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Spatial and seasonal variation of major ions in Himalayan snow and ice: A source consideration

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ABSTRACT

The spatial and temporal variation of major ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, NH_4^{+}, SO_4^{2-}, NO_3^{-} and Cl^{-}) in Himalayan snow and ice is investigated by using two snow pits from the East Rongbuk glacier (28°01′N, 86°58′E, 6500 m a.s.l.), one snow pit from the Nangpai Gosum glacier (28°03′N, 86°39′E, 5700 m a.s.l.), one snow pit from the Gyabrag glacier (28°11′N, 86°38′E, 6303 m a.s.l.), and three ice cores from the Sentik (35°59′N, 75°58′E, 4908 m a.s.l.), Dasuopu (28°33′N, 85°44′E, 7000 m a.s.l.), and East Rongbuk (27°59′N, 86°55′E, 6450 m a.s.l.) glaciers, respectively. In general, the major ions show a significant seasonal variation, with high concentrations during the non-monsoon (pre-monsoon and post-monsoon) season and relatively low concentrations during the monsoon season. Monsoon precipitation with high local/regional dust loading related to summer circulation is possibly responsible for the high concentrations occurring sporadically during the monsoon season. The crest of the Himalayas is an effective barrier to the spatial distribution of Na^{+}, Cl^{-} and NH_4^{+} concentrations, but not to the major ions associated with dust influx (e.g. Ca^{2+} and Mg^{2+}). Atmospheric backward trajectories from the HYSPLIT_4 model used in identifying chemical species sourcing suggest that the major ions in the Himalayan snow and ice come mainly from the Thar Desert located in the North India, as well as West Asia, or even the distant Sahara Desert in the North Africa during the winter and spring seasons. This is different from the conventionally assumed arid and semi-arid regions of the central Asia. Factors, such as different vapor sources due to atmospheric circulation patterns and geographical features (e.g. altitude, topography), may contribute to the differences in major ionic concentrations between the western and eastern Himalayas.

1. Introduction

The Himalayas, situated along the southern margin of the Tibetan Plateau, is about 2400 km from west to east and 200–300 km from south to north, with a mean elevation of about 6000 m. It is regarded as a spontaneous barrier for the vapor transported from the Indian Ocean to the hinterland of the Tibetan Plateau. During summer, low pressure over the surface of the Tibetan Plateau (i.e. Tibetan Low) induces a supply of moist and warm air from the Indian Ocean to the continent (summer monsoon), meanwhile, in the upper troposphere, the Southern Asian High center over the Tibetan Plateau drives air masses off the plateau (Wu and Zhang, 1998; Li, 2002). In winter, high pressure (i.e. Tibetan High) drives cold and dry air off the plateau in the lower troposphere (winter monsoon) (Bryson, 1986; Tang, 1998), while subtropical jet streams bifurcate through the south and north plateau in the middle and upper troposphere. During summer, precipitation in the Himalayan region is caused mainly by moisture transported by the Indian monsoon and/or by local moisture from short distance convective air mass transport, and moisture is transported by the westerly system during winter and spring (October to May) (Stravisi et al., 1998; Thompson et al., 2000).

Studies of glaciochemistry in Himalayan snow and ice provide a valuable record of atmospheric circulation (Qin et al., 2000; Kang et al., 2002), and allow evaluation of past climate change (Thompson et al., 2000; Hou et al., 2003). Studies carried out in the central Himalayas devoted to defining the spatial and temporal distribution in snow and ice chemistry, indicate that variations in chemical components are strongly influenced by seasonality rather than geographical locations (Marinoni et al., 2001; Kang et al., 2000, 2002; Balerna et al., 2003). It is suggested that, over the Tibetan Plateau, snow and ice chemistry is dominated by desert dust coming from the wide arid regions of central Asia (Mayewski et al., 1986; Wake et al., 1990; Williams et al., 1992). Here we synthesize our own data, together with the published results (Table 1) to expand the knowledge of the spatial and temporal characterization of the snow and ice chemistry in the high Himalayan regions and apply the HYSPLIT_4 model to identify new potential source regions for major ions in Himalayan snow and ice.

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Table 1
Snow pits and ice cores details.

	Glacier	Snow/ice	Sampling year	Latitude (N)	Longitude (E)	Altitude (m)	Source
	Sentik	Ice core	1980	35°59′	75°58	4908	Mayewski et al. (1984)
	Dasuopu	Ice core	1997	28°33′	85°44′	7000	Kang et al. (2000)
	East Rongbuk	Ice core	1998	27°59′	86°55′	6450	Qin et al. (2002)
	Baishui No. 1	Ice core	1999	27°07′	100°12′	4955	He et al. (2002)
Cho Oyul	Nangpai Gosum	Snow pit	1998	28°03′	86°39′	5700	This work
Cho Oyu2	Gyabrag	Snow pit	2005	28°11′	86°38′	6303	This work
ER1	East Rongbuk	Snow pit	1998	28°01′	86°58′	6500	Zhang et al. (2002)
ER2	East Rongbuk	Snow pit	2002	28°01′	86°58′	6500	This work

2. Materials and methods

During the past decades, studies of snow and ice chemistry in the high Himalayas have been undertaken despite great logistical and health challenges. Up to now, available chemical data are from both the southern and northern slopes along the west–east transect of Himalayas (Mayewski et al., 1984; Valsecchi et al., 1999; Marinoni et al., 2001; Shrestha et al., 2002; Kang et al., 2002; Qin et al., 2002; Zhang et al., 2002; Balerna et al., 2003). In 1980, a 16.6 m shallow ice core was recovered at an elevation of 4908 m on a relatively flat, single-flow portion of a 3 km long alpine glacier, Sentik Glacier (35°59′N, 75°58′E; Fig. 1, point A), which flows north-east off the Nun Kun massif in the Ladakh Himalayas, India (Mayewski et al., 1984). In September 1997, a 15 m firn core was recovered at an elevation of 7000 m on a platform of the Dasuopu Glacier (28°33′N, 85°44′E; Fig. 1, point B) nearby Mt. Xixabangma (Kang et al., 2000). In September 1998, a 2.26 m snow pit (Cho Oyu1) from the Nangpai Gosum Glacier (28°03′N, 86°39′E; Fig. 1, point C) on the southern slope of the Mt. Cho Oyu, Nepal Himalayas at an elevation of 5700 m was sampled roughly at 4 cm intervals. In October 2005, nine samples were sampled in a 0.87 m snow pit (Cho Oyu2) at an elevation of 6303 m from the Gyabrag glacier (28°11′N, 86°38′E) on the northern slope of the Mt. Cho Oyu. In September 1998, a 2.0 m snow pit (ER1) was sampled at 5 cm intervals from the East Rongbuk Glacier (28°01′N, 86°58′E; Fig. 1, point D) on the northern slope of the Mt. Qomolangma (Everest) at an elevation of 6500 m (Zhang et al., 2002). Another 2.68 m snow pit (ER2) was sampled at the same place as the ER1 snow pit in October 2002. For the ER2 snow pit, the upper 30 samples were sampled at 5 cm intervals and the lower 18 samples were sampled at 7 cm intervals. In addition, an 80.4 m ice core was recovered from the East Rongbuk Glacier (27°59′N, 86°55′E) at an elevation of 6450 m in August 1998. The Cho Oyu1 snow pit and the Sentik shallow ice core are from the southern slope of Himalayas, while all the others are from the northern slope of Himalayas. For a better understanding of the spatial distribution of ice chemistry between the eastern and western Himalayas, we include the Baishui No. 1 firn core (27°07′N, 100°12′E; Fig. 1, point E) for a comparison with the Himalayan snow pits and ice cores. The Baishui No. 1 firn core was drilled at an elevation of 4955 m in June 1999, nearby Mt. Yulong of the Hengduan Mountains (He et al., 2002).

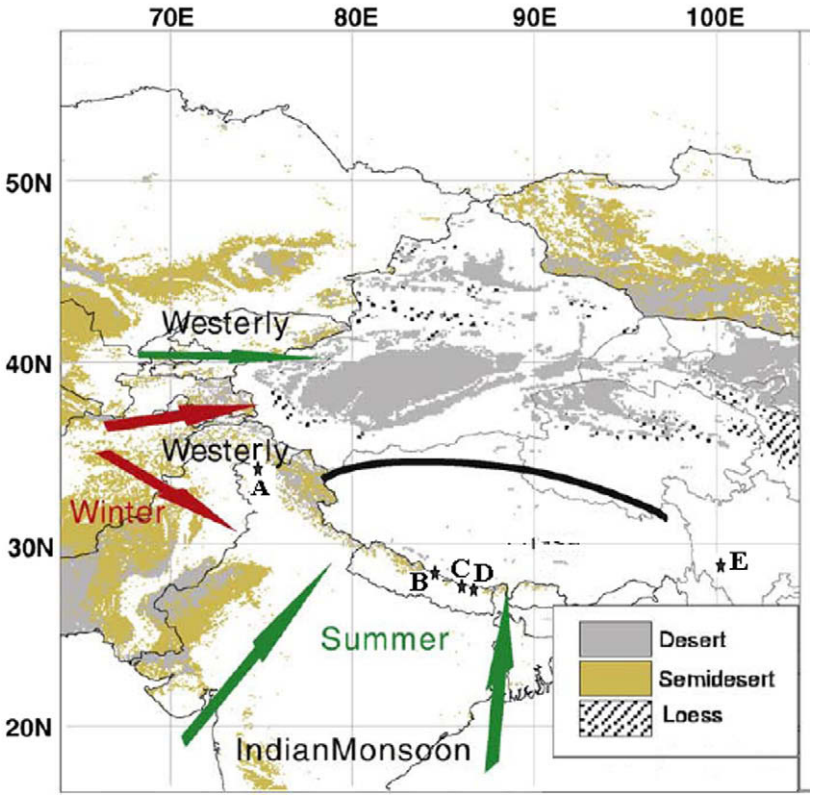

Fig. 1. Location map of sites for snow pits and ice cores in the Himalayas. A: Sentik ice core; B: Dasuopu ice core; C: Cho Oyu snow pits; D: East Rongbuk Glacier snow pits and ice core; and E: Baishui No. 1 glacier ice core.