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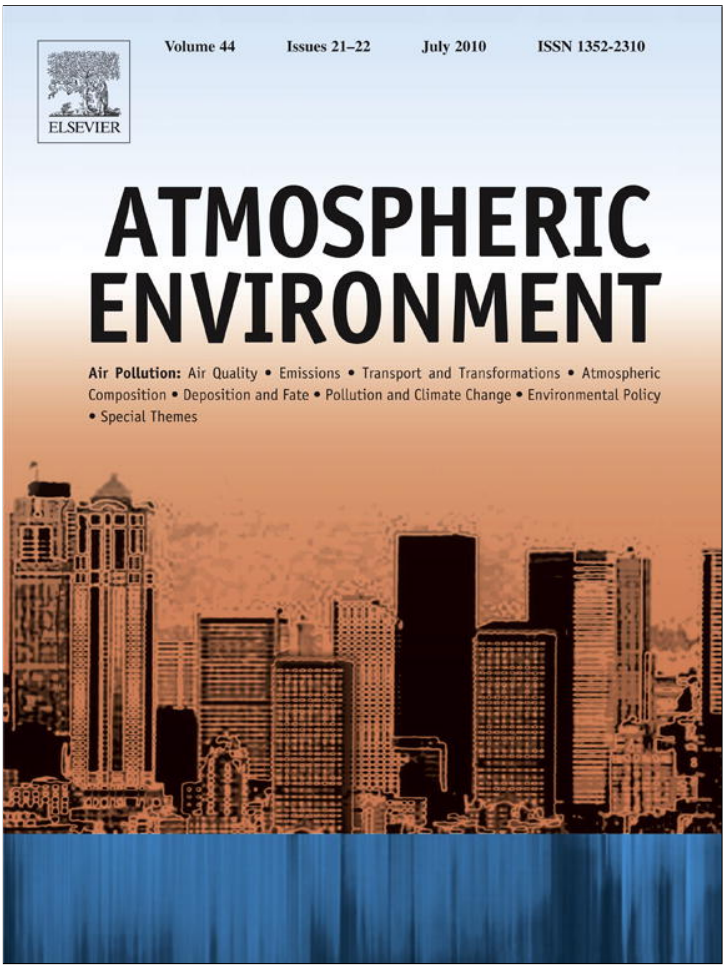


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# New Directions: Historical black carbon and other ice core aerosol records in the Arctic for GCM evaluation

Although much of current understanding about future climate change is based on computer simulations, global climate models (GCMs) must be evaluated against past climate records to adequately underpin policy decisions. With comparatively long atmospheric lifetimes, greenhouse gases (GHGs) and their radiative forcings are relatively well understood and simulated, but climate forcing from direct and indirect effects of short-lived atmospheric aerosols is poorly defined and quantified (IPCC, 2007) in large part because few records of aerosol concentrations or fluxes exist prior to recent decades and understanding of sources and transport processes is limited (Shindell et al., 2009). Such aerosols consist of continental dust, sea spray, particulates such as black carbon (BC; soot) and organic matter from combustion processes, sulfur and trace metals from volcanic emissions, and, during recent centuries, industrial activities.

The international policy community seeks to slow climate change in the Arctic where rates of change are among the highest on Earth (ACIA, 2005). Although warming from increased carbon dioxide and other GHG concentrations is the long-term driver of climate change, reductions in short-lived aerosols such as BC that contribute to climate warming offer the possibility of slowing Arctic climate change in the near-term (Koc et al., 2009; Quinn et al., 2008). Most aerosols found in the Arctic have been transported across great distances from low- and mid-latitude sources so concentrations are modulated by changes in atmospheric circulation at all temporal and spatial scales. Moreover, atmospheric transport into the Arctic is complicated by a polar dome that isolates the cold lower troposphere from the rest of the atmosphere (Law and Stohl, 2007).

With their short lifetimes in the atmosphere, aerosol concentrations and deposition in the Arctic are dominated by regional, rather than global, sources, transport processes, and pathways. Further, intra- and inter-annual variability of aerosol deposition is large (e.g., McConnell et al., 2007). As a result, arrays of historical, high-time-resolution records with a broad range of analytes are required to understand aerosol concentrations, sources, and variability while providing adequate information for evaluating GCM, snowpack radiation, and other models.

Ice core records have played a central role in documenting current climate changes by providing multi-parameter historical information on atmospheric and precipitation chemistry, meteorology (including net snow accumulation), and ocean–atmosphere circulation (e.g., North Greenland Ice Core Project, 2004). Recent improvements in chemical analyses mean that far more detailed information on all classes of aerosols can be obtained from ice cores (e.g., Osterberg et al., 2008; Zheng et al., 2007). With additional advances using continuous, real-time ice core melter systems, it is possible to develop monthly, broad-spectrum (>35 elements and chemical species) aerosol records from ice cores (Banta et al., 2008; McConnell and Edwards, 2008). Such records are comparable to modern measurements of precipitation and atmospheric aerosol chemistry but extend from recent decades to millennia.

BC in snow and water is especially important to climate forcing in the Arctic because of its impact on albedo (Hansen and Nazaranko, 2004; Flanner et al., 2007). A leading climate change scientist recently noted, "*the soot albedo effect is imprecise because of the near absence of accurate albedo measurements and soot in snow inventories and the high efficacy of even a small snow albedo change*" (Hansen et al., 2007). Substantial progress has been made in recent years in expanding measurements of BC in snow (e.g., Clarke and Noone, 1985; Hegg et al., 2009). Using continuous, melter-based ice core analytical techniques discussed previously and exploiting a new method for BC measurements in small volumes of water, McConnell et al. (2007) developed a 1788–2002, monthly resolved record of BC concentration and deposition for a Greenland ice core site spanning recent centuries. Together with associated chemical source tracers, these records indicate that human activities such as fossil fuel combustion have had a marked impact on BC and other aerosols in the Greenland Arctic for the past 130 years.

Initial results of incorporating these data into GCMs suggest that changes in late 19th and early 20th century BC significantly altered Arctic climate forcing (McConnell et al., 2007). Greenland ice core records reflect a marked decrease in industrial BC emissions in North America and Western Europe from the mid-to-late 20th century (Fig. 1) as a result of improved burning technology, better pollution controls, and shifts in fuel sources away from coal (Bond et al., 2007). Because ice core BC records extend only into the 1990s or early 2000s and all are located in the western Arctic, the impact of dramatic recent increases in coal burning and emissions in Asia is unclear. Moreover, these historical BC records are from cores collected at higher elevation sites outside of the restricted atmospheric circulation associated with the Arctic polar dome (Law and Stohl, 2007) and so may reflect a different aerosol history than at lower elevations.

To provide the best scientific underpinning for climate policy, there is clearly a need for the following:

- Exploring source tracers for BC and other Arctic aerosols with a focus on continuous analytical methods.
- Increasing the number of aerosol records from Arctic sites to fully define variability from the pre-industrial to present (priorities include the eastern Arctic to the north of areas of wildfire and industrial emissions in Eurasia).

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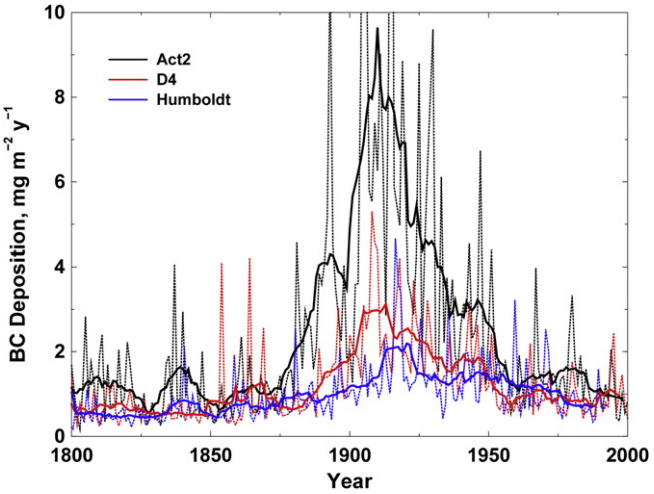


**Fig. 1.** Deposition of BC from 1800 to 2000 along a >1400 km N–S transect of Greenland. Shown are annual (dotted) and decadal (solid) averages of more than 50 measurements per year at the Act2 (66.0°N, 45.2°W) (McConnell and Edwards, 2008), D4 (71.4°N, 43.9°W) (McConnell et al., 2007), and Humboldt (78.5°N, 56.8°W) ice core sites. Industrial emissions in the late 19th and early 20th centuries resulted in pronounced increases in BC deposition at all sites, but increases were far larger in southern Greenland closer to North American and Western European emission sources.

- Comparing methods and coordinating BC and other aerosol measurement programs in snow and ice to ensure compatibility.
- Comparing time and space specific GCM-simulated concentrations and fluxes of aerosols and measurements at high-northern-latitude ice core sites to understand transport pathways and attribute aerosols deposited throughout the Arctic to specific sources and source regions.

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