An outline of the climate of Denmark

By Kr. M. Jensen

Abstract

This article contains a summary of the average temperature conditions, the quantities of precipitation and the wind conditions. Further, an analysis is given of the distribution, over a rather great number of years, of these climatical elements. A representation is given of the diurnal temperature trend and of the diurnal quantity of precipitation at a certain station in the period 1946–1949; thus, we get an impression of the seasonal alternations of the weather conditions.

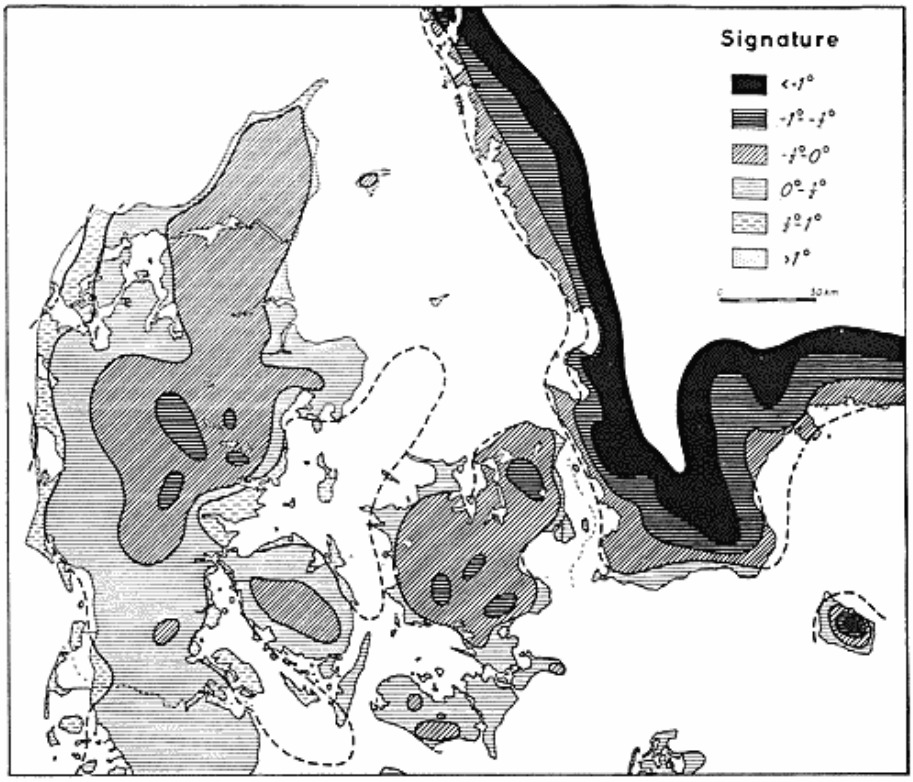
Thanks to its geographical position, Denmark is among the regions of the globe where *the balance between incoming and outgoing radiation* for the whole year shows a considerable deficit, calculated for the ground and the superjacent troposphere as an entity. Expressed in average values, the energy deficit resulting from the radiation amounts to about 40.000 cal./sq.cm. per year in our regions. The total incoming atmospheric radiation to the ground proper is about 85.000 cal./sq.cm. per year, which proves that the above-mentioned deficit is of a considerable size and of great importance for the temperature conditions in the country.

The compensation of this deficit principally takes place as follows: by condensation of the water vapour in the atmosphere and by advection. As stated below, the size of the precipitation varies from a little more than 400 mm. till about 800 mm. annually, and the average for the whole country is estimated at about 650 mm. The evaporation amounts to about 350—450 mm. annually; this gives a condensation excess of about 250 mm., corresponding to a heat transfer to the atmosphere above Denmark of approximately 15.000 cal/sq. cm. per year; in this way about one third of the radiation deficit is covered; the rest of the deficit it compensated by a supply of energy through a transfer of warm air-masses.

The day-to-day temperature of the atmosphere is thus determined

partly by situations with great radiation, partly by the varying heat conditions of the air-masses. The periods with the radiation as a predominant factor and with still or gently moving air have an intensive heating of the ground surface and of the superjacent air during daytime and, under such conditions, a strong nocturnal cooling. However, a radiation fog may hamper the outgoing terrestrial radiation in the last hours of the night, resulting in an asymmetric course of the daily temperature curve. During these periods the mean daily temperatures do not deviate much from the average values for a great number of years; however, as a result of the above-mentioned fogs they may be a little superior to the normal in summer. What characterizes these situations is the relatively big diurnal temperature amplitude and the rather regular course of the diurnal temperature cycle with its maximum at 2—3 p.m. and its minimum just before sunrise. Such conditions are created when big high-pressure systems stay for a rather long time with their nucleus above or in close proximity to Denmark, resulting in long-lasting, bright weather with wind-forces of a few metres per second. The effects of these anticyclones are accentuated in spring, when a steady heating of the air takes place, giving rise to a relative desiccation, which, in its turn, causes small cloud formations and creates better conditions for the in- and outgoing terrestrial radiation.

As the greatest vertical temperature differences in the air layer near the ground occur during these *high-pressure situations* they are of decisive importance to the micro-climate with all its bio-geographical effects. Thus, the frequency of the high-pressure plays a great role in the Danish climate. They are most frequent in January/February, in May and in September/October; however, their occurrence in proportion to the total number of weather types does not vary much from month to month. A quantitative description is given in the analyses which *Hess* and *Brezowsky* have made of the so-called »Grosswetterlagen«. According to their calculations, »high pressure above Central Europe« (abbr.: HM) occurs in 11% of the total number of days (1891—1950) with its maximum, 17%, in September and its minimum, 7%, in April. Most often this group has its centre to the south of Denmark, while other high-pressures are situated farther to the north and are designated »heigh pressures above Fenno-Scandia and the northern Atlantique« (abbr. HF and HNF). The latter high-pressures occur in 7% of the total number of observations with their maximum of 12% in May and their minimum of 2,5% in July.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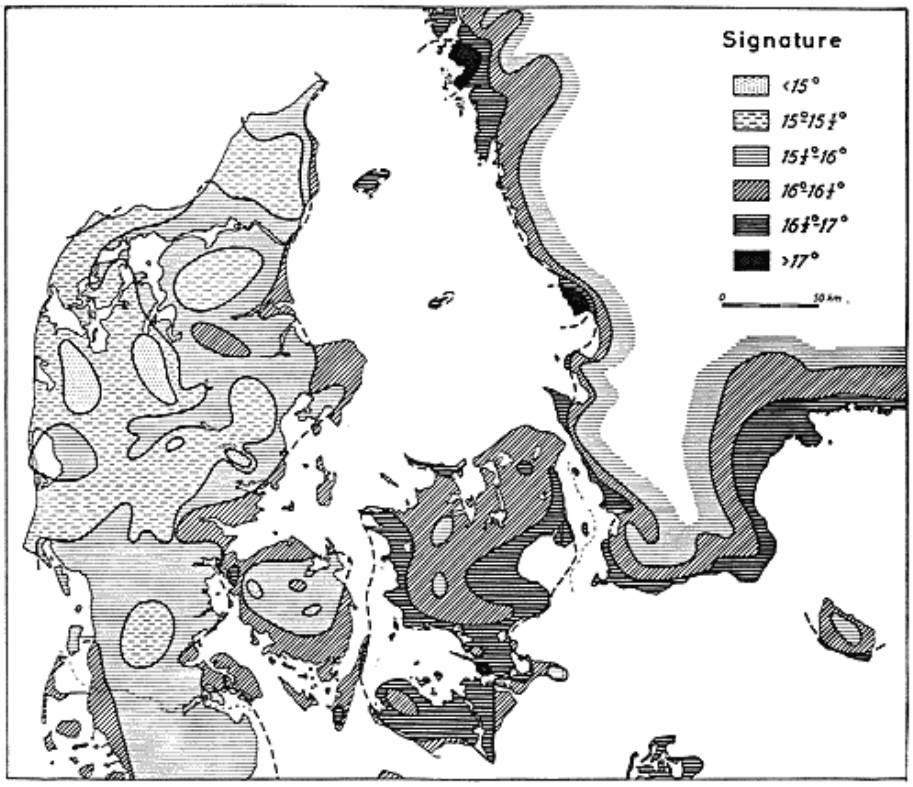
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However, much more often the weather is subjected to the influences of *the moving air-masses*. These masses, when passing above Denmark, have such a great influence on our temperature conditions that the diurnal temperature cycle is almost completely dominated by the alterations of the heat content of the air-masses; consequently, the diurnal temperature variations conditioned by the radiation only manifest themselves to a slight degree. It is the heat accompanying these air-masses which compensates a great part of the negative balance between incoming radiation and outgoing radiation; however, the supply of energy is by no means the result of a constant transport to the region of warm air-masses. Thus, the alternations are frequent between the flow of cold, Arctic or Polar air-masses and warm, Tropical air. The most common air circulation takes place in connection with passages of cyclones, and the geographical position of Denmark on the western side of the Eurasian continent is favourable for the intrusion of the cyclones departing from the North Atlantic Polar Front. Around these frontal depressions a definitive wind-change normally takes place. During a passage of a cyclone north of Denmark we first get eastern to south-eastern winds with a supply of Polar Continental air-masses (cP air), which in winter may result in severe cold. Thereafter, the wind turns towards south-south/west after the passage of a warm front, and the region receives Tropical Maritime air (mT air). Finally, in the course of a day or two the wind turns towards west behind the cold-front which delimits the warm sector with the Tropical air-masses, after which the weather conditions are dominated by Polar Maritime air-masses. In certain cases the Polar Maritime air is replaced by air-masses of a more Arctic character, conveyed to us by the north wind. In the cases where the centre of depression wanders straight south of Denmark a wind-change takes place from eastern to northern or, perhaps, north-western winds. However, this change does not bring about the same pronounced alterations of the air temperature as does the front passage.

As appears from the above-mentioned air-masses, the passages of cyclones are often accompanied by great temperature fluctuations. This is especially the case in winter, the season with the greatest number of cyclones above Denmark. Further, the centres of the cy-

Fig. 1. The two maps p. 105 indicate the average temperatures (not reduced) for January and July. With a view to a judgment of the level-conditioned influence on the temperatures it should be mentioned that it is only small regions in central East Jutland, South Funen and Central Zealand which reach an altitude higher than 150 m. above sea-level (Partly from "Danmarks Klima").

clones often pass over Denmark in winter, resulting in big differences between the northern part of the country, where the Polar-Continental air-masses may reign uninterruptedly, and the southern part, which may be under the influence of Tropic or Polar Maritime air-masses. This difference is particularly noticeable, when occluded depressions are resting above Denmark with back-bent (east-west orientated) frontal systems. If so, North Jutland may have strong, eastern wind with air-temperatures below the freezing point, while the southern part of the country has temperatures up to 10° C.

While, as mentioned, the big primary depressions in winter often pass immediately above or in close proximity to Denmark they move, in summer, far to the north as a consequence of the displacement of the Polar Front in a northern direction; however, the region is touched by the accompanying frontal systems. As for the temperature variations which may follow these front passages, they are relatively small.

Not only the passages of cyclones are followed by moving air-masses above Denmark; also the high-pressure situations may supply »foreign« air-masses in such cases where the centre of the high-pressure is situated at a rather big distance to the north or to the south of Denmark.

Summer as well as winter there are pronounced differences between *the temperatures of the coastal areas* and those of *the interior,* partly as a natural consequence of the differences of the levels (the maximum height is 174 m. above sea-level), partly on account of the Maritime-Continental contrast. In the average values these differences only amount to 1°—2°, whereas in special situations they may reach 10°—12°. The mean monthly temperatures vary for all Danish stations, as appears from the maps, p. 105, between 0° in January/February and about 15°—16° in July. The map of the January temperatures most clearly shows the difference between the areas close to the coast and the interior, both in Jutland and in the bigger Danish islands. A far-reaching maritime influence from west and from south-west also appears from this map, which shows a rather slow decrease of the mean temperature from the west coast of Jutland and towards the interior, while the transition is very sharp in the other coastal regions of Denmark. In the month of July the mean temperature is, on the whole, increasing from the north-western part of the country towards south and east; one of the causes of this is an advance of warm air-masses from south-east of a distinct continental character — the so-called heat-waves; however, the contrast

between the interior and the coasts is less perceptible in this season than in the rest of the year.

In order to further illustrate the *temperature conditions* in the *various parts of the country* the figures on p. 109 have been worked out; they indicate the variations of the mean temperatures of the individual months for a station at the west coast (Nordby on Fanø), for a station in the interior of Jutland (Herning) and finally for a station on Bornholm in the Baltic (Hammershus). Further, these figures show the mean minimum and the mean maximum as well as the absolute minimum and the absolute maximum for the single months. These diagrams as well as the maps p. 105 represent the continental effect in the interior of Jutland in relation to the west-coast station. In the winter half-year the differences between the monthly averages of the two stations are about 1°; however, the variations in the single months are smaller on Fanø than in Herning, and the amplitude between the absolute maximum temperature and the absolute minimum temperature is far greater in Herning than on Fanø in all the months of the year; this is one of the principal causes of the different biological effects of the climate in these parts of the country. The cycle of the average temperatures is practically identical at the two above-mentioned Jutland stations, both of which, however, deviate rather much from the station on Bornholm. What especially distinguishes Hammershus from the other stations is the much smaller variation of the mean temperatures of the winter months, (November—March); this is due to the moderating effect of the Baltic on the trend of temperature. During winter-gales from north-east with a supply of Arctic-Continental air-masses the temperatures, in most cases, are higher in Bornholm than in the rest of the country, as long as the Baltic is not frozen; normally, this freezing does not take place until February—March and only in the years when the winter is sufficiently severe. The milder temperatures are a result of the fact that the air-masses from north-east are heated by the relatively warm waters of the Baltic, whereas, in these cases, the air-flow towards the other parts of the country arrives via Sweden, a fact which contributes to maintain the continental character of the air-masses with severe cold. On the other hand, the slow heating of the waters of the Baltic and the melting of the ice after the winter, result in relatively low temperatures in the months of spring. Both April and May are considerably colder in Bornholm than the corresponding months at the Jutland stations, as appears from the diagrams p. 109.

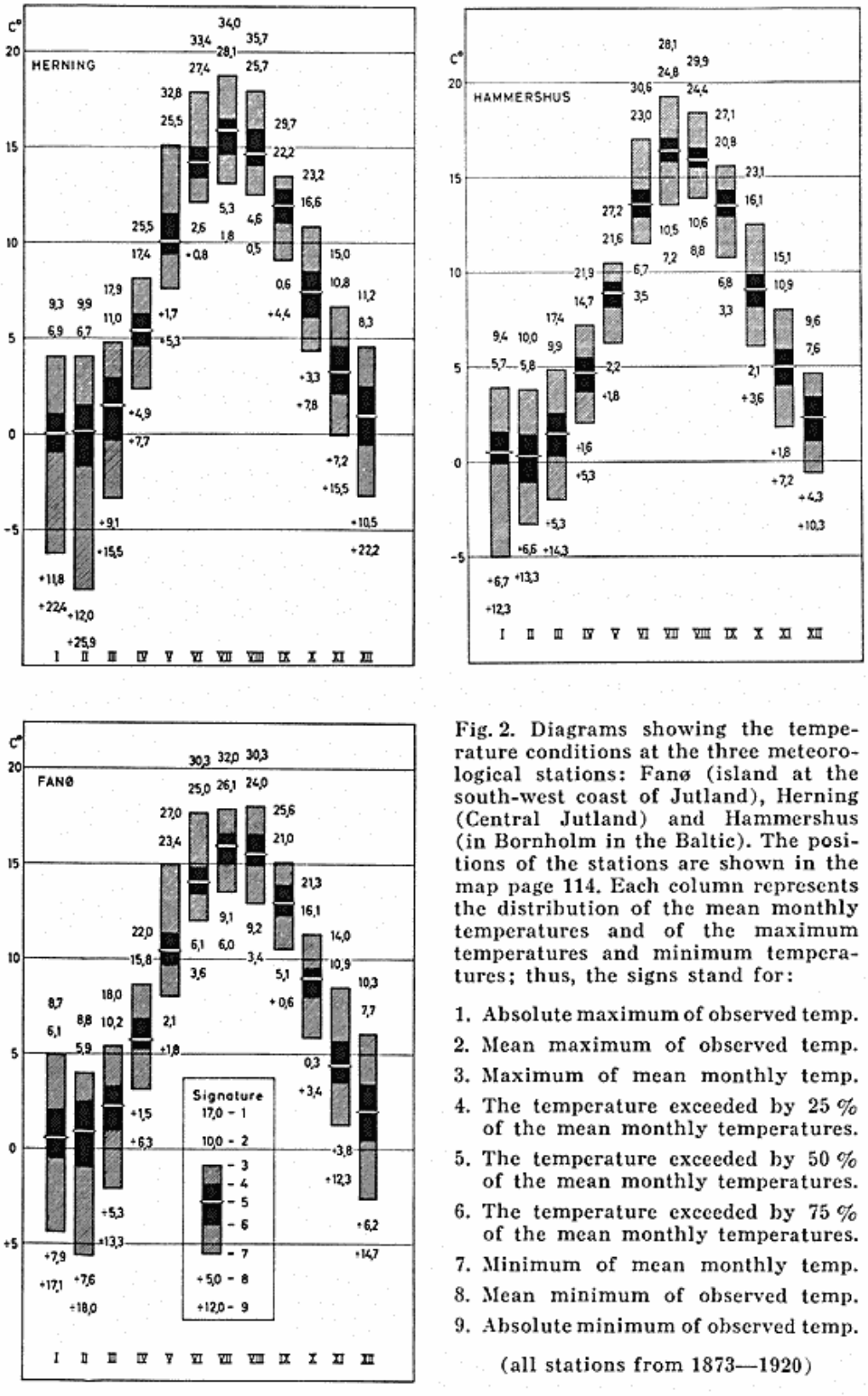


Fig. 2. Diagrams showing the temperature conditions at the three meteorological stations: Fanø (island at the south-west coast of Jutland), Herning (Central Jutland) and Hammershus (in Bornholm in the Baltic). The positions of the stations are shown in the map page 114. Each column represents the distribution of the mean monthly temperatures and of the maximum temperatures and minimum temperatures; thus, the signs stand for:

1. Absolute maximum of observed temp.
2. Mean maximum of observed temp.
3. Maximum of mean monthly temp.
4. The temperature exceeded by 25 % of the mean monthly temperatures.
5. The temperature exceeded by 50 % of the mean monthly temperatures.
6. The temperature exceeded by 75 % of the mean monthly temperatures.
7. Minimum of mean monthly temp.
8. Mean minimum of observed temp.
9. Absolute minimum of observed temp.

(all stations from 1873—1920)

The climatic variations within the frontiers of Denmark in a biologically important period are apparent from *the frequency of frost days* in the two spring months April and May. From the map p. 111 it will be seen that the central parts of Jutland are very much exposed to temperatures below the freezing point at the time when the spring-sown crops are sprouting, whereas the risk is less in the coastal regions. In the interior of Jutland the risk of frost, on an average, begins already about the 10th of October and continues until about the 10th of May. Along the west coast the corresponding period is from about the 10th of November till about the 15th of April, i. e. almost two months less; in East Denmark this period stretches from about the 1st of November till about the 20th of April. In this relation the delayed arrival of the winter-time in Bornholm is also evident from the fact that the frost-danger does not occur until about the 20th of November.

During the three summer months: June, July and August, it is extremely seldom that the minimum temperature drops below the freezing point, and even September is almost frost-free. In May and October the average frequency of frost occurrence is a few days per month. Thus, the unsymmetrical trend of the Danish temperature climate in relation to the summer solstice is distinct, because the slow rise of temperature in spring happens after spring equinox, while the corresponding decline of the temperature does not arrive until after the autumnal equinox. This fact is partly due to the influences of the surrounding waters and, at least as much, to the effect of the maritime air-masses. In the winter months, January—February, the temperature drops below freezing point in twenty days per month, on an average, and in March and December for about half the number of days; however, there are great fluctuations from year to year, as appears, for instance, from the diagrams on planche I.

The average situations hitherto described in this exposé only give a summary of the temperature conditions in Denmark; therefore, the planche I may be useful as an illustration of *the temperatures observed* during a certain number of years. In the diagrams is shown the diurnal variation of the air-temperature for an inland-station (Studsgård in Jutland; the position is shown in the map p. 114), where we may expect great amplitudes for the whole year as well as for single days; thus, we will get the strongest possible impression of the temperature variations.

A study of the four years mentioned (1946—1949) clearly shows a fundamental difference between the trend of temperature in winter

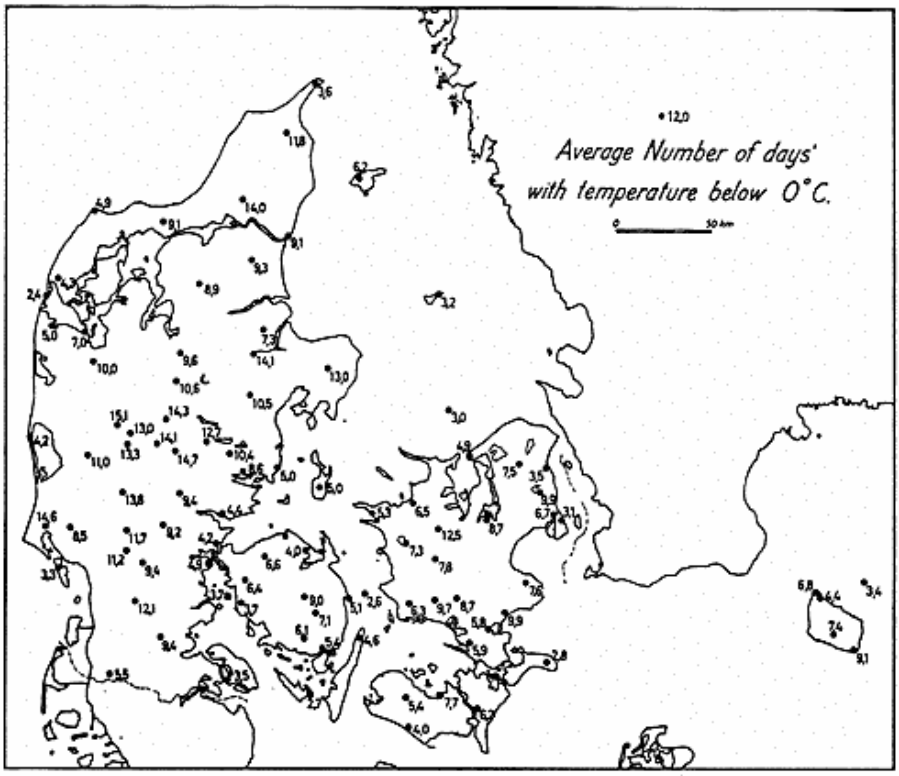


Fig. 3. The average number of frost days in the months April and May (i. e. the number of days with minimum temperatures $\leqq$ -0,1° C.).

and in summer. In the winter half-year the daily temperature range is normally much smaller than in summer; further, in this season the big jumps of the temperature from day to day are much more frequent. Further, in winter the readings reveal a more pronounced, though irregular periodicity of the trend of temperature. This periodicity manifests itself in a temperature rise stretching over two—three days, followed by a decline during the subsequent four—five days, corresponding to a passage of big low pressures with distinct and widely extended frontal systems (example: January—March 1946). In such situations the cloud-layer in connection with the low noon altitude of the sun in winter is greatly contributing to provide a small diurnal temperature amplitude. In the period 1946—1949 this winterly trend of temperature was rather pronounced already from the first half of November, and it ceased as abruptly in the latter half of March.

Another feature characteristic of the winter time appears in the first half of March 1949, when we have a cold wave with constant eastern winds and dry air; this allows the nocturnal terrestrial ra-

diation to go on unhampered, and the angle of incidence of the sun-rays is now so great that a considerable insolation also takes place in daytime. In the diagram the period in question appears with relatively big diurnal temperature amplitudes and with temperatures varying from 0° to - 10 ° C. Similar situations are seen in February 1947 and 1948; they express a pronounced continental feature of the Danish climate with far reaching biological effects.

The four winter situations represented in the diagrams further express the great variations of the levels of the temperatures from year to year. These variations are due to the shifting position of the tracks of depressions in relation to the European Continent and to the extent of the continental high pressure from the central Eurasia towards Western Europe. In the winter 1946—1947 the mean temperatures for a rather long period (almost three months) are between 0° and -10°, whereas 1949, apart from a brief period, had mean temperatures on the positive side of the zero point (3° to 5°). The continental type, of which 1947 is representative, occurs, on an average, fifteen to twenty times per century, and the most important continental winters in this century have been 1928/1929, 1939/1940, 1940/1941 and 1941/1942. These ice-winters have left traces of distinct biological effects; for instance, the agriculture has encountered difficulties with the winter crops at places where the snow has not protected the surface against the dangerous radiation and the cooling.

The rest of the year, from the end of March to the end of October, normally has a trend of temperature with much bigger diurnal temperature amplitudes than in winter; however, on the whole, the temperatures oscillate more regularly in the neighbourhood of the same mean values from day to day. Roughly, a distinction can be made between a period with evenly rising temperatures in spring (April and the beginning of May) and a period with corresponding decreasing temperatures in the autumn (the end of September and October). However, the transitions between these seasons are normally not as sharp as at the beginning and the end of the winter. Characteristic of the early summer are the stable weather conditions with enormous temperature ranges (15°—20°), which often occur in the month of May as a natural consequence of the relative desiccation of the air (see also p. 104). Thus, May is the month which has the smallest cloud-layer and the biggest possibilities of insolation and terrestrial radiation, and the nocturnal terrestrial radiation is only slightly restrained by fogs. On an average, May is also one of the most favoured months as regards the duration of sunshine,

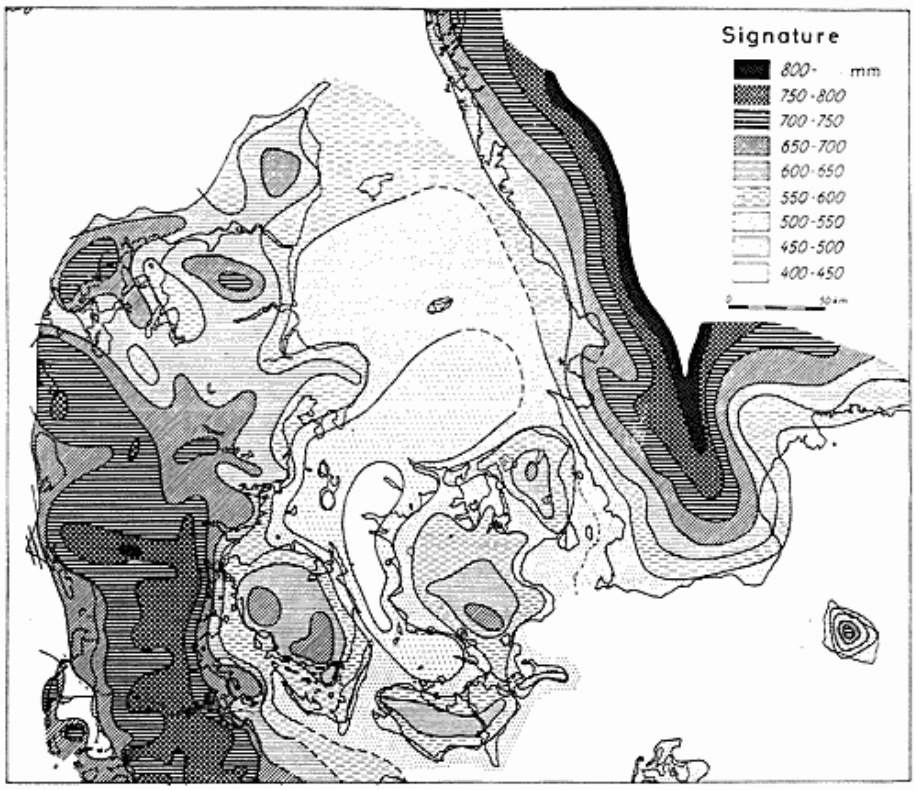


Fig. 4. Precipitation map of Denmark, showing the average yearly precipitation in mm. (Partly from "Danmarks Klima").

though the number of sunshine hours only differs slightly from that of June and July.

When similar stable weather periods occur in the summer months Denmark is often exposed to a heat-wave under the influence of Continental air-masses (cP or cT air-masses), arriving from Eastern Europe and from South-Eastern Europe; 1947 is a good example of such a »continental« summer with big diurnal temperature amplitudes and relatively few disturbances of depressions from West. In contrast to this, 1949 had but few high-pressure periods and frequent passages of the small depressions from the Atlantic Polar Front. Long high-pressure periods in the autumn months September and October procure Denmark with an »Indian summer« as shown in the planche I for the first half of the month of September 1949. However, in this season a lively cyclonic activity is normal, followed by considerable quantities of precipitation (especially in October) in connection with a general decrease of the temperature resulting in an increasing relative humidity.

The average annual rainfall in Denmark varies from 415 mm to

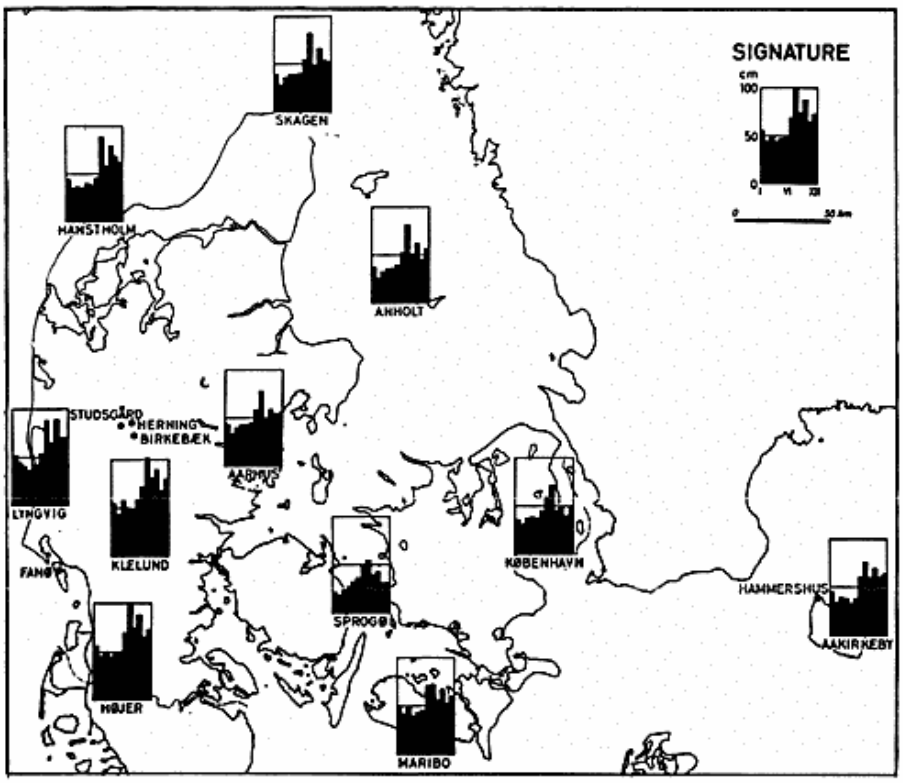


Fig. 5. Diagrams of the average distribution of the precipitation for the individual months for a number of stations.

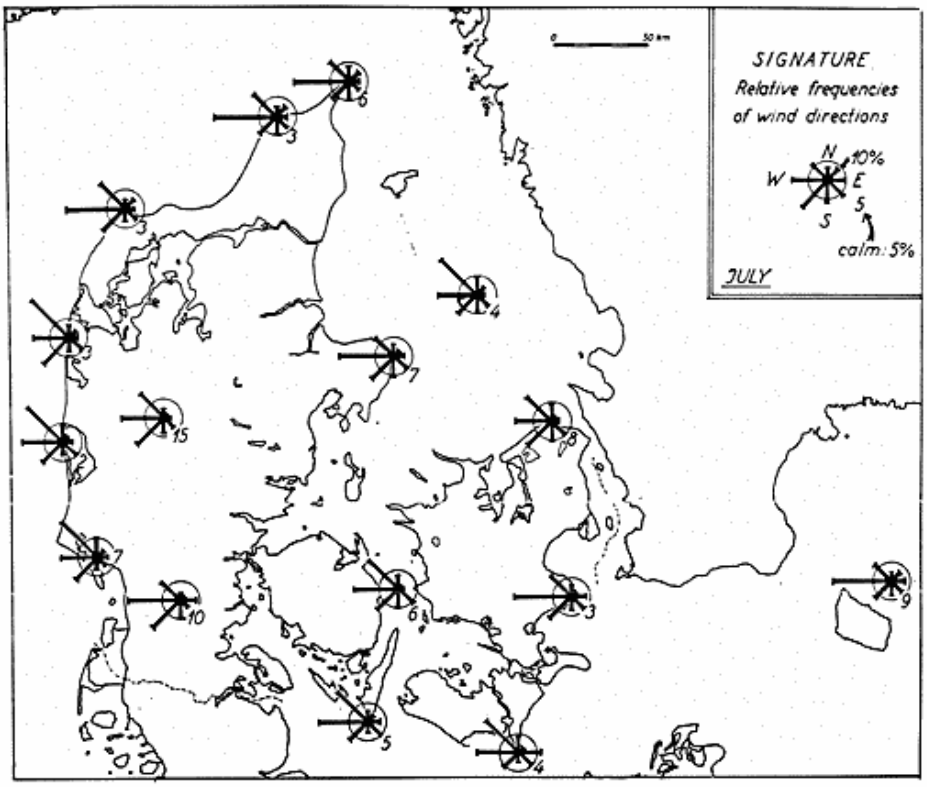
810 mm., quite a considerable variation within such a relatively small region. From the map showing the annual rainfall over Denmark it further appears that the distance between maximum in Central Jutland and minimum around the Great Belt is only 125 km. The greater part of the precipitation falls in connection with the cyclonic passages and but a small part as a consequence of local thunder storms. The passage of the warm front from a depression system is followed by rain all over the country, whereas the cold front most often manifests itself by short, though heavy rainfalls of a more showery character. These frontal systems first reach the western part and the southern part of the country, and here fall the biggest quantities of precipitation, partly as a result of an increasing friction when the air-masses move from sea to land, partly as a consequence of the increasing altitude of the land. Eastern Jutland and especially the region around the Great Belt are in such cases situated in a pronounced rainlee; however, these questions have not yet been submitted to a close examination.

The curves representing the monthly averages of rainfall (fig. 5) for a number of Danish stations further show that it is the autumn

months which are dominating in Western Denmark and in Southern Denmark with pronounced maxima in August and in October. As August is the harvest month for the majority of the Danish grain crops this maximum may cause considerable difficulties for the agriculture, to whom the rainfall distribution, from an agricultural point of view, is by no means favourable. The average number of rainy days in August is 13—17; however, there may be periods with several days without precipitation, facilitating the drying of the crops. The spring months April and May have but 10— 12 days with precipitation and are to be reckoned among our least rainy months. This has extremely unhappy consequences for the agriculture when a draught period occurs simultaneously with continuous winds; if so, the country is exposed to an extensive wind-erosion at a time when the spring-cereals have just been sown or when the first sprouts have come up, so that there is no vegetation for retaining the soil-layer.

As far as the annual distribution of rainfall is concerned, a distinction can be made between two types with even transitions; one type for Western and Southern Denmark, where each of the first six months of the year has 40—50 mm. of precipitation, and where the autumn months reach 70—90 mm. As a contrast to this we have a North-East-Danish type, surrounding the whole of the Kattegat; in the map p. 114 Sprogø in the Great Belt is most representative of this type. Here, seven of the months of the year have 20—30 mm. of precipitation, and the maximum in July/August does not reach far beyond 50 mm. The general feature of the daily precipitation at Studsgård in the years 1946—1949, as appears from the planche I is that the whole winter period and the early summer have small precipitation quantities with an average of about 5 mm. per rainy day. In summer the thunder-storm situations manifest themselves thereby that a few days reach a precipitation of about 40 mm.; in the autumn months (September and October) big quantities of precipitation of 10— 20 mm. often fall for several successive days (for instance: September 1946, September 1948, and October 1949). Further, it is evident that the precipitation principally occurs on days with a thermal shift of the weather, as a natural consequence of its being attached to moving depressions.

A couple of examples will give an illustration of *the variations of the monthly values of the precipitation*. The two stations treated in the planche II fall within the West-Danish and the East-Danish precipitation type, respectively; at the same time Birkebæk (in Cen-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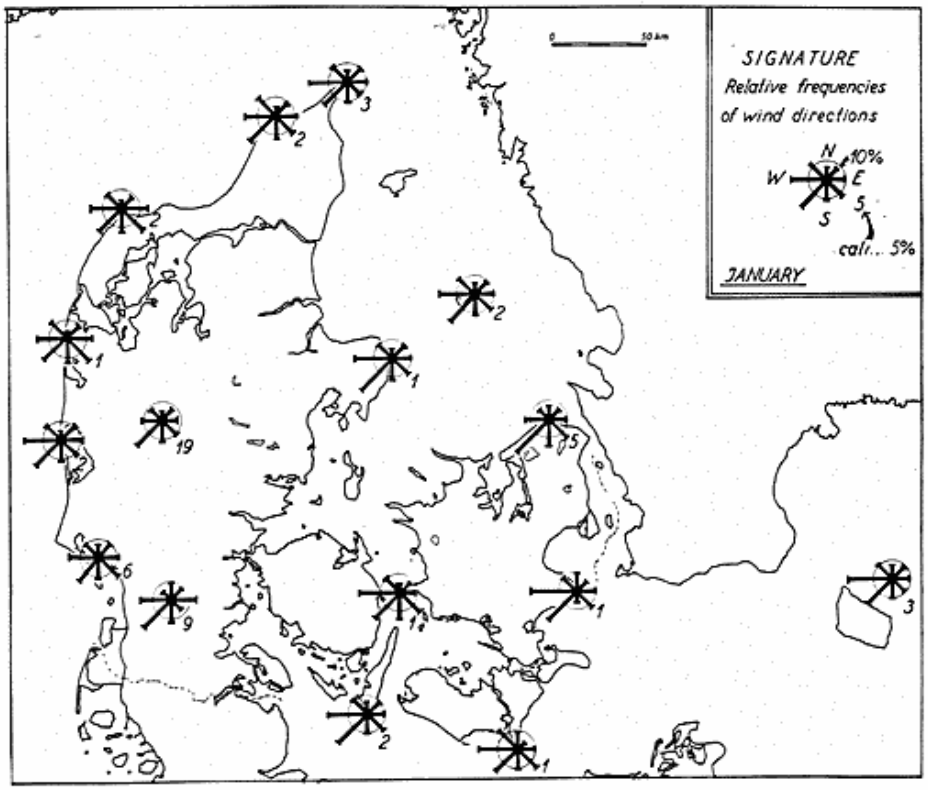
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tral Jutland) is the locality of Denmark where the biggest annual precipitation has been measured: 1276 mm. in the year 1882, while on Anholt (in Kattegat) has been measured the smallest annual precipitation: 305 mm. in 1879.

The two sets of curves have certain common features: Thus, the first five months of the year have rather steeply rising curves as compared with the summer months and the autumn months; this shows a rather small distribution of the monthly values in the first half of the year. Especially August and October have great variations of the quantities of precipitation from year to year. The contrast between the two stations finds its best expression in the fact that the precipitation at the Jutland station is far greater than at the East-Danish station in all the months of the year, and especially in the summer months and in the autumn months the bigger precipitation quantities are much more frequent at Birkebæk than on Anholt. Already in June and July it can be seen that the deviations of the curves in their upper parts are more and more increasing, and in August—November the dominance within the big precipitation quantities at the Jutland station is conspicuous. In the months December—May the distribution pattern is fairly the same for both regions — though in the neighbourhood of rather different mean values.

The position of Denmark in the central part of the westerlies at about 55° N.L. involves a very varying *atmospheric pressure;* this is a consequence of the moving depressions, already mentioned, and their frequent alternance with periods of high pressure. Thus, it would be a rather poor information to indicate the decline of the average atmospheric pressure from 762 mm. in Southern Denmark to 760 mm. to the north in January, and from 760 mm. to 758 mm. in July. If these indications were of general validity Denmark should be under constant influence of western winds in the air-layers above the friction-layer, while the observed winds should show deviations towards south-west, in conformity with the size of the friction. From the maps showing *the wind directions* which have been observed, on an average, with no regard to the wind force (p. 116) it appears that winds from the western sector are the most frequent; however, it is also a question of a considerable number of observations of winds from other directions, especially from east; this is particularly true

Fig. 6. Relative frequencies of wind directions in the months January and July. The circle indicates 10% of the total number of wind observations. The figure to the right of the wind rose represents the relative frequencies of observations with calm. ←

of the winter half-year, where the high-pressure over Eurasia may give rise to eastern winds of long duration. Winds from the south and from the north are, on the contrary, in absolute minority in all seasons.

At all places the biggest *wind-forces* are measured in winter and in the autumn; however, the variations from month to month are but small. The calm most often occurs in the interior of the country; like the other wind-observations these indications may be greatly defective owing to local conditions around the weather stations.

However, when taking into account the small extent of our country and the insignificant variations of altitude it is interesting to note the relatively big climatic differences, both from region to region and from year to year. However, a summary like this only gives a rough outline of the conditions, whereas a detailed analysis would be needed for describing and for finding the causes of the multiple variations.

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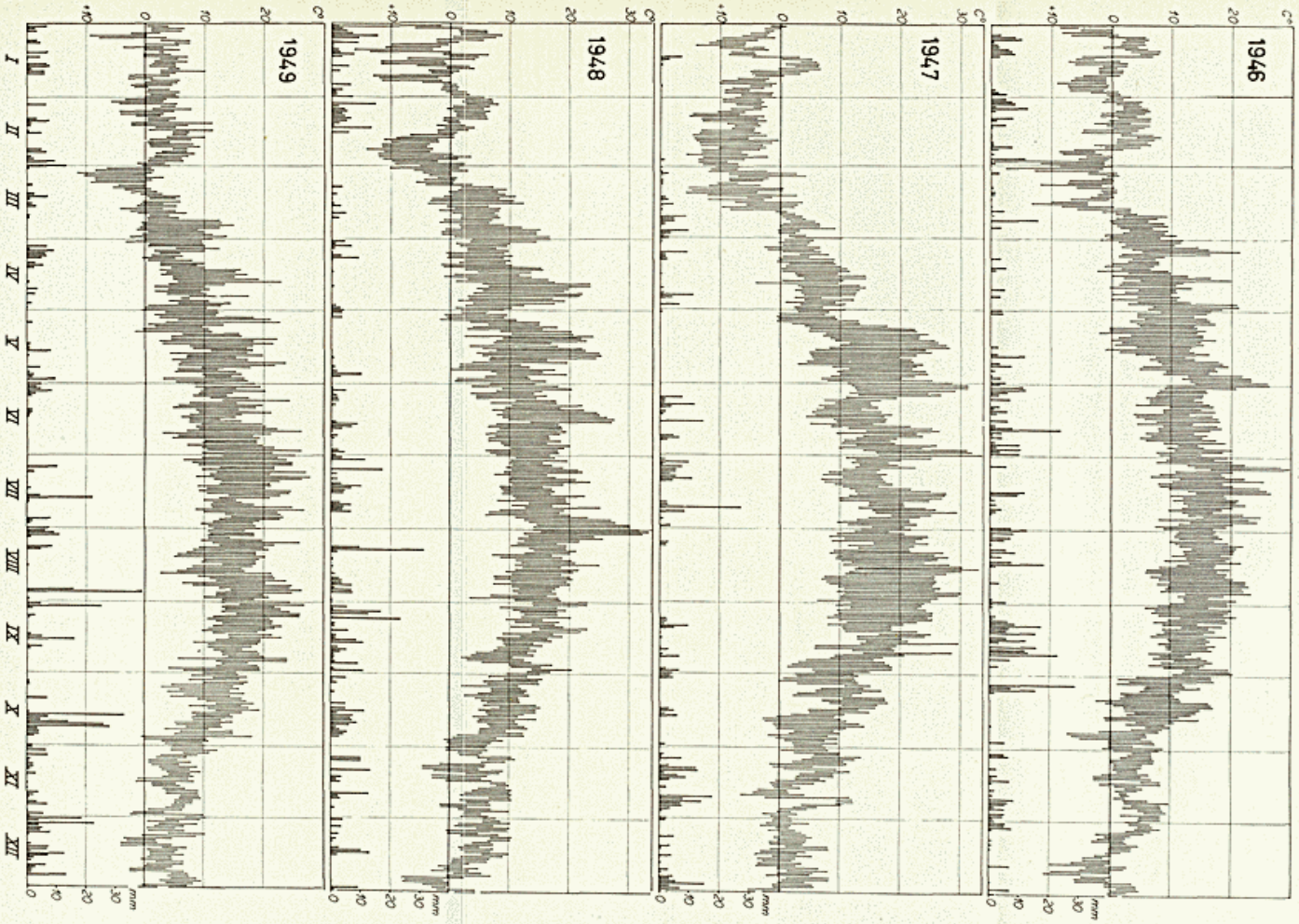

Diagram of the observed temperatures and precipitation quantities for each 24 hours in the years 1946—1949 at Studsgård (Central Jutland). The trend of diurnal temperatures is indicated by lines between the maximum temperatures and the minimum temperatures; these are read daily, for the preceding 24 hours, at eight o'clock a.m.. At the same time is read the precipitation of the preceding 24 hours, here indicated at the bottom of each diagram.

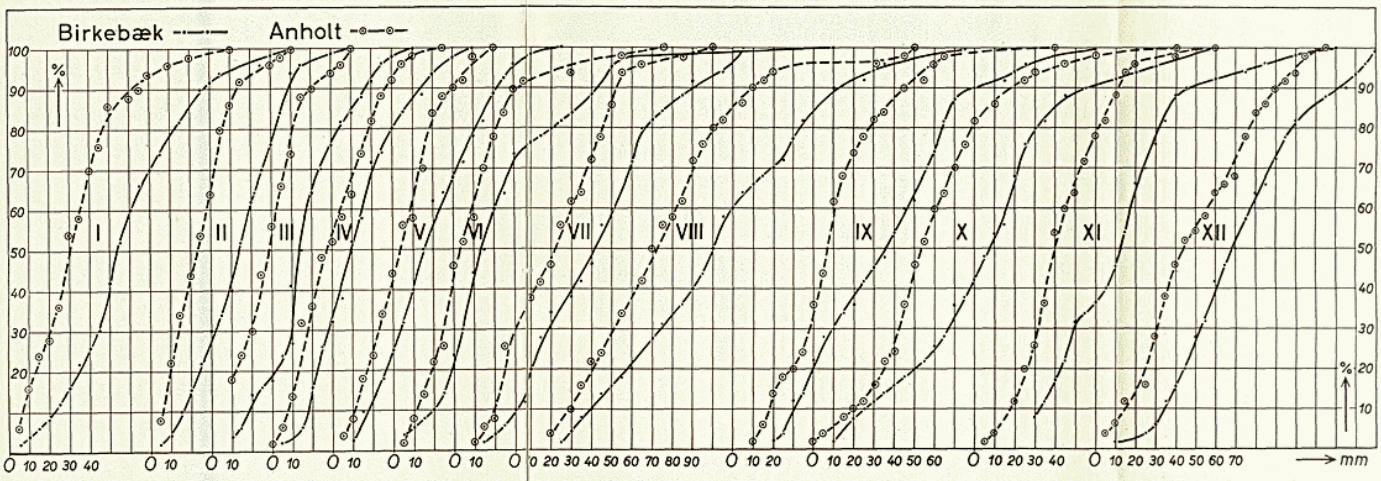

Diagram showing the distribution of the precipitation quantities of the single months in the course of a 50-years' period for the stations Birkebæk (Central Jutland), 1877—1926 and the isle of Anholt (in Kattegat), 1876—1925. The ordinate indicates the cumulative percentage of occasions. The abscissa indicates the quantities in mm., where the zero point has been displaced for each month with a view to the separation of the single curves.

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At all places the biggest *wind-forces* are measured in winter and in the autumn; however, the variations from month to month are but small. The calm most often occurs in the interior of the country; like the other wind-observations these indications may be greatly defective owing to local conditions around the weather stations.

However, when taking into account the small extent of our country and the insignificant variations of altitude it is interesting to note the relatively big climatic differences, both from region to region and from year to year. However, a summary like this only gives a rough outline of the conditions, whereas a detailed analysis would be needed for describing and for finding the causes of the multiple variations.

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