The seasonal distribution of precipitation in the area east of Stockholm and the daily distribution in a few selected cases

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(Manuscript received February 21, 1966)

ABSTRACT

The geographical distribution of precipitation in the coastal area of Sweden east of Stockholm has been studied for the seasons of the year and also for a few selected daily cases with south-easterly winds. A comparison has been made with studies by other authors in the same area and a discussion is given of the orographic and frictional convergence effects.

Introduction

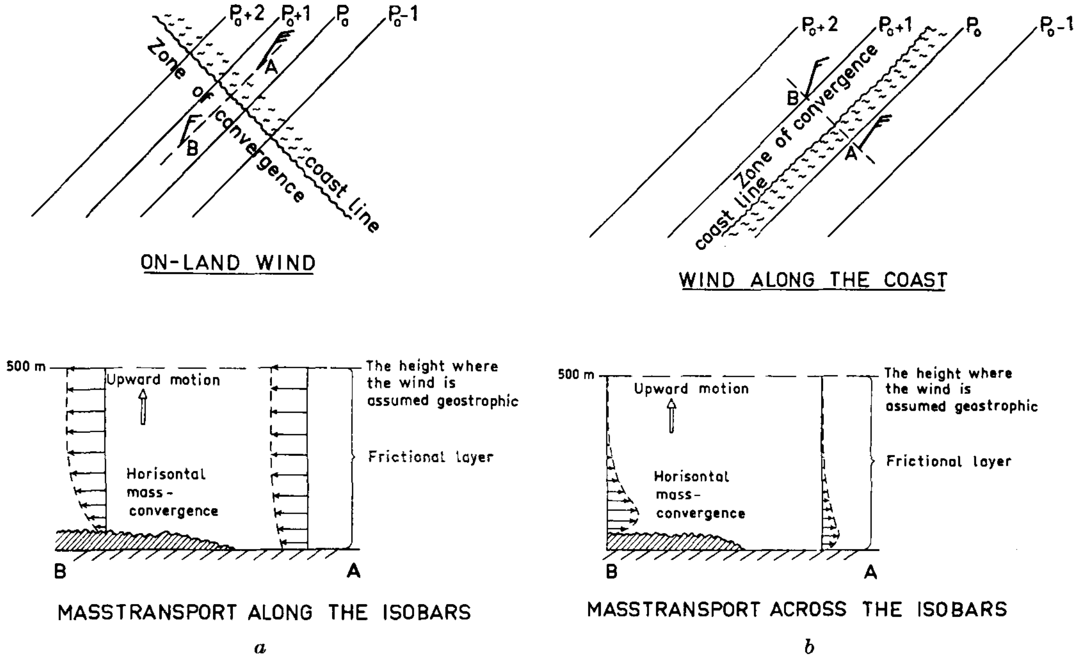
In textbooks on meteorology one finds how the geographical distribution of precipitation depends on various factors (see, e.g., SVERRE PETTERSSEN, 1956). One of these factors is the orographic influence, another is the so-called frictional convergence.

There are in general marked maxima on the windward slope of great mountains. On large islands the windward side also in general gets more precipitation than the leeward side. In his studies of the distribution of precipitation with the aid of a dense network of stations in a relatively flat area T. BERGERON (1961) has found that there may be a considerable effect on the precipitation even of a rather small uneveness of the ground. There is no or little pure orographic precipitation caused by low hills but when precipitation falls for other reasons (frontal rain, showers) there may be a considerable increase in precipitation over the higher regions of a relatively flat land at least when the hills, but not the flat land, are covered by forests so that the friction is increased to some extent. In another study T. BERGERON (1949) has shown how the snow was distributed during north-easterly storms over eastern Sweden near Stockholm. The coast is rather low and the land only rises to about 60 meters 20 km from the coast. The snow was measured by a large number of voluntary observers organized with the aid of the Swedish Radio Corporation. The precipitation was distributed with a marked maximum in a band following in general narrowly the Swedish coast-line east of Stockholm.

Bergeron explains this maximum as a result of increased friction when the air leaving the relatively smooth sea enters the land with its vegetation of trees.

The friction leads to convergence and upward movements of the air at least in the lower levels followed by condensation and precipitation if the air is sufficiently moist. See Fig. 1*a*. If there is a general precipitation in the area, this will be strengthened. The stronger the wind the more the maximum should be displaced inland, as snow is falling with moderate speed, perhaps even less than 50 cm per second. This phenomenon is, however, complicated e.g. by the fact that the snow is formed at various heights and at any rate from only a few cases one cannot find any close relationship between the location of the maxima and the strength of the wind. S. PETTERSSEN & P. A. CALABRESE (1959) have discussed the following effect. If the air is coming from a warm water surface it may be unstable and when passing over cold ground it will become stabilized which will further increase the ground friction and increase the convergence and vertical upward motion and also lead to an inland displacement of the band of precipitation.

In the cases studied by Bergeron the wind was perpendicular to the coast in Uppland, the region north-east of Stockholm, where the line of maximum precipitation was found about 20 km from the sea whereas in Sörmland, the region south-east of Stockholm, the wind was parallel to the coast and the maximum zone was found much closer to the sea. The principal features of the effect of surface friction on hori-



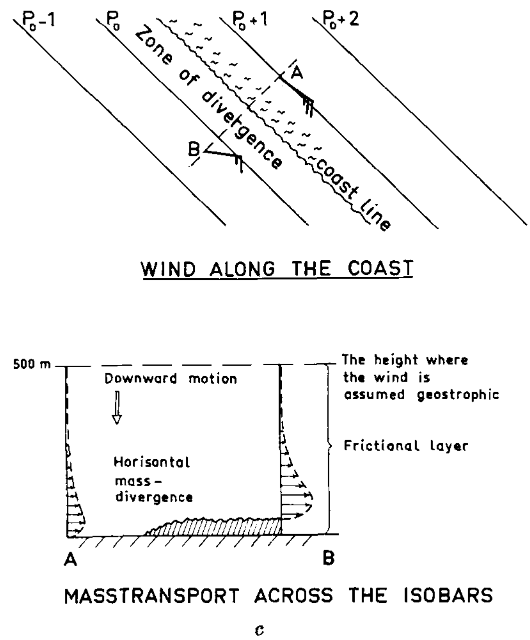


FIG. 1. Sketch showing convergence and divergence in coastal areas due to increased friction when air coming from the sea enters land.

zontal convergence and vertical motions along a coast-line are shown in Figs. 1*a*, *b* and *c*. In the case of on-land wind the pure orographic effect of the upslope wind component on the vertical motion has to be added. In the case of north-easterly winds Fig. 1*a* is representative at the Uppland-coast and Fig. 1*b* at the Sörmland-coast. In the case of south-easterly wind the situation at the Sörmland-coast is easily understood from Fig. 1*a* and the situation on the Uppland-coast is represented by Fig. 1*c*.

The seasonal variation of precipitation in this area

The authors (H. MODÉN & A. NYBERG, 1965), have studied the mean seasonal distribution of precipitation, in the same area as Bergeron, for a period of 30 years, using the regular observations from the official network of the Swedish Meteorological and Hydrological Institute. The results are shown in Figs. 2–5. In Fig. 2 for the winter season the dotted line shows the position of the maximum zone obtained by Bergeron in one of his studies of two daily winter cases. The position in the other case studied by Bergeron was very similar.

In a study of the precipitation measurements in the Bothnian Sea, T. ANDERSSON (1963) also showed some charts of the distribution of precipitation in the Stockholm–Uppsala area.

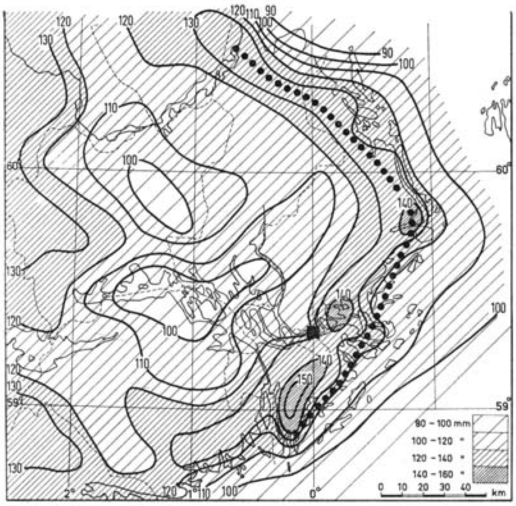


FIG. 2. *The distribution of precipitation in the region around Stockholm during winter (December–February).* The thick dotted line shows the position of the maximum found by Bergeron in his studies of the snowfall on one winter day. ■ marks the location of Stockholm.

He used mainly a few coastal stations but even from a very sparse network he found indications of similar seasonal distributions as is more clearly shown here.

Comparing at first the maps for the various seasons with Bergeron's snow-cover maps one finds great similarities. The maximum along the coast is well marked during the whole year

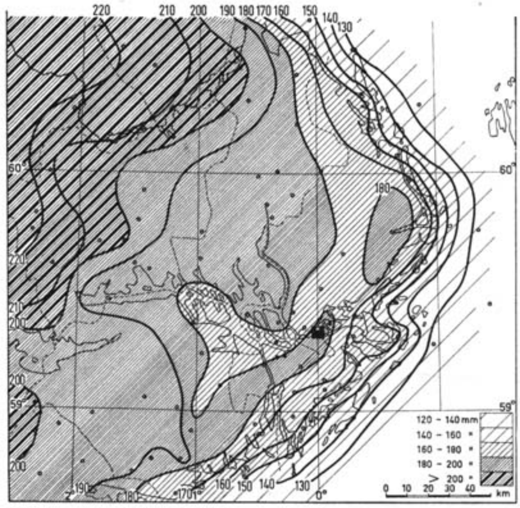


FIG. 4. The distribution of precipitation in the region around Stockholm during summer (June–August).

except during the summer months but even during the summer there is a slight indication of a coast maximum. The difference between the winter precipitation maps and Bergeron's snow-cover maps are that the winter season maxima are markedly displaced from the coast westwards to a line about 20 km from the coast line whereas in Bergeron's study only the north-east (Uppland) maximum is situated 20 km from the coast and thus coincides fairly well with our

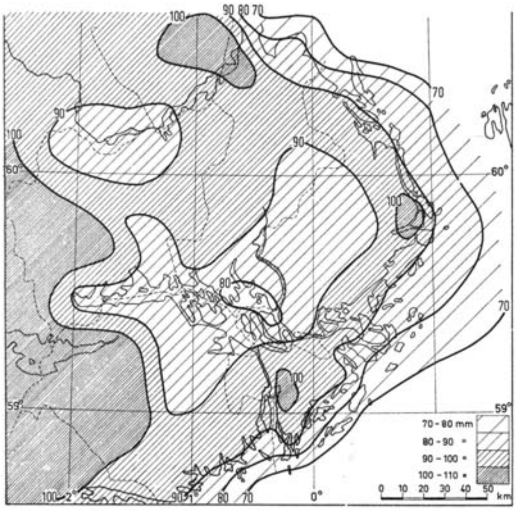


FIG. 3. The distribution of precipitation in the region around Stockholm during spring (March–May).

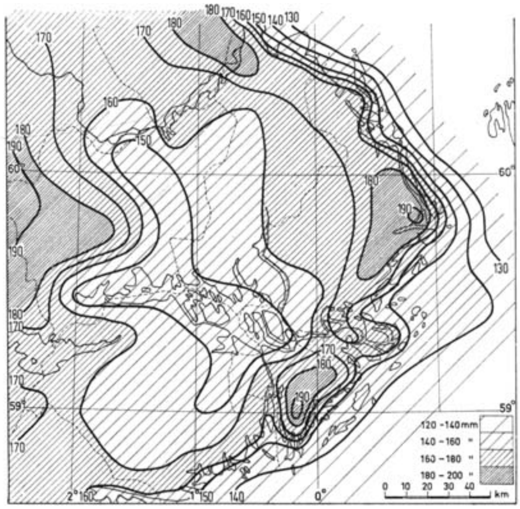


FIG. 5. The distribution of precipitation in the region around Stockholm during autumn (September–November).

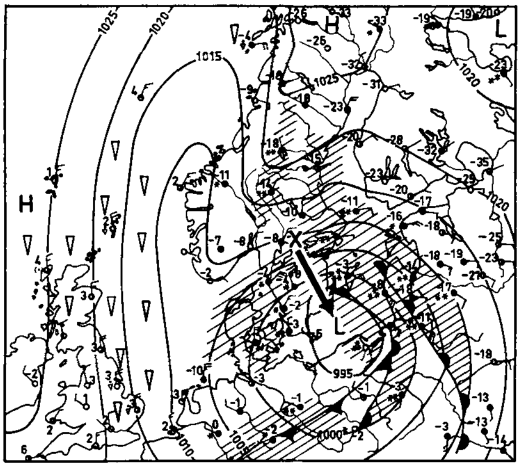


FIG. 6. Weather situation at 07.00 MET 5 February 1953. The × sign indicates position of depression 24 hrs before.

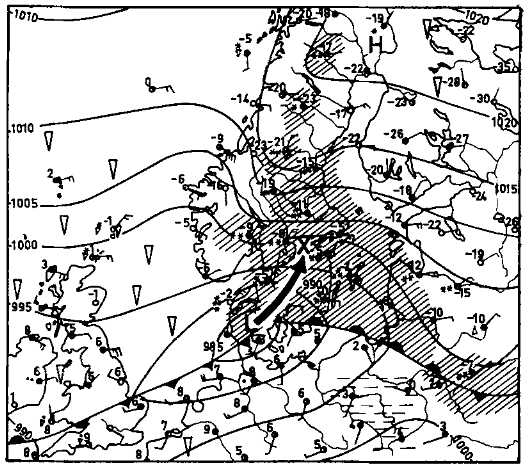


FIG. 7. Weather situation at 07.00 MET 17 December 1955. The × sign indicates position of depression 24 hrs later.

winter maximum. His Sörmland maximum is situated much closer to the coast line. This is not surprising since in Bergeron's paper are presented only a few cases with north-easterly winds whereas our values represent means over longer periods including not only cases with north-easterly winds but also cases with south-easterly winds when precipitation is carried further inland. It is still remarkable that Bergeron's findings from a study of a few winter situations is confirmed as showing main characteristics of the yearly and seasonal distribution of precipitation in this area.

A study of two special cases

In the case of south-easterly winds in the coastal regions east of Stockholm the orographical and frictional effects on the distribution of precipitation would be as follows. In Sörmland, the area south-east of Stockholm, there is an orographical upslope effect as well as an effect of frictional convergence according to Fig. 1*a*. The result is a maximum of precipitation at some distance from the coast. In Uppland, the area north-east of Stockholm, one would expect with south-easterly wind a frictional divergence and a minimum of precipitation in the coastal belt (Fig. 1*c*). Perhaps a somewhat higher amount of precipitation would be found over the sea, i.e., to the right of the flow.

The authors have studied two special cases with prevailing south-easterly winds over the region. In these cases there was not much cooling over land so that the above-mentioned effect by Petterssen and Calabrese may be neglected. When precipitation was falling the weather situations in these cases were as follows:

First case (Fig. 6): A depression was moving from position × at 07.00 MET on 4 February 1953 to the south-east to position *L* on 5 February causing rather persisting snowfall over the Stockholm region. The temperature varied between −1° and −5°C. The winds were at first southerly, then south-easterly and finally easterly 15–20 m/sec. The height of the cloud base at Bromma airport, Stockholm, was recorded as from 150 m to 300 m during 4 February when precipitation was falling. At the very coast even lower cloud heights were reported. The moisture as recorded by the radio-soundings at Bromma was consistently high up to the height of several kilometers.

Second case (Fig. 7): A depression over Denmark at 07.00 MET on 17 December moved north-eastwards with its center located 150 km WSW Stockholm on the following morning. The temperature varied between +1° and −4°C. The precipitation was rain, drizzle and snowfall. The winds were at first easterly, then became south-easterly or southerly in the southern part of the Stockholm region and north-easterly in the northern part of that region. The winds were at first 15–20 m/sec but decreased by and by to

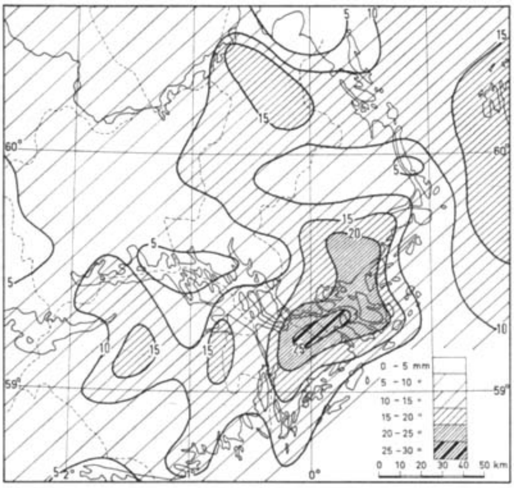


FIG. 8. The distribution of precipitation in the Stockholm region during 24 hrs ending 5 February 1953 at 07.00 MET.

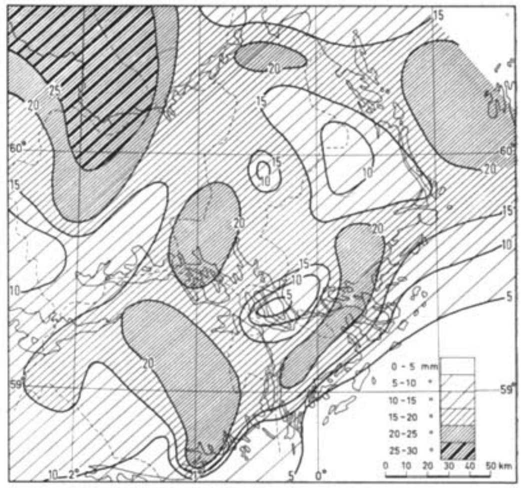


FIG. 9. The distribution of precipitation in the Stockholm region during 24 hrs ending 18 December 1955 at 07.00 MET.

about 10 m/sec. The height of the cloud base at Bromma varied between 90 m and 300 m during the 17 December when snow was falling. Again still lower cloud heights were reported at some coast stations. Also in this case the upper air was recorded humid up to the height of several kilometers.

The distribution of precipitation during the two cases are given in Figs. 8 and 9. They clearly show the maxima in Sörmland, as expected much more inland than obtained in Bergeron's cases. There is also an area of minimum precipitation in Uppland and apparently a slight maximum of precipitation over the north-eastern sea, in agreement with the frictional effects discussed above. In both cases there are maxima inland in the northernmost part of the region at some distance from the coast which may be the result of a northerly component of the wind which prevailed in that area during part of the precipitation period.

We have also compared our results with the results obtained by ÖSTMAN (1927) who studied a few cases with north-easterly, south-easterly, south-westerly and north-westerly flow. The network at that time was less dense than at present and less details can be seen. However, the maps for south-easterly winds show a good agreement with our maps for 4–5 February 1953 and 17–18 December 1955, i.e., in Östman's cases there are marked maxima at the same place south-east of Stockholm and there is no maximum at the coast in Uppland and even indications of a maximum at the sea.

Conclusion

The average precipitation distribution in the region east of Stockholm is characterized by an area of a maximum precipitation about 20 km inland from the coast especially during the winter but also during most of the other seasons.

The frictional convergence effect which, according to Bergeron, causes a maximum of precipitation on the south-eastern coast-line very close to the sea when the wind is north-easterly was studied during a few cases when south-easterly winds prevailed. In these cases the precipitation maximum south-east of Stockholm was found about 20 km from the coast near the highest hills whereas on the north-eastern side of the region no maximum at all was found at the coast but rather over the sea in agreement with the expected divergence and vertical circulation established at the coast-line (Fig. 1*c*).

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СЕЗОННОЕ РАСПРЕДЕЛЕНИЕ ОСАДКОВ В РАЙОНЕ ВОСТОЧНЕЕ СТОКГОЛЬМА И ЕЖЕДНЕВНОЕ РАСПРЕДЕЛЕНИЕ В НЕКОТОРЫХ ИЗБРАННЫХ СЛУЧАЯХ

Исследовано географическое распределение осадков в прибрежном районе Швеции к востоку от Стокгольма для различных сезонов года и для некоторых избранных дней с юго-восточными ветрами. Сделано сравнение с исследованиями других авторов для того же района и обсуждаются орографический эффект и конвергентный эффект трения.