SHORT COMMUNICATIONS

CLIMATIC SIGNIFICANCE OF D/H RATIOS OF A TEMPERATE GLACIER IN SIKKIM

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THE stable isotope ratios of hydrogen and oxygen (δD and $\delta^{18}O$ respectively) of precipitation are linearly related to the air temperature at the site of precipitation[1]. As the accumulation zones of glaciers preserve the yearly precipitation in the form of annual layers of ice, vertical profiles of δD and $\delta^{18}O$ of ice in well-dated cores from glaciers could aid in reconstructing the past temperature history of regions where instrumental records of climate are not available. Whereas stable isotope studies in polar glaciers[2] have yielded paleoclimatic information for the past several millenia, such studies on temperate glaciers have not received adequate attention for the following reasons. First, the ice at the base of a temperate glacier is relatively young, even under favourable conditions dating back to a maximum of only 2000 years[3]. Second, the processes of melting and percolation down the ice obliterate seasonal cycles (present in the original precipitation) in the ice column. Finally, snow-drifting, evaporation and sublimation processes may alter the original isotopic composition of the ice[4]. Despite such complications certain temperate glaciers are known to preserve the climatic history of the region in their δD and $\delta^{18}O$ contents[5]. Very few stable isotope studies have been reported[6–7] for the Himalayan region, rich in glaciers. Here we present the δD measurements on a temperate glacier in Sikkim and discuss the climatic implications.

Changme-Khangpu is a glacier, 5–6 km long, 0.88 km wide at its maximum, situated at an altitude of 4800–5500 m in the north Sikkim valley (27°58′N, 88°42′E). During the 1981 expedition 32 samples (each representing a depth of 30 cm) were collected from an ice face in a crevasse in the accumulation zone (5250 m above sea level). This profile covers 9.6 m from the surface. Two samples were lost (4.2 m to 4.8 m) in the transit. Each sample was analyzed for bomb-produced ^{137}Cs and ^{210}Pb isotopes. Correlating their concentrations with the dates of Chinese nuclear tests; the ice core has been dated[8]. The mean accumulation rate was estimated to be ~0.7 m/yr.

About 10 ml of water from each sample was passed through uranium filings kept at 800°C and quantitatively reduced to hydrogen[9]. The gas was then analyzed in a mass spectrometer (VG Micromass 602D) and the D/H ratio was measured as δD and expressed in parts per thousand (‰) relative to the international standard[10], SMOW. The data are shown in figure 1, as a function of depth (and time).

Since the peaks of ^{210}Pb and ^{137}Cs are distinct and are correlatable with the Chinese nuclear explosions[8], it appears that melting and percolation of melt water have not caused any significant homogenization of the ice profile. The reason for the conspicuous absence of seasonal cycles in the annual ice layers could be the following. About 85% of precipitation in this region falls during the monsoon season[11] (summer) and only 1% during winter. Therefore the mean isotopic composition of precipitation might resemble more closely to that of the summer (June–September) precipitation than the winter (December–February) precipitation. Thus it appears reasonable to believe that the absence of seasonal cycles in the annual layers of the glacier ice is not an artifact of melting and percolation of melt waters (particulary when the sampling was done on the crevasse) but is due to the nonuniform seasonal distribution of precipitation, which peaks in the summer months. This may not be true for glaciers in the western Himalayas, where significant winter contribution to precipitation is made by the western disturbances[12].

Though the isotopic homogenization of the ice column is unlikely, it is not necessarily true that the isotopic composition of an annual ice layer is identical to that of the corresponding precipitation. This is because, though located at a very high altitude, the glacier is subjected to intense sunshine during the summer, which causes a partial melting and sublimation of the surface snow. This molten snow runs off and only part of the yearly precipitation is preserved in the annual layer. This causes a considerable heavy isotopic enrichment in the remaining snow. Fresh precipitation in the accumulation zone of Changme-Khangpu in 1981 was found[7] to have a $\delta^{18}O$ value of -19 ± 2‰. The corresponding δD would be[9] ~ -142‰. But the ice preserved in the top layer has a

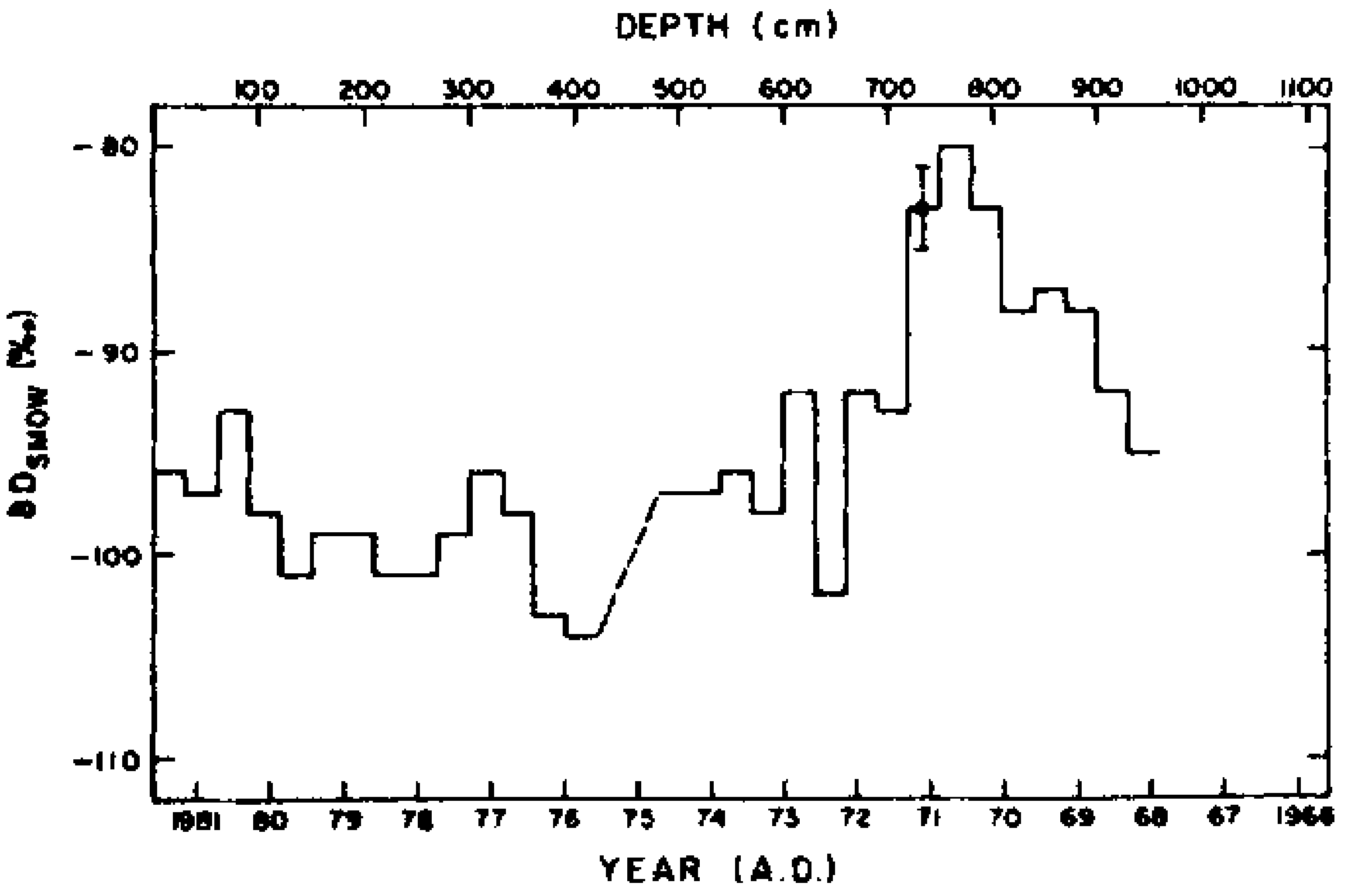

Figure 1. δD values of ice samples as a function of depth (and time) in the Changme-Khangpu glacier, Sikkim.

δD value ~ −96‰. This enrichment of δD (~46‰) corresponds to ~25% run-off[6], i.e. only 75% of the annual precipitation is preserved in the glacier. This run-off varies from year to year depending on the ambient climate. This isotopic enrichment, fortunately, may not hinder the climatic interpretation of the δD and $\delta^{18}O$ of the glacier ice because the enrichment of δ values in the precipitation due to the higher ambient temperature and the enrichment in the ice layer due to sublimation and partial melting (with increased ambient temperature) are in the same direction[6]. It may therefore be useful to compare the δD data with instrumental weather data. However, several complications arise. First, our assumption of a uniform deposition rate is not valid. The amount of ice preserved in an annual layer depends on the annual precipitation, which varies from year to year. Furthermore, depending on the ambient weather conditions like temperature, sunshine and wind velocity, the amount of run-off varies too. The dating based on nuclear debris is not accurate because there may be some time-lag between the nuclear test and the deposition of the debris in the glacier. This depends on the month when the test was conducted and the prevailing atmospheric circulation pattern. Thus, assigning a unique year to a particular ice layer and hence the comparison of the data with meteorological records are made difficult. Second, the nearest meteorological observatory (Shillong) for which some data are available, is situated more than 400 km away (25°57′N, 91°88′E) and at a different altitude (1598 m above sea level). Even here, the data on δD of precipitation and temperature are not continuous[11]. Thus, it is virtually impossible to compare our data with instrumental records. Nevertheless, our data can be interpreted qualitatively. From 1971 to 1981, the δD of the annual ice layers has remained more or less at a constant value of ~ −98‰. But from 1968 to 1971, δD values are higher in general by about 10‰. This indicates that this period was relatively warmer by about 2°C. This inference must be viewed with caution since the dating is only tentative, as explained above.

To summarize, it appears possible to infer qualitative climatic changes from temperate glaciers despite the complications of partial melting of the surface snow layers. Longer cores from Himalayan glaciers with better dating methods could help build a short term palaeoclimatic picture for this region. Useful estmates on the run-off ratio could also be made. Stable isotope studies on tree rings, the only other system which records annual changes in climate, suffer from several complications[13]. In this context, such studies on temperate glaciers, coupled with accurate dating can yield useful complementary information.

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LOW-LEVEL WINDS OVER THE WESTERN INDIAN OCEAN AS OBSERVED BY INDIAN OCEAN SATELLITE (GOES) DURING THE SUMMER MONEX OF 1979

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DURING the months of northern summer, sea-level pressure continuously increases from a heat low over Southern Asia to a subtropical high pressure ridge of the southern hemisphere. This pressure distribution results in a buffer zone straddling the equator between southeast trade-winds and southwest monsoon winds. Thus, the low-level air current circulating over the western Indian ocean is characterized by three different winds: (1) Southwesterly monsoonal flow over the Arabian sea, (2) Cross-equatorial flow along the Somali coast and adjoining ocean and (3) Southeasterly flow in the southern hemisphere. This strong low-level air current, known as Somali jet, however, is a major component of the Asian summer monsoon. The jet originates in the southern hemisphere in the region of small islands near Mauritius. It then penetrates across the northern tip of Madagascar, flat eastern Kenya, Ethiopia, Somalia, Arabian sea and thence flows towards the Indian peninsula. Moisture-laden air current in low-level flows directly over the Indian peninsula during the southwest monsoon season. The southeast trades over the South Indian ocean are deflected by the Coriolis force after crossing the equator to reach the Indian subcontinent as a southwesterly flow. The cross-equatorial flow is not uniform at all longitudes. It is weak over the eastern Indian ocean (east of 60°E) and strong over the western Indian ocean (west of 60°E), particularly along the east African coast. The major low-level current, most pronounced at a height of 1–1.5 km with speeds reaching $\sim 30\ \mathrm{m\,sec^{-1}}$ is one of the most intriguing phenomena of the monsoon system[1]. A correlation has been found between the strength of cross-equatorial flow over Kenya and the amount of rainfall along western coast of India[2]. However, this question deserves careful consideration[3]. It has been observed that the intensity of cross-equatorial flow is greater in good monsoon years than in bad monsoon years[4]. The low-level strong current is forced by low-level divergence in the subtropical high pressure belt (the Mascarene high) and the zone of continental low pressure (the monsoon trough) over northern India[5, 6]. It is seen that wind discontinuity found to the east of Madagascar during eastward propagation of midlatitude depression in the southern hemisphere may be related to the weakening of low-level jet[7].

Use of low-level winds based on the cloud motion vectors in weather analysis has become a regular feature over the Pacific and Atlantic oceans where the geostationary satellites are located. During FGGE year 1979, Indian ocean geostationary satellite (GOES) belonging to the United States was specially brought to a new location (60°E) over the Indian ocean for the benefit of Monex. This gave researchers their first opportunity to view the monsoon circulation over the Indian ocean. This provided exceptional coverage of cloud wind tracers, particularly during summer monsoon months of May–July. GOES measurements are ideal because they possess both high spatial and high temporal resolution (1 km in visible, 8 km in infrared and half-hourly sampling frequency). GOES produces images of the earth and its cloud cover in the spectral bands 0.5–0.9 μm (visible) and 11–12 μm (infrared) respectively. Estimates of low-level wind fields deduced from cloud motions were extracted in LMD (Laboratoire de Meteorologie Dynamique)[8].

Had the satellite been in perfect geostationary orbit, the sequence of images would have shown true cloud motions. Since the orbits are not perfect, the sequence shows apparent motion of earth due to the motion of space craft. The orbit inclination, inclination of spin axis of the satellite relative to the spin axis of the earth and improper alignment of camera axis with the satellite axis all cause image motion and it must be corrected before cloud tracking operations. The basic concept behind cloud drift wind is that some clouds are passive tracers of air motion in the vicinity of clouds. The growth and decay of clouds are related to their size and lifetime which contribute random errors to cloud tracked winds.

GOES satellite imagery of 14 June (figure 1) shows the monsoon cloud cover over the Arabian sea. The low-level clouds are not seen along northern Somalia