Carbon Dioxide Variations in the Atmosphere

by

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(Manuscript received February 24, 1956)

Abstract

The Scandinavian CO_2-sampling in 1955 is described. The mean results for the calendar year are given. Earlier CO_2-measurements are discussed and a figure showing most of these values is given. The theory of Callendar is discussed and the Scandinavian values are compared with Callendar's. The seasonal variations at the Scandinavian stations are compared and the results discussed. The possibility of drawing synoptic maps is discussed and one example is shown. The desirability of systematic CO_2-measurements on a global scale is emphasized.

Introduction

During a conference on atmospheric chemistry at the Institute of Meteorology, University of Stockholm (ERIKSSON 1954), professor Buch pointed out the importance of the CO_2-problem in the atmosphere and proposed the organization of a network of sampling stations in Scandinavia for regular analyses. This proposal was accepted, and the authors of the present article were charged with the responsibility of organizing the work. The station network has been in operation since November 1954. The location of the stations, the sampling technique and the method of analysis have been described earlier (FONSELIUS, KOROLEFF 1955); current data are published in Tellus.

From the data available up to now, it is possible to calculate yearly averages for individual stations and to discuss certain aspects of the CO_2 problem. The results are shown in table 1.

Table I

CO_2 in ppm by volume					
Station	Mean	Station	Mean	Station	Mean
Abisko	325	Plönninge	324	Ödum	326
Öjebyn	323	Bodö	319	Luonetjärvi	347
Bredkälen	324	Vågåmo	328	Tvärminne	340
Ultuna	328	Bergen	337	Rissala	337
Flahult	319	Askov	324	Kauhava	335

The average for all stations together is 329 ppm (504 analyses). In order to avoid systematic errors between the analyses made in Stockholm and Helsingfors, double samples have been taken on several occasions during the year both in Stockholm and Helsingfors and analysed in both places. Table II shows that satisfactory agreement was obtained.

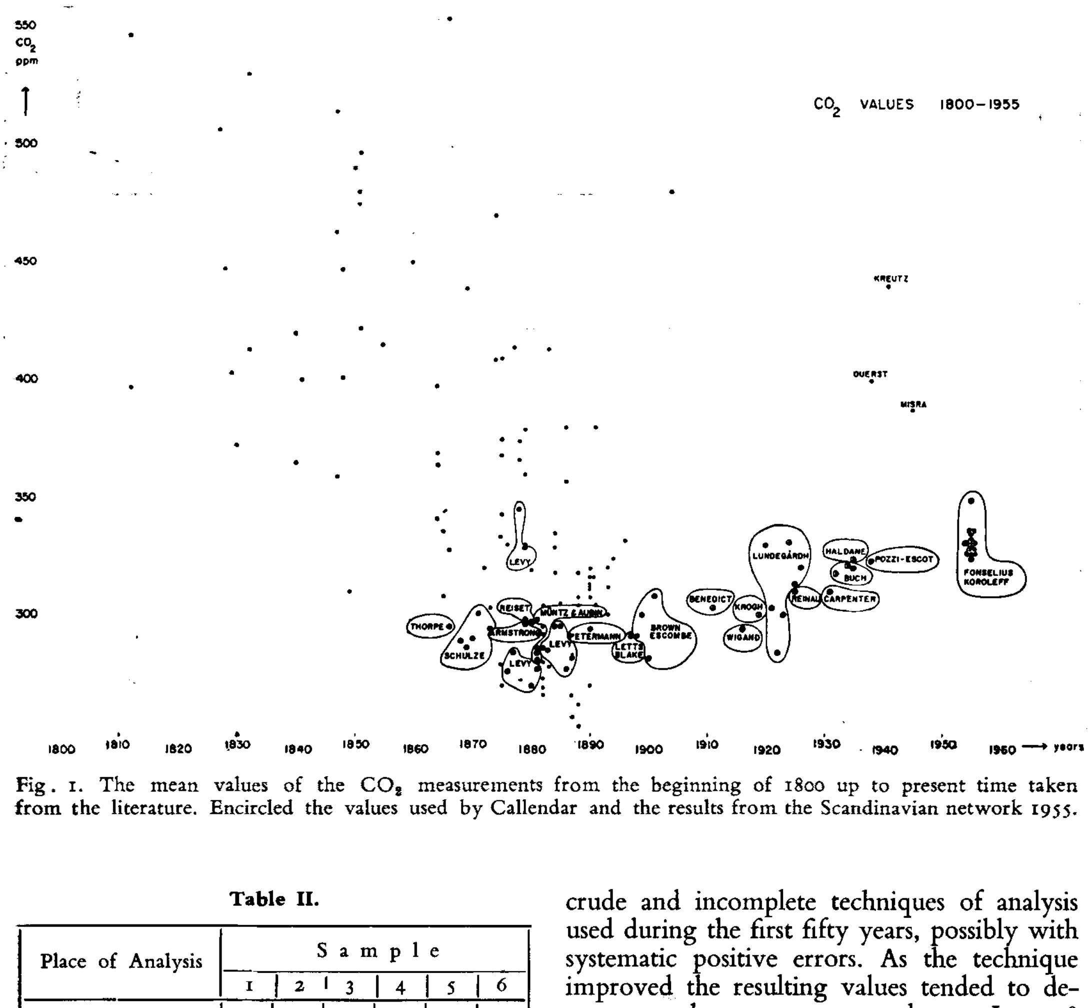

Fig. 1. The mean values of the CO_2 measurements from the beginning of 1800 up to present time taken from the literature. Encircled the values used by Callendar and the results from the Scandinavian network 1955.

Table II.

Place of Analysis	Sample					
	1	2	3	4	5	6
Helsingfors	325	351	347	337	347	348
Stockholm	330	348	340	331	345	347

A great lot of earlier CO_2-measurements have been published and many surveys written (references 1—10, 14—16, 18—28, 30) but it is difficult to find much regularity in these measurements. If we put these earlier values, or in the case of series of measurements, the mean values for each year, in a diagram, we find that they spread over a large range, the highest values being greater than 600 ppm and the lowest about 250 ppm (Fig. 1). The highest values are found in the beginning of the 19th century, but from 1860 the means are concentrated around 300 ppm. This scatter in early values probably depends on the rather crude and incomplete techniques of analysis used during the first fifty years, possibly with systematic positive errors. As the technique improved the resulting values tended to decrease to about 300 ppm or lower. In 1938 Callendar published a paper (CALLENDAR 1938) in which he discussed the possibility that the atmosphere had increased its CO_2-content during the last 50 years, this increase being attributed to industrial combustion of fossil carbon in western Europe. He used the mean values of the longest and most accurate measurements published in the literature and thus obtained a series of values, showing a mean value of 294 ppm in the period 1865 to 1900, with no trend, and then an increase to about 322 ppm during the period from 1900 to 1935 (CALLENDAR 1940, 1949, BUCH 1939 a.b.).

The last measurements in this series were made by Buch 1935 in Scandinavia and the northern Atlantic, but since then very few

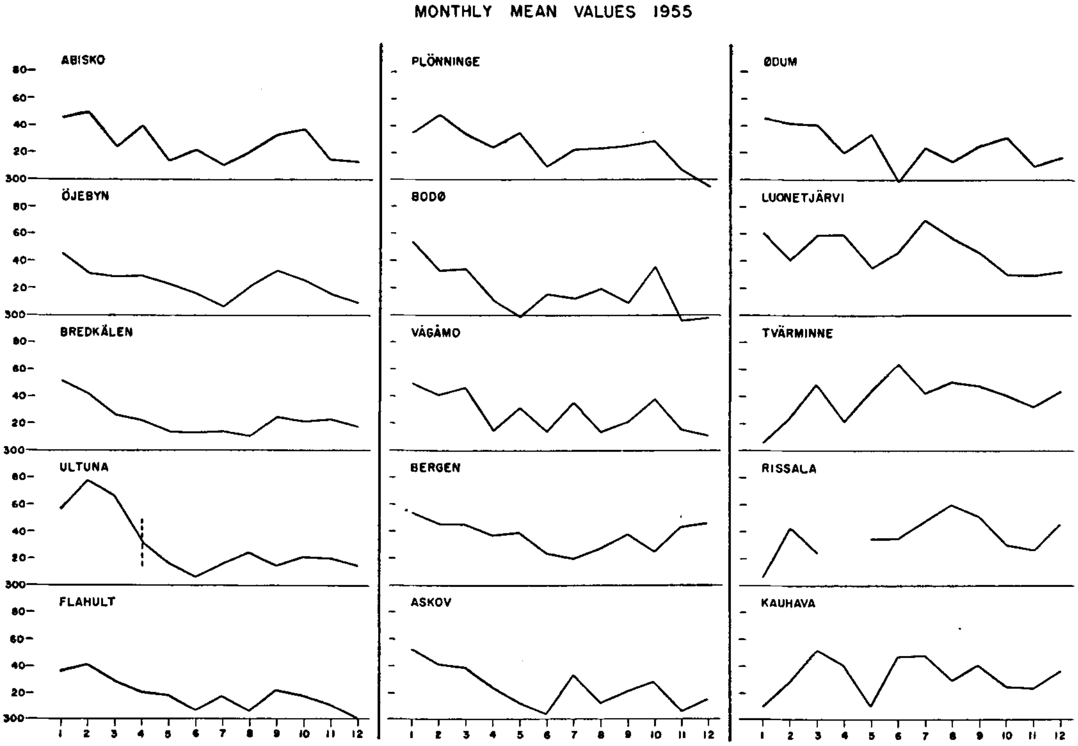

Fig. 2. The monthly mean values during 1955 for all stations in Scandinavia.

measurements have been published. It is therefore interesting to compare our values with Buch's. Buch used the same technique in sampling and analysis as we use, a modified form of Krogh's and Brandt Rehberg's technique, which makes the analytical data strictly comparable. In the diagram, the values used by Callendar and our mean values are encircled and we can see that our values fit in quite well. In spite of Callendar's careful selection of values it remains a fact that the samples were taken with different techniques and that the analyses were made in different ways. Some samples were taken in few minutes in gas burettes, others during many hours or days by slow absorption. No attention was paid to the geographical distribution of the sampling places and to the seasons. If we are to detect trends, we need samples taken by the same technique, at the same hour of the day and at same place for several years, and the analyses have to be carried out with identical techniques. The best thing would be to get samples from a network covering a representative portion of the earth's surface. This ambitious program we have not yet been able to accomplish. However, the difference between Buch's and our values suggest an increase of the CO_2 content in Scandinavia, but it is impossible to say at present whether this increase is just a fluctuation in the regional CO_2-climate or if it represents a steady increase since 1935.

As we know, the CO_2 in the sea tends to approach equilibrium with the CO_2 of the atmosphere (BUCH 1939 b). Due to the large amount present in the sea, practically all CO_2 produced by industrial combustion would therefore sooner or later be taken up by the sea. This adjustment may be a very slow process and it is therefore possible that balance will be reached first after many years. Some CO_2 may also be taken up by the plants, thereby increasing the mass of assimilating matter (HUTCHINSON 1954). Lundegårdh (1953) and others have shown that the plants increase their assimilation in higher CO_2-concentrations. If Callendar's theory is right the increase of CO_2 in the air is now about 10 %. In recent years one has tried to investigate the CO_2 problem by means of radio carbon dating, but very few satisfactory results have been obtained up to now. We know that the fossil carbon does not contain C^{14}. If therefore the CO_2 content of the air has increased by 10 % due to burning of fossil carbon, the relative content of C^{14} in the atmosphere should now be lower than 50 years ago. If we investigate still living old trees the content of C^{14} in the oldest rings should be higher than in the last rings. This would indicate an increase of CO_2 in the air by industrial combustion. SUESS (1955) has recently shown that the samples of trees from the 20th century have a lower C^{14} content than older samples but that the worldwide increase due to industrial combustion computed this way amounts to less than 1 %. This he interprets to mean that the absorption of CO_2 by the ocean must be greater than previously assumed.

Monthly and seasonal variations in Scandinavia

If we take a look upon the results during the year 1955 for the individual stations in our network, we find quite large variations with time and it is difficult to compare the stations with each other. If, however, we use the monthly mean values it is easier to study time variations. These values are highest during the winter and decrease during the spring to the very low summer and autumn values and increase again during the winter, with some exceptions. The Finnish stations, for instance, show an opposite curve with the highest values during the summer. If we then look at the Danish stations (Fig. 2) we find that they all vary in a mutually consistent manner. This shows that stations in the same area are not much influenced by local CO_2 sources. This similarity of seasonal patterns is also shown by the Swedish and Norwegian stations. This comparison suggests the existence of regional variations in the CO_2-climate but that one can avoid purely local effects by careful selection of station locations. To illu-

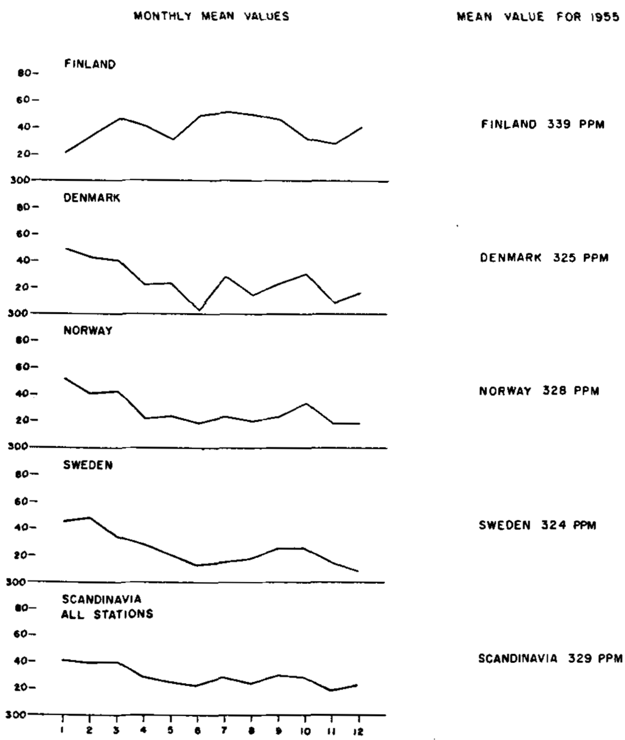

Fig. 3. The regional monthly and yearly mean values for Finland, Denmark, Norway and Sweden during 1955. The result for all stations in Scandinavia together is also given.

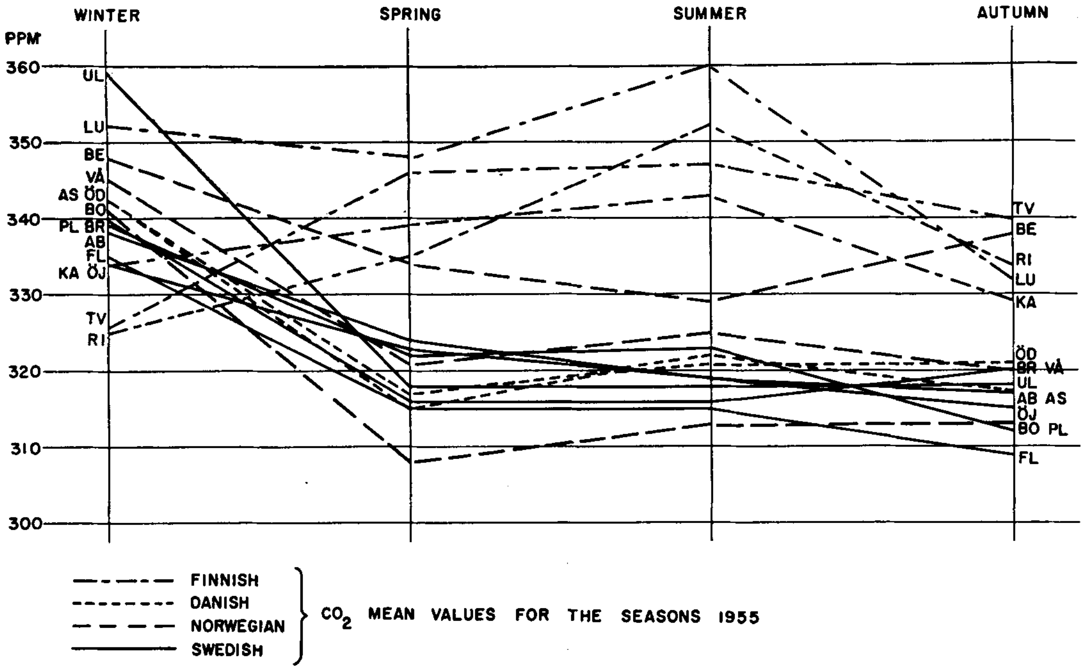

Fig. 4. The seasonal means for all stations during 1955 using mean values of 3 months for each season.

strate this we have lumped together the Danish, the Finnish, the Norwegian and the Swedish values in four separate curves (Fig. 3). The mean values for 1955 for each of the four countries are also shown in Fig. 3. The curve for the monthly mean values for Scandinavia is also given in the same figure. During 1955 Finland had a much higher CO_2 mean value than the other countries. This may be a consequence of the prevailing air circulation, which brought more continental air to Finland than to the Scandinavian peninsula. Unfortunately the Finnish spring values are to some degree uncertain, depending on a post strike in Finland in March during which seven samples were lost.

The difference between Finland and the other countries is brought out quite clearly if we use mean values for the seasons, taking the values for three months in every mean value. We have divided the year in seasons taking January, February and March as wintermonths in order to get all months from the same calendar year. Then we get April, May and June as springmonths, July, August and September as summermonths and the last three months as autumn.

If we now take a look upon the seasonal curves (Fig. 4) we find that all stations except the Finnish ones, show very similar behaviour. The only one which differs much in winter

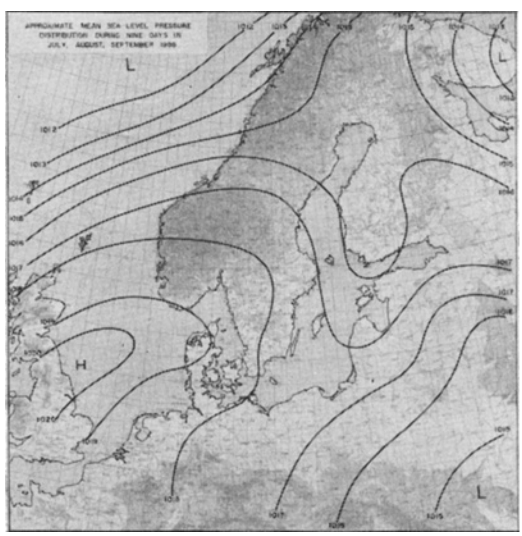

Fig. 5. The approximate mean sea level pressure distribution during the summer 1955 from the pressure of nine days in July, August and September (the 1:st, 10:th and 20:th).

is Ultuna which shows a very high value. This, however, is due to the fact that the samples were taken on an unsuitable place during the winter.

The reason why the Finnish stations show a different curve, may also be due to the more *continental climate* of Finland. The many lakes in Finland cannot deliver CO_2 by warming up during the summer sufficient to account for the difference. It has been suggested that forest fires in Russia might influence the CO_2 content of the air in Finland, but the air circulation over Finland during the summer of 1955 shows very few cases with air flow from the forest belt region of Russia and smoke from such large forest fires were not observed in Finland that summer. Earlier they were common. If, however, we draw up a sea level mean pressure map (Fig. 5) over northern Europe for the nine days in the summer during which the air samples were taken, we find that there was a slow westerly air current coming in over Scandinavia with a ridge of high pressure extending towards N.E. and producing stable anticyclonic weather. In Finland, on the other hand, air came up from the south or southeast and there are indications of a feeble low pressure system over southern Finland. The corresponding CO_2-chart shows a minimum over Sweden with much higher values over Finland (Fig. 6). It is perhaps not inconceivable that the high summer time assimilation of CO_2 by vegetation was only partially compensated by relatively feeble downward transfer in the stable air over Sweden while more adequate compensation was possible over Finland through vertical transfer and through advection from the south.

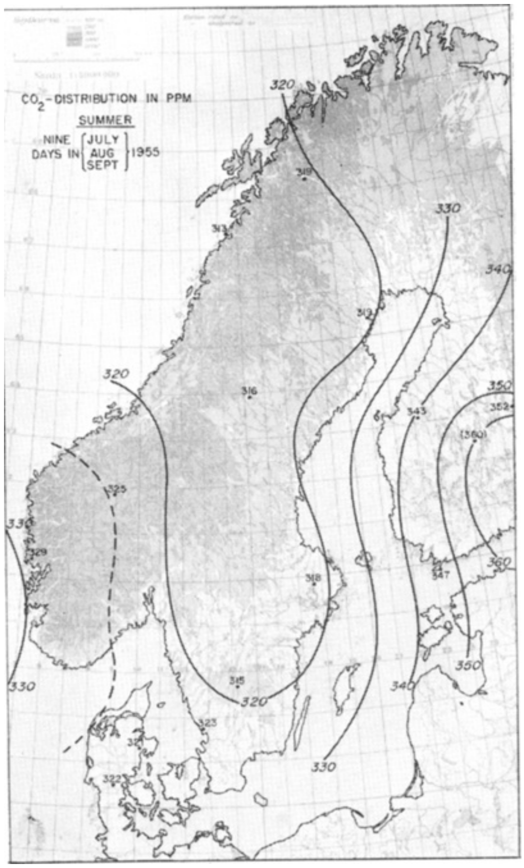

Fig. 6. The CO_2 *mean distribution in ppm during the same days as in fig.* 5.

CO_2 in different air masses

Sometimes it is possible to distinguish between airmasses by means of the CO_2-values. In some cases we had a front just over Scandinavia during the time the air samples were taken and we can compare the CO_2 values on each side of the front. On 20th of September 1955 a warm front moved westward over Finland and the front was just over the Bothnian Sea at 12^{00} GMT. (Fig. 7.) Warm continental air from Russia moved in over Finland, while over Sweden and Norway a northerly current of polar maritime air prevailed. The air samples in Finland showed very high CO_2 values, over 350 ppm, while in the other parts of Scandinavia the values were much lower. In a second case, 1st of September 1955, cold air was moving from west to east over Scandinavia and the front was located at 13 o'clock over Sweden, going east of Ultuna, west of Bredkälen and east of Öjebyn. The values in Finland and Bredkälen showed still warm continental air with higher CO_2 content.

In a third case, 10th of August 1955 we have the front between continental and maritime air just over Finland and again the Finnish stations showed higher values except Kauhava, which is located on the maritime side of the front.

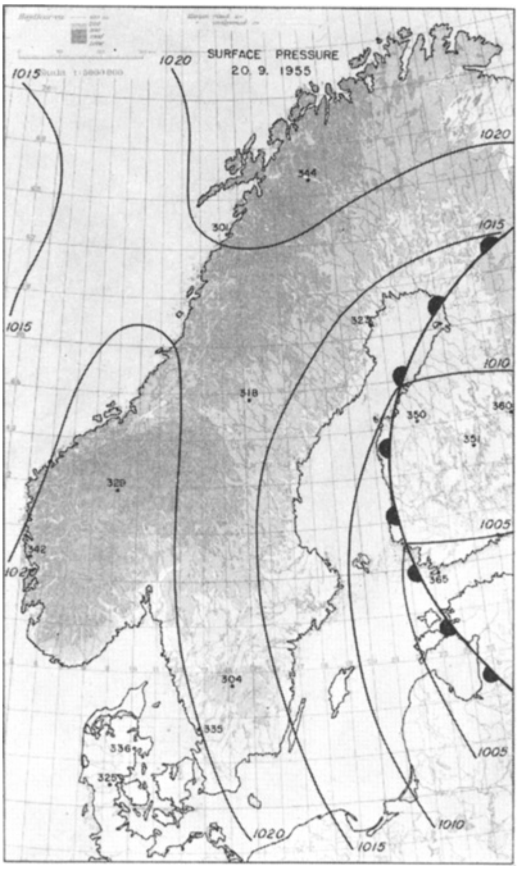

Fig. 7. The surface pressure the 20:th of September 1955 with the CO_2 values for the same day.

These investigations will be continued and the results published in Tellus. We plan to increase the number of stations in Scandinavia and during the Geophysical Year samples will be taken on Nordöya at Spitzbergen by the Swedish-Finnish-Swiss Expedition. It would be highly desirable if systematic CO_2 investigations could be carried out also in other countries during the Geophysical Year. The knowledge about the CO_2 concentration and the geographical distribution, the yearly and monthly variation and the whole CO_2 cycle in the nature is very incomplete and the only way to investigate this problem is to carry out sampling and analyses over a large area simultaneously and consider all the meteorological factors.

Acknowledgment.

The authors wishes to thank Professor C. G. Rossby and Agr. Lic. E. Eriksson for their critical review of this paper.

REFERENCES

1. Benedict, F. G., 1912: *The Composition of the Atmosphere With Special Reference to its Oxygen Content.* Washington D.C., Carnegie Inst.
2. Brown, H. and Escombe, F., 1905: On the Variations in the Amounts of Carbon Dioxide in the Air of Kew during the years 1898—1901. Roy. Met. Soc., London, *Proceedings Ser. B* **76**, pp. 118—21, 19.
3. Buch, K., 1934: Beobachtungen über chemische Faktoren in der Nordsee, zwischen Nordsee und Island, sowie auf dem Schelfgebiete nördlich von Island. Conseil perm. intern. p. l'exploration de la mer. *Rapp. et Proc. verb.* **89**, p. 13.
4. Buch, K., 1939: Kohlensäure in Atmosphäre und Meer an der Grenze zum Arktikum. *Acta Acad. Aboensis. Met. et Phys.* **XI**, p. 12.
5. Buch, K., 1939: Beobachtungen über das Kohlensäuregleichgewicht und über den Kohlensäureaustausch zwischen Atmosphäre und Meer im Nordatlantischen Ozean. *Ibid.* **XI**., p. 9.
6. Callendar, G. S., 1938: The Artificial Production of Carbon Dioxide and its Influence on Temperature. *Quart. Journ. of the Met. Soc.* **64**, pp. 223—37.
7. Callendar, G. S., 1940: Variations of the Amounts of Carbon Dioxide in Different Air Currents. *Ibid.* **66**, p. 395.
8. — 1949: Can Carbon Dioxide Influence Climate? *Weather* **4**, p. 310.
9. Carpenter, Th. M., 1937: The Constancy of the Atmosphere with Respect to Carbon Dioxide and Oxygen Content. *Am. Chem. Soc. Journ.* **59**, **pp.** 358—60.
10. Effenberger, E., 1951: Messmethoden zur Bestimmung des CO_2-Gehaltes der Atmosphäre und die Bedeutung derartiger Messungen für die Bioklimatologie und Meteorologie (2. Teil). *Ann. der Meteorologie* **4**. 10/12, p. 417.
11. Eriksson, E., 1954: Report on an Informal Conference in Atmospheric Chemistry Held at the Meteorological Institute, University of Stockholm, May 24—26, 1954. *Tellus* **6**, **3**, p. 302.
12. — 1955: Report on the Second Informal Conference on Atmospheric Chemistry Held at the Meteorological Institute, University of Stockholm, 31 May—4 June, 1955. *Ibid* **7**, 3, p. 388.

13. FONSELIUS, S., and KOROLEFF, F., 1955: Microdetermination of CO_2 in the Air, with Current Data for Scandinavia. *Ibid.* **7**, 2, p. 258.
14. HALDANE, J. S., 1936: Carbon Dioxide Content of Atmospheric Air. *Nature* **137**, p. 575.
15. HAMBERG, A., 1884: Hydrografisk-kemiska iakttagelser under den svenska expeditionen till Grönland. *K. Sv. Vetenskapsakademiens Handl.* **10** (13), p. 1—57.
16. HANN, J., 1915: *Lehrbuch der Meteorologie*, **5**, p. 7, Leipzig.
17. HUTCHINSON, G. E., 1954: The Biochemistry of the Terrestrial Atmosphere, Carbon Dioxide and Other Compounds. *The Earth as a Planet, Kuiper II*, p. 379.
18. KREUTZ, W., 1941: Kohlensäuregehalt der unteren Luftschichten in Abhängigkeit von Witterungsfaktoren. *Angew. Bot.* **23**, p. 89.
19. KROGH, A., 1904: The Abnormal CO_2 Percentage in the Air in Greenland. *Komiss. for Led. af de geol. og geogr. Undersøg. i Grønland.* **26**, pp. 409—34.
20. — 1919: Composition of the Atmosphere, on Account of the Preliminary Invest. and a Program. *Danske Videnskabernes Selskab, Math. fysiske Medd.* **1** (12), pp. 1—19.
21. LETTS, E., and BLAKE, R. F., 1900: The Carbonic Anhydride of the Atmosphere. *Roy. Dublin Soc. Scient. Proceedings. New Ser.* **9** (2), pp. 107—270.
22. LUNDEGÅRDH, H. G., 1924: Der Kreislauf der Kohlensäure in der Natur. Ein Beitrag zur Pflanzenökologie und zur Landwirtschaftlichen Düngungslehre. Jena. *Gustav Fischer Verlag.* pp. 1—308.
23. — 1953: Die Kohlensäure als Standortfaktor. *Klima und Boden*, Lundegårdh 1953, pp. 514.
24. MISRA, R. K., 1950: Studies on the Carbon Dioxide Factor in the Air and Soil Layers Near the Ground. *Ind. Journal. of Met. and Geophys.* **1**, **4**, p. 275.
25. PALMQVIST, A., 1893: Undersökningar öfver atmosferens kolsyrehalt. *K. Sv. Vetensk. Akademiens Handlingar* **18** (2), pp. 1—39.
26. PETERMANN, A., and GRAFTIAU, J., 1892: *Mem. cour. Acad. R. Belg.*, **47**, **87**.
27. POZZI-ESCOT, E., 1938: Hacia el conocimiento de la composición del aire en Lima, su Riqueza en anhidrido carbónico. *Revista de Ciencias Lima* **40** (423), pp. 133—140.
28. STEPANOVA, N., 1952: Bibliography on Carbon Dioxide in the Atmosphere. *Met. Abstr. and Biblio.*, **137**.
29. SUESS, H. E., 1955: Radio Carbon Concentration in Modern Wood. *Science* **122**, *3166*, *p. 416*.
30. WOLLNY, M. E., 1880: Untersuchungen über den Einfluss der Pflanzendecke und der Beschattung auf den Kohlensäuregehalt der Bodenluft. *Biedermanns Zentralblatt für Agrikulturchemie und rationellen Lantwirtschaftsbetrieb.* **9**, pp. 402—6 *Cit. Met. Abstr. and Biblio.* 1952, p. 146.