GEOPHYSICAL RESEARCH LETTERS, VOL. 22, NO. 2, PAGES 89-92, JANUARY 15, 1995

Biomass burning record and black carbon in the GISP2 ice core

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Abstract. We have determined the black carbon concentration in three sets of ice core samples from the GISP2 (Greenland Ice Sheet Project 2) ice core. The major peaks in black carbon concentration between 320 and 330 A.D. correlate well with peaks in ammonium concentration and with the dips in electrical conductivity measurements (ECM), which allows us to identify extensive forest fires in this time period. The average black carbon concentration during the 320 to 330 A.D. decade is found to be 2.1 μg of black carbon per 1kg of snow melt water. The current snow (1989 and 1990) from the GISP2 site shows an average black carbon concentration of about 2.0 μ/kg suggesting that the rate of black carbon deposition at the GISP2 Greenland site during 1989-1990 was about the same as 1670 years ago.

Introduction

The main pre industrial source of black carbon (soot) in the atmosphere is biosphere burning in the form of forest fires or land clearing for agriculture. Black carbon forms the important solar radiation absorbing component of atmospheric aerosols It is removed from the atmosphere primarily by wet deposition processes [*Cadle and Dasch, 1988*]. Deep ice cores contain long time records of black carbon deposited in polar regions that can provide information concerning the biosphere. We present the black carbon analysis of three sets of the GISP2 ice core samples ranging from the very recent to almost 20,000 years old.

Black Carbon From 320 to 330 A.D.

The direct current electrical conductivity, which is dependent on the concentration of H^+ ions [*Hammer, 1980*], has been continually measured along the length of the GISP2 ice core [*Taylor et al., 1993*]. Decreases in the H^+ concentration of the ice are caused by increases of NH^+_4 or Ca^{++} and can cause an order of magnitude decrease in the electrical conductivity of ice [*Taylor et al., 1992*]. During the Holocene short duration decreases in the ECM that appear to be associated with single storm events are caused by increased levels of NH_4 from biomass burning [*Legrand et al., 1992*]. The ability of the ECM to resolve features in the ice core as small as 1mm makes the ECM an ideal method for identifying the occurrence of these short duration features.

We present the GISP2 ECM record from the years [*Meese et al., 1994*] 300 to 350 A.D. (Fig. 1). The abrupt short duration decreases in electric conductivity (denoted by solid triangles in Fig. 1) are conjectured to correspond to episodes of extensive forest fires in the northern hemisphere. To verify this we determined the black carbon and ammonium concentrations on a two meter long section of ice core where the abrupt decreases in ECM frequently occurred. Because the carbon determination requires 150 to 300 ml sample, only 21 carbon samples could be obtained from this section of core. The ECM was used to select intervals such that ice containing biomass burning byproducts would not be split into two adjoining samples. The details of the method of black carbon analysis has been described elsewhere [*Chylek et al., 1987; 1992a; 1992b*]. Blank tests yielded black carbon concentrations between zero and 0.05μg/kg. Ammonium concentration was measured using the Grasshoff-Johannsen method [*Grasshoff-Johannsen, 1972*] with sensitivity about 0.1 μmol/L.

The results of the black carbon analysis (top panel in Fig. 2) confirm the usefulness of the ECM to identify periods of suspected extensive biosphere burning. The average black carbon concentration found in the 320 to 330 A.D. decade is 2.1 μg/kg with the standard deviation of 1.7 μg/kg. Two black carbon peaks around the years of 324 and 326 A.D. show an elevated black carbon concentration which is by more than 2.5 times the standard deviation above the average decadal value. When these two peaks are removed from the average calculation, the decadal black carbon average is 1.7 μg/kg with the standard deviation of 0.9 μg/kg.

The ammonium concentration (the lower panel of Fig. 2) shows the decadal average of 0.9 μmol per liter with the standard deviation of 1.1 μmol/L. The peaks around 324 and 326 A.D. show NH^+_4 concentrations more than two standard deviation above the average. When these two peaks are removed from the average calculation the decadal average is 0.55 μmol/L with the standard deviation 0.32 μmol/L. Our decadal average ammonium concentration is comparable with concentrations found in the 674 to 1985 A.D. section of the GISP2 ice core [*Mayewski et al., 1993a*] as well as with the 1259 to 1900 A.D. average [*Whitlow et al., 1992*].

The sharp dips in electric conductivity around years 324 and

Paper number 94GL02841
0094-8534/95/94GL-02841$03.00

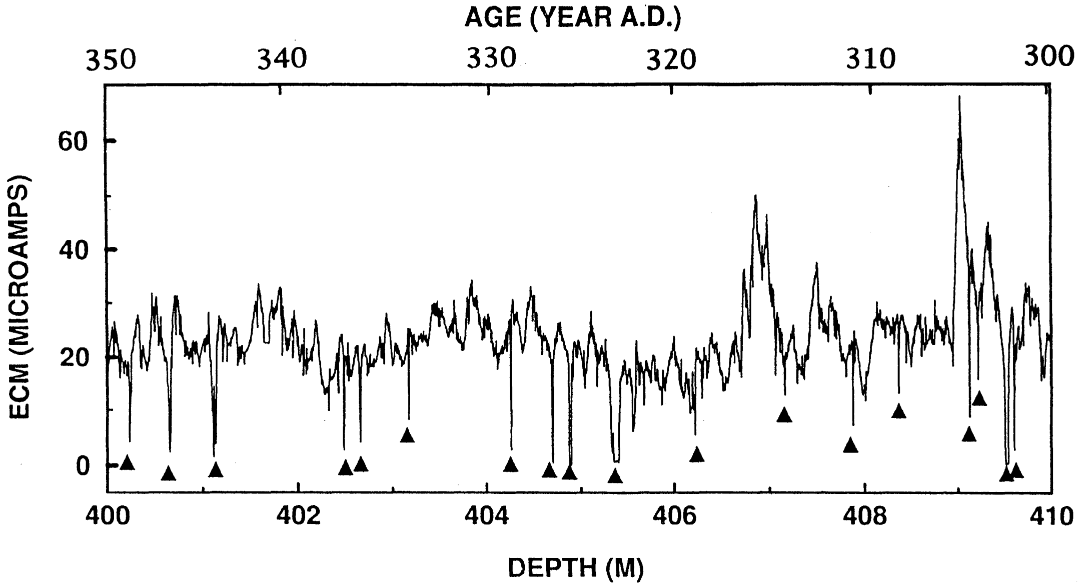

Fig.1 Changes in electric conductivity along the length of the GISP2 ice core between the years of 300 to 350 A.D. Sharp dips in conductivity are suspected to be connected to the periods of extensive biosphere burning.

326 A.D. coincide with observed significant peaks in black carbon and NH_4^+ concentrations (Fig.2), confirming that these observed ECM dips can be indeed connected to biosphere burning. Although the remaining two dips in electric conductivity (around 327 and 329 A.D.) also show elevated levels of black carbon and ammonium concentrations, these elevations are less than the standard deviation above the mean. Because of simultaneous occurrence of dips in electric conductivity and peaks in black carbon and ammonium concentrations we also associate these events with biomass burning. However, a peak of comparable height appears in ammonium concentration at the year 321 A.D. which is not accompanied by a peak in

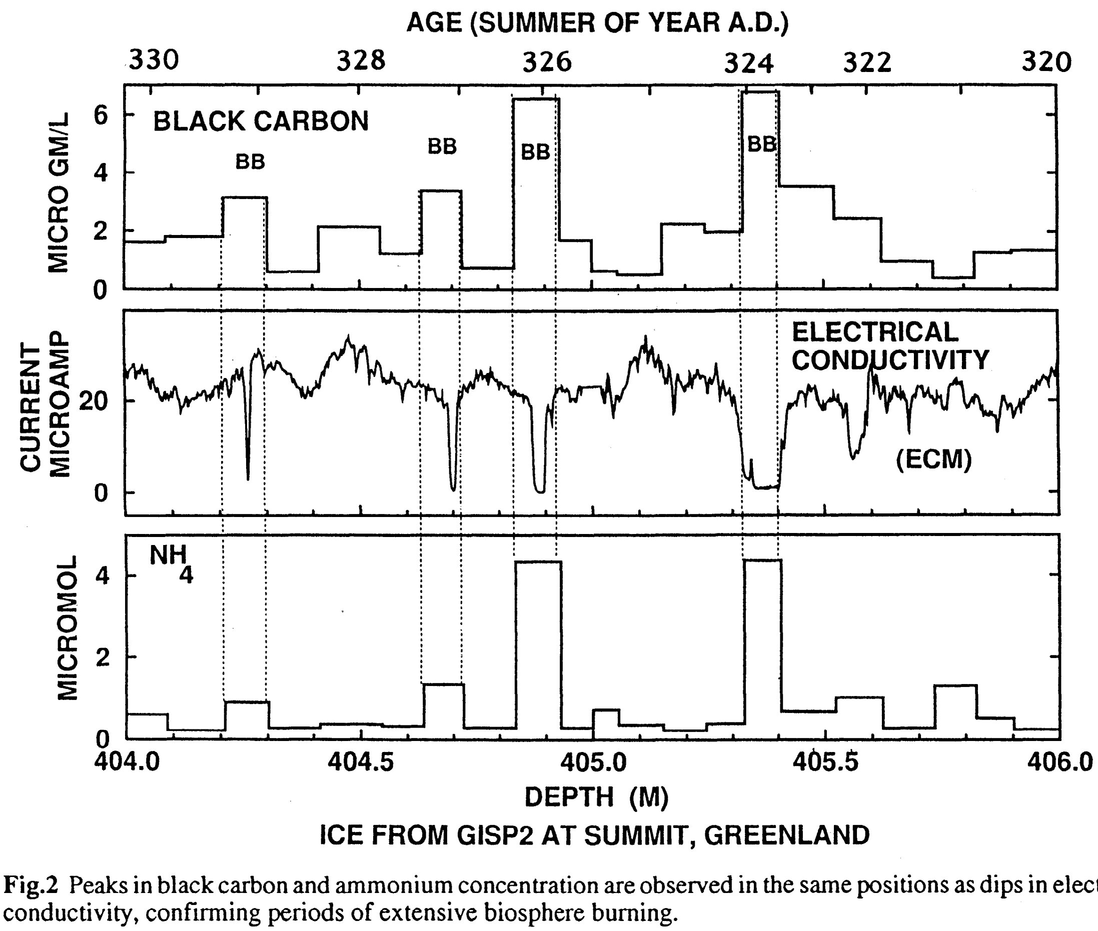

Fig.2 Peaks in black carbon and ammonium concentration are observed in the same positions as dips in electric conductivity, confirming periods of extensive biosphere burning.

Table 1. Black carbon and ammonium in 9900 to 20000 years old ice core samples

Ice core depth	Age YBP	Age Error	Black Carbon μg/kg	Ammonium μmol/L
1559.0- 1559.3	9934- 9936	±100	<0 05	0.5
1831.7- 1832.0	15982- 15995	±330	yes	0.3
1903.0- 1903.3	19129- 19142	±480	<0.05	0.4

The black carbon concentrations in 1559 and 1903m samples were consistent with no carbon present. The black carbon was identifies in the 1832m sample, however, due to an extraordinary large amount of crustal aerosol pressent we were not able to make a quantitative determination. The sample at the depth of 1903m also contained a large amount of crustal aerosols, though less than the sample from 1832m.

black carbon concentration or dip in electric conductivity and thus it cannot be connected to biosphere burning.

Within the investigated decade from 320 to 330 A.D. we see four possible periods of biosphere burning with two major forest fire episodes taking place in 324 and 326 A.D. From the conductivity measurement (Fig. 1) for the years 300 to 350 A.D. we deduce that the 320 to 330 A.D. decade was an extraordinary decade for major forest fires during the investigated time interval. Only four major forest fire episodes are observed in the ECM from 300 to 350 A.D. (302, 324, 326 and 344 A.D.) and two of those are in the analyzed portion of the ice core in the years 324 and 326 A.D.

Black Carbon 10 to 20 KYBP

Our analysis from this time interval is limited to three samples available to us for the black carbon analysis. It is apparent that no general conclusions can be drawn from such a limited collection of samples. Our purpose of publishing the following results is to make available as much as possible of the black carbon data for the use by other researchers and to emphasize the need for future measurements.

The results of our black carbon and ammonium concentration measurement are shown in Table 1. The level of ammonium concentrations varies between 0.3 and 0.5 μmol/L. The years before present (YBP) means years before 1950 A.D. The years from 15982 to 15995 are within the last part of the Older Dryas period when high amounts of crustal aerosols are found in ice core [*Mayewski et al., 1993b*].

Black Carbon in Current Snow

The third set of investigated samples consisted of the GISP2 ice core from 30 to 100cm below the surface, corresponding to the recent ice deposition (part of 1989 and 1990). The core was divided into 5 segments for black carbon determination. The results are shown in Fig. 3. The average black carbon concentration of 2.0 μg/kg is almost identical to the 320 to 330 A.D. average. The average ammonium concentration of 0.45 μmol/L is close to the 320 to 330 A.D. average of 0.55 μmol/L (when two major forest fire episodes are removed from the average calculation).

Conclusions

We note that the 320 to 330 A.D. black carbon background concentration in the GISP2 core of 2.1 μg/kg (or 1.7 μg/kg when two major forest fires are neglected from average consideration) found in this work is close to the Holocene concentrations found in other Greenland ice cores, namely 1.5 μg/kg for Dye-3 ice core and 1.8 μg/kg for the Camp Century ice core samples [*Chylek et al., 1987; 1992b*]. The higher average value (2.1 μg/kg) found in this study is probably caused by the chosen decade (320 to 330 A.D.) having more than an average number of extensive forest fires.
The Greenland ice cores are found to have consistently three to four times higher black carbon concentration than the Byrd Station (Antarctica) ice core Holocene average [*Chylek et al., 1992a*] reflecting differences in sources, transportation routes and atmospheric circulation patterns.

Analysis of the recent snow from the GISP2 site suggests that the 1989-1990 rate of black carbon deposition at the GISP2 location is about the same as that during the 320 to 330 A.D. decade. Summary of measurements from other locations (Table 2) indicate only a slightly higher black carbon deposition rates in recent snow compared to the rates a few thousand years ago.

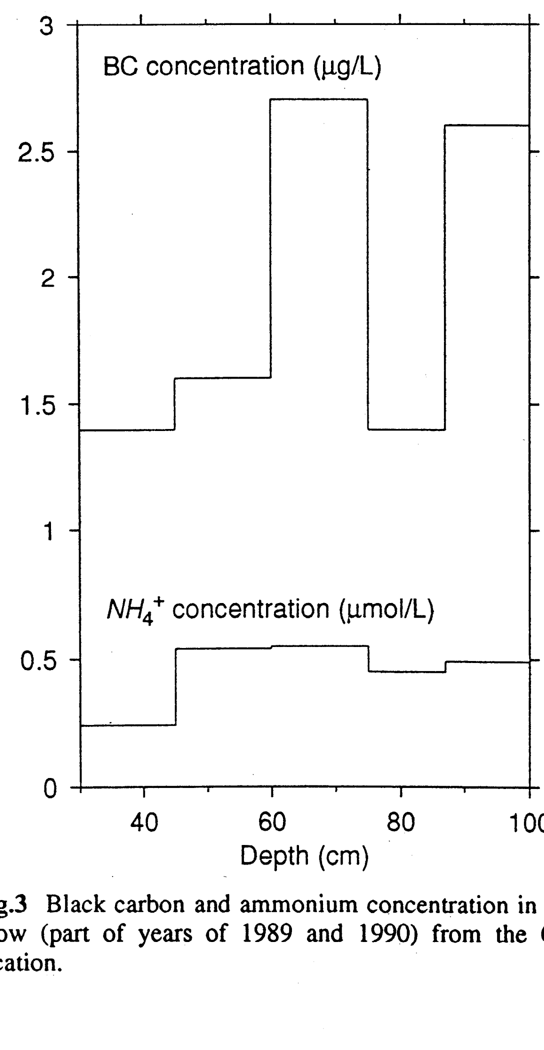

Fig.3 Black carbon and ammonium concentration in recent snow (part of years of 1989 and 1990) from the GISP2 location.

Table 2. Black carbon concentration in snow and ice core samples

Location	Black Carbon μg/kg	Number of Ice Core Samples	Age KYBP or as specified	Reference
GISP2	2.1	21	320-330 A.D.	This work
GISP2	2.0		1989-1990	This work
Dye 3	1.5	22	0.1 - 3.4 KYBP	Chylek et al., 1992b
Dye 3	<3.5		Recent Snow	Clarke and Noone, 1985
Camp Century	1.8	2	6 -10 KYBP	Chylek et al., 1987
Camp Century	2.4		Recent Snow	Chylek et al., 1987
Byrd Station	0.1 to 0.5	22	0.7 -14 KYBP	Chylek et al., 1992a
South Pole	0.1 to 0.3		Recent Snow	Warren and Carke, 1990

Only the upper limit is provided for the snow analysis from Dye-3 site due to large amount of mineral particles in the snow [*Clarke and Noone, 1985*].

Acknowledgement. The reported research was supported in part by the United States National Science Foundation Office of Polar Programs, by the Atmospheric Environment Service and by the Natural Sciences and Engineering Research Council of Canada. The authors thank the National Science Foundation and the GISP2 Scientific Team for providing the ice core samples and P. Mayewski and R. Alley for stimulated discussions.

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(Received July 21, 1994; revised October 5, 1994; accepted October 10, 1994)