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Evidence of the Kuwaiti oil fires in the Dasuopu glacier ice core, central Himalaya

During the Persian Gulf War in 1990–91, more than 740 oil wells in Kuwait were sabotaged (Ferek and others, 1992), and more than 600 wells were set afire. The world, and in particular the Middle East, was left with one of the largest man-made environmental disasters, producing a pronounced impact on regional and global climate and environment (Bakan and others, 1991). Oil fire products during the Persian Gulf War migrated over the Northern Hemisphere. The smoke aerosol from long-range transport of Kuwaiti oil fires was observed in Japan (Okada and others, 1992), Pakistan (Limaye and others, 1991), Hawaii (Lowenthal and others, 1992), as well as Wyoming in the U.S.A. (Deshler and Hofmann, 1992).

In summer 1997, a 15 m ice core, covering the period 1988–97, was collected from 7000 m a.s.l. on a relatively flat portion of Dasuopu glacier (28°23′ N, 85°44′ E) on the northwest margin of Mount Xixiabangma in the central Himalaya. Detailed methods of ice-core sampling and chemical analysis are described by Kang and others (2000), along with a discussion of monsoon and dust signals in the core. Profiles of $\delta^{18}O$ and major-ion (Ca^{2+}, NO_3^- and SO_4^{2-}) concentrations against water-equivalent depth are shown in Figure 1. In general, variations of SO_4^{2-} are in agreement with those of Ca^{2+} and NO_3^- in the ice core, mainly reflecting dust input from central Asia (Kang and others, 2000). The highest SO_4^{2-} concentration, 730.7 ppb (marked by an arrow in Figure 1), in the core is recorded during early 1991. The lowest SO_4^{2-} concentration is 6.1 ppb, and mean SO_4^{2-} is 122.9 ppb (std dev. 132.2). Ca^{2+} and NO_3^- concentrations during early 1991 do not have anomalous peaks. Thus, the 1991 SO_4^{2-} is unique and appears not to be related to dust deposition.

In June 1991, the explosive eruption of Mount Pinatubo, Philippines, injected an estimated $(18 \pm 2) \times 10^6$ t of SO_2 directly into the atmosphere (Krueger and others, 1995). The volcanic aerosol mass was dispersed gradually in the global atmosphere, covering the entire Earth by mid-1992 (Hitchman and others, 1995). Pinatubo volcanic signals were identified in South Pole snow, which occurred from early or mid-1992 to mid-1994 (Cole-Dai and Mosley-Thompson, 1999). Though we cannot confirm when volcanic aerosol was transported to the Dasuopu core site, it was probably later than June 1991. However, the highest SO_4^{2-} value in the Dasuopu core is recorded in early 1991 (Fig. 1). Thus, we consider that the 1991 spike of SO_4^{2-} concentration is not related to the Pinatubo eruption.

We assume that the SO_4^{2-} peak in 1991 in the Dasuopu ice core is related to the Kuwaiti oil fire products during the Persian Gulf War. Firstly, the Kuwaiti oil wells were set afire

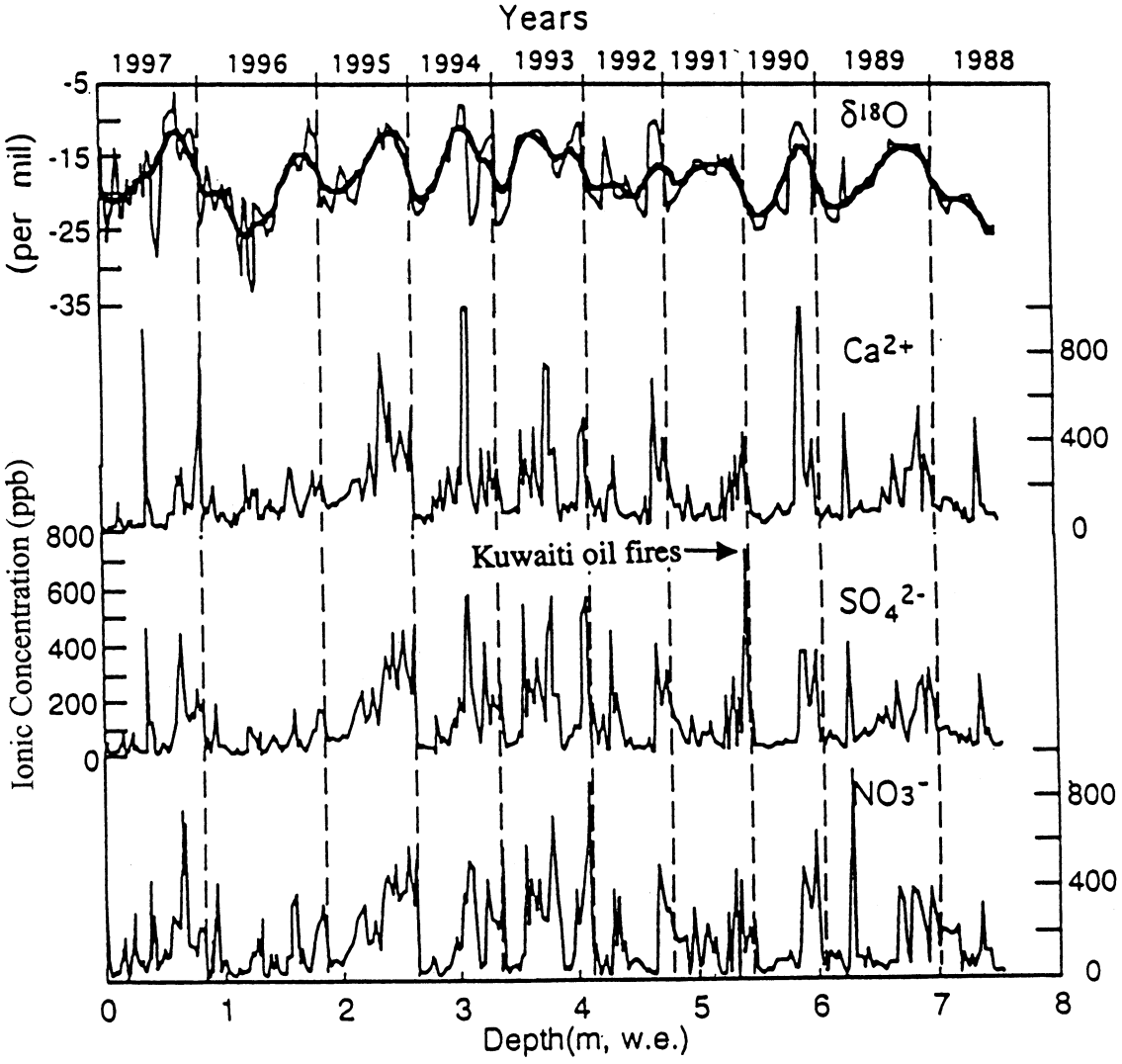

Fig. 1. Depth profiles of $\delta^{18}O$ and ionic concentrations with depth (water equivalent) in the Dasuopu ice core. Dating was performed by counting seasonal peaks of $\delta^{18}O$ and major ions. The coarse solid line is a weighted smoothing (5 points smoothing). Dashed lines indicate annual layers.

in early 1991 (Ferek and others, 1992) and the aerosol smoke from oil fires was transported to the Himalayan region by a southern westerly jet, which only took 1–2 days (Bodhaine and others, 1992). Secondly, measurements of organic matter in the same core indicate that concentrations of some organic compounds from petroleum residues were higher during 1988–92 than in 1997 (Xie and others, 2000). Thirdly, chemical analysis of smoke plumes from the Kuwaiti oil fires shows that SO_2 concentrations are 1–2 orders of magnitude higher than NO_x, and SO_4^{2-} is the dominant species among major ions in smoke plumes (Ferek and others, 1992). These points suggest that pollutants from Kuwaiti oil fires were transported to Dasuopu glacier by the westerly jet and recorded in snow at 7000 m a.s.l. in the Himalaya. Thus, ice-core records from the Himalaya provide a unique opportunity to recover pollutant signals and reconstruct environmental changes in the past.

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