# Composition of Atmospheric Precipitation in Sweden

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## *Abstract*

Preliminary charts are presented based on two years of data, to demonstrate the geographic distribution over Sweden of the annual amounts of Na, Cl, K, Ca, $NH_3$-N and $NO_3$-N brought to the surface of the earth by precipitation. The ratios of these total amounts to the total amounts of Na deposited during the same time interval are shown to possess systematic geographic distribution patterns. Comparisons are made between these ratios and the corresponding quantities in sea water. The investigation is now being resumed to provide additional data from a larger number of stations and for longer time periods.

The present paper contains an analysis of some of the results obtained in an investigation of the chemical composition of atmospheric precipitation and in particular of the geographic distribution over Sweden of the various chemical deposits brought down by rain or snow. This investigation, which was carried out during the period October 1, 1947—September 30, 1950, was initiated by professor G. Torstensson and Dr H. Egnér at the Royal Agricultural College of Sweden and by Dr A. Ångström, Director of the Swedish Institute of Meteorology and Hydrography. Financial support was obtained from the Agricultural Research Council of Sweden. The sampling technique and the analytical methods were worked out by the authors and have been described earlier (EGNÉR et al., 1947). The planning of the network of sampling points and the installation of sampling devices was done by Egnér and Eriksson and all analyses were carried out under the supervision of Egnér. Some data from this investigation, on the content of ammonia and nitrate in precipitation, have been published by ÅNGSTRÖM and HÖGBERG (1952 a, b). A detailed but unpublished discussion of the results has been given by one of the authors (Emanuelsson) as part of the requirements for an agronomic licentiate degree at the Royal Agricultural College of Sweden. The geographic distribution charts presented in this paper were analysed jointly by Emanuelsson and prof. C.-G. Rossby.

### General information

The accumulated amounts of atmospheric precipitation were collected monthly at 28 places. The geographic position of these (except one which represents a pollution center) are shown on the map in Fig. 1. It is seen that southern Sweden is much better represented than the northern part since the original purpose of the investigation was to study the

agricultural importance of chemical compounds in atmospheric precipitation.

The precipitation samples were shipped to Ultuna and analysed for sodium, calcium, potassium, ammonia, chloride and nitrate. Due to the sampling technique used sulphur had to be excluded. The data on nitrate, and in some measure also those on chloride, are somewhat doubtful but will nevertheless be presented here. Magnesium, which seems to be a significant element in precipitation was not determined due to difficulties associated with the analysis technique used at the time.

The data include all kinds of atmospheric precipitation, except dew and rime; the collecting funnels, which were mounted approximately 1.6 m above the ground, were exposed at all times. The data thus represent chemical compounds brought to the ground by gravitational forces. Excepting those measurements which represent deposits from sources of local character, these data should provide us with information of considerable importance for the interpretation of the general circulation of atmospheric compounds. By far the larger portion of these compounds were brought down by rain or snow.

The mean annual precipitation (rain and snow) for the two-year period October 1, 1948 to September 30, 1950 at the sampling points is also given in Figure 1. It is seen that the Swedish westcoast and the adjacent inland have the highest precipitation values whereas the remaining stations, with the exception of Riksgränsen in the north, have fairly uniform rates. The station at Riksgränsen is located in

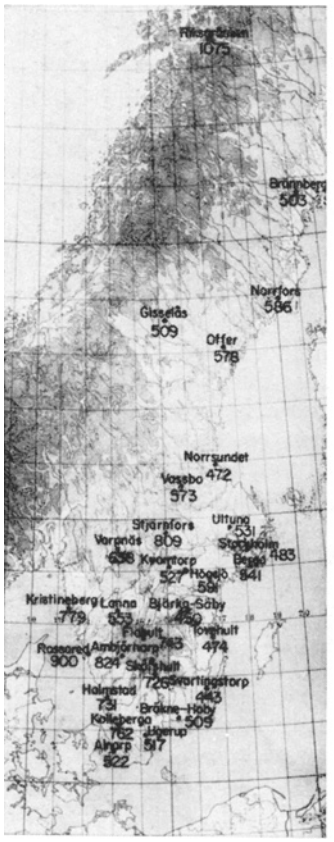


Fig. 1. Station locations and precipitation in mm per year during 2-year period 1 October 1948—30 September 1950.

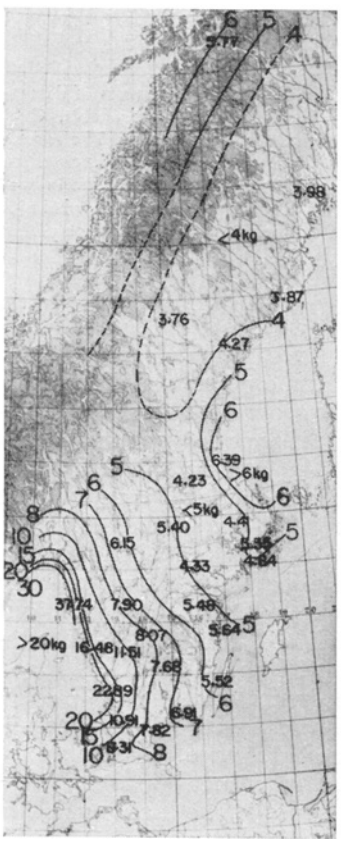


Fig. 2. Yearly amounts of Na (kg/har).

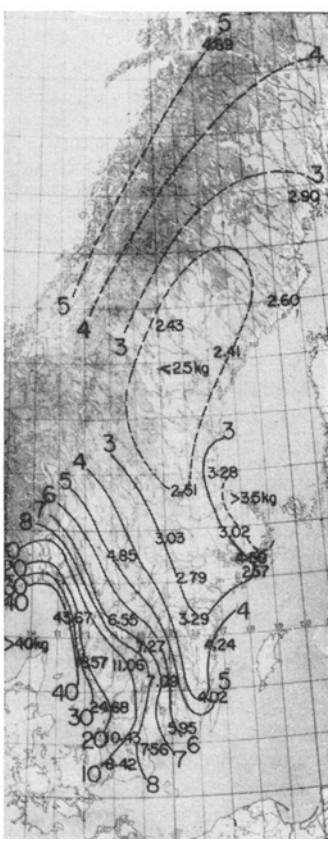


Fig. 3. Yearly amounts of Cl (kg/har).

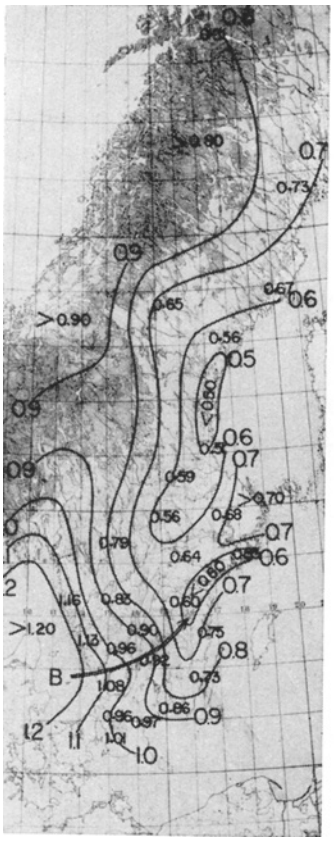


Fig. 4. Weight ratio Cl/Na.

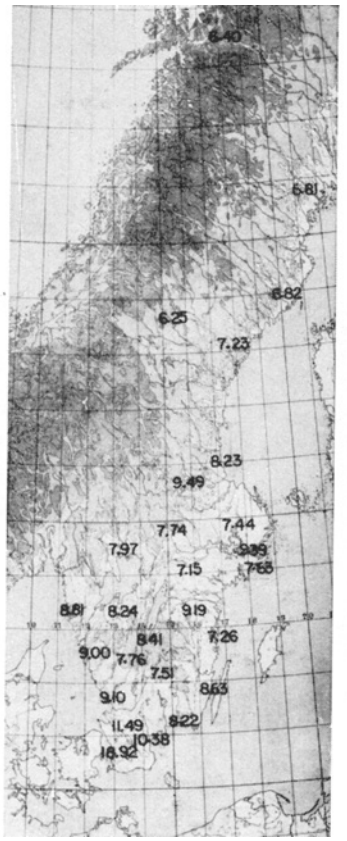


Fig. 5 Yearly amounts of Ca (kg/har).

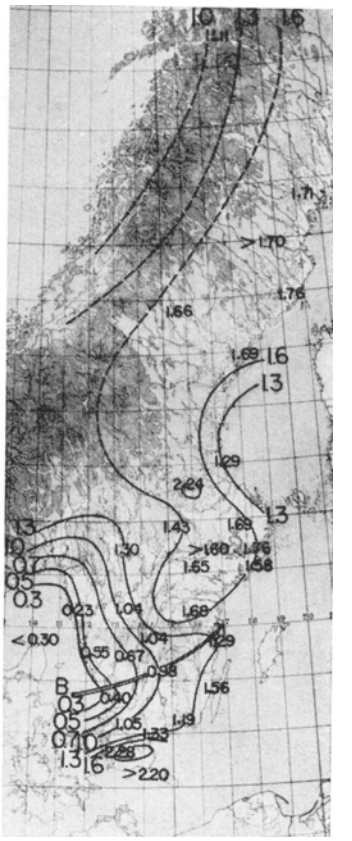


Fig. 6. Weight ratio Ca/Na.

a mountain pass at an elevation of 508 m and is the only one representing mountain conditions.

During the first year of the investigation nitrogen compounds only were determined. Therefore the data given here are based on the two-year period October 1, 1948 to September 30, 1950, in order to provide a fair comparison between ammonia nitrogen and the other elements. The monthly variations in the amounts brought down at the different stations are of considerable interest but will not be discussed here. The average yearly values only will be given because of their obvious geochemical importance. All data have been plotted on maps, and, to give the general patterns of the distribution of the elements, isolines have been drawn. The yearly amounts are given in kg/ha (1 ha = $10^4$ m$^2$). When multiplied with ten these figures give the amounts in $\mu$g/cm$^2$.

On another series of maps the weight ratios of the different elements to sodium have been plotted and are represented by isolines. These values are computed from the total amount of any particular chemical component deposited over the entire two-year period and from the total amount of sodium deposited during the same period at the same station. Data on the ratios of the different elements over sodium in sea water are shown in Table 1.

**Table 1. The ratios of some elements over sodium in sea water**

| Cl/Na | Ca/Na | K/Na | $H_3N-N$/Na | $NO_3-N$/Na |
|---|---|---|---|---|
| 1.8 | 0.038 | 0.036 | $\sim 5 \cdot 10^{-7}$ (at surface) | $\sim 7 \cdot 10^{-7}$ |

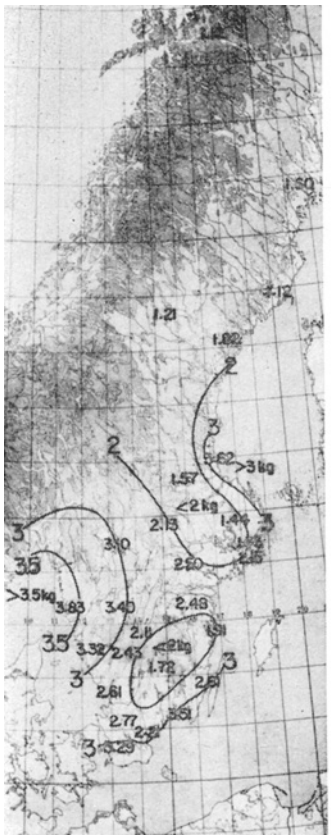

Fig. 7. Yearly amounts of K (kg/har).

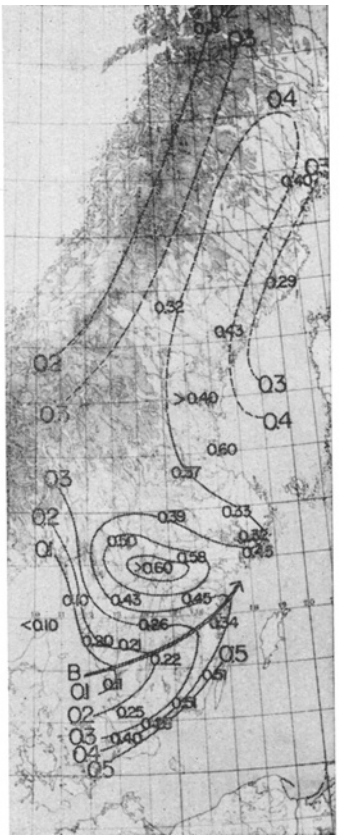

Fig. 8. Weight ratio K/Na.

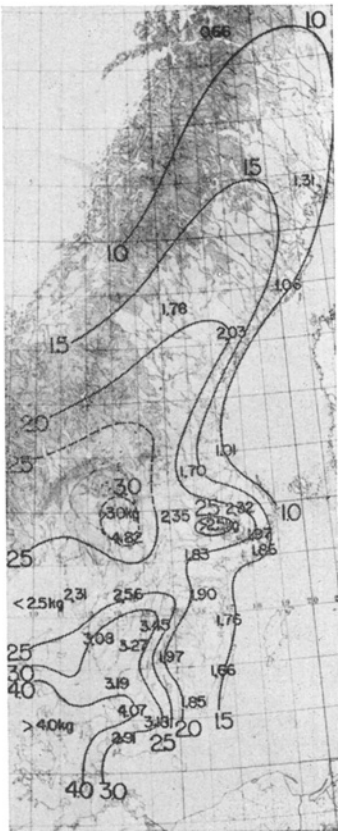

Fig. 9. Yearly amounts of $H_3N$—N (kg/har).

**Sodium and chloride**

The yearly amounts of sodium are shown in Fig. 2. The highest values are, of course, found on the freely exposed part of the west coast; inland the amounts decrease roughly logarithmically with distance from the coast. There is a slight indication of a weak secondary maximum along the Baltic coast north of Stockholm. In this region northeasterly winds from time to time give rise to cyclonic-orographic precipitation from low-level clouds; one may perhaps venture a guess that it is this type of precipitation that gives rise to the weak secondary maximum in the deposit of sodium and of some of the other elements observed along this part of the Baltic coast.

A fairly broad minimum or saddle area runs from NNW to SSE across lake Mälaren, just west of Stockholm. To the north the stations are too far apart to permit any conclusions regarding the detailed distribution of the sodium deposit.

The distribution of the yearly deposits of chloride is shown in Fig. 3. The pattern if similar to that of sodium, as might be expected, the sea presumably being the only important source for both of these elements.

Finally the weight ratio Cl/Na is shown in Fig. 4. It is seen that there is a significant geographic variation also in this ratio which, furthermore, even near the coast has a much lower value, around 1.2, than that characteristic of sea water (1.8). This low ratio of Cl/Na at the coast and the further decrease inland certainly is of great geochemical interest. The land surface can hardly be a significant source for either Na or Cl. With the sea as the only significant terrestrial source and disregarding

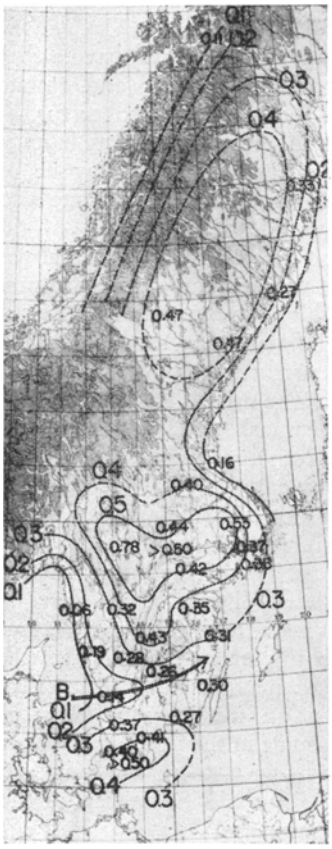

Fig. 10. Weight ratio $NH_3$—N/Na

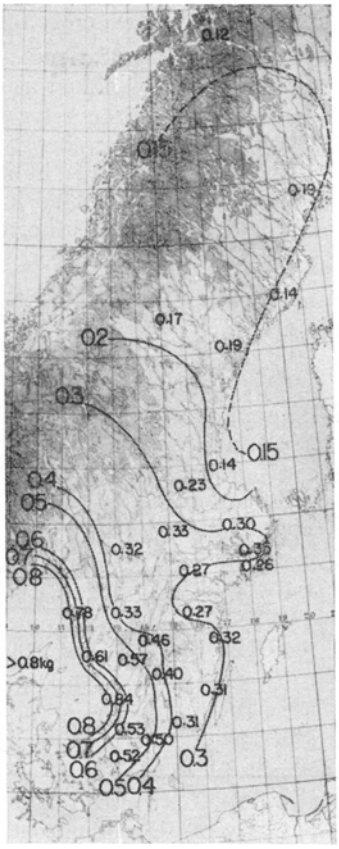

Fig. 11. Yaerly amounts of $NO_3$—N (kg/har).

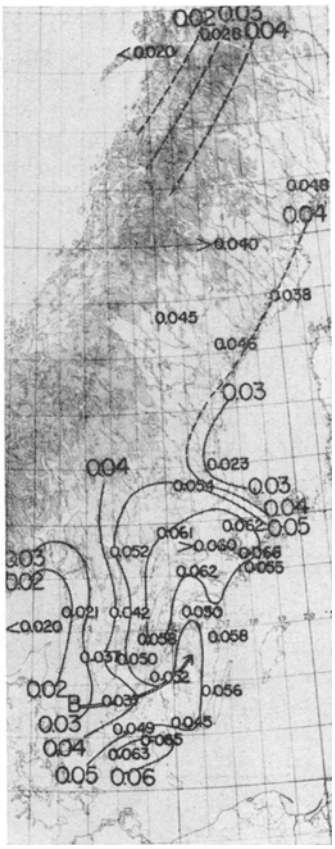

Fig. 12. Weight ratio $NO_3$—N/Na.

extraterrestrial sources for either of these elements, the distribution of the Cl/Na ratio becomes somewhat of an enigma.

If it is supposed that Na and Cl are brought from the sea to the atmosphere in the same ratio as in the sea (mainly by spray) and that both elements are brought to the ground entirely by precipitation, then either an addition of sodium or a removal of chloride must have taken place in the air during its travel or during the formation of precipitation. Also, these processes must have started before the air entered land. Further, if Na is added and there are no extraterrestrial sources for this element, or if chloride is removed and there are no extraterrestrial sinks for this element then there must be regions on our planet where precipitation contains relatively more Cl than Na as compared to sea water. It seems fruitless at our present state of knowledge to enter into speculations on various possibilities to explain the variation in the Cl/Na ratios. It should be mentioned, however, that CAUER (1949) has suggested a process whereby Cl can be released from solution as $Cl_2$, chlorine. But in this case the $Cl_2$ released has to be accounted for in some other way as it is most likely that it ultimately must be brought down by precipitation.

In this connection it is pertinent to refer to an experimental investigat on by KÖHLER and BÅTH (1952), in which they reported on the composition of droplets formed by blowing air over a sample body of sea water. Their conclusion is that »all our experiments indicate that there are droplets of splitted sea water with ratios between the components significantly different from the ratios in sea water in bulk. Droplets with relative excess of Mg and Na

are presumably positively charged, whereas excess of $Cl^-$ (and $SO_4^{--}$) entails negative charge. Droplets with relative excess of either Mg or Cl are smaller than droplets with normal ratios. It is not possible to conclude from the experiments if there is a relative excess of Mg or Cl in the smallest droplets."

**Calcium**

The yearly amounts of calcium are shown in Fig. 5 where it is seen that they are fairly uniform, decreasing somewhat to the north. A high value in the south is due to local pollution from a cement factory. No gradient from the west coast can be detected, indicating that this element is fairly widespread in the atmosphere. As the Ca/Na ratio in the sea is 0.038 the sea can hardly be any appreciable source for Ca in precipitation. The soil must be a considerable source as Ca is the most abundant soluble element in soils. However, extra-terrestrial sources can not be excluded completely.

In Fig. 6 the ratios Ca/Na are plotted. As Ca is fairly uniform the pattern is entirely dominated by the variation in Na.

**Potassium**

In Fig. 7 the yearly amounts of K are plotted. There is a small but definite gradient from the west coast and a slight increase at the east coast north of Stockholm. As potassium in sea water is low (K/Na = 0.036) the sea cannot be the only prominent source although the gradient would so suggest. In Fig. 8 the ratios K/Na are plotted. They increase to a maximum inland and, further, there is a through line in the south indicated by the arrow B. On the west coast the ratio K/Na is about 0.10, which is about three times higher than that in sea water. As the ratios increase inland this means that potassium decreases at a slower rate than sodium. Some of the high values inland may be due to local pollution from cement factories.

As to the origin of K some no doubt comes from the sea but K may also be a rather widespread component in the atmosphere. Some may be released in combustion, forming very small condensation nuclei which, as they are growing slowly, are not readily washed uot by precipitation. Extra-terrestrial addition of K is also conceivable.

**Ammonia nitrogen**

ÅNGSTRÖM and HÖGBERG (1952) have earlier published results for ammonia and nitrate nitrogen for the whole period October 1947—September 1950. As the period here investigated is limited to two years it may be of interest to include ammonia and nitrate also for this shorter period.

The yearly amounts of $H_3N$—N are shown in Fig. 9. One of the most outstanding features is the ridge of high amounts in the southwest where the influence of Denmark on the prevailing soutwesterly winds over Sweden is very pronounced. The origin of this maximum is, no doubt, Denmark and as ammonia is mainly released from the ground as gas it is readily picked up and washed out by precipitation. In the east coast area the amounts are generally small, presumably due to washing out by precipitation. There is a small maximum in the Lake Mälaren district which may be significant as this is an important agricultural area. The other maximum to the west is more doubtful and may be due to the effect of local pollution on the readings taken at Varpnäs. The amounts in the north are smaller than in the south since there are but few source regions of ammonia in this part of the Scandinavian peninsula.

In Fig. 10 the ratios $H_3N$/Na are plotted. The only remarkable is again the trough line indicated by the arrow B.

Though agricultural areas are no doubt important source regions over land, the sea may also contribute to the ammonia content of the air.

**Nitrate nitrogen**

The $NO_3$-N also includes $NO_2$-N which at most can amount to five or ten per cent of the total. In Fig. 11 the yearly amounts are plotted. One remarkable thing is the general pattern of isolines which runs parallel to the coast. Now, it must be admitted that the sampling technique used was not favourable to nitrates, therefore too much weight should not be given to this figures until the results have been confirmed through more reliable data. It is uncertain if these will change the general pattern in Fig. 11 though the amounts may be changed. The $NO_3$ – N/Na ratios are shown in Fig. 12. Also here a through is in-

dicated by the arrow B on the same place as before. This trough, which appears fairly well-marked in the three charts for $\frac{NH_3 - N}{Na}$, $\frac{N}{Na}$, and $\frac{NO_3 - N}{Na}$, extends from the Swedish west coast eastward and northeastward through a forest district (Småland) of southern Sweden where the population density, agricultural and industrial activities are lower than in the rich agricultural plain to the south and also somewhat lower than in the areas to the north. It is not inconceivable that this fact is reflected in the slower increase in the relative amounts of K, $NH_3 - N$ and $NO_3 - N$ along the axis of tongue B.

Though there exist many earlier investigations on the composition of atmospheric precipitation, the present study is the only one which gives a coherent picture of the distribution over a larger area. As such it should be of some geochemical interest. The present investigation suffers from several defects both in planning and inexecution but from the experience gained it has been possible to plan a similar investigation on a much larger scale (ERIKSSON 1954) which will start operating very soon. From the results of this it should be possible to confirm the distribution patterns over Sweden or to correct them, if necessary, and to get the distribution patterns for various elements over a much larger area. Then it may be possible to gain more definite information on the origin of atmospheric compounds than we now possess.

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