Periodical Variations of the Atmospheric CO_2-content in Scandinavia[1,2]

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Abstract

From the CO_2-data of the years 1955—59 for Scandinavia the annual cycle was determined. The picture is changing from year to year showing time displacements of the maxima and minima, which can, however, be placed "in phase" by shift of the time axis. One gets a mean value of the annual cycle of the years 1955—59 with two maxima and two minima. The total annual mean value obtained for Scandinavia is for 1955 326 ppm, 1956 321 ppm, 1957 323 ppm, 1958 315 ppm, 1959 331 ppm.

Introduction

In most investigations on atmospheric CO_2-content the interest has been concentrated on seasonal variation, where the usual summer minimum is assumed to be associated with the assimilation of vegetation.

There are very few data on the complete annual variation of CO_2. Furthermore they are difficult to interpret due to the fact that during the vegetation period considerable fluctuations have been observed between day- and night values (HUBER and POMMER, 1954). This phenomenon can be observed most markedly in the first few meters of the atmosphere. As most investigations are confined to this layer, they can be used for studies of the CO_2-content in the "free" atmosphere only to a limited extent. This is particularly evident, if one considers that the difference between the day- and night values can be as large as 100 ppm while at the same time the

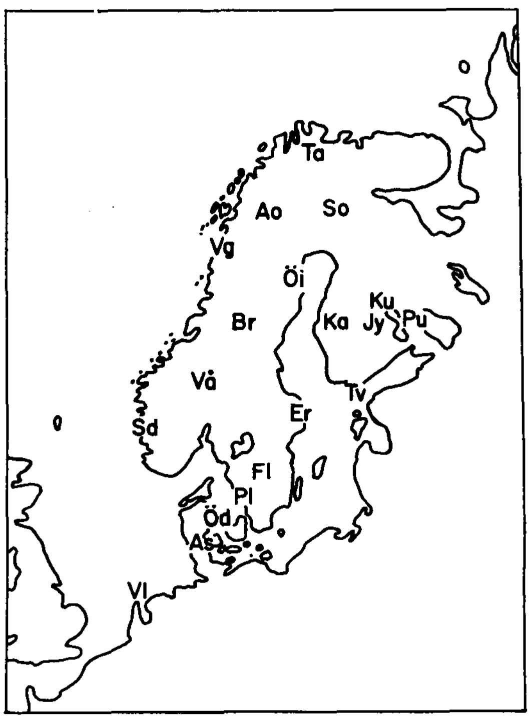

Fig. 1. The net of stations.

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contribution effect of the vegetation on the whole atmospheric CO_2-distribution amounts only to about 2 % (KALLE, 1943).

Since 1955 there exists in Scandinavia a network of about 19 stations,[1] where air samples are collected three times a month (ERIKSSON, 1954) (FONSELIUS, KOROLEFF and BUCH, 1955) (Fig. 1). The data obtained are published in Tellus regularly. A condensed report of the results obtained during the first year was published by FONSELIUS, KOROLEFF and WÄRME (1956). These data show considerable seasonal variations but good agreement between the stations, except for the Finnish ones. In the present paper an investigation of the data from 1955—59 is made and critically reviewed.

Accuracy of measurements

Already at the sampling errors can be introduced through air respired by the man doing the sampling. This danger is greatest in calm weather. Also in calm weather respiration from the vegetation during the previous night can spread into the lower layer of the air whereby an entirely wrong picture of the CO_2-content of the free atmosphere is obtained. Samples, which are taken during calm weather have therefore received particular attention in the evaluation.

Leaky gas burettes may be influenced by outside air. At the sample collection the burette is, therefore, provided with overpressure. If this overpressure is noticed when analyzing the sample there has been no contamination during transport and storage. In the chemical analysis an accuracy of about ± 3 ppm can be expected. Since May 1959 a gas analyser (IRGA) has been used instead of the chemical analysis and has an accuracy of measurement of ± 1 ppm.

Evaluation of the data

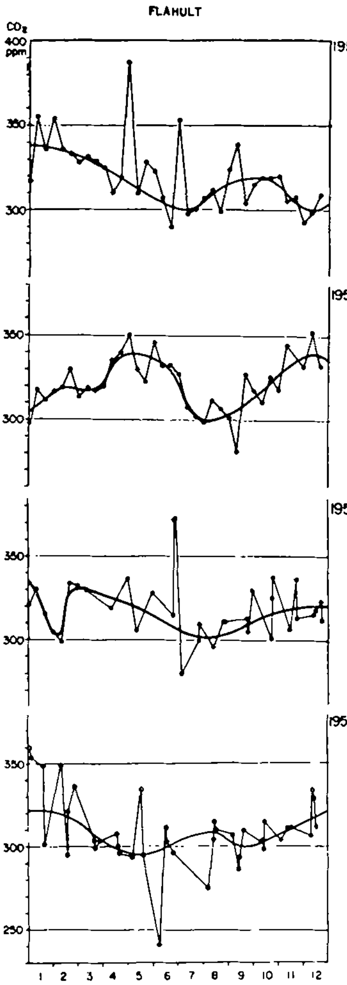
The data obtained by analyses are normally plotted chronologically as Fig. 2 shows, making it possible to check the reliability with reference to the errors discussed earlier. Samples taken at calm weather and from burettes without overpressure are denoted by open circles.

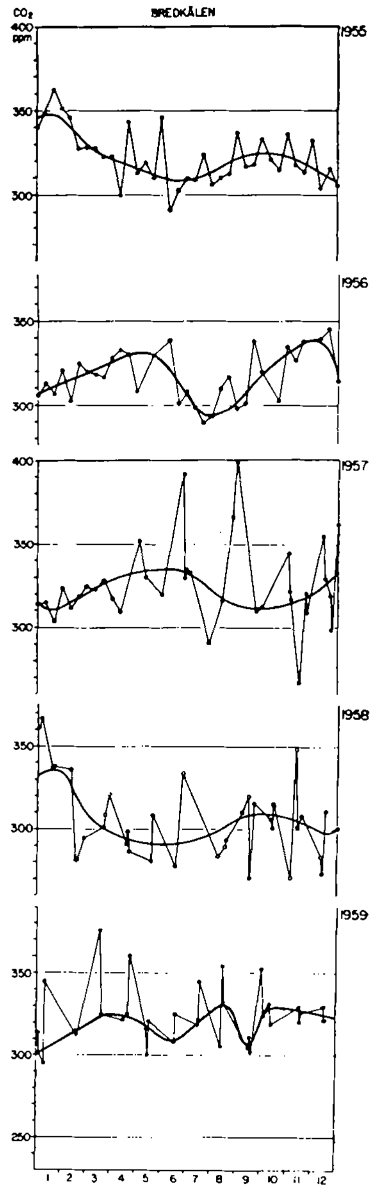
The data scatter considerably, which, in many cases, may be due to errors; the extreme values are, indeed, not always identical with the "reliable" ones. For the values in the figure it is therefore necessary to find a curve representing the annual cycle. This has been done for the stations Fl and Br in Figs. 2 and 3. A seasonal variation with maxima and minima at different dates from year to year can be observed. From this smoothed curve the monthly mean values are obtained and shown in Figs. 4 a and b—now for all stations. For a period of one year one obtains generally two maxima and two minima, which by displacement of the time axis can be put "in phase" (Figs. 5 and 6). In some cases the periodicity is interrupted by small irregularities; sometimes a maximum or minimum is very weak. This is particularly the case in the autumn, but the periodicity is, in general, resumed, thus making the reconstruction of the annual cycle possible. The values of 1959 make a general exception. Here an independent maximum between the existing spring- and autumn maxima has appeared. Again the deviating tendency of the Finnish data is striking as already shown by FONSELIUS et al. In the further discussion the Finnish data are therefore treated separately from those of the remaining Scandinavian stations.

In Figs. 5 and 6 the time adjusted curves from Figs. 4 a and b for different stations are shown for each of the years together with their average. With the exception of the values from 1959 rather uniform curves with two maxima and minima are obtained. These maxima and minima, consecutively marked 1—2—3—4, are represented in Fig. 7, in which the time of the maxima and minima for every station is entered. The annual mean curves from Figs. 5 and 6 are collected in Figs. 8 and 9.

In order to compare the annual mean curves with each other a representation as in Fig. 10 was chosen. First the deviations of the monthly mean values from the yearly means have been computed and the average of these deviations for each month. This again has been done separately for Finland and for the remaining Scandinavian stations, and cover the years of 1955—59. The striking fact about this figure is that the Finnish data now can be fitted into the remaining Scandinavian ones, if the time axis is displaced about 3 months.

[1] In the Scandinavian network the Dutch station Vl (Vlieland) is also included.





Figs. 2 and 3. The distribution of CO_2-data for several years at the station Fl (Flahult) Fig. 2, and Br (Bredkälen), Fig. 3.

As it would be very interesting to connect these annual variations with climatological events, a program for this purpose is at present under preparation but so far consistent results are not yet available. The monthly mean values in Figs. 4 a and b have been used to compute the annual mean values for every station found in Fig. 11. By graphical integration one obtains an annual mean value for the whole area. A comparison of these and averaged monthly means obtained by graphical integration are shown in Table 1.

Table 1. Annual mean values of CO_2-content in ppm

	1955	*1956*	*1957*	*1958*	*1959*
Scandinavia without Finland[1]	319	320	323	308	326
Finland[1]	337	326	325	335	340
The whole Scandinavia[2]....	326	321	323	315	331

[1] From monthly mean values.
[2] From the graphical integration.

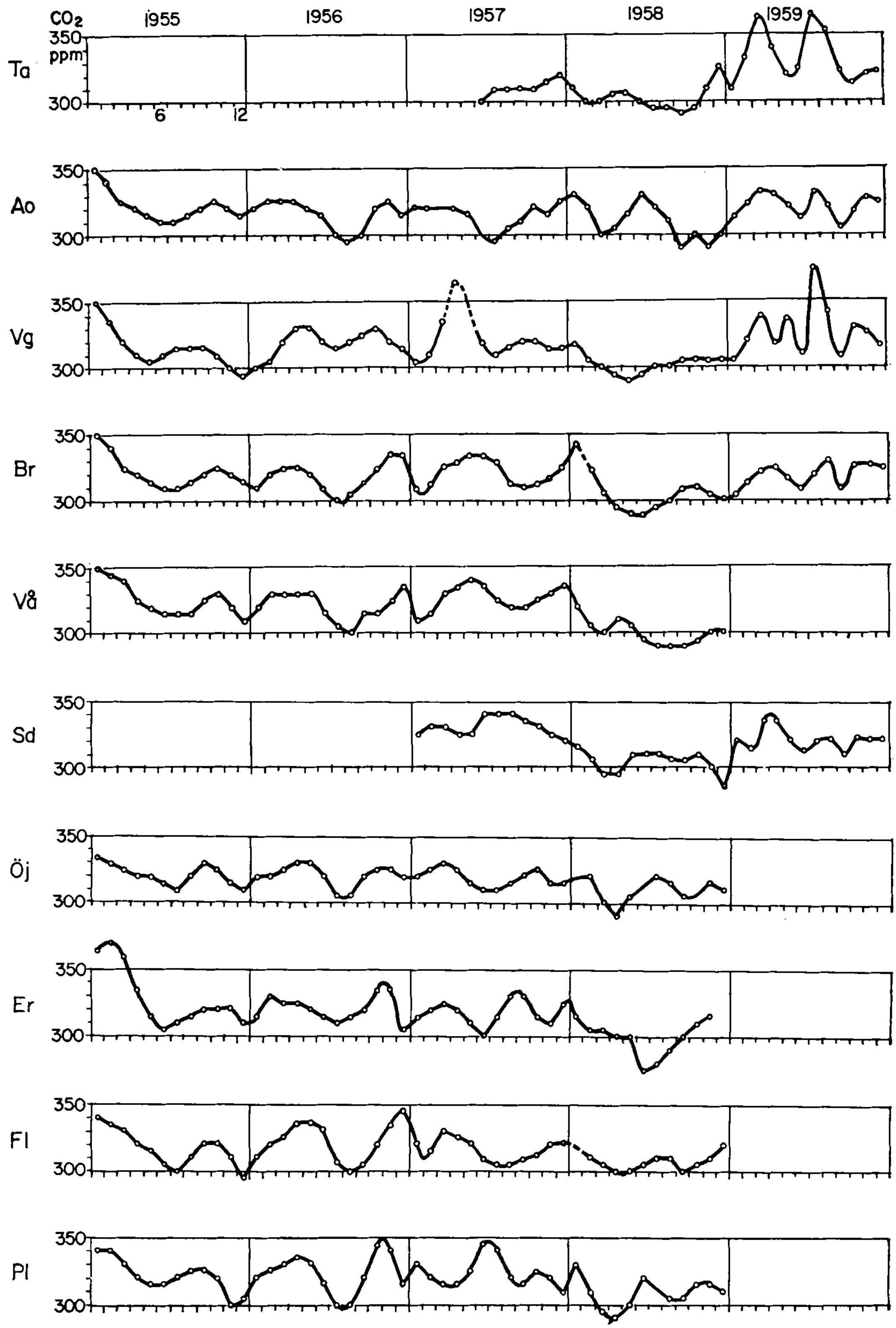


Fig. 4 a. The monthly mean values for all stations.

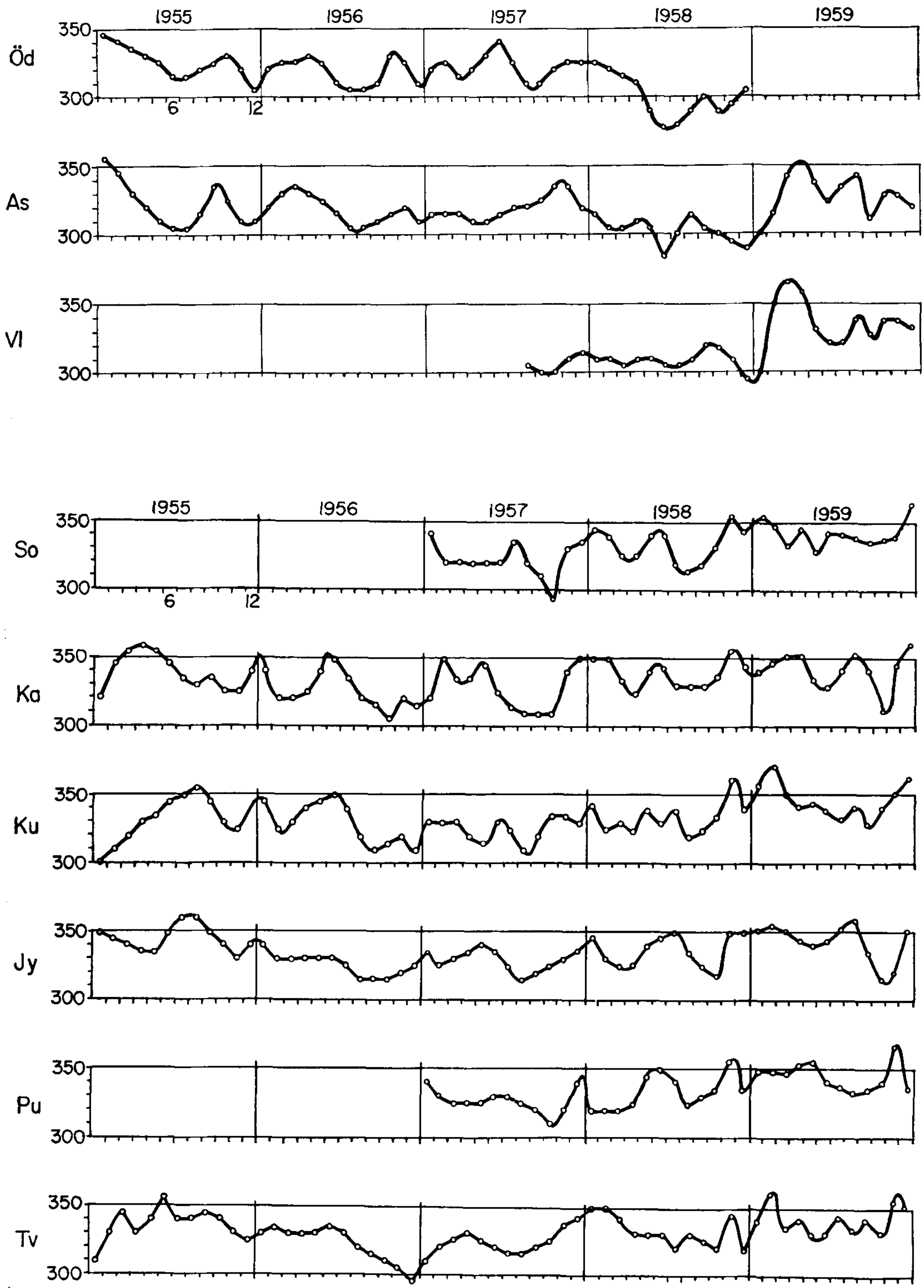


Fig. 4 b. The monthly mean values for all stations.

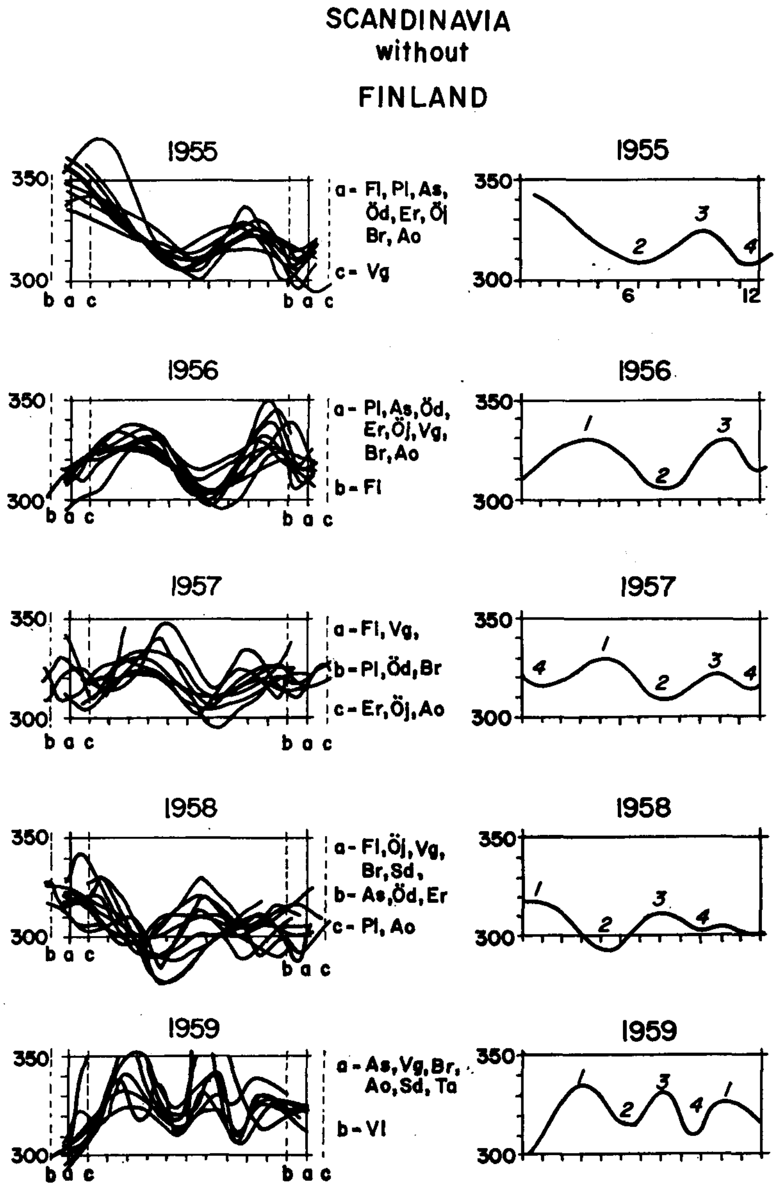


Fig. 5. The annual cycle of all stations without the Finnish. a—b—c marks the displacement of time axis for getting the curves "in phase".

Discussion of the results

a. *Comparison with other investigations*

There are, as already stated, very few investigations ranging over a whole year. In STEINHAUSER's (1958) data one can find an annual cycle for 1957 showing a winter maximum in December—January, and a summer minimum in May—June (Fig. 12). BRAY (1959) presents a collection of a great number of European investigations in which he transforms the monthly mean values into percentage of the maximum month. He receives a winter maximum in January and a

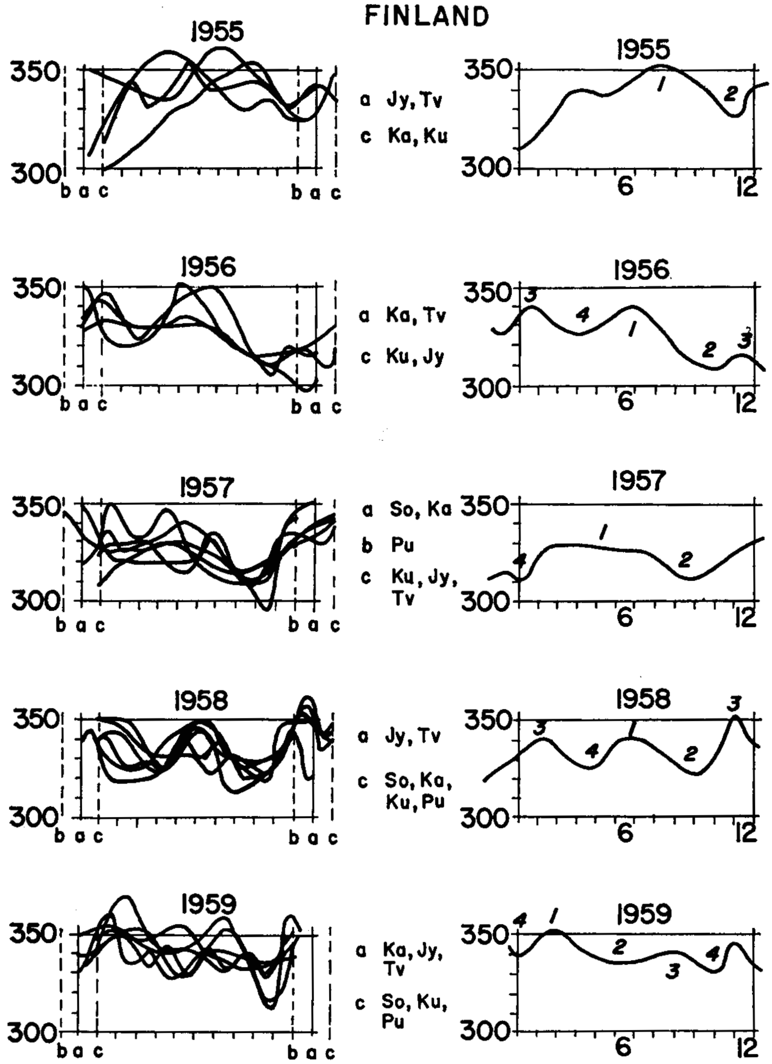


Fig. 6. The monthly mean values for the Finnish stations.

summer minimum in August. Effenberger (1951) used partly the same data as Bray; he determined the deviations of the monthly mean values and obtained an annual cycle with maxima in January to March and besides that in August to October, as well as minima in June to July and in December (Fig. 10). Here, indeed, a good coincidence with the Scandinavian investigations is found.

Huber and Pommer (1954) have used continuous measurements over a period of one year. The annual cycle, however, becomes unrecognizable because of the big amplitudes between day- and night values.

b. *Time sampling with respect to the daily cycle of the CO_2-content*

In the Scandinavian investigations the sampling time is chosen to be 1300 hr local time, but Huber's and Pommer's investigation points to the necessity of taking the daily cycle into consideration. The daily cycle shows, as is well known, a considerable CO_2-excess near the ground during the night. This

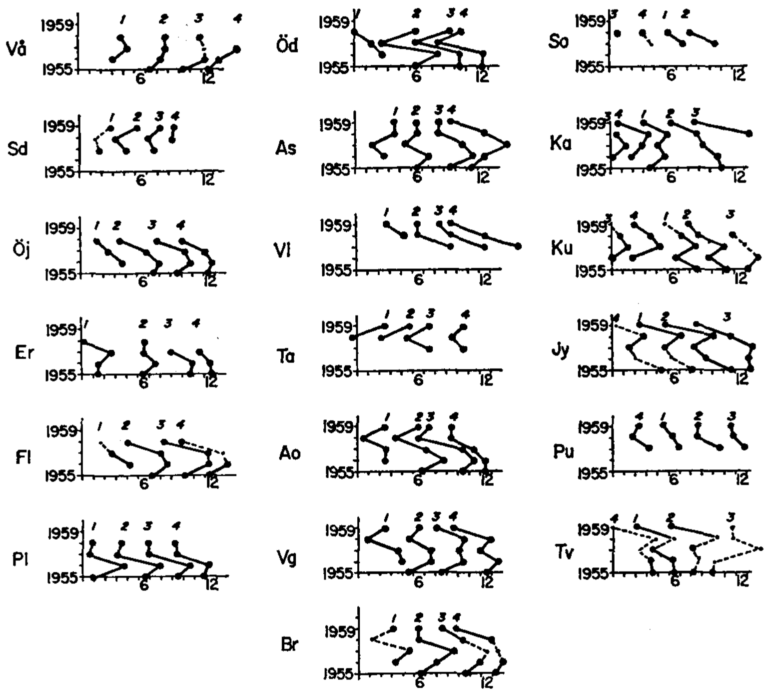
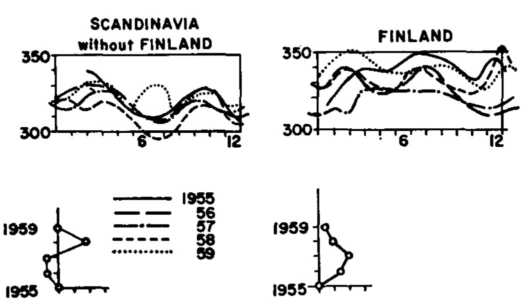


Fig. 7. The date of the maxima and minima marked with 1—2—3—4 as shown in Figs. 5 and 6.

excess is consumed by the "CO_2-hunger" of the assimilating vegetation in the course of the forenoon. In case the consumption of CO_2 cannot be covered sufficiently by the night excess, CO_2 will be taken from the atmosphere. According to measurements performed by HUBER (1951) over a corn field a well-developed daily cycle still can be observed at a height of 22 m. In the data by CHAPMAN et al.



Figs. 8 and 9. The annual mean values collected from the representation in Figs. 5 and 6 by putting curves "in phase". The time for displacement of time axis is shown at the lower picture.

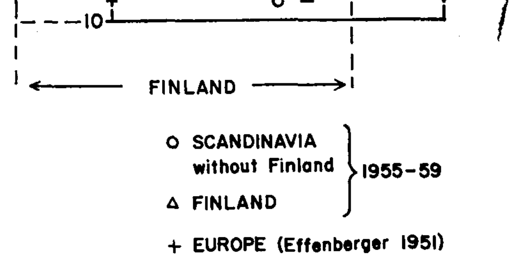


Fig. 10. Comparison of deviations of monthly mean values in relation to respective annual mean content for the Scandinavian stations and for Finland separately. The time axis for the Finnish data is displaced about 3 months. The "Europe" data are taken from EFFENBERGER 1951, Fig. 1, and correspond to selected data from about 50 years.

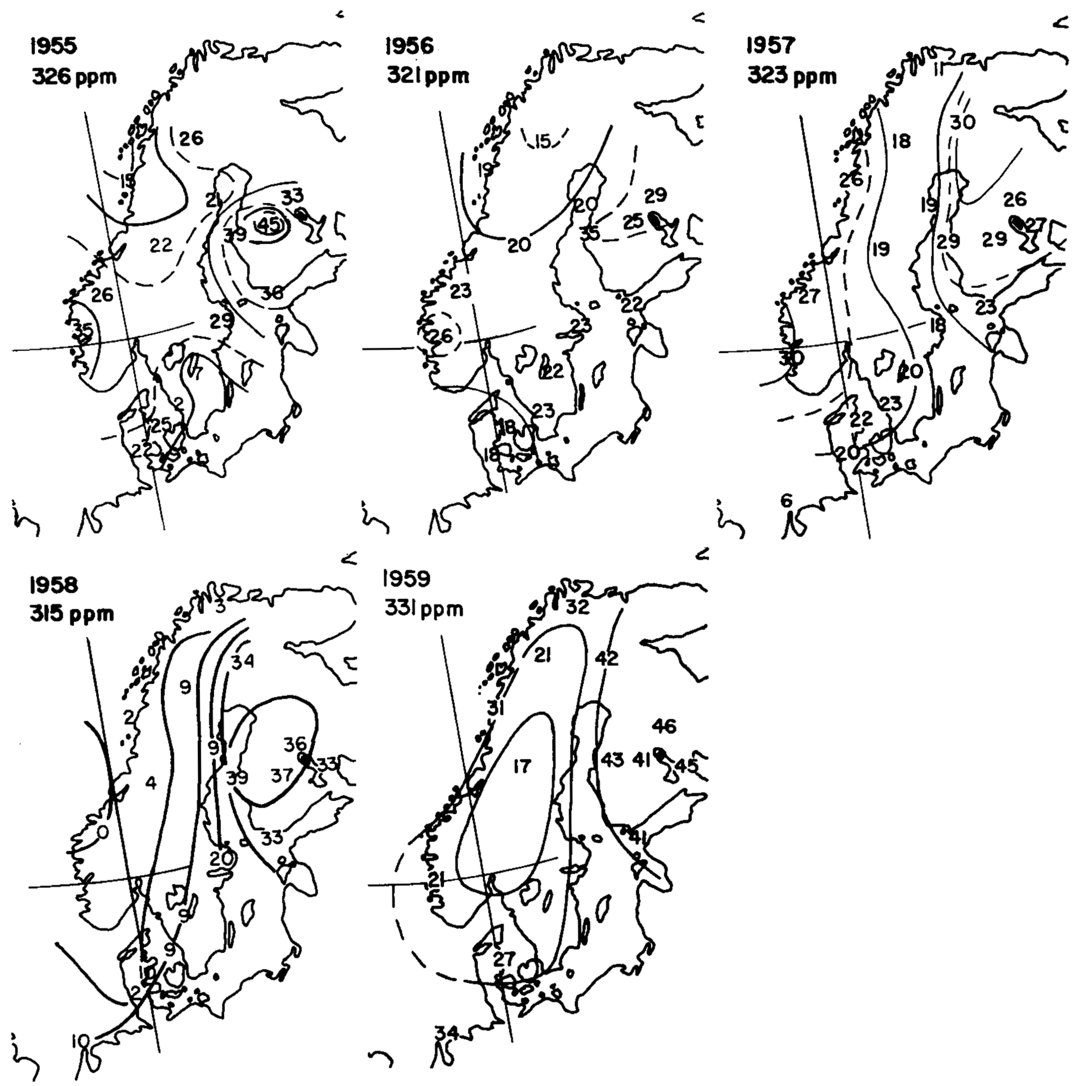


Fig. 11. The distribution of annual mean values for every station. The annual mean value for the whole Scandinavian network is found by graphical integration.

(1954) the influence of assimilation at a height of 152 m—also over a corn field—is still noticeable.

A result of vertical sampling during flight, shown in Fig. 13, indicates the influence from ground up to a height of 800 m, thus to the presumptive height of the atmospheric boundary layer in which the turbulent exchange is still effective. The daily cycle of CO_2 is, of course, influenced by the extent of the turbulent exchange of the lower atmosphere. In the Scandinavian project this effect has been taken into consideration by chosing 1300 LT for the collection of air samples, as at that time the exchange of the ground air is best developed. Moreover, in the choice of stations the proximity of excessive vegetation and industry has been avoided.

Some of the results from an investigation in the vicinity of Stockholm are here of interest. It is seen from Fig. 14 that at the two collection points, a local factor is clearly present in spite

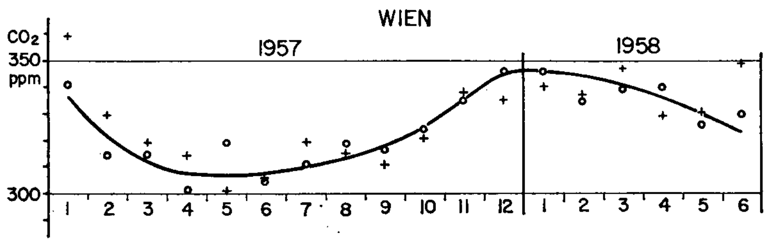


Fig. 12. The annual cycle for 1957 at Wien, from STEINHAUSER 1958, Table 1.
o monthly mean values of the daily samples.
+ monthly mean values of the samples taken 3 times every month.

of the small distance. Here "golfbanan" signifies measurements at a golf course, about 10 km north of Stockholm, "bryggan" those at a place only 1 km east of the golf course at the shore of a narrow bay of the Baltic with an easterly wind. In order to avoid the influence of vegetation as much as possible, a series of experiments was also done on a small rocky island situated in the archipelago on the east coast of Sweden. Again an easterly wind was blowing. Fig. 14 shows the results. Here, the nightly respiration from vegetation is missing, but the day values increase somewhat.

Later measurements at the golf course on July 28, September 1 and December 2, 1959 show a displacement of the day minimum to a later hour and decreasing amplitude.

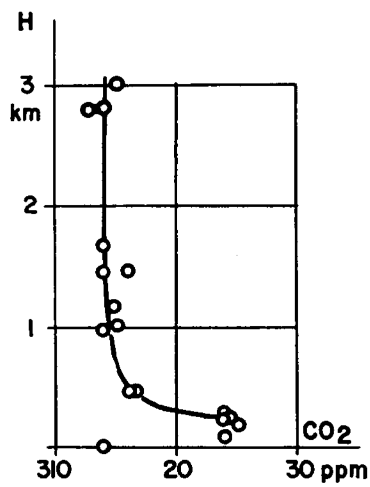


Fig. 13. Vertical CO_2-distribution at a flight 28.10.1959, 1400 LT.

c. *Consideration of single samples for ascertaining monthly mean values*

The small choice of samples—about 3 a month—brings up the question how far these represent the monthly mean value. To investigate this a series of measurements on daily samples taken at the golf course may give some information. In Fig. 15 the daily data are entered. Out of these current values the following ones:

328, 332, 323 ppm for the 11th, 12th, 13th

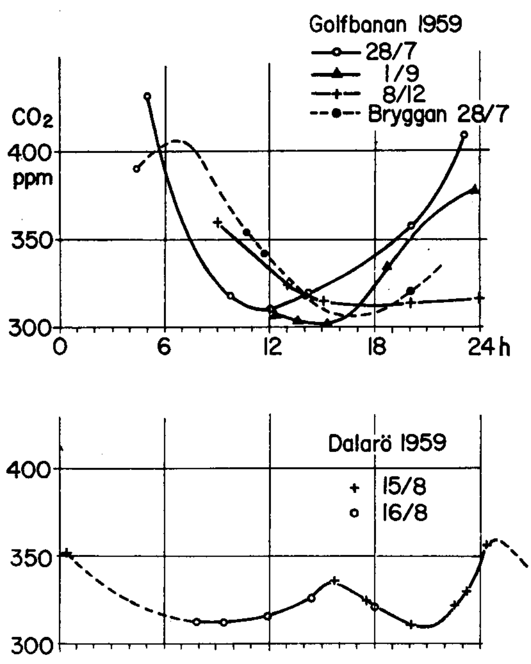


Fig. 14. The daily cycle of CO_2-content at the golf course (golfbanan) on several occasions and comparison with a place 1 km away at a Baltic creek (bryggan), and at a small island (Dalarö).

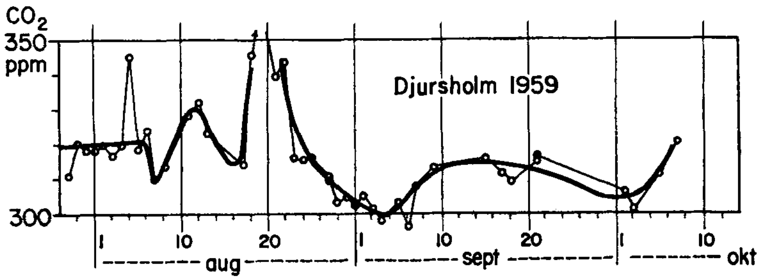


Fig. 15. Daily CO_2-data, 1300 LT from a golf course 10 km north of Stockholm.

of August and 316, 314, 312 ppm for the 15th, 16th, 17th of September

corresponding to the appointed days of sampling in the Scandinavian network give the monthly mean values for August 328 and for September 314 ppm. The correct values are for August 317 and for September 310 ppm.

Even more easy to compare are the single samples mentioned by STEINHAUSER (1958). In Fig. 12 the monthly mean values of the samples taken three times every month—the first, the tenth and the twentieth—are compared with the monthly mean values of the daily samples (as in Tab. 1 of Steinhauser's paper). Although these monthly mean data deviate from each other up till 10 ppm, the annual cycle can still be distinguished and does well agree with that using all data.

Besides the present routine program in Scandinavia preparations are being made for continuous measurements at two or more stations in Sweden. Further investigations on the vertical distribution of CO_2-concentration are also planned.

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