

STUDIES ON CLIMATE
AND THE GLACIAL SYSTEM,
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ABSTRACT: Investigations of the glacial system in Mt. Yulong, Lijiang, China, where is controlled by the south-western monsoon climate, have been carried out since 1999, with the following achievements. (1) The climatic records in a 10.10 meter long firn core indicate that the amplitude of isotopic variations in the profile decreased with increasing depth, and isotopic homogenization occurred below 7.8 meters as a result of meltwater percolation. Variations of $\delta^{18}\text{O}$ above 7.8 meters showed an approximate correlation with the winter climatic trend at Lijiang station, 25 kilometers away. Concentrations of Ca^{2+} and Mg^{2+} were much higher than those of Na^{+} and K^{+} , indicating that the air masses for precipitation were mainly from a continental source, and that the core material accumulated during the winter period; (2) Investigations of the spatial variations of oxygen isotopes in the atmosphere-glacier-river system confirm that there is an apparent inverse relation between the oxygen isotopic composition of precipitation and air temperature/precipitation amount in this region, with lower $\delta^{18}\text{O}$ values when the amount of precipitation and air temperature in summer is higher, due to the influence of intense summer monsoons in the study area. There are marked differences of the $\delta^{18}\text{O}$ values of winter-accumulated snow, glacial meltwater, summer precipitation and the glacier-fed river water. Spatial and temporal variations of isotopic composition are controlled by varied weather conditions at different altitudes; (3) Glaciers have greatly retreated after the Little Ice Age because of climate warming. The recent 50-year climate data at Lijiang, the closest meteorological station to Mt. Yulong, indicate that there are 2 to 3 year periodic changes for the local temperature and apparent 11 to 12 year periodic cycles for precipitation, showing a corresponding pattern with that in the northeastern part of India. During the most recent half-century, glaciers in Mt. Yulong have alternately retreated and advanced, with smaller amplitudes. Those glaciers on Mt. Yulong with the lowest latitude and smallest area have reduced in size by 60 percent from the Little Ice Age to the present (He et al, 2003a). It is evident that there is a close relation between the atmospheric temperature and glacier retreat at Mt. Yulong. Therefore we conclude that global warming is the major and most important reason for glacier retreat in the Lijiang-Mt. Yulong region.

Keywords: climate change, glaciers, China

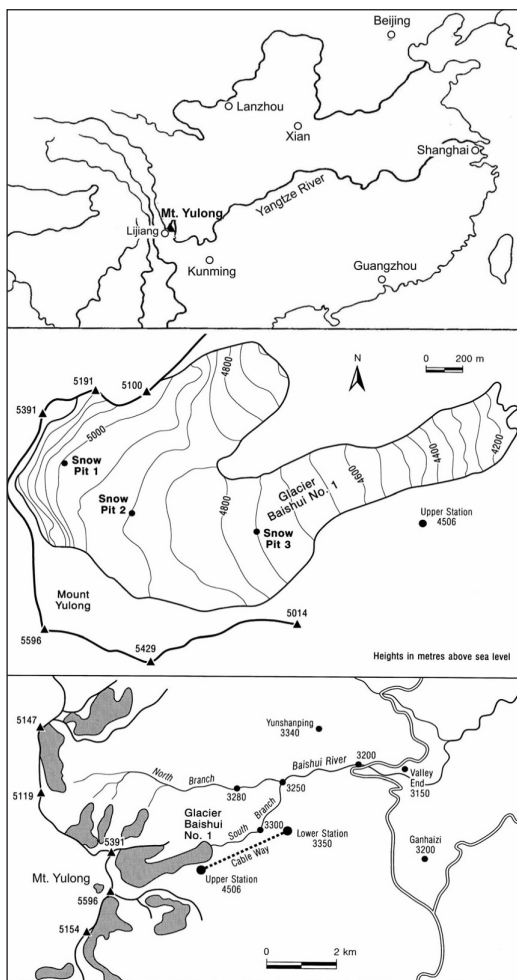
1. Introduction

Mt. Yulong, located in the Hengduan Mountain Range (southeastern edge of the Tibetan Plateau), north of Lijiang, Yunnan Province, China ($27^{\circ}10' - 27^{\circ}40'N$; $100^{\circ}07'E - 100^{\circ}10'E$), is the southernmost glacierized area in Eurasia (see Figure 1). The climate of the high altitude area (above 4100 meters) on Mt. Yulong, which is controlled by the South-Asia/Indian monsoon, has provided the cold, moist conditions necessary for glacier development. The 19 glaciers on Mt. Yulong cover 11.61 square kilometers. Their high accumulation and ablation, high temperatures, basal sliding and rapid movement are typical of sub-tropical temperate- glaciers (Li and Su, 1996). The largest glacier, Baishui No.1, has an area of 1.52 square kilometers and is 2.7 kilometers long (see Figure 1). Its broad, flat accumulation area covers about 1.0 square kilometers between 4800 and 5000 meters. The glacier terminates at about 4150 meters. Its tongue is heavily crevassed, reflecting very active motion. Glacial meltwater flows to the Baishui River, within the upper Yangtse River basin.

FIGURE 1

Location of Baishui Glacier

The sketch map indicating the location of Mt. Yulong in southeastern Asia (top), the glacier Baishui No. 1, with the of locations of snow pits used in 2000 (middle), and the area around Mt. Yulong, with precipitation and river water sampling sites (bottom).



Mt. Yulong, with a highest peak, Satseto, of 5596 meters, is in the subtropical zone. 70 percent of the region's precipitation falls between June and September from the warm, moisture-rich air masses of the prevailing southwestern summer monsoon from the Indian Ocean. In the winter, the climate is relatively dry, controlled by the winter monsoon of closer continental origin. The multi-year mean annual precipitation at Lijiang meteorological station (2393 meters) is 772 millimeters, and the four-year average at the mountain foot (3240 meters) is 1646 millimeters (Su and Pu, 1996). An ice core acquired in 1999 at around 4950 meters indicated a four-year mean annual net accumulation of 900 millimeters water equivalent (He et al., 2001). Because the measured net accumulation is the only data obtained in relation to the atmospheric precipitation above 4800 meters in Mt. Yulong, it is assumed to represent an "average" rate in the glacier's accumulation area although it might be different in other sites. Using the mean net accumulation rate recovered in the core, together with the ablation rates measured by Su and Wang (1996), the mean annual precipitation amount in the accumulation area (above 4800 meters) of the glacier is roughly estimated in a range of 2400-3100 millimeters (He et al., 2001). However, the precipitation in the glacier's ablation area between 4150 and 4800 meters is still unknown.

The mean annual temperature at Lijiang is 12.6 degrees Celsius, with a positive mean temperature in every month. At 5400 meters, the mean annual temperature is about -7.5 degrees Celsius, and all monthly mean temperatures are below 0 degrees Celsius. The mean annual temperature above the equilibrium line (4800-5000 meters) is -3.3 to 4.7 degrees Celsius (Wang, 1996). This suggests an adiabatic lapse rate of about 0.7 degrees Celsius/100 meters, which is higher than that for a pure maritime area because Mt. Yulong is distant from India Ocean, under the monsoon climate of wetter summer but drier winter. Since 1999, studies in relation to the climatic records in a shallow ice core, environmental signals in the atmosphere-glacier-river system, and glacial variations in the 20th century have been conducted (He et al, 2000abc, 2001, 2002ab, 2003ab). The results of these scientific investigations are reviewed and summarized in this paper.

2. Climatic Records in a Shallow Ice Core

In July of 1999, a 10.10 meter long core was drilled at 4950 meters in the accumulation area of the glacier Baishui No. 1, using a US-made PICO corer. 101 samples, each 0.1 meters long, were collected for isotopic and ionic

analysis. Five net accumulation layers could be identified from the periodic variations of the $\delta^{18}\text{O}$ values in the core, with their abrupt changes between higher and lower values. These were at depths of 0-2.0 meters, 2.0-3.2 meters, 3.2-5.0 meters, 5.0-6.5 meters and 6.5-7.8 meters, corresponding to the balance years 1998/99, 1997/98, 1996/97, 1995/96 and 1994/95, respectively. The variations of $\delta^{18}\text{O}$ values within an annual layer represent air temperature trends during precipitation events. The decreasing amplitude between the surface and 7.8 meters, and smoothed values below 7.8 meters, reflect a gradual homogenization process caused by meltwater percolation. $\delta^{18}\text{O}$ values between the surface and 7.8 meters are roughly correlated with the variations of temperature and precipitation at Lijiang station during the winter months between the balance years of 1998/99 and 1994/95 (see Figure 2). Below 7.8 meters, however, the climatic signals are smoothed as a result of a slowly occurring homogenization process because the glacier at Mt. Yulong is a high-melting temperate glacier. The correspondence between cationic

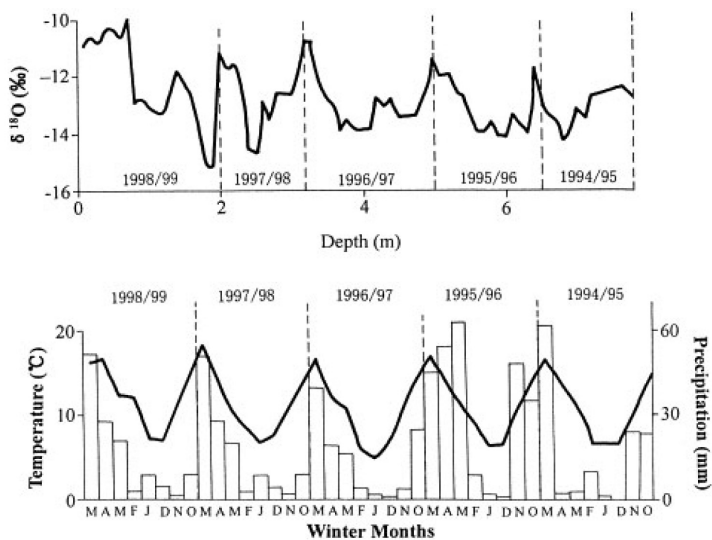


FIGURE 2

Isotopic variations above the depth of 7.8 meters in the core collected in 1999 (top) and the mean temperature and total precipitation at Lijiang meteorological station during the winter months of the balance years 1994/95 to 1998/99 (bottom).

concentrations and the isotopic profile is pronounced. Peak values of cationic content appear at the depths of identified summer surfaces and the positions of thick dirty ice layers.

There is a significant relationship between Cl^- and Na^+ and the correlation coefficient between the two ions for 101 samples is 0.53 (see Figure 3), indicating their common source. The ratios of Na^+/Cl^- are also calculated and plotted. Gradually reduced variation amplitude of the ratios, corresponding to those of $\delta^{18}\text{O}$ and other ions, further indicates a progressive effect of meltwater percolation and the homogenization process in the core. Concentrations of Ca^{2+} and Mg^{2+} are much higher than that of Na^+ . This reflects the fact that more of the impurities in the core came from a continental source rather than from a marine one. Most materials in the core are believed to be deposited during the winter season, between October and May. Winter air masses, forced

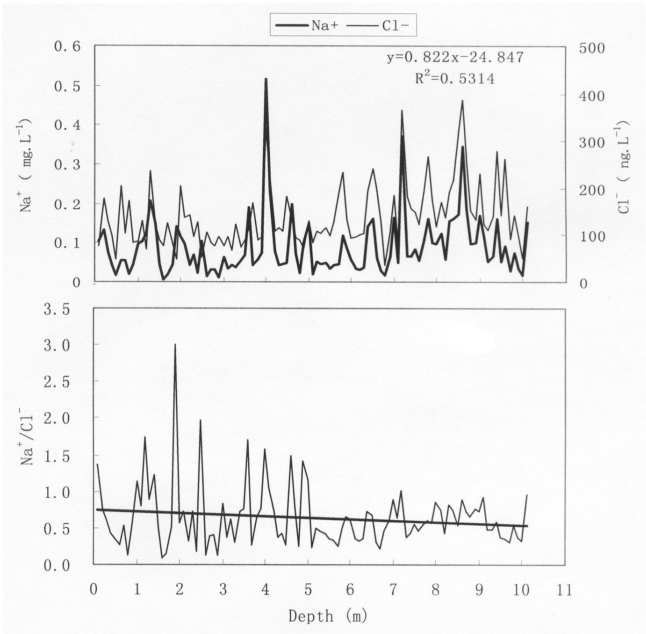


FIGURE 3 The relationship between Cl^- and Na^+ and variation of Na^+/Cl^- ratios in the core from the glacier Baishui No.1 indicates their common source.

upwards by the blocking mountain, carry more land-surface impurities, resulting in the higher concentrations of Ca^{2+} and Mg^{2+} because of the positive mean air temperature in the study area between July and September.

3. Environmental Signals in the Atmosphere-Glacier-River System

Stable isotopes and ions are useful tracers in glaciological and hydrological research (Dansgaard, 1964; Moser and Stichler, 1980). In July 1999, samples of recently deposited snow, summer rain, supraglacial and subglacial meltwater were collected from the glacier Baishui No.1, and river water samples were collected from the glacier-fed Baishui River. The samples were collected at the field sampling sites (see Figure 1). The analyzed results are shown in Figures 4 and 5.

The high-altitude winter deposited snow samples were more enriched in the heavy isotope than any other samples, such as recently deposited (one month) snow and summer rain obtained during the 1999 study. The general increase of $\delta^{18}\text{O}$ values with altitude (see Figure 4) indicates an irregular and varied spatial pattern, in contrast with the situation in the northern part of the Tibetan plateau (Yao et al., 1991), in this monsoon-dominated region.

Four samples of summer rainfall were collected at the Baishui No. 1 glacier during a single precipitation event in July 1999. There was a trend of increasing $\delta^{18}\text{O}$ values with decreasing elevation (see Figure 4), but the range was low (1.23‰). $\delta^{18}\text{O}$ values of precipitation samples collected during a single event may differ, and their average value, which depends strongly on the meteorological situation at different altitudes of the air in which it is produced and through which it falls (Rozanski et al., 1993). Accordingly, the slight differences of $\delta^{18}\text{O}$ values in this single summer rain event are caused by the different climatic conditions at varied elevations. Decreasing $\delta^{18}\text{O}$ values with altitude rising corresponds to increasing of precipitation amount and decreasing of temperature with increasing altitude, indicating a complicated isotopic variation during the course of the single precipitation.

Eight meltwater samples were collected in the glacier's ablation area. Their $\delta^{18}\text{O}$ values tended to increase with decreasing altitude, but the range was small (0.80‰). In general, the samples were less depleted of ^{18}O than were the rainfall samples (see Figure 4). The $\delta^{18}\text{O}$ values of the samples from the Baishui

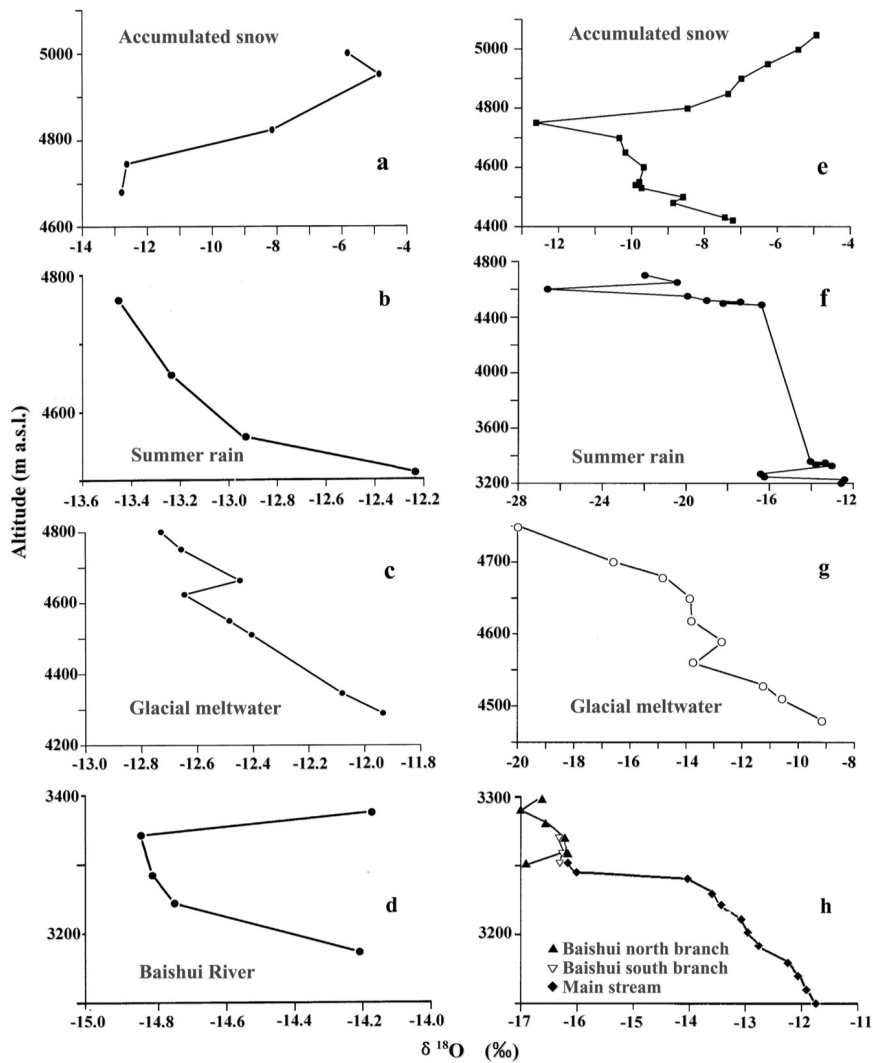


FIGURE 4

Altitudinal variations of $\delta^{18}\text{O}$ values in accumulated snow, summer rainfall and glacial meltwater at the glacier Baishui No.1, and in glacier-fed river water, July 1999 and July 2000.

River varied only slightly from a mean of 14.56‰, suggesting that glacial meltwater was mixed with water that was more depleted of the heavy isotope.

Variations of dissolved ions in the different sources of supply to, and output from, a glacio-hydrological system reflects their different origins. Most of the ions in the accumulation area of the Baishui No. 1 glacier probably came from nearby sources: wind-blown crustal materials from the mountain slopes; impurities carried by moist air moving up the slopes; avalanches from the valley walls; and contact with the glacier bed by flowing ice and meltwater. Ionic concentrations in rainwater were low, particularly at high altitude (see Figure 5), and it is apparent that the impurity content of the precipitation falling on the Baishui No. 1 glacier was small. Solutes are acquired by meltwater and glacier river water as a result of contact with other sources. The increasing contact area between meltwater and the glacier bed with decreasing altitude led to higher ionic concentrations in the meltwater and the Baishui River (see Figure 5). The increase of Cl^- indicates gradual absorption of dissolved chloride from bedrock and till.

In most of the samples collected in 1999, Ca^{2+} and Mg^{2+} concentrations were much higher than those of Na^+ and K^+ (see Figure 5). Ca^{2+} inputs to the Baishui No. 1 glacier catchment probably are from local (continental) sources primarily. K^+ may originate from continental dust sources. Mg^{2+} has marine as well as continental sources. The data suggests that the impurities deposited in the glacier's system were mainly of a continental origin. Concentrations of Mg^{2+} , Ca^{2+} and K^+ were higher in snow at high altitude than in that closer to the equilibrium line, but Na^+ and Cl^- concentrations were lower at higher altitude. In general, the elution of Ca^{2+} and Mg^{2+} from a snowpack is more rapid than is that of Na^+ and K^+ (Davies et al., 1987). Thus, the decrease of ionic concentrations with decreasing altitude in the surface snow at the Baishui No. 1 glacier might be the result of a longer period of melting at lower elevations. However, this cannot account for the pattern of Na^+ and Cl^- concentrations. SO_4^{2-} was detected in surface snow only at the highest site (5000 meters). Most SO_4^{2-} in snow is removed relatively rapidly in the early part of the melt season, and concentrations decrease particularly quickly at lower altitudes, where melting starts earlier (Raben and Theakstone, 1994). Early-season ionic elution of snow results in meltwater with a high ionic content. This has readily observed effects on river water (Tranter et al, 1987). The supraglacial meltwater formed from the leached snow is depleted of SO_4^{2-} . SO_4^{2-} was detected in meltwater at the glacier Baishui No.1 only at

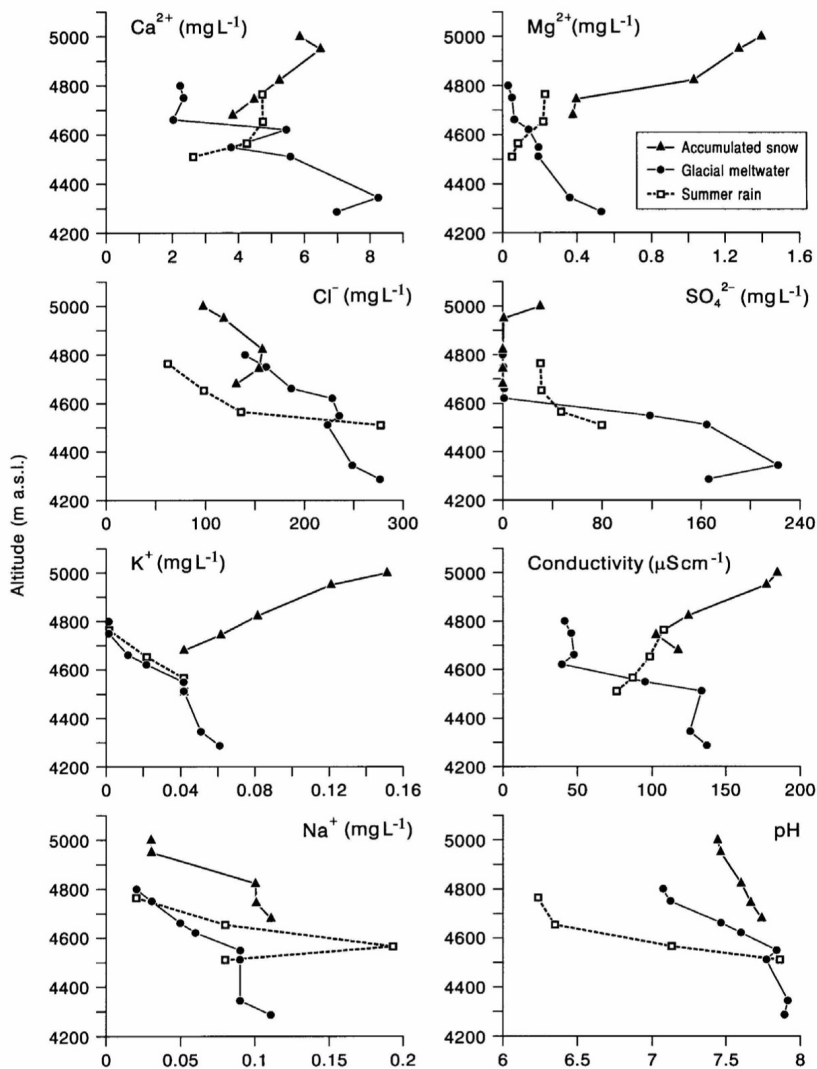


FIGURE 5

Altitudinal variations of Ca^{2+} , Cl^- , K^+ , Na^+ , Mg^{2+} , SO_4^{2-} , conductivity and pH values in accumulated snow, summer rainfall and glacial meltwater at the glacier Baishui No.1, Mt. Yulong, July 1999.

lower altitudes; the concentrations were higher than in the one sample of summer rain in which SO_4^{2-} was found (see Figure 5).

Differences of conductivity of the samples of surface snow, rainfall, and meltwater reflected the general trends apparent in the concentrations of individual ions (see Figure 5).

Sampling in the Mt. Yulong area in 2000 was more detailed than those carried out in 1999. $\delta^{18}\text{O}$ of all samples were analyzed with a new Delta Plus mass spectrometer in the Laboratory of Ice Core and Cold Environment, Chinese Academy of Sciences.

The $\delta^{18}\text{O}$ values of winter accumulated snow, collected at the surface above the elevation of 4800 meters on 5 July, decreased with decreasing altitude (see Figure 4). However, the $\delta^{18}\text{O}$ values of a set of samples from about 30 millimeters of newly precipitated snow, which were collected on 10 July between 4400 and 4750 meters when the temperature was lower (about -5 to 0 degrees Celsius), decreased with increasing altitude. The samples of surface snow from above 4800 meters represent a winter precipitation event, but those from new accumulated snow below 4800 meters represent a summer precipitation event. The $\delta^{18}\text{O}$ values indicate that the patterns of variation of winter and summer snowfalls differ.

Samples of summer rain were collected during a single precipitation event with a higher amount of precipitation (50 millimeters on average). Air temperature during sampling between 4700 and 3200 meters ranged from 10 to 20 degrees Celsius. Summer rain was much more depleted of ^{18}O than the winter and summer snow covers were (see Figure 4). Four rainfall samples were collected at each of four locations (see Figure 4) - Ganhaizi (3200-3270 meters), the Lower Cableway Station (3330-3360 meters), the Upper Cableway Station (4490-4520 meters), and the glacier (4550-4700 meters). The $\delta^{18}\text{O}$ values were highest at Ganhaizi where precipitation amount was lowest. The lowest values were for the samples collected between 4600 and 4700 meters, where precipitation amount was highest.

It is apparent that, below 4800 meters, the higher $\delta^{18}\text{O}$ values of summer snow correspond to a lower-temperature environment and the lower values of summer rain is associated with a higher-temperature condition. The lowest values of summer deposited snow between 4650 and 4750 meters and of

summer rain between 4600 and 4700 meters (see Figure 4) suggest that there probably is a highest precipitation-amount zone between 4600 and 4750 meters in the glacier area. This irregular and varied pattern is characterized by an obvious reverse relation between $\delta^{18}\text{O}$ values and temperature/precipitation amount in the prevailing summer monsoon period when samples were collected.

Ten samples of glacial meltwater were collected between 4530 and 4750 meters. $\delta^{18}\text{O}$ values displayed a general increase with decreasing elevation (see Figure 4). The mean value (13.94‰) was much lower than the means of winter deposited snow (9.46‰) and accumulated snow at the pit sites (6.70‰), indicating that alternative isotopic depletion and fractionation occurred during the processes of snow-ice transformation, ablation, evaporation, and supraglacial meltwater flow.

Water samples were collected from various sections of the glacier-fed Baishui River at altitudes between 3300 and 3150 meters. The mean of the five $\delta^{18}\text{O}$ values of samples from the river's southern branch was 16.59‰ and that of the three from the northern branch was -16.28‰ (see Figure 4). Below the junction at 3250 meters (16.09‰), values increased, suggesting that re-fractionation occurred during water flow, percolation, evaporation and contact with the river bed and groundwater. The highest $\delta^{18}\text{O}$ value (11.75‰) was at the valley's end (see Figure 1). The mean value of the twenty Baishui River samples (-15.44‰) was between those of glacial meltwater (13.94‰) and summer rain (16.98‰), demonstrating that the river water was a mixture of glacial meltwater and sources more depleted of ^{18}O , including summer precipitation. Ground water may enter the river, and further sampling and analysis is needed to calculate the relative contributions of meltwater, groundwater and precipitation to river discharge. The spatial and temporal variations of stable isotopes in the river may be used to identify the different sources of supply.

4. Glacier Variations since the Little Ice Age

Glaciers have greatly retreated after the Little Ice Age because of warming of the climate. The recent 50-year climatic data at Lijiang, the closest meteorological station to Mt.Yulong, indicates that there are 2 to 3 year periodic changes for the local temperature and apparent 11 to 12 year periodic cycles for precipitation, showing a corresponding pattern with that

in northeastern part of India (see Figure 6). During the most recent half-century, glaciers in Mt. Yulong have alternately retreated and advanced, with smaller amplitudes (see Table 1). Since the 1950's, global climatic change has had a significant response in China's monsoonal temperate-glacier region. Observed data indicate that, in the Lijiang–Mt. Yulong region, the average annual temperature between 1982 and 2001 was 0.2 degrees Celsius higher than that of 1962–1981 and, in particular, the average annual temperature between 1998 and 2001 was 0.6 degrees Celsius higher than that of 1982–1997. In Zhongdian, close to Lijiang, the average annual temperature during the 20 years 1982–2001 increased by 0.7 degrees Celsius in comparison with that of the previous 20 years, 1962–1981. The average annual temperature during the most recent 4 years (1998–2001) was 0.8 degrees Celsius higher than that between 1982 and 1997, demonstrating a rapid warming trend in the area (He et al, 2000a, 2003ab, Jones et al, 1999). Against this climatic background, a more rapid speed of glacial changes has occurred on Mt. Yulong (see Table 1), indicated by increased ablation of the glaciers, retreat of the glacier margins, reduction of the glaciers' areas and a rise of the snow line.

The Baishui glacier No.1 on Mount Yulong (see Figure 1), the southernmost glacier of Eurasia, with a small area, is most sensitive to climate, and its area has decreased by 60 percent from the Little Ice Age to the present. The data

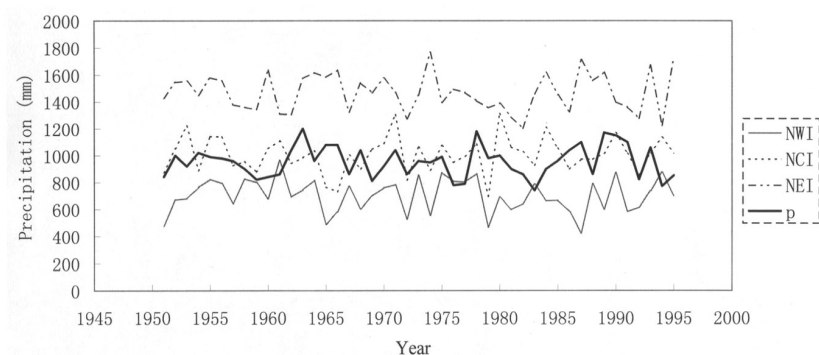


FIGURE 6

Variations of mean annual precipitation at Lijiang station (P), northwestern India (NWI), north central India (NCI) and northeastern India (NEI) from 1950 to 1996, indicating 11–12 year periodic cycles and 2–3 year sub-periodic cycles for southwestern monsoon.

Table 1 Variation of Baishui No. 1, Mt Yulong since the Little Ice Age Biashui Number 1 Glacier, Mt. Yulong (Area, 1.7 square kilometers; Length, 2.5 kilometers)		
TIME PERIOD	ALTITUDE OF GLACIER END IN METERS (M)	ADVANCE (+) AND RETREAT (-), IN METERS (M)
Little Ice Age (17-19 centuries)	3800	+
19th century to 1957	4353 (1957)	-1250
1957 – 1982	4100 (1982)	+800
1982 – 1997	4200 (1997)	-150
1998 – 2002	4250 (2002)	-100

listed in Table 1 was from local historic records and geomorphic evidences of newer moraine and snow line variations, indicating that the glacier retreated about 1250 meters between the Little Ice Age and the middle of the 20th century, and it has retreated again since the 1980s (see Table 1). As a distinct indicator of climate change, the end of glacier Baishui No.1, the largest glacier on Mt. Yulong, has retreated by 100 meters during the most recent 4 years, from 1998 to 2002, and the glacier’s size and thickness have been reduced at the same time (He et al, 2000a, 2003ab).

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6. References

Dansgaard W. 1964. Stable isotope in precipitation. *Tellus*, 14(4): 436-468.

Davies, T.D., P. Brimblecombe, Tranter, M., Tsiouris, S., Vincent, C.E., Abrahams, P., Blackwood, I.L. 1987. The removal of soluble ions from melting snowpacks. In ‘Seasonal snowcovers: physics, chemistry, hydrology’ (eds. Jones, H.G., Orville-Thomas, W.J.) NATO Advanced Science Institute Series C, Mathematical and Physical Sciences, 211: 337-392.

He Yuanqing, Yao Tandong, Yang Meixue, 2000a, Spatial features of glacial hydro-chemistry and recent variations of a Chinese temperate glacier in Mt. Yulong. *Journal of Mountain Science*, 18(6): 481-488 (in Chinese with English summary)

- He Yuanqing, Yao Tandong, Yang Meixue, Sun Weizhen. 2000b. The new results of $\delta^{18}\text{O}$ studies in the system of precipitation, snow-ice and glacial runoff at the glacier Baishui No.1 region in Mt. Yulong, China. *Journal of Glaciology and Geocryology*, 22(4): 391-393 (in Chinese with English summary)
- He Yuanqing, Yao Tandong, Yang Meixue, Shen Yongping. 2000c. Contemporary significance of snow and ice indicated by the record in a shallow ice core from a temperate glacier in southwestern monsoon region. *Journal of Glaciology and Geocryology*, 22(3): 235-241 (in Chinese with English summary)
- He, Yuanqing, Yao, Tandong., Cheng, Guodong., Yang, Meixue, 2001. Climatic records in a firn core from an alpine temperate glacier on Mt. Yulong in southeastern Tibetan Plateau. *Episodes*, 24(1):13-18.
- He Yuanqing, Yao Tandong, W.H. Theakstone, David Zhang et al. 2002a, The Irregular Pattern of Isotopic and Ionic Signals in a Typical Monsoon Temperate-Glacier Area, Mt. Yulong, China. *Annals of Glaciology*, 35: 167-174.
- He Yuanqing, Yao Tandong, W.H. Theakstone, Yang Meixue et al., 2002b, Recent climate significance indicated by the chemical signals in a shallow ice core at an glacier in south-Asia monsoon region. *Journal of Asia Earth Science*, Vol.20, No.3: 289-296
- He Yuanqing, Zhang Zhonglin, Yao Tandong et al., 2003a, Changing Features of Climate and Glaciers in China's Monsoonal Temperate-Glacier Region since the Little Ice Age. *Journal of Geophysical Research*, 108(D17): 4530-4536.
- He Yuanqing, Gu Juan, Zhang Dian, 2003b, What is the major reason for glacier retreat on Yulong mountain, China. *Journal of Glaciology (SCI??)*, 49(165): 325-326.
- Jones, P. D., T. M. L. Wigley, and G. Farmer, 1991. "Marine and land temperature data sets: a comparison and a look at recent trends" in *Greenhouse-Gas-induced Climatic Change: A Critical Appraisal of Simulations and Observations*, M. E. Schlesinger, Ed., Elsevier Scientific Publishers, New York, 153-172.
- Li Jijun., Su Zhen (eds.), 1996. *Glaciers in Hengduanshan Range, Beijing*, Science Press (in Chinese with English summary).
- Moser, H., Stichler, W. 1980. Environmental isotopes in snow and ice. In: *Handbook of Environmental Isotope Geochemistry*. Elsevier Scientific Publishing Co., Vol. 1:141-148.
- Raben, P., Theakstone, W.H. 1994. Isotopic and ionic changes in a snow cover at different altitudes: observations at Austre Okstindbreen in 1991. *Annals of Glaciology*, 19: 85-91.

- Rozanski, K., Araguás-Araguás, L., Gonfiantini, R. 1993. Isotopic patterns in modern global precipitation. *Geophysical Monograph*, 78: 1-36
- Su, Zhen., Pu, Jianchen. 1996. The developing conditions, numbers and form of the glaciers in Hengduan Mountain Range . In: Lijijun and Su Zhen eds. '*Glaciers in Hengduanshan Range*'. Beijing: Science Press: 1-25
- Su, Zhen, Wang, Lilun, 1996. Characteristics of ablation, hydrology and hydrogeochemistry of glaciers in the Hengduanshan Range, In: Li Jijun and Su Zhen eds. '*Glaciers in Hengduanshan Range*', pp.70-110
- Tranter, M., Abrahams, P.W., Blackwood, I., Davies, T.D., Brimblecombe, P., Thompson,
- I.P., Vincent, C.E. 1987. Changes in streamwater chemistry during snowmelt. In '*Seasonal Snowcovers: Physics, Chemistry, Hydrology*' (eds. Jones, H.G. and Orville-Thomas, W.J.). NATO Advanced Science Institute Series C, Mathematical and Physical Sciences, 211: 575-597.
- Wang Yu. 1996. *The Introduction of Climatic Changes in Yunnan*. Beijing, Meteorology Press (in Chinese).
- Yao, Tandong., Ding, Liangfu., Pu, Jianchen. 1991. The relationship between $\delta^{18}\text{O}$ of the snowfall and vapor sources in Tanggula region of the Tibet. *Chinese Science Bulletin*, 36(20): 1570-1573 (in Chinese).