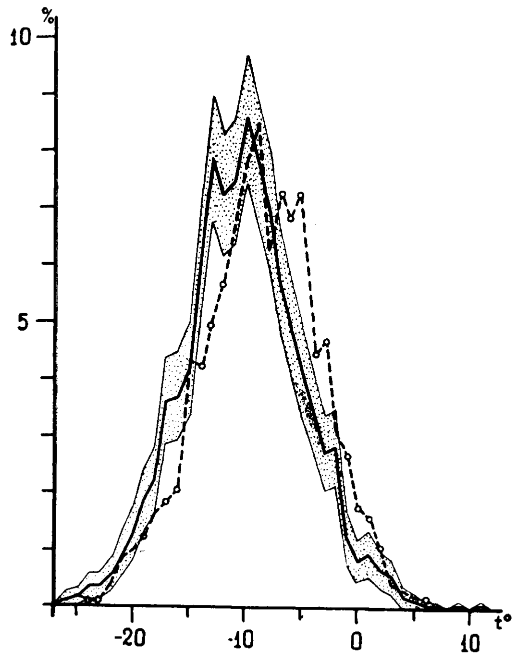

Fig. 24. Frequency of Temperatures for Upernivik in November.

The data for December (Table 13) show a considerable warming in West Europe, North America, Siberia, and Java, where in many stations the rise of temperature surpasses its fourfold mean error.

Table 13.

Name	Δt	ε	Name	Δt	ε
Tartu	1.8	0.4	Bogoslovsk . . .	0.4	
Helsingfors . . .	2.2	0.8	Barnaoul	1.2	1.0
Oulu	1.7	0.9	Touroukhansk . .	—0.4	
Haparanda . . .	3.6	1.0	Verkhoiansk . . .	1.2	1.3

Name	Δt	ε	Name	Δt	ε
Stockholm	2.0	0.6	Thorshavn	0.5	0.4
Vardö	3.2	0.4	Grimsey	0.8	0.5
Bergen	2.4	0.5	Stykkisholm . . .	2.0	0.5
Copenhagen . . .	1.8	0.4	Ivigtut	0.8	0.7
Königsberg . . .	0.8	0.6	Jacobshavn . . .	3.0	0.9
Hamburg	2.5	0.5	Upernivik	2.8	1.0
Munich	3.6	0.7	Toronto	2.6	0.4
Aberdeen	1.5	0.4	Buffalo	0.3	
Valentia	—0.2		Detroit	0.6	0.6
San Fernando . .	1.1	0.3	Chicago	0.8	0.8
Ponta Delgada . .	0.0		Savannah	1.8	0.6
Vienna	2.5	0.6	New Orleans . . .	2.1	0.6
Graz	3.1	0.5	Bismarck	—0.2	
Budapest	4 5	0.7	Portland	—0.4	0.4
Milan	2.7	0.4	San Francisco . .	0.2	0.4
Prague	2.0	0.6	San Diego	—0.7	0.4
Warsaw	2.4	0.6	Bombay	0.2	
Moscow	1.2	0.8	Batavia	0 9	0.1
Sverdlovsk . . .	3.2	1.0			

The regions with a cooling do not contain any stations at which the decrease of temperature exceeds its twofold mean error (Fig. 25).

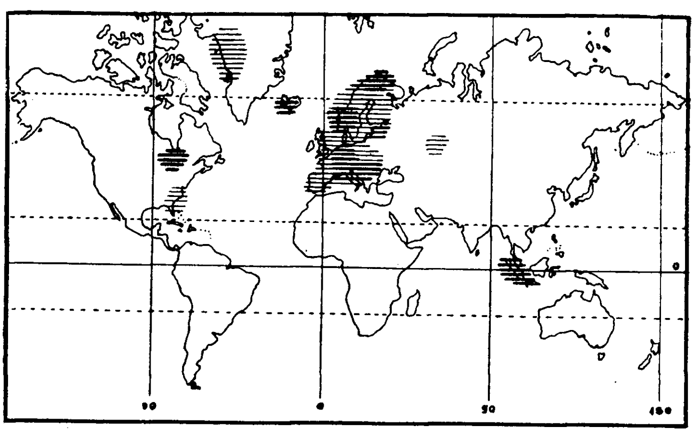

Fig. 25. Variations of Temperatures for December.

The frequency curves are composed for Haparanda and for Jacobshavn (Fig. 26 and Fig. 27).

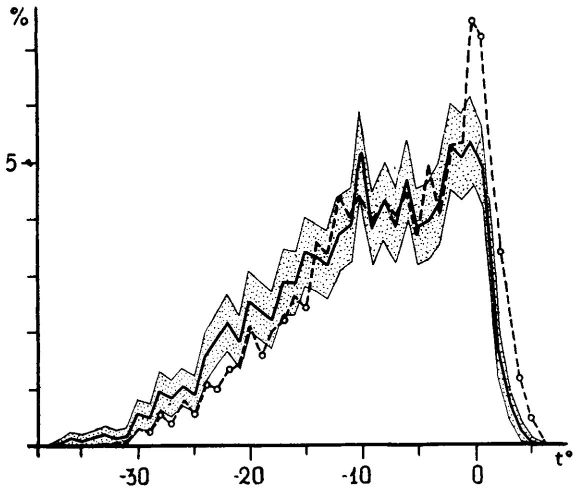

Fig. 26. Frequency of Temperatures for Haparanda in December.

They both show an increase of high temperatures, which gives the corresponding probability for

Haparanda $P = 3.10^{-33}$ and
Jacobshavn $P = 10^{-51}$.

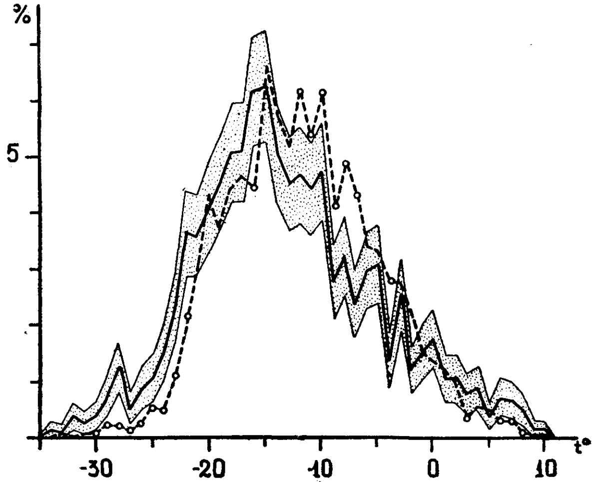

Fig. 27. Frequency of Temperatures for Jacobshavn in December.

The accidental occurrence of these changes requires for Haparanda a period of 10^{34} years, for Jacobshavn — 3.10^{52} years.

In order to determine more exactly the change of temperature for the discussed period, we have reckoned the variations of yearly amplitudes and the shifting of the maximal and minimal points in the yearly range of temperature. For this purpose the whole period of observation was divided into groups of 10 years each. By means of the polynom

$$y = a_0 + a_1 x + a_2 x^2 + a_3 x^3$$

we have calculated for each ten years' period the moments of the highest and lowest temperature in the yearly range for each station. Harmonic analysis was not applied because it takes all the average monthly temperatures equally into con-

Table 14.

Name	Δd	ε	Name	Δd	ε
Tartu	10.2	1.6	Bogoslovsk	—4.1	2.2
Helsingfors	11.5	1.8	Barnaoul	—0.9	1.8
Oulu	7.3	1.2	Touroukhansk	9.6	3.0
Haparanda	3.1	2.0	Verkhoiansk	13.5	2.0
Stockholm	9.6	2.0	Thorshavn	0.0	
Vardö	—9.1	4.2	Grimsey	4.5	2.8
Bergen	15.1	4.0	Stykkisholm	1.3	2.8
Copenhagen	4.1	2.8	Ivigtut	19.6	6.2
Königsberg	11.3	3.0	Jacobshavn	15.7	1.8
Hamburg	15.6	4.2	Upernivik	5.2	1.8
Munich	0.1		Toronto	—4.7	1.4
Aberdeen	7.8	2.0	Buffalo	5.0	1.6
Valentia	—3.0	3.4	Detroit	11.8	1.8
San Fernando	7.0	3.0	Chicago	10.0	3.8
Ponta Delgada	0.0		Savannah	3.0	1.4
Vienna	3.2	4.2	New Orleans	2.0	1.0
Graz	1.1	2.6	Bismarck	4.8	4.0
Budapest	—0.9	1.6	Portland	—0.8	1.6
Milan	9.6	2.0	San Francisco	—3.7	4.0
Prague	2.2	2.0	San Diego	—18.2	3.4
Warsaw	16.1	3.0	Bombay	5.0	2.6
Moscow	2.4	3.6	Batavia	0.3	0.7
Sverdlovsk	—9.5	1.6			

Table 15.

Name	Δd	ε	Name	Δd	ε
Tartu	9.6	6.4	Bogoslovsk	9.4	5.2
Helsingfors	—16.8	2.6	Barnaoul	—4.2	2.8
Oulu	3.2	5.8	Touroukhansk	—2.2	3.6
Haparanda	—3.8	3.4	Verkhoiansk	4.4	4.8
Stockholm	—11.1	4.4	Thorshavn	—15.0	6.6
Vardö	—2.0	2.2	Grimsey	—43.8	11.2
Bergen	—16.6	6.4	Stykkisholm	—41.1	11.2
Copenhagen	6.3	2.4	Ivigtut	—17.8	4.0
Königsberg	4.7	5.8	Jacobshavn	—17.4	3.0
Hamburg	26.2	4.8	Upernivik	—8.6	6.8
Munich	12.0	4.6	Toronto	—3.5	2.4
Aberdeen	29.6	11.2	Buffalo	—9.6	2.2
Valentia	17.5	15.2	Detroit	—10.5	1.2
San Fernando	—4.4	6.0	Chicago	—25.2	4.0
Ponta Delgada	0.0		Savannah	0.8	5.0
Vienna	22.9	5.2	New Orleans	0.9	6.4
Graz	7.4	5.2	Bismarck	—31.8	4.2
Budapest	14.4	4.4	Portland	—21.9	2.0
Milan	12.0	3.0	San Francisco	—21.0	3.4
Prague	20.4	2.8	San Diego	—0.2	0.8
Warsaw	14.4	5.0	Bombay	7.4	3.2
Moscow	5.7	4.2	Batavia	0.1	0.7
Sverdlovsk	5.2	5.6			

sideration, whereas in our case we are interested only in the maximal and minimal temperatures of the annual range. The coefficients in the abovegiven polynom were determined by means of least squares. We find the moment of the highest temperature from the monthly averages of May, June, July, August, and September; the moment of the lowest temperature is found from the averages of December, January, February, March, and April. On the basis of these moments for each ten years' period the shifting of the highest and lowest points in the yearly range of temperatures has been reckoned for each station by means of least squares. For the stations of America the monthly average max. temperatures have been used for determining the variation of the maximal points and the monthly average minimum temperatures for the variation of the minimal point. These data expressed in days (Δd) are given in tables 14 (Shifting of max. temperature) and 15 (Shifting of min. temperature) with their corresponding mean errors (ε). In both tables a minus sign (—) is put before the number of days showing a premature occurrence of the extreme points of temperature in the yearly range. In order to obtain a better

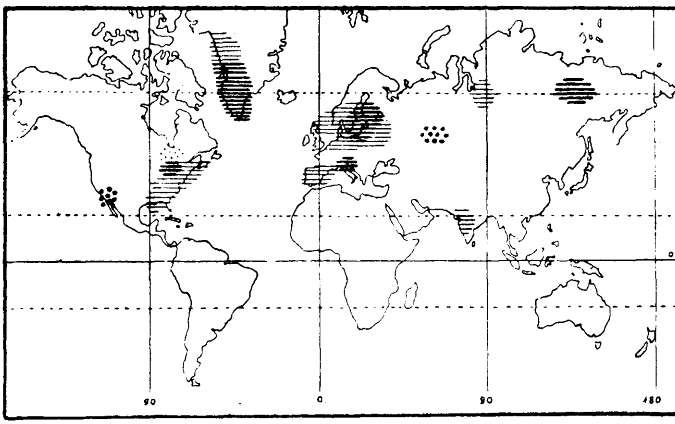

Fig. 28. Shifting of Max. Temperature.

survey the variations of the maximal and minimal points expressed in days are represented graphically. In Fig. 28 the thin lines denote the districts, where the retardation of the max. temperature surpasses its double mean error, and the thick lines — the districts, where it surpasses its fourfold mean

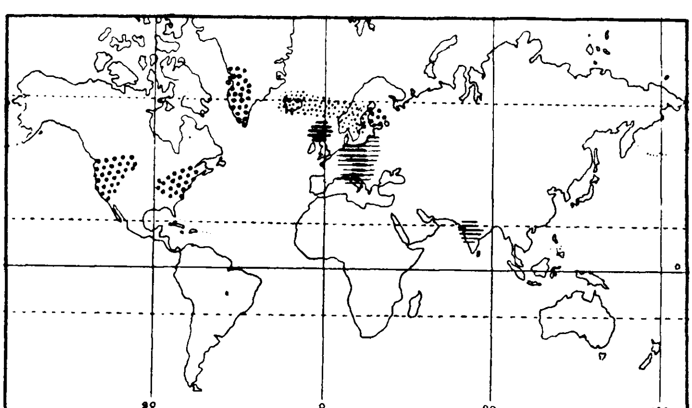

Fig. 29. Shifting of Min. Temperature.

error. The thin dots mark the regions, where the premature occurrence of the max. temperature surpasses its double mean error, the thick dots — the regions, where it surpasses its fourfold mean error. In the same way the shifting of min. temperature is represented in Fig. 29.

As can be seen from the figures the maximal point of the temperature in the yearly range is late in Europe (except Vardö), partly in Siberia, India, Greenland, and on the East Coast of North America. An advance of the maximal point is observed in the Eeast of North America. As regards the shifting of the minimal point, a considerable retardation is seen in Middle Europe and an advance is marked in North America, Greenland, Iceland, and Scandinavia.

The change of the amplitude of the annual range of temperature has been found in the same way by means of

Table 16.

Name	Δt	ε	Name	Δt	ε
Tartu	—2.0	0.7	Bogoslovsk . . .	—1.1	0.8
Helsingfors . . .	—0.2	1.0	Barnaoul	—1.7	1.2
Oulu	—0.2	1.4	Touroukhansk . .	0.2	
Haparanda . . .	1.7	0.8	Verkhoiansk . . .	—1.7	0.4
Stockholm	—0.9	0.6	Thorshavn	—0.4	0.2
Vardö	0.0	0.5	Grimsey	—4.1	0.3
Bergen	—1.6	0.4	Stykkisholm . . .	—1.7	0.2
Copenhagen . . .	—0.7	0.4	Ivigtut	0.6	0.6
Königsberg . . .	1.8	0.7	Jacobshavn . . .	—1.6	1.3
Hamburg	—0.8	0.6	Upernivik	—3.4	1.0
Munich	—3.5	0.7	Toronto	2.3	0.4
Aberdeen	—1.7	0.5	Buffalo	—1.8	0.5
Valentia	—0.2	0.4	Detroit	—0.6	0.6
San Fernando . .	0.2	0.3	Chicago	—1.9	0.2
Ponta Delgada . .	—1.3	0.2	Savannah	—1.6	0.5
Vienna	—1.0	0.9	New Orleans . . .	—0.8	0.5
Graz	—1.6	0.6	Bismarck	—3.6	0.7
Budapest	—2.8	0.6	Portland	0.4	0.4
Milan	—1.0	0.4	San Francisco . .	1.8	0.2
Prague	—1.4	0.6	San Diego	—0.3	0.4
Warsaw	—2.6	0.6	Bombay	0.2	0.2
Moscow	—1.6	0.9	Batavia	0.0	
Sverdlovsk	—2.0	0.6			

least squares. These data (Δt) with their mean errors ε are given in Table 16.

The corresponding Fig. 30 shows a decrease of the yearly amplitude (marked with dots) in the greater part of North America, Greenland, the Azores, Iceland, Siberia, and East

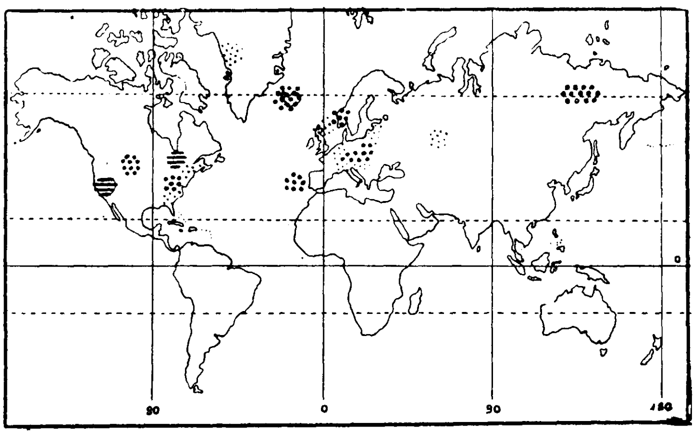

Fig. 30. Change of Yearly amplitude of Temperature.

Europe. An augmentation of amplitude (marked in Fig. 30 with lines) is observed only in North Scandinavia, Königsberg, and the Western Coast of North America.

The aim of this work was only to show the variations of temperatures that have taken place during the last 60—70 years. The causes of the variations are not discussed, because the analysis of that question requires a much thicker net of climatic and hydrologic observations in both hemispheres.