Variability of Summer Temperature in Sweden and its Connection with Changes in the General Circulation

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Abstract

A method of calculating moving standard deviations to give an idea of long-periodic fluctuations in the interannual variability of summer temperature is described and discussed from a statistical point of view. The method was applied to summer temperature records from 15 stations in Sweden and changes in the variability at those stations are treated. In addition the actual variability during the period 1920—39 is determined and compared to the interdiurnal variability of the same period.

In the second part of this investigation are studied frequency fluctuations of different circulation patterns over southern Scandinavia based upon the catalogue of daily weather situations during the period 1881—1950 published by the German Weather Service of the U.S. Zone in 1952. These fluctuations are compared with changes in the summer-temperature and its variability in South Sweden during the same period. It is found that the recent rise of summer temperature has been connected with a definite decrease in frequency of north-meridional situations over Europe and with an increase of south and warm-meridional cases as well as zonal situations. High variability seems to be connected with meridional circulation, low variability with zonal circulation. In a special chapter the fluctuations in variability of the Stockholm summer temperature since 1756 are discussed.

1. Introduction

Investigations of changes in the temperature climate have always played a dominant role in studies of climatic fluctuations. Such investigations usually deal with variations of mean temperature or of frequencies of temperature. It is generally taken for granted that fluctuations in climatic elements, as temperature, reflect in some way or another variations in the general circulation of the atmosphere. It is impossible, however, to conclude only from the temperature trend how the circulation has changed from one period to another.

From glacial-meteorological investigations in northern Sweden, I have reached the conclusion that not only the summer temperature itself might be of importance in glacier retreat but also the variability from one summer to another (WALLÉN 1948). It also seemed to me that fluctuations in the variability of the temperature climate would probably even better reflect long-periodic fluctuations in the general circulation than do the long-period changes in temperature itself. In order to investigate this, I have taken up a study of the variability of the summer temperature in Sweden, which would in some respects complete the careful analysis of the fluctuations in temperature itself carried out by LILJEQUIST (1949).

Variability in the temperature climate is usually studied as the interdiurnal variability. Studies of long-periodic fluctuations in interdiurnal variability would, however, require tremendous work lying beyond the scope of this investigation. Therefore, it has been necessary to adopt some other, less elaborate method. Some studies of the actual interdiurnal variability has been made, however, and will be treated in a subsequent chapter.

If the general circulation of the atmosphere is subject to quasi-periodic fluctuations of several years—which we certainly have reason to believe from earlier studies—it seems likely that the interannual variability of the temperature would very often change with these periods. For instance, if we assume that the general circulation oscillates between a zonal and more meridional type, as suggested by WILLETT (1944), it may be accepted as a hypothesis that in Sweden the zonal type of circulation would imply a maritime climate of low variability and the meridional type a more continental climate of a larger variability.

2. Statistical methods

As the interannual variations in temperature are often rather great it is necessary even in studies of the temperature changes themselves to adopt some method of smoothing in order to separate more long-periodic variations. The usual method of smoothing applied in recent investigations has been that of overlapping means.

It occurred that it might be possible to adopt some method of overlapping means also to the problem of second order: the fluctuations of the variability. In all series of temperature observations it is possible to calculate the p-year overlapping means and to determine, for each one of these overlapping periods, the standard deviation, giving a measure of the interannual variability of that same period. The graphical representation of these standard deviations would then give an idea of the long-range fluctuations of this variability. We may call the temperatures in a series of n summers $t_1, t_2, t_3 \ldots . t_n$, where 1, 2 ... n represent consecutive years. The p-years overlapping means ($p < n$) are

$$t_{m_1} = \frac{\sum_1^p t_i}{p};\ t_{m_2} = \frac{\sum_2^{p+1} t_i}{p};\ t_{m_3} = \frac{\sum_3^{p+2} t_i}{p};\ \ldots\ldots$$

where 1, 2 ... indicate the order of the overlapping periods, which are initiated by the temp. t_1, t_2 etc.

The standard deviations (σ) for a single year of these periods are then

$$\sigma_1 = \sqrt{\frac{\sum_1^p (t_i - t_{m_1})^2}{p}};\ \sigma_2 = \sqrt{\frac{\sum_2^{p+1} (t_i - t_{m_2})^2}{p}}$$

....

There is no doubt but that this method of moving standard deviations gives some idea of the long-periodic fluctuations in the interannual variability of the climate, but there are the following complications involved with the method.

We have presumed, and it has also evidently been proven by the method of overlapping means, that the summer temperature is in itself subject to long-range fluctuations which must influence the year to year variability and also the fluctuations demonstrated by the moving standard deviations. An increased variability may be caused both by a rise in the year to year temperature range and also to some extent by a more or less sudden transition from a period of low to one of high temperature or vice versa. In other words, the general trend of the original temperature curve influences the variability.

In fig. 1 the broken curve represents a part of an original temperature curve, the dotted

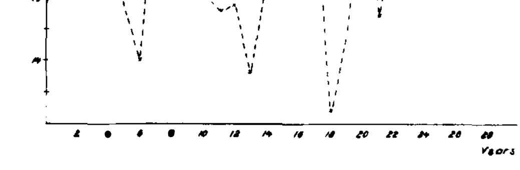

Fig. 1. Principal sketch of a temperature curve with secular trend. Broken line: original curve; dotted line: overlapping mean curve; heavy straight line: probable trend of the original curve; light horizontal lines: mean for certain periods around which the standard deviation is calculated.

curve the overlapping means and the heavy straight line the probable trend of the original curve. The light horizontal lines represent the mean around which the standard deviation is calculated for some periods. If a trend does exist, the right method of studying the variability is, according to more exact statistics, to calculate overlapping means of the standard deviations from the trend line and not from the horizontal lines representing the mean value as suggested in the above theory. We can express this mathematically as follows.

Let σ be the value of the standard deviation obtained by the method suggested above. Then as before mentioned

$$\sigma^2 = \frac{\sum_{1}^{p} (t_i - t_m)^2}{p} \tag{1}$$

Let σ' be the value of the standard deviation from the trend line T. This value is expressed by

$$\sigma'^2 = \frac{\sum_{1}^{p} (t_i - T)^2}{p} \tag{2}$$

The relationship between the sums of the squares in these two expressions is quite generally

$$\sum (t_i - t_m)^2 = \sum (t_i - T)^2 + k^2 \sum (\tau_i - \tau_m)^2 \tag{3}$$

Where k expresses the slope of the trend line, τ_i are consecutive time values and τ_m is the average of the time values. The last sum of squares can be rewritten

$$\sum (\tau_i - \tau_m)^2 = \sum \left(i - \frac{p+1}{2}\right)^2 = \frac{p^3 - p}{12} \tag{4}$$

Inserting (1), (2) and (4) in (3) gives

$$\sigma'^2 = \sigma^2 - k^2 \cdot \frac{p^2 - 1}{12} \tag{5}$$

This expression gives an idea of the influence upon σ of a linear trend in the original temperature curve. Unfortunately it is not possible to determine in any exact way the trend of the original temperature curve. Thus it does not seem reasonable to try to eliminate the exaggeration of the variability, introduced by long-range fluctuations of the temperature, as we do not even know if the trend always can be expressed as a linear one. However, as can be seen from fig. 1, the overlapping mean curve is a very good approximation to the real trend curve. When obvious trends do occur and can be estimated from the overlapping mean curve, the above formula can be used to estimate the influence of the trend upon the value of σ.

Now it is easily shown that the influence of linear trends of the order of magnitude occurring in the temperature observations used, is often very little. In order to do so it must first be decided which value of p should be used for the overlapping means.

According to LILJEQUIST (1949) it is recommended to use a period of years about half as long as the period of the climatic fluctuations to be studied. As we are interested in fluctuations greater than 5 to 10 years we should probably apply 5-year overlapping means. This is, however, not possible because it would give us to few years for a determination of the standard deviations. If these deviations should have any meaning they must be calculated from a series of numbers including at least 20 values. Consequently it is necessary with this method to use at least 20-years overlapping means. This implies then that we can not be sure of the phase fluctuations shorter than 20 years.

If we adopt a value of 20 for p, equ.(5) becomes

$$\sigma'^2 = \sigma^2 - 33.3\ k^2 \tag{6}$$

From fig. 1 and curves shown later on we find that the largest probable value of the temperature change during a 20-years period is around 2° C which implies a continuous increase or a decrease of the summer temperature by 0°.1/year. A reasonable mean value of σ is 1°.00 C. Accepting these values, we obtain from equation(6) $\sigma' = 0.82$, implying that the variability obtained by the suggested method of moving standard deviations is in this case 15—20 %. When a high interannual variability is connected with a linear trend, the exaggeration is smaller. If we assume $k = 0.1$, and $\sigma = 1°.50$, we get $\sigma' = 1.39$.

The exaggeration of the approximate method is then quite small. However, if the

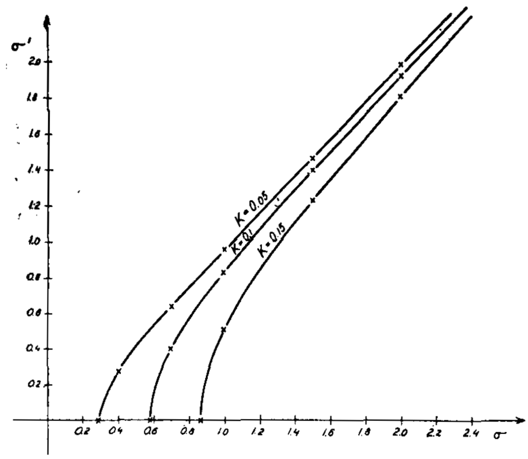

Fig. 2. Relation between σ' and σ for some different values of k.

year to year variability is small compared to the trend, the exaggeration is of larger significance. Assuming $\sigma = 0^{\circ}.7$ (a minimum value) and $k = 0^{\circ}.1$/year we get $\sigma' = 0.40$.

Fig. 2 shows the relation between σ' and σ for some values of k. The rapid increase of the exaggeration with a decrease of σ implies that the top values of fluctuations in the moving deviations are rather independent of the trend while the bottom values become too high. The fluctuations of the variability are thus always underestimated and not overestimated with the method suggested.

In fig. 2 is also drawn a curve for $k = 0.05$ showing that such a weak linear trend has no influence of importance if $\sigma > 0.5$. It will be seen later on that no values < 0.5 have been found.

The above discussion has shown then that the first mentioned method of moving standard deviations can be applied if due attention is paid to the influence of trends in the original temperature curve. Therefore, in the following analysis this method has been used; but, special discussion has been taken up in every case where the overlapping mean curves show a trend of importance to be hidden in the original temperature curve.

3. Variability of summer temperature in different parts of Sweden

The actual variability

20-years overlapping standard deviations of the summer temperature (June—Aug.) have

Karesuando	Tärnaby
Riksgränsen	Gäddede
Haparanda	Östersund
Jokkmokk	Härnösand
Falun	Göteborg
Skara	Växjö
Linköping	Lund
Visby	Stockholm

been calculated for the following stations in Sweden in order to study changes from one place to another in the variability (tab. 1):

The period of observation from these stations is rather short, starting for most of them around 1860 and for two of them[1] as late as around 1900. The observation period from Stockholm is considerably longer, starting in 1758. It will be dealt with in a special chapter below. All stations have reliable and homogeneous series of observations.

Before entering into the question of long-range fluctuations of the variability, it seems advisable to discuss the actual variability of the summer temperature in different parts of Sweden.

For that purpose we have selected the 20-year period of 1920—1939, which gives an idea of the order of magnitude of the variability during a recent period of high variability. The values from this period should, in fact, all be somewhat reduced, for a general trend of temperature increase occurs during the period. However, as seen from the Stockholm curve fig. 10 for example, this reduction will be only around 10 % as all standard deviation values reach around 1.30 and the trend slope never exceeds $0.^{\circ}1$/year. The value is in this way changed from 1.32 to 1.20. In fig. 3 maps are given of the mean temperature and its standard deviation in the period of 1920—39 at the above-mentioned stations (cf. also tab. 1). In order to clarify even more the distribution of mean temperature and its standard deviation such values have been calculated also for the following stations: Riksgränsen, Umeå, Stensele, Sveg and Karlstad. The values have not been reduced for the trend in the temperature curve.

The decrease of the summer temperature with increasing latitude and from east to west is very typical in northern Sweden. It is also

[1] Tärnaby and Gäddede.

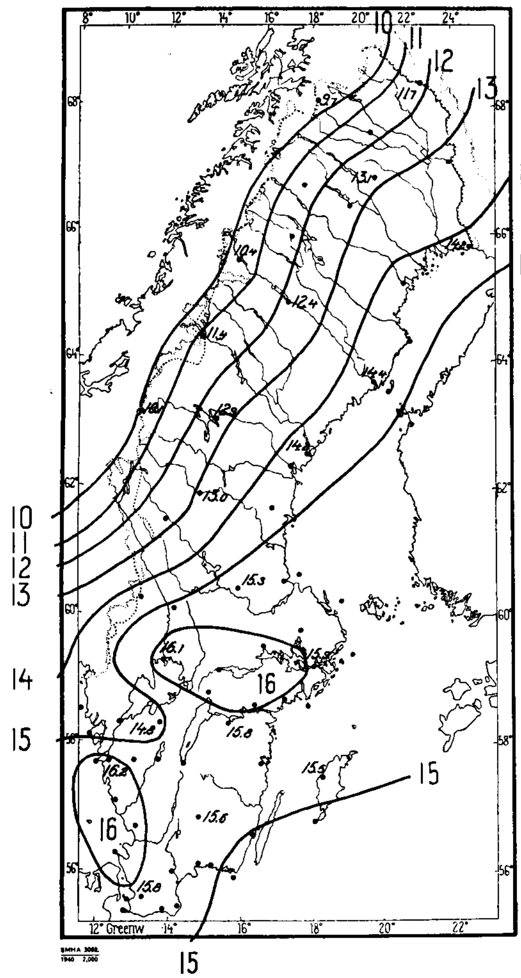

Fig. 3 a. Geographical distribution of summer mean temperature (June—Aug.) in Sweden during the period 1920—39.

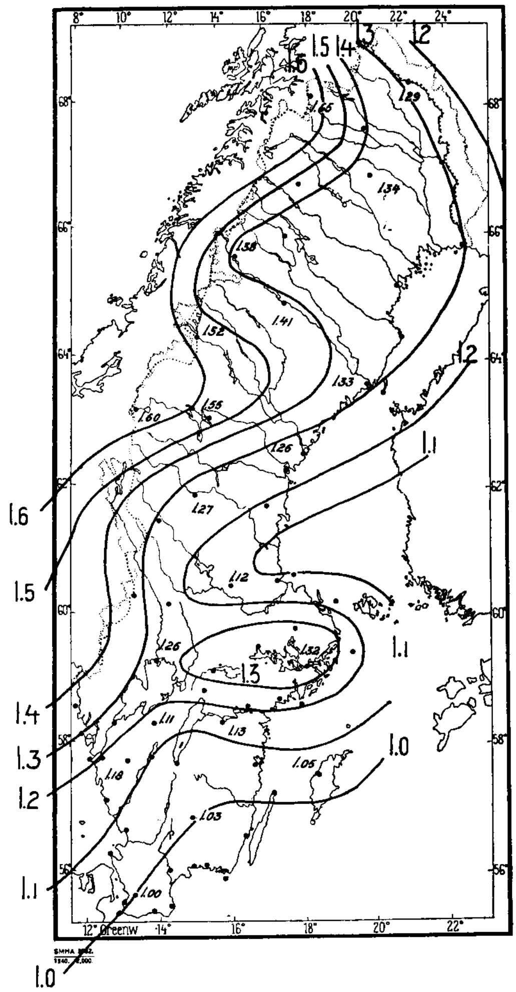

Fig. 3 b. Geographical distribution of the standard deviation of summer temperature during the same period.

evident that there are only small variations in Svealand and Götaland, but nevertheless two maxima can be distinguished: one in central Svealand around the lakes of Mälaren and Hjälmaren and another on the west coast.

On the whole the standard deviation in different parts of the country varies oppositely of the mean temperature. The absolute maxima of variability are found at the high mountain stations of Riksgränsen and Storlien, which show the lowest mean temperature. The lowest variability is found in the southernmost part of the country where the mean temperature is considerably higher. On the other hand there is a variability maximum connected with the temperature maximum in the region around the middle Swedish lakes.

There is nothing surprising in the relatively high values of variability in the mountain region. These values reflect the wellknown fact that the Scandinavian mountains are situated on a borderline zone between two different climatic areas: the Atlantic to the west is the summertime source of cool, maritime air-masses, and eastern Europe is the source of warm, continental air. The high variability shows the sensitiveness of the

Table 1. 20 years overlopping means and standard deviations

Period	Karesuando		Jokkmokk		Tärnaby		Haparanda		Gäddede		Östersund		Härnösand	
	t_m	σ	t_m	σ	t_m	σ	t_m	σ	t_m	σ	t_m	σ	t_m	σ
1859—78	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1860—79	—	—	—	—	—	—	13.1	1.07	—	—	—	—	—	—
1861—80	—	—	—	—	—	—	13.0	1.05	—	—	12.3	0.99	—	—
1862—81	—	—	12.6	1.12	—	—	12.8	0.87	—	—	12.2	0.98	13.4	0.78
1863—82	—	—	12.7	1.10	—	—	12.9	0.83	—	—	12.3	0.98	13.5	0.74
1864—83	—	—	12.8	1.15	—	—	13.0	0.86	—	—	12.3	0.99	13.5	0.78
1865—84	—	—	12.8	1.12	—	—	13.0	0.85	—	—	12.4	0.99	13.6	0.77
1866—85	—	—	12.8	1.13	—	—	13.0	0.89	—	—	12.3	1.01	13.5	0.78
1867—86	—	—	12.8	1.13	—	—	13.1	0.95	—	—	12.3	0.97	13.6	0.83
1868—87	—	—	12.8	1.14	—	—	13.1	0.90	—	—	12.3	0.99	13.7	0.74
1869—88	—	—	12.7	1.15	—	—	13.0	0.89	—	—	12.2	0.94	13.7	0.72
1870—89	—	—	12.7	1.12	—	—	13.1	0.90	—	—	12.3	0.89	13.8	0.71
1871—90	—	—	12.7	1.14	—	—	13.0	0.89	—	—	12.2	0.88	13.7	0.72
1872—91	—	—	12.6	1.17	—	—	13.0	0.90	—	—	12.2	0.94	13.8	0.69
1873—92	—	—	12.4	1.16	—	—	12.9	0.91	—	—	12.1	0.87	13.8	0.71
1874—93	—	—	12.2	1.07	—	—	12.8	0.86	—	—	12.1	0.79	13.7	0.69
1875—94	—	—	12.4	1.07	—	—	13.0	1.00	—	—	12.2	0.80	13.8	0.71
1876—95	—	—	12.4	1.04	—	—	13.0	1.01	—	—	12.2	0.80	13.8	0.71
1877—96	—	—	12.4	1.05	—	—	13.1	1.04	—	—	12.3	0.85	13.8	0.74
1878—97	—	—	12.4	0.98	—	—	13.1	1.00	—	—	12.4	0.87	13.9	0.74
1879—98	10.3	1.25	12.4	0.94	—	—	13.2	0.98	—	—	12.4	0.85	14.0	0.73
1880—99	10.2	1.18	12.3	0.96	—	—	13.1	1.00	—	—	12.3	0.84	13.9	0.74
1881—00	10.1	1.27	12.2	1.00	—	—	13.1	1.01	—	—	12.3	0.84	13.9	0.75
1882—01	10.2	1.35	12.4	1.17	—	—	13.3	1.10	—	—	12.6	0.99	14.1	0.78
1883—02	10.0	1.44	12.2	1.25	—	—	13.1	1.21	—	—	12.5	1.06	13.9	0.91
1884—03	9.8	1.41	12.0	1.18	—	—	13.1	1.20	—	—	12.4	1.07	13.8	0.93
1885—04	9.8	1.43	12.0	1.18	—	—	13.0	1.22	—	—	12.3	1.07	13.8	1.00
1886—05	9.9	1.44	12.0	1.19	—	—	13.1	1.20	—	—	12.5	1.05	13.8	0.97
1887—06	9.8	1.39	12.0	1.16	—	—	13.1	1.16	—	—	12.5	1.06	13.8	0.95
1888—07	9.8	1.38	12.0	1.15	—	—	13.1	1.16	—	—	12.5	1.04	13.7	1.00
1889—08	9.9	1.36	12.0	1.15	—	—	13.1	1.15	—	—	12.5	1.03	13.7	1.00
1890—09	9.8	1.32	12.0	1.13	—	—	13.1	1.15	—	—	12.5	1.03	13.6	0.98
1891—10	9.8	1.33	12.0	1.13	—	—	13.0	1.16	—	—	12.6	1.02	13.7	0.98
1892—11	9.8	1.32	12.0	1.13	—	—	13.0	1.15	—	—	12.6	1.02	13.6	0.96
1893—12	10.0	1.21	12.2	1.09	—	—	13.1	1.12	—	—	12.7	1.03	13.7	0.96
1894—13	10.1	1.21	12.3	1.10	—	—	13.2	1.12	—	—	12.7	1.03	13.8	0.98
1895—14	10.0	1.09	12.2	1.05	—	—	13.1	1.01	—	—	12.8	1.17	13.8	1.01
1896—15	10.0	1.09	12.2	1.05	—	—	13.1	1.00	—	—	12.8	1.20	13.7	1.03
1897—16	10.0	1.12	12.2	1.06	—	—	13.0	0.94	—	—	12.7	1.19	13.6	1.01
1898—17	10.1	1.18	12.3	1.17	—	—	13.1	0.96	—	—	12.8	1.24	13.6	1.01
1899—18	10.1	1.19	12.3	1.17	—	—	13.0	0.96	—	—	12.8	1.22	13.6	1.01
1900—19	10.3	1.26	12.4	1.19	—	—	13.1	1.00	—	—	12.8	1.23	13.7	1.02
1901—20	10.4	1.25	12.5	1.15	—	—	13.2	0.98	—	—	12.8	1.25	13.7	1.03
1902—21	10.4	1.17	12.3	1.02	—	—	13.1	0.84	—	—	12.5	1.22	13.6	0.93
1903—22	10.6	0.99	12.5	0.88	10.3	0.93	13.2	0.69	—	—	12.6	1.15	13.7	0.84
1904—23	10.6	0.83	12.5	0.92	10.3	0.99	13.2	0.78	—	—	12.6	1.19	13.6	0.89
1905—24	10.8	0.89	12.6	0.86	10.4	1.00	13.3	0.76	—	—	12.6	1.18	13.7	0.83
1906—25	10.9	0.98	12.6	0.90	10.5	1.11	13.4	0.86	11.0	0.97	12.7	1.18	13.7	0.88
1907—26	10.9	0.95	12.7	0.91	10.6	1.13	13.4	0.87	11.1	0.98	12.7	1.20	13.8	0.90
1908—27	11.1	0.95	12.8	0.94	10.7	1.15	13.5	0.96	11.1	0.98	12.8	1.18	13.9	0.85
1909—28	11.1	0.97	12.7	1.02	10.7	1.16	13.5	1.00	11.0	1.08	12.7	1.31	13.8	0.98
1910—29	11.1	0.97	12.7	1.08	10.7	1.20	13.5	1.01	11.0	1.14	12.6	1.36	13.8	1.01
1911—30	11.2	0.96	12.8	1.13	10.8	1.27	13.7	1.05	11.1	1.27	12.7	1.44	13.9	1.08

(cont.)

of summer temperature at selected Swedish stations.

Falun		Skara		Linköping		Göteborg		Visby		Växjö		Lund		Period
t_m	σ	t_m	σ	t_m	σ	t_m	σ	t_m	σ	t_m	σ	t_m	σ	
—	—	—	—	—	—	—	—	—	—	—	—	15.6	0.88	1859—78
14.9	0.96	14.8	1.10	16.3	0.95	15.9	0.89	14.9	1.15	15.1	1.03	15.4	0.86	1860—79
15.0	1.01	14.8	1.10	16.3	0.96	16.0	0.92	14.9	1.16	15.2	1.03	15.5	0.86	1861—80
14.9	1.00	14.7	1.11	16.2	1.00	15.9	0.94	14.8	1.12	15.1	1.05	15.4	0.85	1862—81
15.1	0.91	14.8	1.02	16.3	0.93	16.0	0.88	14.9	1.13	15.2	0.97	15.5	0.81	1863—82
15.1	0.91	14.8	1.02	16.3	0.93	16.0	0.87	14.9	1.13	15.2	0.96	15.5	0.81	1864—83
15.1	0.88	14.9	0.98	16.3	0.97	16.1	0.81	15.0	1.11	15.2	0.93	15.6	0.77	1865—84
15.1	0.89	14.9	1.01	16.2	1.02	16.1	0.81	15.0	1.11	15.2	0.93	15.5	0.78	1866—85
15.2	0.90	14.8	1.02	16.2	1.02	16.0	0.84	15.0	1.11	15.2	0.93	15.5	0.78	1867—86
15.3	0.82	14.8	1.02	16.2	1.01	16.1	0.83	15.1	0.94	15.2	0.91	15.5	0.76	1868—87
15.1	0.76	14.6	0.95	15.9	0.84	15.9	0.73	14.9	0.82	15.0	0.73	15.4	0.62	1869—88
15.2	0.72	14.7	0.94	16.0	0.83	16.0	0.73	15.0	0.79	15.1	0.71	15.4	0.64	1870—89
15.2	0.74	14.6	0.99	15.9	0.89	16.0	0.78	15.0	0.79	15.0	0.76	15.4	0.66	1871—90
15.2	0.74	14.6	0.99	15.8	0.91	16.0	0.78	15.0	0.73	15.1	0.75	15.4	0.65	1872—91
15.2	0.76	14.5	0.89	15.8	0.92	15.9	0.77	15.0	0.75	15.0	0.75	15.3	0.64	1873—92
15.2	0.76	14.5	0.89	15.7	0.91	15.9	0.80	14.9	0.74	15.0	0.76	15.3	0.66	1874—93
15.2	0.77	14.5	0.88	15.7	0.89	16.0	0.83	14.9	0.74	15.0	0.76	15.4	0.66	1875—94
15.2	0.77	14.4	0.82	15.6	0.84	16.0	0.81	14.9	0.69	15.0	0.73	15.3	0.63	1876—95
15.2	0.74	14.3	0.71	15.6	0.81	16.0	0.90	14.9	0.74	15.0	0.76	15.3	0.67	1877—96
15.3	0.78	14.4	0.76	15.7	0.88	16.1	0.95	15.0	0.77	15.1	0.84	15.4	0.72	1878—97
15.3	0.79	14.3	0.76	15.7	0.88	16.1	0.97	15.0	0.78	15.1	0.85	15.4	0.76	1879—98
15.2	0.79	14.4	0.80	15.7	0.89	16.2	1.00	14.9	0.81	15.1	0.87	15.4	0.74	1880—99
15.2	0.76	14.3	0.78	15.7	0.86	16.2	0.99	14.9	0.80	15.2	0.91	15.5	0.75	1881—00
15.4	0.89	14.5	0.88	15.8	0.94	16.3	0.98	15.1	0.90	15.3	0.94	15.6	0.77	1882—01
15.2	1.05	14.4	1.01	15.7	1.08	16.2	1.07	14.9	1.05	15.2	1.05	15.5	0.87	1883—02
15.2	1.07	14.3	1.01	15.6	1.10	16.1	1.09	14.9	1.05	15.1	1.06	15.4	0.87	1884—03
15.2	1.06	14.3	1.02	15.6	1.08	16.1	1.09	14.9	1.06	15.1	1.06	15.4	0.87	1885—04
15.3	1.04	14.4	1.00	15.7	1.07	16.2	1.07	14.9	1.08	15.2	1.06	15.4	0.88	1886—05
15.2	1.03	14.4	1.00	15.7	1.07	16.3	1.04	14.9	1.07	15.3	1.06	15.5	0.87	1887—06
15.1	1.11	14.3	1.07	15.6	1.14	16.2	1.13	14.8	1.14	15.2	1.14	15.4	0.95	1888—07
15.2	1.11	14.4	1.04	15.7	1.09	16.3	1.10	14.9	1.09	15.2	1.09	15.5	0.90	1889—08
15.1	1.08	14.3	1.03	15.6	1.09	16.2	1.12	14.8	1.09	15.2	1.11	15.4	0.90	1890—09
15.1	1.07	14.4	1.01	15.7	1.06	16.3	1.08	14.9	1.09	15.3	1.07	15.4	0.89	1891—10
15.2	1.07	14.5	1.00	15.7	1.05	16.3	1.09	14.9	1.09	15.3	1.07	15.5	0.90	1892—11
15.2	1.07	14.5	1.00	15.8	1.03	16.4	1.05	15.0	1.10	15.4	1.03	15.5	0.88	1893—12
15.2	1.05	14.5	1.00	15.7	1.03	16.3	1.06	14.9	1.09	15.4	1.03	15.5	0.88	1894—13
15.3	1.14	14.6	1.10	15.8	1.14	16.4	1.11	15.1	1.20	15.4	1.10	15.5	0.95	1895—14
15.2	1.17	14.6	1.11	15.8	1.15	16.3	1.15	15.0	1.20	15.4	1.10	15.5	0.96	1896—15
15.1	1.15	14.4	1.08	15.7	1.15	16.2	1.12	14.8	1.21	15.3	1.08	15.4	0.92	1897—16
15.1	1.14	14.5	1.09	15.7	1.15	16.2	1.12	14.8	1.22	15.3	1.13	15.4	1.01	1898—17
15.1	1.15	14.5	1.08	15.7	1.16	16.2	1.12	14.8	1.22	15.3	1.12	15.5	0.99	1899—18
15.1	1.15	14.4	1.08	15.6	1.16	16.1	1.11	14.9	1.21	15.2	1.13	15.4	1.00	1900—19
15.1	1.12	14.4	1.07	15.5	1.15	16.0	1.09	14.9	1.20	15.2	1.10	15.4	0.98	1901—20
14.9	0.99	14.3	0.98	15.4	1.03	15.9	1.02	14.8	1.09	15.1	1.03	15.3	0.93	1902—21
15.0	0.88	14.3	0.89	15.4	0.92	15.9	1.00	14.9	0.92	15.1	0.94	15.3	0.88	1903—22
14.9	0.89	14.3	0.94	15.4	0.98	15.9	1.05	14.8	0.95	15.1	0.98	15.3	0.92	1904—23
15.0	0.89	14.3	0.94	15.4	0.98	15.8	1.05	14.9	0.94	15.1	0.97	15.3	0.92	1905—24
15.0	0.96	14.3	0.98	15.4	1.03	15.9	1.10	14.9	0.94	15.2	0.96	15.3	0.94	1906—25
15.0	0.96	14.3	0.99	15.5	1.04	15.9	1.12	14.9	0.96	15.2	0.96	15.4	0.96	1907—26
15.1	0.88	14.4	0.90	15.6	0.99	16.0	1.05	15.1	0.91	15.3	0.92	15.5	0.89	1908—27
15.0	1.03	14.3	0.99	15.5	1.07	15.9	1.13	15.0	0.99	15.2	0.97	15.4	0.95	1909—28
14.9	1.05	14.3	1.01	15.4	1.09	15.9	1.14	15.0	0.99	15.2	0.97	15.4	0.94	1910—29
15.0	1.08	14.3	1.02	15.5	1.12	15.8	1.13	15.1	1.03	15.2	0.98	15.4	0.94	1911—30

(cont.)

(cont.)

Period	Karesuando		Jokkmokk		Tärnaby		Haparanda		Gäddede		Östersund		Härnösand	
	t_m	σ	t_m	σ	t_m	σ	t_m	σ	t_m	σ	t_m	σ	t_m	σ
1912—31	11.2	0.97	12.8	1.16	10.8	1.28	13.7	1.03	11.1	1.29	12.7	1.47	13.8	1.11
1913—32	11.2	0.97	12.7	1.15	10.6	1.25	13.7	1.03	11.0	1.23	12.6	1.44	13.8	1.10
1914—33	11.3	1.00	12.8	1.20	10.7	1.27	13.7	1.03	11.1	1.28	12.6	1.48	13.8	1.12
1915—34	11.4	1.05	12.8	1.22	10.7	1.26	13.8	1.08	11.1	1.31	12.6	1.37	13.8	1.11
1916—35	11.4	1.04	12.8	1.20	10.7	1.28	13.8	1.07	11.1	1.29	12.6	1.35	13.9	1.09
1917—36	11.4	1.09	12.9	1.22	10.7	1.28	13.9	1.12	11.2	1.33	12.7	1.41	14.0	1.15
1918—37	11.6	1.15	13.0	1.33	10.7	1.36	14.0	1.28	11.3	1.49	12.7	1.51	14.0	1.22
1919—38	11.7	1.29	13.0	1.34	10.8	1.38	14.2	1.30	11.4	1.51	12.8	1.53	14.1	1.24
1920—39	11.7	1.29	13.0	1.34	10.8	1.38	14.2	1.32	11.4	1.52	12.9	1.55	14.2	1.26
1921—40	11.6	1.29	13.1	1.36	10.8	1.38	14.2	1.31	11.4	1.52	13.0	1.52	14.2	1.26
1922—41	11.7	1.28	13.1	1.31	10.9	1.30	14.3	1.29	11.5	1.44	13.1	1.40	14.3	1.22
1923—42	11.7	1.28	13.1	1.37	10.9	1.30	14.3	1.30	11.5	1.43	13.1	1.40	14.3	1.20
1924—43	11.8	1.16	13.2	1.20	11.0	1.16	14.4	1.12	11.7	1.29	13.2	1.32	14.4	1.10
1925—44	11.7	1.18	13.2	1.22	10.9	1.17	14.4	1.14	11.7	1.28	13.2	1.32	14.5	1.09
1926—45	11.8	1.18	13.2	1.24	10.9	1.13	14.4	1.13	11.7	1.32	13.2	1.33	14.5	1.11
1927—46	11.8	1.17	13.2	1.24	10.9	1.12	14.4	1.13	11.8	1.32	13.2	1.33	14.5	1.11
1928—47	11.8	1.18	13.2	1.26	10.9	1.15	14.4	1.11	11.7	1.33	13.3	1.40	14.6	1.19
1929—48	11.8	1.12	13.3	1.18	—	—	—	—	—	—	13.5	1.18	—	—

mountains for an interchange between maritime and continental summers.

It is also evident from the map that regions in the mountains of generally higher maritimity show in summer a greater variability than do more continental regions[1]. For instance, the pass across the Norwegian border from Storlien to Östersund is in summer clearly demonstrated as a region of higher temperature variability compared to the more shielded areas in Västerbotten.

The general decrease of variability as one gets further south seems to be related to the shifting northwards in summer of the subtropical high-pressure belt. No doubt, the chances for more constantly warm summers must increase in areas more or less regularly under control of the subtropical high which extends over middle Europe in summer.

In south Sweden, finally, it seems as if the west coast is subject to a higher variability than is the east coast for we find a value of 1.18 in Gothenburg but only 1.05 in Visby. If we consider the fact that the trend towards a secular increase of temperature is larger in Visby than in Gothenburg, the standard deviation from Visby is too high and the difference between the east and the west coast even greater. This fact suggests the influence of the zonal westerly winds to be of special importance in the variability on the west coast.

Summarizing, the variability of the summer temperature in different parts of Sweden can be expressed by the following means:

Götaland = 1°.09 C (6 stations)	Norrland coast and forest land = 1°.32 C (7 stations)
Svealand = 1°.23 C (3 stations)	Norrland mountain region = 1°.54 C (5 stations)

Fluctuations of the variability

It is already evident from a general inspection of the curves in fig. 5 that in the recent century the period of 1920—39 is one of relatively high variability. It is, therefore, interesting to compare the distribution of the variability of this recent period with an older one of low variability. In fig. 4 the temperature and its variability are plotted for the period of 1880—99 at the same stations as for the recent period and isolines are drawn as in fig. 3.

It is seen that the distribution of variability is somewhat different from the one during the more recent period. A general decrease of variability from north to south is certainly

[1] This increase of variability with increasing maritimity is rather unexpected and may be caused by influences of the topography. Sumnet (1953) has shown the variability to increase in North-America with the continentality.

(cont.)

Falun		Skara		Linköping		Göteborg		Visby		Växjö		Lund		Period
t_m	σ	t_m	σ	t_m	σ	t_m	σ	t_m	σ	t_m	σ	t_m	σ	
15.0	1.09	14.3	1.03	15.4	1.12	15.8	1.12	15.0	1.04	15.1	1.03	15.3	0.93	1912—31
15.0	1.07	14.3	1.03	15.4	1.12	15.8	1.14	15.0	1.03	15.1	1.04	15.4	0.98	1913—32
15.0	1.13	14.4	1.02	15.5	1.17	15.9	1.22	15.1	1.04	15.2	1.03	15.5	1.02	1914—33
14.9	1.01	14.3	1.02	15.4	1.05	15.8	1.15	15.0	0.92	15.1	1.02	15.4	0.99	1915—34
15.0	1.01	14.4	1.04	15.5	1.07	15.9	1.15	15.1	0.93	15.2	1.00	15.5	1.01	1916—35
15.1	1.07	14.5	1.09	15.6	1.10	16.0	1.18	15.3	0.92	15.3	1.07	15.6	1.02	1917—36
15.2	1.11	14.5	1.11	15.6	1.10	16.0	1.18	15.3	0.96	15.3	1.04	15.6	0.96	1918—37
15.2	1.10	14.6	1.10	15.7	1.09	16.1	1.18	15.4	0.95	15.4	1.05	15.7	0.97	1919—38
15.3	1.13	14.7	1.11	15.8	1.13	16.2	1.18	15.5	1.05	15.5	1.03	15.8	1.00	1920—39
15.4	1.13	14.7	1.11	15.9	1.12	16.3	1.19	15.6	1.05	15.5	1.03	15.8	1.00	1921—40
15.5	1.11	14.8	1.15	16.0	1.15	16.4	1.19	15.6	1.05	15.6	1.04	15.9	1.02	1922—41
15.5	1.09	14.9	1.11	16.1	1.10	16.4	1.15	15.6	1.03	15.6	1.02	15.9	0.96	1923—42
15.6	1.03	15.0	1.00	16.1	1.00	16.5	1.04	15.7	0.96	15.7	0.94	16.0	0.87	1924—43
15.6	1.02	15.1	0.99	16.2	0.98	16.6	1.02	15.8	0.99	15.7	0.93	16.2	0.88	1925—44
15.6	1.01	15.1	1.00	16.2	0.97	16.6	1.00	15.8	1.00	15.7	0.92	16.2	0.87	1926—45
15.6	1.01	15.1	1.00	16.2	0.97	16.5	1.00	15.8	1.00	15.7	0.93	16.1	0.87	1927—46
15.7	1.05	15.2	1.08	16.3	1.05	16.6	1.03	15.9	1.03	15.7	0.96	16.2	0.94	1928—47
15.8	0.82	15.3	0.89	16.4	0.85	16.7	0.83	16.0	0.85	15.8	0.80	16.4	0.78	1929—48

found even during 1880—99, but the region of low variability in south eastern Norrland is much more accentuated than in recent time. The smallest changes from the older to the more recent period, reaching not more than 20 %, are found in the far north and in the south. In southern Norrland and central Sweden, especially in south eastern Norrland, the change is considerable (from 1.20 to 0.80 or 30 %); but, generally speaking, the maritime regions seem to show the largest differences. They are evidently more sensitive to changes of the variability than are the continental areas.

It should be emphasized that the general temperature distribution over the country does not show any significant changes from the period 1880—99 to 1920—39. This is seen from a comparison between fig. 3 a and fig. 4 a. This fact might suggest that the change of the variability is of larger significance in studies of the variations of the general circulation than is the mean temperature itself. An attempt to explain the changes in the variability with regard to fluctuations in the general circulation is made in chapter 5.

From the comparison between the variability of the two periods it is then clear that even inside a comparatively small land area as Sweden considerable differences in the fluctuations of variability do occur between various parts of the region. This fact becomes even more evident from an inspection of the moving standard deviation curves for stations in different parts of the country (fig. 5).

In northern Norrland the variability shows a maximum during a period from 1890 to 1910 while there are very small indications of a maximum at that time in southern Norrland. In middle Sweden this maximum again shows up; it is, however, of much less intensity than in the northernmost part of the country. Only in Visby is it again very marked. Practically no maximum is found in southern Sweden at that time.

We find a very marked minimum in the variability around 1915. This seems to hold good for all the country but the intensity is much larger in the northern than in the southern parts. This variability minimum is most accentuated in Karesuando and Haparanda and practically insignificant in Göteborg and Lund.

During the following decades an increase connected with the rise of the summer mean temperature is rather clear over most of the country. This increase is—as was to be expected—most accentuated in northern Sweden; at some stations, however, this was caused by the somewhat larger rise of temperature in this part of the country. The very small rise of the variability shown in the curves from the

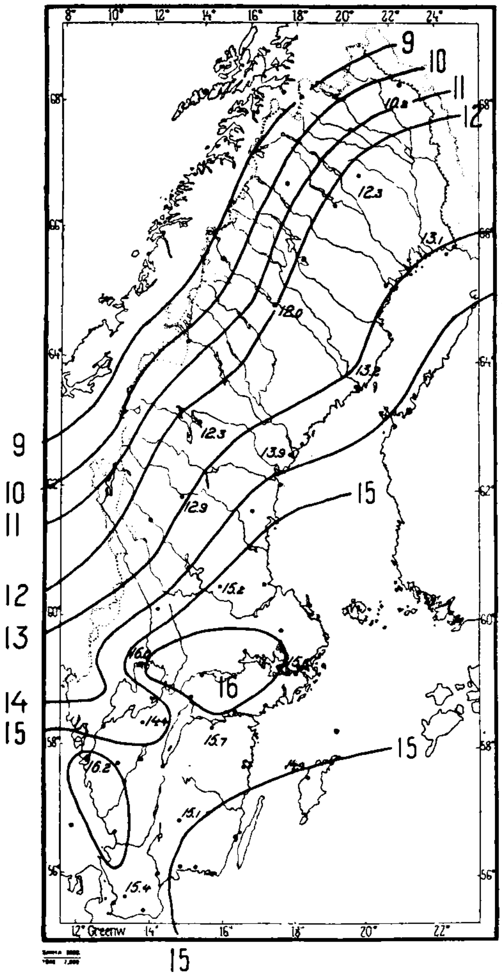

Fig. 4 a. Geographical distribution of summer mean temperature in Sweden during the period 1880—99.

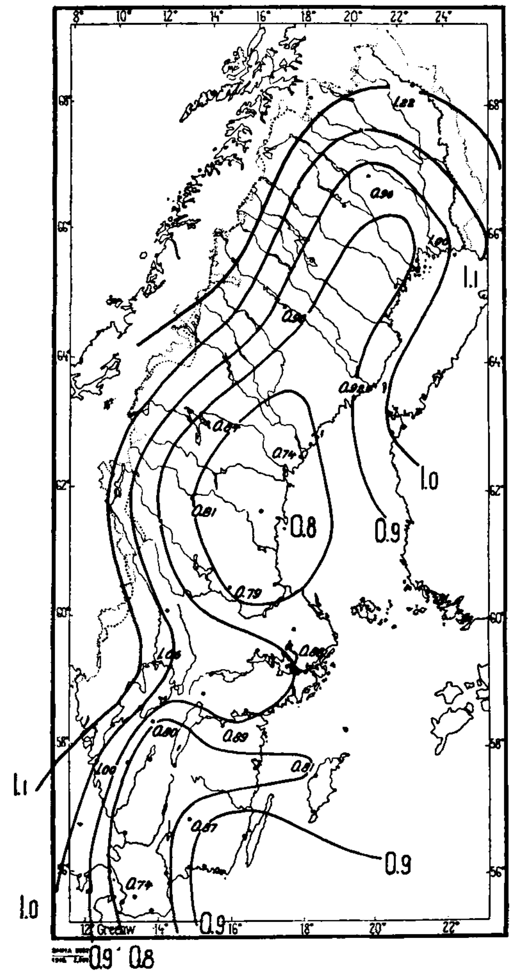

Fig. 4 b. Geographical distribution of the standard deviation of summer temperature during the same period

southern parts—at some places only insignificant secondary maximas are found—is rather surprising. Although smaller, there is a very definite rise of the mean temperature also in this region.

Finally, a decrease of the variability has occurred in all parts of the country during the last decade showing up in a fall of the curves since around 1930.

Looking at the country as a whole we can summarize as follows. The period around 1880 was in all parts a period of low variability being then everywhere relieved by a very definite increase culminating in northern Norrland around 1895 and showing in southern Sweden a maximum somewhat later, about 1905. In southern Norrland and middle Sweden there is no culmination around the turn of the century but a continuous rise until the maximum of the period centered around 1930. In Norrland the maximum at the turn of the century was followed by a minimum around 1915 showing up rather smoothed out even in the curves for southern Sweden but to a very small extent in southern Norrland. The rise from this minimum to the maximum of 1930 is very much accentuated in northern and middle Sweden but is of no significance in south Sweden and in Gotland.

From this summary it seems possible to

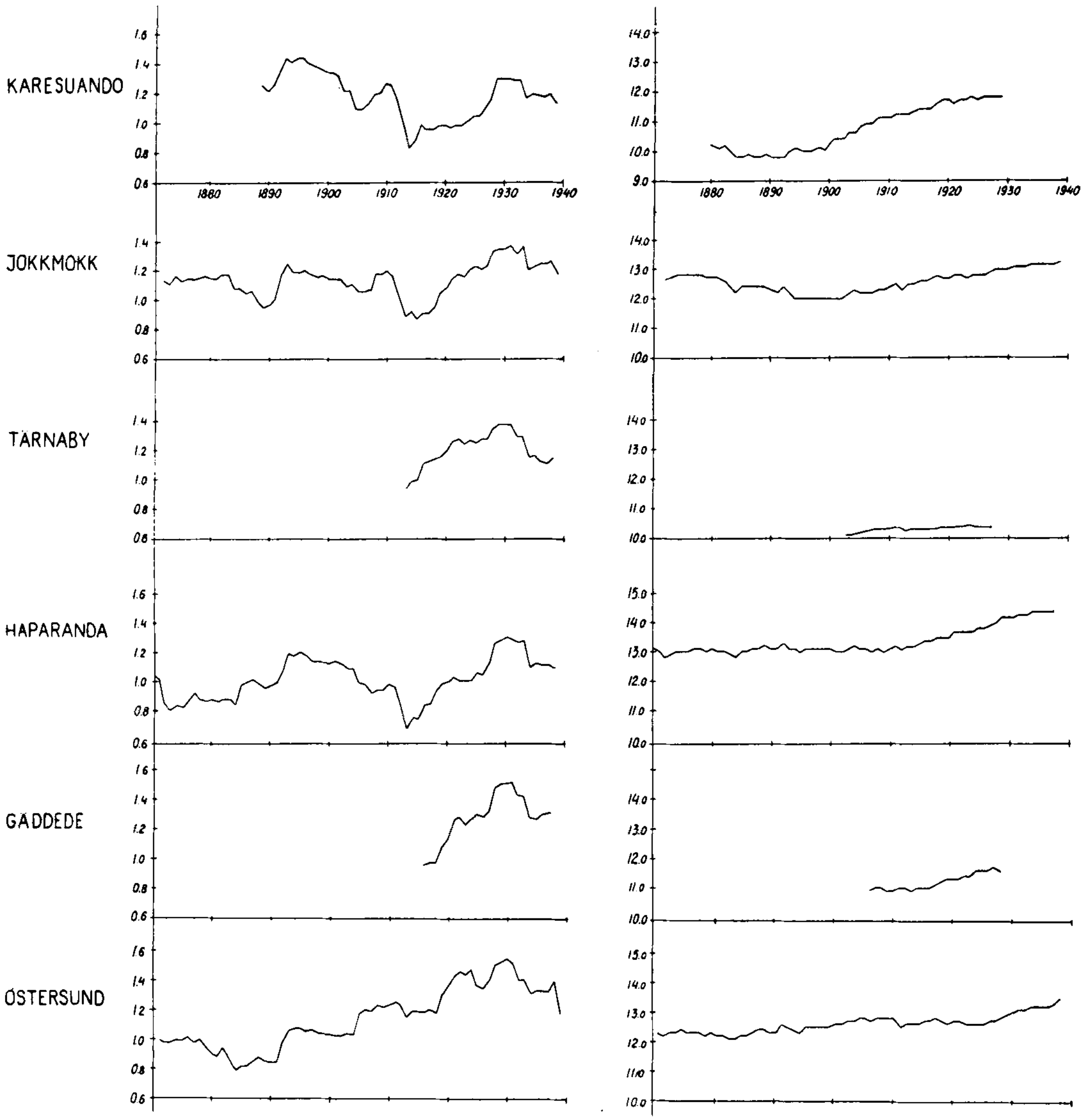

Fig. 5 a. 20-years overlapping means of summer temperature (right) and its standard deviation (left) at selected stations.

conclude that the country can be separated into three regions showing definite differences in the change of the variability; namely, northern Norrland, southern Norrland and south Sweden. There are, however, certain reasons to conclude that differences exist even inside south Sweden. At least we might say that the curve of Visby definitely shows different features than do the others. Furthermore, the curves of Gothenburg and Lund do not show any typical minimum about 1915 as do the other curves and likewise show no typical maximum at the turn of the century. There seems to exist a maritime western type and a maritime eastern type; this is by no means surprising if we consider the differences in the influence of the normal general circulation in summer on the Swedish west coast and in Gotland. From this reasoning the decision was made to separate the stations in the following groups representing different types of fluctuations in the variability:

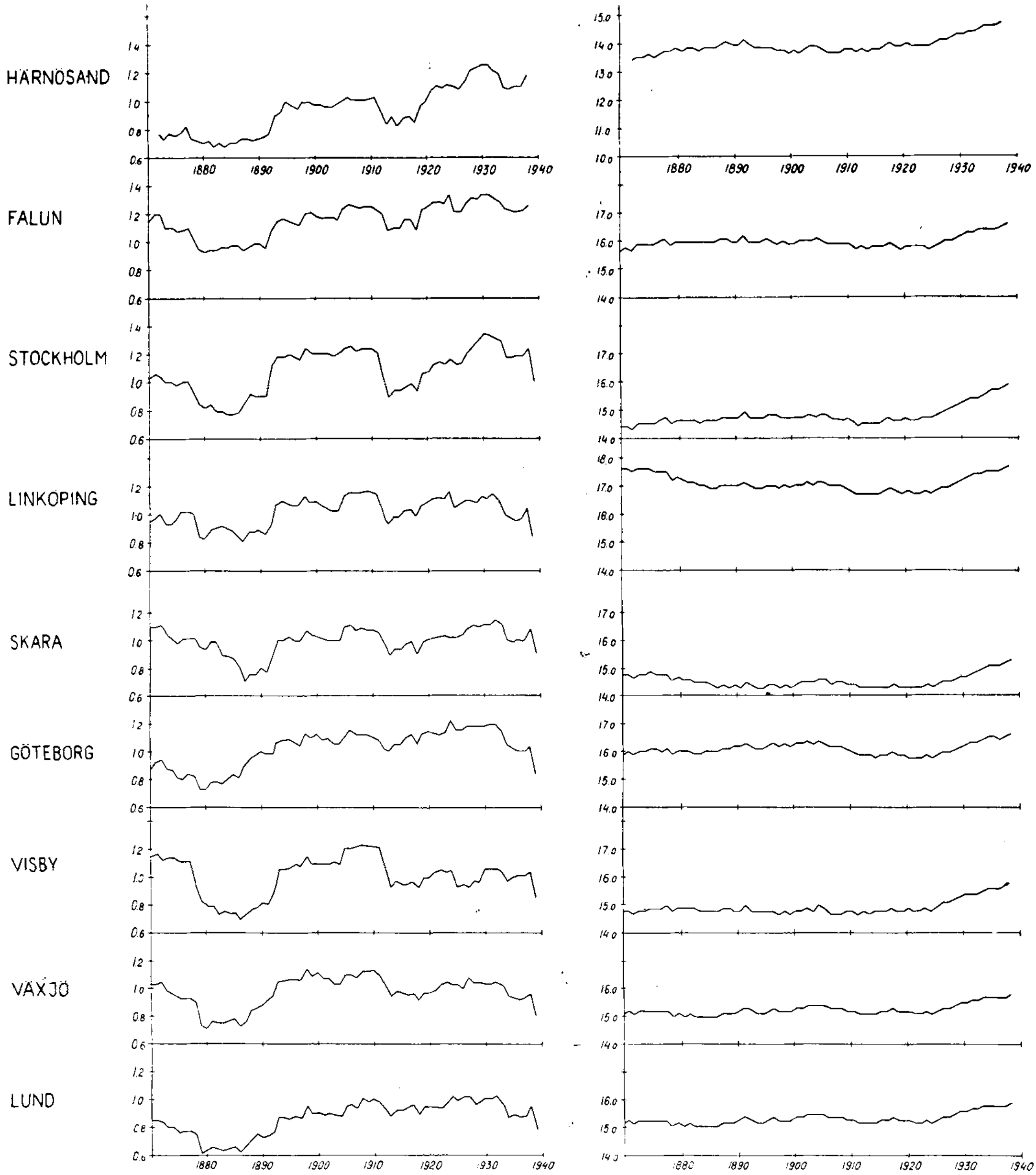

Fig. 5 b. 20-years overlapping means of summer temperature (right) and its standard deviation (left) at selected stations.

1. *Northern Norrland*

Karesuando
Jokkmokk
(Tärnaby)
Haparanda

2. *Southern Norrland and northern Svealand*

(Gäddede)
Östersund
Härnösand
Falun

3. *Central middle and south Sweden*

   Stockholm
   Linköping
   Skara
   Växjö

4. *Gotland*

   Visby

5. *The west coast*

   Göteborg
   Lund

4. The interdiurnal summer temperature variability in Sweden

In order to give a general idea of the order of magnitude of the interdiurnal summer variability in Sweden, the values given in table 2 have also been calculated.

From the table it is evident that the interdiurnal variability decreases during the summer being everywhere largest in June and smallest in August. It is also clear that in general it decreases rapidly from north to south being in all months much larger in Gällivare than at the other stations. The order of magnitude of the interdiurnal variability is surprisingly similar to that of the interannual variability and although the calculations have been made for too few stations to give any definite results there seems to be indications that the variation of the interdiurnal variability inside Sweden is rather similar to the interannual summer variability as given in fig. 3 b. This is indicated from a comparison between the values of col. 4 and col. 5 of table 2.

Table 2. Interdiurnal variability of summer temperature 1920—1939

	June	July	Aug.	Summer	Interannual var. Summer
Gällivare....	1.90	1.70	1.40	1.67	1.34
Härnösand..	1.50	1.20	1.10	1.27	1.26
Stockholm..	1.60	1.40	1.00	1.33	1.32
Göteborg...	1.20	1.10	0.90	1.07	1.18
Malmö.....	1.30	1.10	1.00	1.13	1.00

5. Changes in summer circulation pattern over Scandinavia since 1880 and their relation to temperature and its variability

Changes in the circulation pattern.

In order to investigate to what extent the fluctuations in temperature variability reflect changes in the general circulation it is necessary to make in some way an analysis of such changes that have occurred over Europe during the last decades. There has been much discussion on the increased general circulation in middle latitudes during recent years but very few investigations have been made in order to find out in which way the general circulation patterns have changed.

Willett (1944) has introduced, in his extensive studies on the variations in the general circulation in all middle latitudes, the important definitions: zonal and meridional, which characterize two principally different types of circulation: high-index and low-index circulation resp. These definitions have been used to a considerable extent by authors dealing with circulation patterns. Among these I wish to mention Petterssen (1949), who has investigated the basic circulation changes of this century over the North Atlantic-European sector of the hemisphere. This investigation, however, only deals with the winter. Nothing very definite has been published concerning the summer circulation. However, some indications regarding an increased importance of "blocking-situations" during the summers of the last decades, implying a special type of low-index, were found in a study of synoptic climatology by Rex (1950, 1951).

In 1952 the German weather service of the U.S. Zone published (Hess and Brezovsky, 1952) an extensive catalogue of daily weather situations having occurred over Europe since 1881, principally based upon a classification of circulation patterns introduced by Baur. Of course this classification was made with particular reference to middle Europe and therefore is not especially well-suited for an analysis of secular variations in the circulation pattern over Scandinavia. Such an analysis has been made, however, since it was expected that it would, in any event, give some indications as to how the circulation patterns have changed at least in south and middle Sweden.

Hess and Brezovsky have made their classification from 500 mb upper-air charts, and introduced Willetts basic idea of zonal and meridional circulation types. Among eighteen different classes of weather situations, two are considered purely zonal in character, three are mixed situations and the rest are considered meridional. The authors have in every situation distinguished between cyclonic and anticyclonic situations and so obtained at least two sub-classes for each principal class. In characterizing the weather situation of each day since 1881, most of these principal and sub-classes were used. It is certainly impossible to apply in Scandinavia all the characteristics of the different classes expressed by these authors; for instance, a situation being considered as anticyclonic in central Europe may very well be cyclonic over Scandinavia. On the whole, however, the general principle of zonal and meridional situations hold good also over central and southern Scandinavia. Among the mixed situations there are some which might be referred to as zonal in Scandinavia but as meridional over central Europe.

In beginning, an attempt has been made to determine, from among the basic situations, which are zonal and which are meridional over Scandinavia. It was accepted that the following types were zonal (the designators and characteristics are the ones used by Hess and Brezovsky and the air-flow everywhere refers to southern Scandinavia).

NW Cyclonic or anti-cyclonic north-westerly zonal flow.
W Cyclonic or anti-cyclonic westerly flow.
SW Cyclonic or anti-cyclonic south-westerly flow, considered as a mixed type by the authors.
BM High-pressure ridge from the Azores to eastern Europe giving south-westerly to westerly zonal flow.

The following situations were referred to as definitely meridional.

HN High-pressure area over the North Sea; northerly flow.
HF High-pressure area over Scandinavia; light variable flow.
HNF High-pressure over the North Sea and Scandinavia; light variable flow.
N Northerly meridional flow mostly caused by blocking-highs over the eastern Atlantic.
TrM Trough over northern and middle Europe giving southerly meridional flow.
TrW Trough over the North Sea and eastern Atlantic; southerly meridional flow.
TM Cut-off low, central Europe; south-easterly meridional flow.
TB Cut-off low, British Isles and eastern Atlantic; mainly southerly flow.
S Blocking-ridge Scandinavia and the Baltic; southerly meridional flow.
SE Blocking-ridge from south-east toward north-west; south-easterly flow in southern Scandinavia, generally north-westerly in the north.
NE High-pressure ridge from British Isles over Scandinavia to Russia. Mainly southerly flow.
Ww Blocking-high, central Russia; low eastern Atlantic. Southerly meridional flow.

Besides there are two types of situations, which are, as type SE, difficult to classify definitely in the zonal or meridional groups:

HM Expanded high-pressure over most of central Europe giving sometimes zonal, but more often north-westerly flow over Scandinavia.
HB Blocking-high, British Isles giving generally northerly meridional flow over Scandinavia, this flow transporting, however, more or less warm air masses around the high ridge extending northwards.

Both of these types have been referred to the meridional groups.

The frequency of different situations during the summer months June—August was calculated for each year from 1881—1950 according to this classification. The frequency of all zonal and all meridional situations was then determined for each year, and finally 20-years overlapping means were calculated from these frequencies. The overlapping mean curves are shown in fig. 6 together with 20 years overlapping means for Stockholm summer temperature from the same period.

Table 3. 20 years overlapping means of frequencies of certain summer circulation patterns

Period	Zon	Mer	S	N	W	S + W	HM	HB	Z + N
1881—00	48.4	43.6	7.8	12.2	9.4	17.2	10.2	4.1	60.6
1882—01	47.3	44.7	7.9	12.2	10.5	18.4	9.8	**4.4**	59.5
1883—02	46.9	45.1	7.7	13.0	10.2	17.9	10.1	4.2	59.9
1884—03	46.8	45.2	7.9	13.0	10.2	18.1	10.1	4.0	59.8
1885—04	47.3	44.7	*7.5*	13.9	8.7	*16.2*	10.4	4.3	61.2
1886—05	47.1	44.9	7.7	13.2	9.2	16.8	10.9	4.2	60.3
1887—06	46.4	45.6	7.9	13.4	9.5	17.4	10.6	4.3	59.8
1888—07	47.5	44.5	8.9	12.7	9.6	18.5	9.5	3.9	60.2
1889—08	47.1	44.9	9.3	12.6	9.9	19.2	9.3	3.9	59.7
1890—09	47.2	44.8	9.9	13.0	9.0	18.9	9.1	3.9	60.2
1891—10	45.8	46.2	10.2	13.8	9.2	19.4	9.1	4.0	59.6
1892—11	44.8	47.2	10.1	14.3	9.1	19.2	9.4	4.4	59.1
1893—12	44.2	47.8	11.3	13.7	9.7	21.0	9.3	3.8	57.9
1894—13	44.5	47.5	11.0	13.7	10.3	21.3	9.2	3.4	58.2
1895—14	42.8	49.2	12.0	13.3	10.9	22.9	9.8	3.3	56.1
1896—15	42.2	49.8	11.9	14.1	10.8	22.7	9.9	3.2	56.3
1897—16	42.4	49.6	12.0	13.9	10.6	22.6	9.9	3.4	56.3
1898—17	*41.4*	**50.6**	12.4	13.7	11.0	**23.4**	10.3	3.3	55.1
1899—18	42.1	49.9	12.3	13.7	10.9	23.2	9.2	3.4	55.8
1900—19	44.1	47.9	12.3	13.8	10.2	22.5	8.9	2.7	57.9
1901—20	44.0	48.0	12.4	14.0	10.9	23.3	8.2	2.6	58.0
1902—21	45.1	46.9	11.9	**14.4**	10.2	22.1	8.0	2.4	59.5
1903—22	46.1	45.9	12.1	14.0	9.9	22.0	7.4	2.4	60.1
1904—23	46.5	45.5	11.5	14.2	9.4	20.9	7.8	2.4	60.7
1905—24	47.2	44.8	12.2	13.4	9.7	21.9	7.3	*2.1*	60.6
1906—25	47.1	44.9	12.1	13.8	9.6	21.7	*7.1*	2.2	60.9
1907—26	46.9	45.1	12.4	13.6	9.3	21.7	7.2	2.5	60.5
1908—27	46.2	45.8	12.6	13.7	9.7	22.3	7.6	2.3	59.9
1909—28	47.2	44.8	12.2	13.2	9.1	21.3	8.0	2.4	60.4
1910—29	47.0	45.0	11.6	12.8	8.6	20.2	9.1	2.6	59.8
1911—30	47.1	44.9	11.5	11.8	9.4	20.9	9.7	2.7	58.9
1912—31	48.0	44.0	11.8	11.7	8.5	20.3	9.7	2.5	59.7
1913—32	48.6	43.4	10.6	12.4	7.9	18.5	9.9	2.6	61.0
1914—33	48.7	43.3	10.6	11.9	7.5	18.1	10.5	2.7	60.6
1915—34	49.4	42.6	10.0	12.3	7.5	17.5	10.0	2.8	**61.7**
1916—35	49.6	42.4	10.5	11.1	8.1	18.6	10.0	2.8	60.7
1917—36	49.8	42.2	10.0	11.0	7.8	17.8	10.5	2.7	60.8
1918—37	**50.6**	*41.4*	9.1	10.9	8.0	17.1	10.0	3.3	61.5
1919—38	49.6	42.4	9.4	10.6	8.7	18.1	10.4	3.2	60.2
1920—39	48.4	43.6	10.3	10.3	9.5	19.8	10.2	3.2	58.7
1921—40	48.6	43.4	10.6	9.7	9.4	20.0	10.1	3.6	58.3
1922—41	48.5	43.5	11.4	9.0	8.9	20.3	10.7	3.5	57.5
1923—42	46.7	45.3	11.8	8.8	8.9	20.7	12.0	3.8	55.5
1924—43	46.2	45.8	12.3	8.6	9.2	21.5	11.9	3.8	54.8
1925—44	45.4	46.6	12.4	9.6	9.6	22.0	11.4	4.0	55.0
1926—45	45.8	46.2	12.5	9.2	9.0	21.5	11.5	4.0	55.0
1927—46	45.6	46.4	12.5	8.7	9.8	22.3	11.7	4.1	54.3
1928—47	45.3	46.7	13.1	8.5	9.0	22.1	12.4	4.1	53.8
1929—48	44.9	47.1	**13.5**	*8.3*	8.9	22.4	**12.7**	4.0	*53.2*

Provided that the above classification can be used to describe the circulation types also over southern Scandinavia, it is clear that very obvious interchanges between periods of dominating zonal and meridional circulation have occurred since 1880. In the mean, however, the two types of circulation balance each other surprisingly well (tab. 3). The mean frequency of zonal summer situations is 47 or almost exactly half of the total (92). In the mean

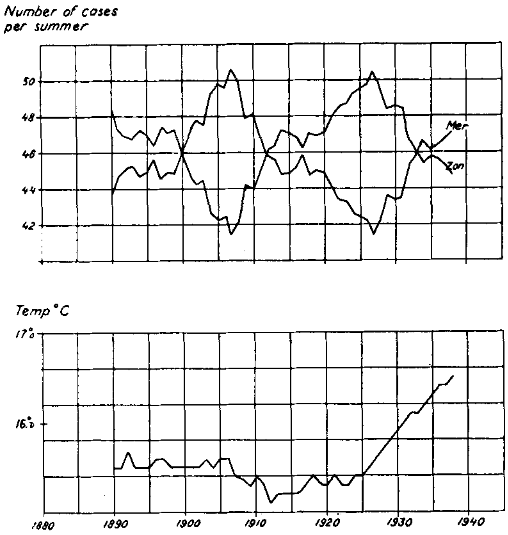

Fig. 6. 20-years overlapping mean curves of frequencies of zonal (zon) and meridional (mer) circulation patterns in summer together with 20-years overlapping means of Stockholm summer temperature.

for the whole period 1881—1950, a zonal circulation of any kind is, in the summer, as common as a meridional one.

Looking at the fluctuations we find that the summerly frequency of meridional situations increased very markedly from 1890 until the period centered around 1910, reaching a maximum of 51 cases out of 92. From the period 1898—1919 it dropped to a minimum at the end of the 1920's showing in the mean a frequency of only 41 cases out of the total. From the period 1918—37 it has increased continuously again. Evidently the frequency of zonal cases shows the opposite variations, i.e. a minimum between 1905 and 1910 and a maximum at the end of the 20's.

The connection of circulation changes with temperature

Comparing now these fluctuations with those we have found in the temperature variability, it seems reasonable to consider only the stations in southern Sweden as the applied classification seems more likely to be valid in the southern parts than in the northern. Generally speaking the fluctuations in the variability from 1881—1950 as given in fig. 5 seem to coincide very well with the changes found in the frequency of meridional situations. In details, however, the coincidence is not so good. A maximum in variability is reached between 1905 and 1910, then it decreases to a minimum which occurred, however, much earlier than that for the frequency of meridional situations, namely around 1915 instead of around 1925. In Visby, however, a secondary minimum in variability is found as late as 1927. An increase of the variability and of the meridional frequency is found everywhere after the minimum but the coincidence in time is not at all perfect.

The question is now if it is likely that a high temperature variability would correspond to a high frequency of meridional situations. Before going into this question we must investigate how the frequency fluctuations do correlate with the changes in the summer temperature itself.

In order to do so we have studied the overlapping means of the frequencies of some combined circulation types. It was assumed that it is possible to combine those meridional situations in the above scheme giving warm, southerly flow over Scandinavia on the one hand and the ones giving cold, northerly flow on the other. The following situations were referred to a general group of *warm-meridional* situations (w):

HF, HNF and NE

The following were classified as *south-meridional* (s) situations:

Ww, SE, S, TrM, TrW, TM, TB

and the following as *north-meridional* (n)

N, HN, HB, HM.

Assuming that in summer HM, in most cases, must give above normal temperatures (Rex, 1951) in Scandinavia, we have then combined the HM frequency with the frequency of warm and south-meridional situations and calculated the correlation coefficient between this combined frequency and the summer temperature in Stockholm based upon the period 1881—1950. The coefficient was found to be $r = +0.55 \pm 0.05$ showing a rather significant correlation.

The correlation coefficient between the same temperature and the frequency of zonal situations was found to be $r = -0.41 \pm 0.06$ showing that the zonal flow generally gives temperatures below normal in Stockholm.

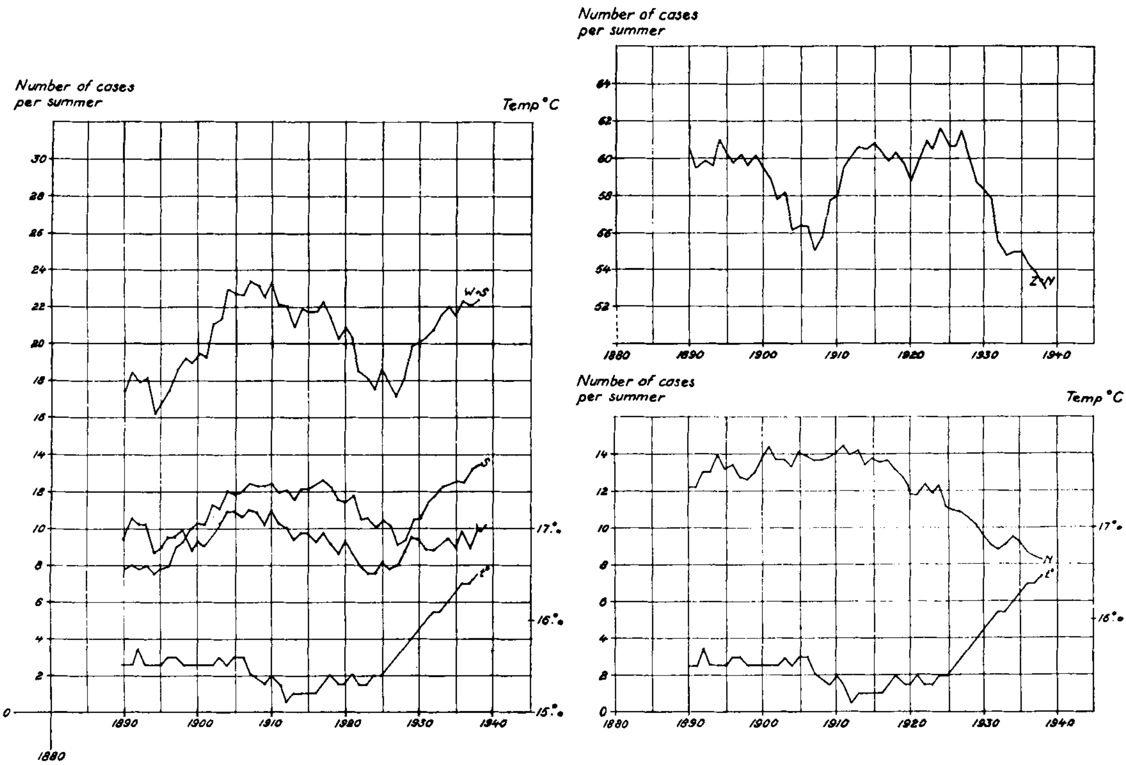

Fig. 7. 20-years overlapping means of frequencies of south-meridional (S), warm-meridional (W), and north-meridional (N) situations together with the corresponding overlapping mean curve for the Stockholm summer temperature. Combined curves (Z + N) and (W + S) are also entered.

Finally, the coefficient between a combination of zonal and north-meridional situations (except HM cases) was determined to be $r = -0.51 \pm 0.06$.

From these calculations of correlation coefficients, it can be concluded that the summer temperature may be considered as being rather closely related to the frequency of these basic types of circulation.

The fluctuations in frequency of south-meridional (*s*), warm-meridional (*w*) and north-meridional (*n*) situations since 1881 are shown by 20-year overlapping means in fig. 7 a and b together with the corresponding temperature curve from Stockholm. Combined curves ($w + s$) and ($z + n$) are also entered in the diagrams.

It is evident from these figures that there has been a continuous increase in number of south-meridional situations but on the whole a decrease of north-meridional cases. The warm-meridional situations do not show such a definite trend but a certain increase is found there also.

Comparing now these curves with the temperature curves from Stockholm and other places in south Sweden we find quite an intimate relationship between the temperature and the frequency of warm and south-meridional situations. Looking at the curves from Göteborg and Växjö (fig. 5), the increase of the summer temperature from around 1890 to the period centered in 1905—07 is quite obvious. The frequency of warm-meridional situations continuously increased during that period. At the same time, however, the north-meridional cases—though being fewer—are also increasing in frequency. So it is natural that the temperature rise can not be so large as when the warm-meridional situations increase at the cost of north-meridional instead of the zonal cases as occurs towards the end of the investigated period. In fact no particular rise in the temperature curve from 1890—1907 is found, for instance, at Stockholm.

The temperature practically everywhere in south Sweden shows a decrease from the maximum period between 1905 and 1910 and remains then quite low until it again starts to rise around 1925. From the period around 1907 until that of 1927 the frequency of warm and south-meridional situations is continuously falling. The number of north-meridional cases is also decreasing but with a lower rate. The frequency of zonal cases rises considerably, and this period of low temperature may be characterized as one of typically zonal circulation. From the middle of the 1920's an extraordinary increase of the summer temperature has set in all over northern and middle Europe. According to the circulation changes found in fig. 7 the south and warm-meridional situations again started to increase considerably, this time at the cost of both zonal and north-meridional circulation patterns.

As mentioned the HM and HB cases could not be definitely referred either to the north-meridional or to the warm-meridional group. From the point of view of circulation patterns they are mainly north-meridional over Scandinavia but give quite often rise in summer to high temperatures. On the other hand a very small shift westwards of the axis of high pressure may cause a considerable cooling-off over Sweden and a complete change in the distribution of temperature and precipitation over Scandinavia. This fact has been shown by REX (1951, 1952) in his study of blocking-highs over northwestern Europe. The HM and HB cases in the German classification are namely quite often identical with the blocking-highs studied by Rex.

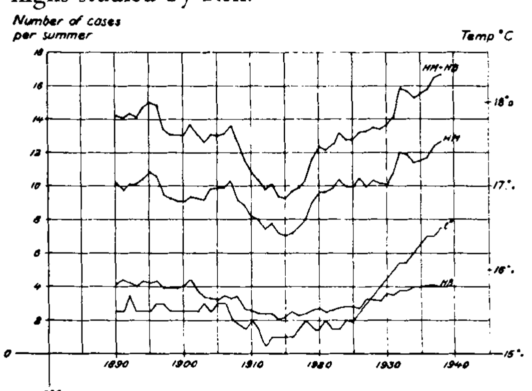

Fig. 8. 20-years overlapping means of frequencies of HM and HB situations as compared to the corresponding overlapping mean curve for the Stockholm summer temperature.

Rex in his investigation stressed, however, that the development of the temperature conditions in Scandinavia during the last decades is exactly that which could be expected if the frequency of westerly blocking-highs—centered not too for west—has increased in the same period of time. In order to clarify this point we have studied the frequency fluctuations also of the HB and HM cases.

The average number of HM-cases per summer during the whole period 1881—1950 is 10 and of HB cases between 3 and 4. These numbers are so small that it is impossible that any high correlation could be found between the summer temperature at a single station and the frequency of cases. One finds that the correlation between the summer temperature in Stockholm and the frequency of HM cases, for instance, is expressed by $r = 0.14$, which certainly is quite insignificant. Looking at the long-range fluctuations illustrated by 20-year overlapping means, the coincidence between the frequency trend and temperature on the whole in Sweden is, however, quite remarkable. The general trend for HM and HB is quite similar so we may combine the two cases to obtain the curve in fig. 8. The relatively high mean temperature around the turn of the century corresponds to a well-defined secondary maximum in the frequency of HM and HB; the cool summers period from around 1907 to 1920 corresponds to a very marked minimum in the same frequency; and the considerable warming up in the last two and a half decades corresponds to a very strong increase in the frequency of HM and HB. It should be noted that this increase in the summer HM-frequency has already been stressed by BREZOVSKY (1952) in a special study of the fluctuations in frequency of different situations. It seems unlikely that this coincidence should be just accidental, so we may at least conclude that the summer mean temperature in Sweden on the whole is favoured by a high frequency of blocking-highs over the British Isles extending over central Europe.

The increase of summer temperature in middle and northern Europe since around 1925 then seems to have been caused by a considerable increase of the frequency of south-meridional and warm-meridional situations and also of blocking-highs appearing rather far to the east. This fact is in agreement with the finding of ERIKSSON (1943) that in July the southerly flow over Scandinavia and over the northern-most Atlantic has increased from the beginning of the century to the 1930's. Such a change towards a more warm-meridional circulation over Scandinavia has been shown to have occurred also in winter both by ERIKSSON (1943) and PETTERSSEN (1949). *It seems rather obvious that this is the fundamental change of the circulation over Europe having caused the considerable warming up in northern latitudes which has so evidently shown up, for instance, in the retreat of glaciers* (AHLMANN 1948, WALLÉN 1948, WILLETT 1950).

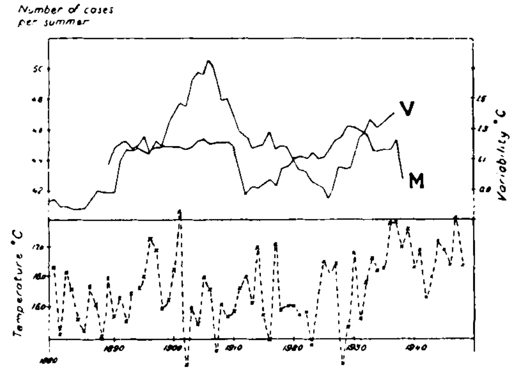

Fig. 9. Stockholm summer remperature and variability (V) curves (1881—1950) compared to the overlapping mean curve of frequencies of meridional (M) circulation patterns.

Changes in circulation and the temperature variability.

Comparing now more conclusively the fluctuations of the general circulation with changes in the variability of the summer temperature, it is found from fig. 9 and a comparison between figs. 5 and 6—8 that there is on the whole a definite tendency to high variability during the period 1890 to 1910; this period was, especially in the latter part, characterized by a very high frequency of meridional situations. The decrease in the variability around 1910 coincides with a development towards a more zonal circulation, although the maximum of zonal situations occurs much later than does the minimum of the variability. It should be noted, however, that the increase of the variability, starting again around 1915, is to some extent caused by the general temperature trend towards a warmer summer climate, which is in turn a consequence of the decreasing frequency of north-meridional situations and increasing frequency of south-meridional and HM and HB situations as well. The high variability is then probably caused by a rapid interchange between zonal summers on the one side and summers with high frequency of south-meridional and HM, HB situations on the other. The maximum of the variability in the latter 1920's coincides with a high frequency of south and warm-meridional circulation patterns and a rather high frequency of zonal situations. Later on, when the frequency of zonal cases goes down together with a continued decrease of north-meridional cases and the south-meridional frequency remains high, the variability decreases again (compare also fig. 9).

Summarizing the fluctuations in summer circulation over north-western Europe since 1881 and comparing with fluctuations in temperature and its variability in southern Sweden we recognize the following periods:

Around 1890 to around 1910:

Period of summer temperature slightly above normal and high temperature variability. The circulation was characterized by a high frequency of meridional circulation both from a northerly and southerly direction. The frequency of HM and HB cases was comparatively high. The zonal circulation was low and decreasing throughout the period.

Around 1910 to around 1927:

Period of summer temperature around or below normal, temperature and its variability increased during the latter part of the period.

Circulation was first characterized by a rapid decrease in frequency of meridional situations and an increase of the zonal flow. South-meridional situations became more rare and HM and HB cases showed a definite minimum at the same time as the minimum in variability (around 1915).

Towards the end of the period the frequency of south-meridional cases increased again.

Around 1927 to 1950:

Period of increasing summer-tempera-

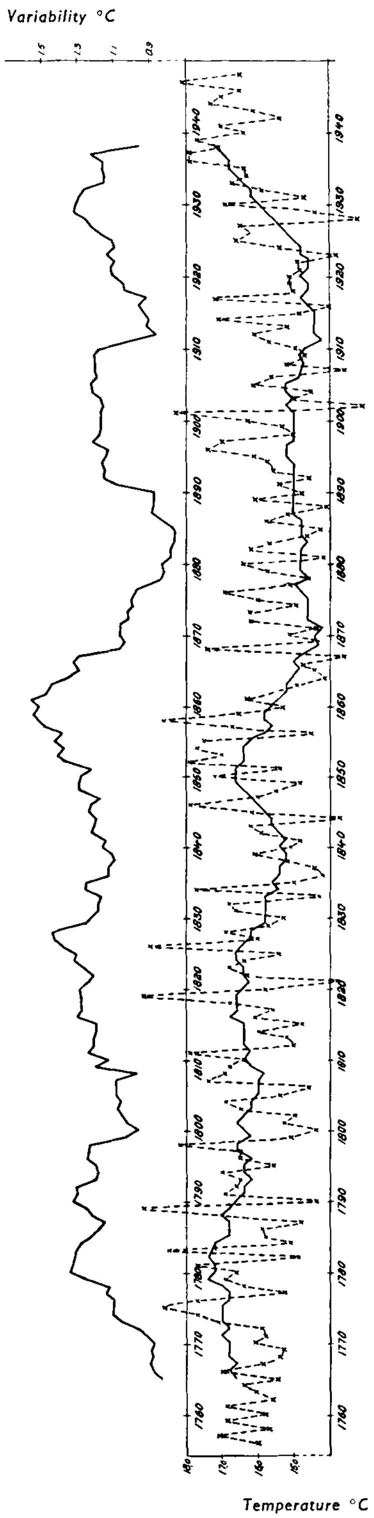

Fig. 10. Year to the year changes in summer temperature in Stockholm since 1756 together with the corresponding 20-years overlapping mean curve (below) and 20 years overlapping means of standard deviation (above).

ture and variability. The latter decreased at the end of the period.

Circulation was characterized by a continuous increase of the frequency of south and warm-meridional situations and HM, HB cases. North-meridional and zonal circulation decreased rapidly. When, during the 40's, the frequency of warm and south-meridional cases kept high together with that of HM and HB cases the variability decreased again.

6. Analysis of the complete Stockholm temperature curve

Temperature observations are available from Stockholm since 1756 so it is possible to make a particularly interesting study of the fluctuations of the variability. In fig. 10 is drawn the year to year changes in the summer temperature (June—Aug.) together with the 20-years overlapping mean curve. Above these curves the 20-year overlapping standard deviation curve is given.

From inspection it is even more evident than from the other curves that the long-range fluctuations in the variability really correspond to periods of a large year to year variability. A period of continuously rather high summer temperature in the 1750 and 60's is followed by still warmer decades but of much higher variability. This suggests that the famous warm period at the end of the 18th century was characterized by a quite high variability (1.2—1.3). There is no doubt that the high variability is somewhat influenced by the general increase of temperature, but from the trend shown by the overlapping mean curve, it is obvious that this influence can not be dominant.

During the first decades of the 19th century the summer temperature begins to fall and there occurs a slight decrease in the variability corresponding to a cooler and more monotonous period of summers. Between 1810 and 1825 there is another period of increasing variability combined with a much cooler climate than had the period at the end of the preceding century. After 1825 the summer temperature continues to drop while the variability shows a small decrease but still remains rather high. From the beginning of the 1840's a very typical increase in the mean

Table 4. 20 years overlapping means and standard deviations of summer temperature at Stockholm

Period	t_m	σ
1756—75	16.3	0.84
1757—76	16.4	0.88
1758—77	16.3	0.90
1759—78	16.4	0.89
1760—79	16.4	0.89
1761—80	16.4	0.88
1762—81	16.5	0.92
1763—82	16.4	0.96
1764—83	16.5	1.06
1765—84	16.5	1.11
1766—85	16.5	1.10
1767—85	16.4	1.10
1768—87	16.4	1.15
1769—88	16.5	1.13
1770—89	16.7	1.25
1771—90	16.6	1.34
1772—91	16.6	1.33
1773—92	16.7	1.32
1774—93	16.6	1.31
1775—94	16.6	1.29
1776—95	16.4	1.22
1777—96	16.4	1.19
1778—97	16.4	1.16
1779—98	16.5	1.23
1780—99	16.4	1.26
1781—00	16.3	1.33
1782—01	16.2	1.31
1783—02	16.2	1.31
1784—03	16.1	1.20
1785—04	16.2	1.19
1786—05	16.2	1.20
1787—06	16.1	1.25
1788—07	16.3	1.24
1789—08	16.3	1.24
1790—09	16.1	1.04
1791—10	16.2	0.97
1792—11	16.3	1.03
1793—12	16.2	1.06
1794—13	16.1	1.08
1795—14	16.1	1.06
1796—15	16.0	1.09
1797—16	16.0	1.09
1798—17	16.0	1.09

Period	t_m	σ
1799—18	15.9	0.98
1800—19	16.1	1.20
1801—20	16.2	1.13
1802—21	16.1	1.24
1803—22	16.2	1.21
1804—23	16.2	1.21
1805—24	16.2	1.20
1806—25	16.2	1.20
1807—26	16.4	1.30
1808—27	16.3	1.28
1809—28	16.3	1.28
1810—29	16.3	1.28
1811—30	16.2	1.29
1812—31	16.2	1.24
1813—32	16.2	1.22
1814—33	16.2	1.27
1815—34	16.3	1.32
1816—35	16.3	1.31
1817—36	16.2	1.38
1818—37	16.1	1.43
1819—38	16.1	1.44
1820—39	15.9	1.24
1821—40	15.9	1.26
1822—41	15.9	1.19
1823—42	15.9	1.19
1824—43	15.9	1.17
1825—44	15.7	1.25
1826—45	15.8	1.25
1827—46	15.7	1.13
1828—47	15.7	1.13
1829—48	15.6	1.10
1830—49	15.6	1.11
1831—50	15.7	1.16
1832—51	15.6	1.15
1833—52	15.7	1.22
1834—53	15.8	1.21
1835—54	15.8	1.20
1836—55	15.9	1.24
1837—56	16.0	1.23
1838—57	16.1	1.18
1839—58	16.2	1.28
1840—59	16.3	1.29
1841—60	16.3	1.28

Period	t_m	σ
1842—61	16.3	1.23
1843—62	16.2	1.38
1844—63	16.2	1.41
1845—64	16.2	1.37
1846—65	16.1	1.43
1847—66	15.9	1.39
1848—67	15.8	1.48
1849—68	15.9	1.52
1850—69	15.9	1.54
1851—70	15.8	1.52
1852—71	15.7	1.55
1853—72	15.6	1.47
1854—73	15.6	1.44
1855—74	15.5	1.37
1856—75	15.4	1.29
1857—76	15.5	1.32
1858—77	15.4	1.29
1859—78	15.2	1.09
1860—79	15.2	1.04
1861—80	15.2	1.07
1862—81	15.1	1.06
1863—82	15.3	1.02
1864—83	15.3	1.02
1865—84	15.3	0.99
1866—85	15.3	1.00
1867—86	15.4	1.00
1868—87	15.5	0.91
1869—88	15.3	0.84
1870—89	15.4	0.82
1871—90	15.4	0.83
1872—91	15.4	0.79
1873—92	15.4	0.79
1874—93	15.3	0.77
1875—94	15.4	0.77
1876—95	15.4	0.78
1877—96	15.4	0.83
1878—97	15.5	0.89
1879—98	15.5	0.88
1880—99	15.5	0.88
1881—00	15.5	0.88
1882—01	15.7	1.09
1883—02	15.5	1.16
1884—03	15.5	1.16
1885—04	15.5	1.17

Period	t_m	σ
1886—05	15.6	1.15
1887—06	15.6	1.14
1888—07	15.5	1.22
1889—08	15.5	1.18
1890—09	15.5	1.18
1891—10	15.5	1.18
1892—11	15.5	1.18
1893—12	15.6	1.17
1894—13	15.5	1.18
1895—14	15.6	1.22
1896—15	15.6	1.23
1897—16	15.4	1.20
1898—17	15.4	1.21
1899—18	15.4	1.21
1900—19	15.4	1.21
1901—20	15.3	1.19
1902—21	15.1	0.99
1903—22	15.2	0.87
1904—23	15.2	0.92
1905—24	15.2	0.91
1906—25	15.2	0.94
1907—26	15.3	0.96
1908—27	15.4	0.92
1909—28	15.3	1.04
1910—29	15.3	1.50
1911—30	15.4	1.10
1912—31	15.3	1.11
1913—32	15.3	1.10
1914—33	15.4	1.14
1915—34	15.4	1.10
1916—35	15.5	1.11
1917—36	15.6	1.18
1918—37	15.7	1.23
1919—38	15.8	1.26
1920—39	15.9	1.32
1921—40	16.0	1.31
1922—41	16.1	1.29
1923—42	16.1	1.27
1924—43	16.2	1.15
1925—44	16.3	1.15
1926—45	16.4	1.16
1927—46	16.4	1.16
1928—47	16.5	1.23
1929—48	16.6	0.97

temperature is caused by a certain number of very warm summers interrupted by rather cold ones. This means that the variability again reaches very high values during the 1850's.

A most remarkable drop in the summer temperature curve of Stockholm occurred at the beginning of the 1860's. For about 10 years after 1860 the summers were extremely cold and even later on remained cool for several decades. Contemporarily the variability decreased quite rapidly around 1860 and remained continuously low until the 1890's. It should be noted that the influence of the temperature decrease is to increase the variability so the values of variability obtained are in fact somewhat to high. Then again—as has been discussed above—the variability increased while temperature was rather unchanged and remained low until around 1925 when rather suddenly it started to increase very definitely. The variability, having dropped again slightly around 1915, started to rise very soon thereafter and reached a maximum for the period 1920—1939. Since then it has dropped again.

Considering now the more general trend of the fluctuations in the Stockholm summer temperature and its variability, it is seen from fig. 10 that the summers generally became colder and colder from the middle of the 18th century until the 1860's and then, on the whole, remained cool until 1925. Since then they have become considerably warmer. During the same time the variability has changed as follows.

During the last half of the 18th century the variability increased considerably and then remained high or rather increased (maximum 1.60) for a century until it suddenly dropped to low values in connection with the deterioration of the summer climate around 1860. During this century of high variability there were short periods of decrease, correlating fairly well with periods of cool summers. On the whole, the variability during this first century rather definitely differed from that during the following one. After 1860 the variability has been particularly low until it rose at the turn of the century. On the whole the variability during the century since 1860 was lower than during the foregoing one especially if we note that the rise after 1925 was to some extent caused by the general temperature increase starting at that time.

Even if the conclusions given in chapter 5 regarding the relation between the variability and changes of the general circulation have to be proven further it is interesting to make an attempt to analyse the older part of the Stockholm temperature curve. It seems, at least, probable that the long period of high variability in the summer temperature, characterizing the century from 1760 to 1860, was one of comparatively high frequency of meridional circulation. As the period from 1860 to our days shows on the whole a lower variability it is likely to have been of a more zonal character than the first century. If it is allowed to draw conclusions for shorter periods we may suggest that the warm period 1770—1795 was one of a typical meridional circulation with dominating south to east meridional circulation. 1800—1820 shows a definite cooling off with lower variability indicating a period of more zonal character. The following decades show further cooling off until 1840 but at least the 1820's seems likely to have been of a more north-meridional character. The famous 1840's and 1850's are again periods of high variability and increasing temperatures; they are therefore likely to have been meridional decades with dominating southerly flow. From 1860 to the periods discussed in foregoing chapter, the circulation was probably again of a more zonal character.

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