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ANNUAL TEMPERATURE IMPACT ON MORAINE LAKE OUTBURSTS IN TIBET, CHINA

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ABSTRACT

Glacier-lake outburst is common in Tibet. Global warming is expected to increase the frequency of outburst. This paper attempts to find out the relationship between the outburst and annual temperature variation based on analysis of 16 outburst events in Tibet. Multiyear climate data from meteorological stations in the study area are used. We find that the outbursts are sensitive to acute change in annual temperature. Specifically, the outburst probability increases when average annual temperature rises by more than 0.5°C. Finally, we put forwards an evaluation of the increasing risk of potential outburst of glacier lake in Tibet.

Key words: *annual temperature, impact on, moraine lake outbursts, Tibet*

INTRODUCTION

Glaciers retreat continuously and glacier lakes have increased both in number and size over the last decades because of the global warming. As a result, lakes dammed by moraines are getting likely to collapse, especially in Tibet. Dam failure usually brings about devastating flood or even debris flow. For example, in July, 2009, flood induced by glacier-lake outburst (GLOF) happened in the Zhemaico Lake and Cilaco Lake in Tibet, which killed 2 persons, destroyed 53 km highways, 20 bridges and 3 culverts.

Glaciers in the Tibetan Plateau are of considerable interest because of their high sensitivity to climatic change and changes in glaciers and glacier-lakes are considered as indicator of warming (Liu & Sharma, 1988; Ding & Liu, 1992; Zhang, 1992; Walder & Driedger, 1994; Mool, 1995; Reynolds, 1995; Walder & Costa, 1996; Bishop *et alii*, 1998; Clague & Evans, 2000; Shaun & John, 2000; Rudoy, 2002; thus may be an important indicator for global climatic change (Thompson *et alii*, 1989; Li & Kang, 2006; Ames, 1998). In response to warming, glaciers in Tibet have been retreating since the early 20th century, and the retreats have been accelerating since the 1980s (Zhang & Yao, 1998; Liu & Kang, 1999; Shi & Liu, 2000; Shi *et alii*, 2000; Shi, 2001; He e*t alii*, 2002a, 2002b; Pu & Yao, 2004; Shen, 2004; Yao *et alii*, 2004). As a result, lakes dammed by moraines are getting likely to collapse, especially in Tibet. Dam failure usually brings about devastating flood or even debris flow. For example, in July, 2009, a flood was induced by glacier-lake outburst (GLOF) in the Zhemaico Lake and Cilaco Lake in Tibet, which killed 2 persons, destroyed 53 km highways, 20 bridges and 3 culverts.

Changes in glaciers and glacier-lakes are considered as indicator of warming (Liu & Sharma, 1988; Ding & Liu, 1992; Zhang, 1992; Walder & Driedger, 1994; Mool, 1995; Reynolds, 1995; Walder & Costa, 1996; Bishop *et alii*, 1998; Clague & Evans, 2000; Shaun & John, 2000; Rudoy, 2002), but few studies focus on the relationship between GLOFs and temperature variation.

Many end-moraine lakes were formed when glaciers retreat at the end of the Little Ice Age (Clague,

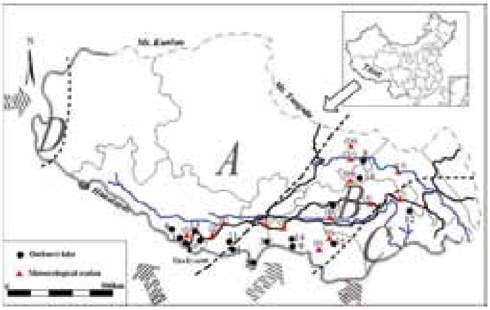

Fig. 1 - Distribution of outburst lakes and nearby meteorological stations in Tibet of China (The serial numbers of meteorological stations(▲):(1) Nielamu; (2) Dingri; (3) Lazi; (4) Jiangzi; (5) Langkazi; (6) Cona; (7) Longzi; (8) Jiacha; (9) Linzhi; (10) Jiali; (11) Biru; (12) Bomi; (13) Luolong; (14) Suo. The outburst lakes labeled serial number according to chronological order. Several information comes from IMDE1999)

Tab 1 - The nineteen outbursts of sixteen lakes in Tibet

Number	Lake	County	Outburst date	Latitude N	Longitude E	Elevation (m)
1	Taco	Nielamu	1935-08-28	28°17.57'	86°7.91'	5245
2	Qiongbihemacoo	Yadong	1940-07-10	27°30.93'	89°5.44'	4660
3	Sangwangco	Kangma	1954-07-16	28°3.81'	91°21.94'	5150
4	Jilaico	Dingjie	1964-09-21	27°57.82'	87°48.57'	5271
5	Damenlakeco	Gongbujiangda	1964-09-26	29°18.15'	93°6.36'	5210
6	Longdaco	Jilong	1964-08-25	28°31.61'	85°18.72'	5460
7	Ayaco(1st) Ayaco(2nd) Ayaco(3rd)	Dingri	1968-08-15 1969-08-17 1970-08-17	28°20.9'	86°29.66'	5560
8	Pogeco	Suo	1972-07-23	31°57.68'	94°9.92'	4332
9	Zharico	Luozha	1981-06-24	28°54.44'	92°18.71'	5130
10	Cirenmaco	Zhangmukouan	1981-07-11	28°4.75'	86°2.32'	4640
11	Jingco	Dingjie	1982-08-27	28°11.69'	87°38.42'	5353
12	Guangxieco	Bomi	1988-07-15	29°27.9'	96°29.96'	3816
13	Jialongco(1st) Jialongco(2nd)	Nielamu	2002-05-23 2002-06-29	28°12.9'	85°51.07'	4410
14	Degaco	Luozha	2002-09-18	28°7.42'	90°34.02'	5316
15	Zhemaico	Cona	2009-07-3	28° 0.9'	92° 20.6'	5300
16	Cilaco	Bianba	2009-07-29	30°44.05'	93°58.53'	5060

Ayaco(1 st) denotes the first outburst in Ayaco Lake and Ayaco(2 nd) is the second outburst, and so forth.

2003; Hambrey & Alean 2004). Climate fluctuations play a role in stimulating the outbursts. Dry weather is favorable for the outburst in Alps, and more than 95% of the outbursts there happened in June to September (Tufnell, 1984). Lv (1989) found that humidity and dry heat are most likely to cause dam failure in Tibet, while Li (1992) thought the major motivating factors are sustained high temperatures and abnormal

rainfall. All these studies advocate the influence of climatic changes but few focuses on the relationship between GLOFs and temperature variation. This paper is devoted to the relationship between lake break and temperature change in Tibet based on analysis of 16 outburst events in Tibet from 1960-2009.

OUTBURSTS IN TIBET SINCE 1950s

BACKGROUND OF STUDY AREA

Glaciers in Tibet include continental glaciers and maritime glaciers according to their characteristics (SEQTP, 1986), which are distributed in two distinct regions of different climate conditions. The two regions can be further divided into four subregions A, B, C, and D, as shown in Fig. 1 (SEQTP, 1986): Continental glaciers, in subregions A and C, grow and melt slowly, are less active and receive less rainfall; Maritime glaciers in B and D regions are mainly influenced by marine climate, they have high temperature, low snow line, and intense activity.

Since 1950s, more than 20 outbursts have taken place in the area. Among them, 19 events in 16 lakes have been recorded in details. Figure 1 shows the sites and 14 meteorological stations in vicinity

The outbursts are listed in Table 1, including data from field surveys. Among them, the Ayaco Lake and Jialongco Lake have collapsed for several times. Some events were reported by local inhabitants and difficult to be located in the map. Their locations are inferred from the literatures and topographic maps.

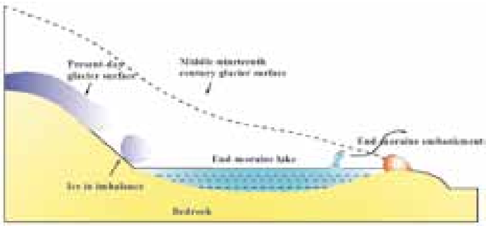

Fig. 2 - Schematic diagram showing the formation and outburst of moraine-dammed Lake (modified from Clague *&* Evans*, 1993, Fig. 8)*

Outburst-lake Name (Lake)	Data from stations	Outburst-lake Name (Lake)	Data from stations
Jilaico	Dingri, Jiangzi,	Jingco	Dingri, Jiangzi, Lazi
Damenlakeco	Jiali, Linzhi	Guangxieco	Bomi, Linzhi
Ayaco	Dingri, Nielamu	Jialongco	Nielamu, Dingri
Pogeco	Biru, Suo	Degaco	Langkazi, Cona
Zharico	Langkazi, Cona	Zhemaico	Longzi, Cona
Cirenmaco	Nielamu	Cilaco	Biru, Jiali, Luolong

Tab. 2 - The data of 12 lakes from different stations

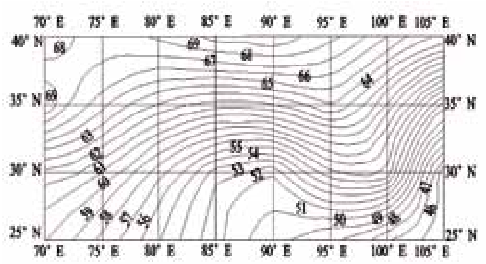

*Fig. 4 - Lapse rate of temperature in Tibet (the number is the correction coefficient) (*Li*, 2006)*

FORMATION AND OUTBURST OF MORAINE LAKES

There are many kinds of glacier lakes, such as superglacial lake, englacial lake (the water body), and ice-dammed lake (formed by the valley glacier blocking the mainstream channel). . And on aspects about glacier retreat, there are end-moraine lake, ice-erosion trough valley - moraine lake, cirque lake and lateral moraine lake. All the 19 outbursts in Tibet occurred in moraine lakes (IMHE, 1999). The moraines are formed by unsorted soil, rock, and other material left by the glaciers. Rock debris rolls off the glacier edges and builds piles of unconsolidated rocks called "glacier moraine". "Lateral moraines" form along the side of a glacier and curl into a "terminal moraine" at the glacier's downvalley end. Terminal moraines are formed at the farthest limit reached by a glacier and lateral moraines are formed along the sides of a glacier (Scot Dahms, 2006). lakes considered were caused by avalanches closely related to temperature

Having steep slopes and contain unsolidated sediment, moraine dams are highly susceptible to failure (Clague, 2003). Fig.2 shows the forming and outburst of a moraine lake. The snout of glacier near the lake may extend into the lake. The dam is typically narrow and high with poor structural strength. Large volume of water impounded increases the pressure against the dam while ice avalanche fall into lake. Limited freeboard between the dam crest and the lake level reduces the height of waves needed to overtop the dam (Reynolds Geo-Sciences Ltd., 2003). Having steep slopes and contain unsolidated sediment, moraine dams are highly susceptible to failure (Clague, 2003).

The lakes lie in the high altitude and it is difficult to obtain field data. In this study, weather data is analyzed to find the possible impact of annual temperature on outburst.

DATA AND CORRECTION

The data come from 14 weather stations near the lakes and 12 lakes which have relatively complete data are taken for case studies, which list in Table 2.

As elevation impacts temperature considerably (Dodson, 1997; Hulme M, 1995; Robeson, 1998), the recorded temperature is corrected to diminish the elevation effect by the following formula (Li, 2006)

$$T_H = T_0 - k\,\Delta H \quad (1)$$

where T_0 is the recorded temperature from the set of Chinese surface climate data, ΔH is the elevation difference between the lake and the station, k is the correction coefficient, as showed in Fig. 4 (Li, 2006).

And the refinement of inverse distance weighted interpolation is

$$T = \frac{\sum_{t=1}^{n} \frac{1}{D_t} T_H}{\sum_{t=1}^{n} \frac{1}{D_t}} \quad (2)$$

where T is the final value used in study, T_H is the revised value, D_t is the horizontal distance between the lake and the nearby stations.

ANNUAL TEMPERATURE VARIATION IMPACT ON GLACIER-LAKE OUTBURSTS

MEAN ANNUAL TEMPERATURE

We collect annual mean temperature to find its impact on outburst. Figure 5 demonstrates the temperature variation for the lakes in the years around the outburst (denoted by black dot). The fluctuations is remarkable in 1960s, 1970s and recent years, but it is gentle in 1980s.

The signed number, e.g., 0.7604, in Fig.5, means the temperature is increased by 0.7604°C over the year prior to the outburst. Similarly, -0.9 means the temperature is decrease by 0.9°C comparing with the year before the outburst.

It is found that the outbursts occurred at the inflections of temperature fluctuation, either from high to low or from low to high. High temperature may increase the outburst probability because it contributes to melting and icefall. The annual mean temperature and the increment of Jilaico and Damenlakeco Lake were both the maximal till 1964. And in the early 1960s, especially in 1962 and 1963, the regions were under wet cold weather,. The difference of mean annual temperature was about 1°C between 1963 and 1964, when the climate began to warm. Ayaco Lake broke successively in the three years. The years of 1965 and 1966 constituted a cold period. The average annual temperature in 1966 was the lowest. And it increased to -2.5°C in 1968 and to -1.6°C in 1969, the maximum till 2002.

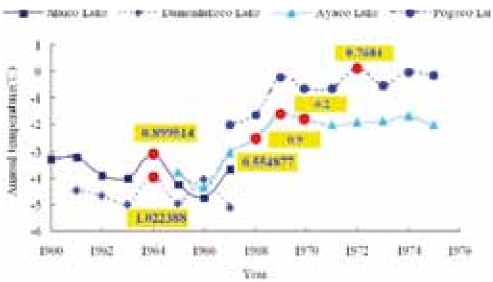

Fig. 5a - Variation of annual temperature of 12 lakes between 1960 and 2009 (● indicates the outburst years) (a) The outbursts in 1960s and 1970s

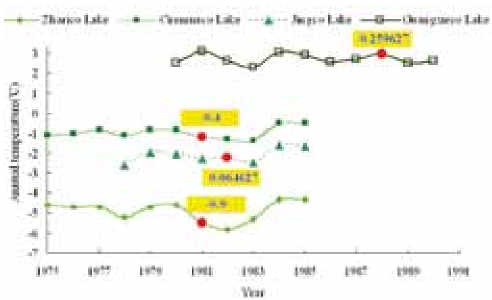

Fig. 5b - Variation of annual temperature of 12 lakes between 1960 and 2009 (● indicates the outburst years) (b) The outbursts in 1980s

The glaciers advanced in the cold period of 1965-1967 and the ice snout moved forwards or even entered into the lake. While temperature rose rapidly, the glacier melted and collapsed into the lake and finally led to the outburst. The annual temperature of Cilaco Lake and Zhemaico Lake went up rapidly by 1.1°C and 1.3°C in 2009 after a sharp decline in 2008. It can be concluded that stronger annual temperature fluctuation, which may be more than about 0.9°C, increases the possibility of outburst.

This disagrees with the conclusion of the previous studies (IMHE, 1999) that most outbursts occur after high temperature year. We observe that outburst occurred when temperature increased by only 0.5°C or more for seven cases. However, there are five cases like Zharico Lake where the outbursts occur on a low annual temperature point.

TEMPERATURE ANOMALY YEAR

Fluctuation of temperature makes some years abnormal, having a large deviation from the mean

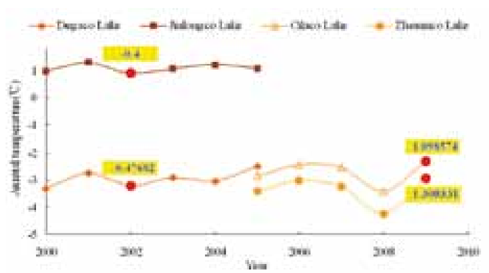

Fig. 5c - Variation of annual temperature of 12 lakes between 1960 and 2009 (● indicates the outburst years) (c) The outbursts in 2000s

Table 3. The temperature anomaly year of outburst and the preceding years

emperature Anomaly Year	Outburst Year	Temperature Anomaly Year	Outburst Year
1963—lower(-)	1964 (Jilaico)	1980—higher (+) 1981—higher (+)	1981(Cirenmaco)
1963—anomaly(-) 1964—higher(+)	1964 (Damenlakeco)	No anomaly	1982(Jingco)
No anomaly	1968 (Ayaco(1_{st}))	1987—close to the anomaly (-)	1988(Guangxieco)
1969—higher(+)	1969 (Ayaco(2_{nd}))	2002—higher (+)	2002(Degaco)
1970—higher(+)	1970 (Ayaco(3_{rd}))	2009—anomaly (+)	2002(Jialongco(1_{st} and2_{nd}))
1972—close to the anomaly(+)	1972 (Pogeco)	2002—close to the anomaly (+)	2009(Zhemaico)
1980—close to the anomaly(+) 1981—anomaly(-)	1981 (Zharico)	2008—close to the anomaly (-) 2009—anomaly (+)	2009(Cilaco)

Tab 3 - The temperature anomaly year of outburst and the preceding years

temperature of many years. According to World Meteorological Organization (WMO), a year is defined as anomal when the temperature variation is two times higher than the standard deviation, or when the return period is longer than 25 years.

The annual temperature variation C is

$$C = |T_A| / S_D$$

where T_A is annual average temperature and SD is standard deviation.

In the following, we take $C \geq 2$, $1.5 \leq C \leq 2$ and $1 \leq C \leq 1.5$ as the categories for anomaly, close to the anomaly, and drift slightly higher or lower, respectively. The results are listed in Table 3 for the outburst years and the preceding years. (+ means high anomaly and - means low anomaly.)

Glacier-lake outbursts are induced by great change in temperature. 12 out of the 15 events occurred on climate change point, especially in the turning years from cold to warm. The possibility of outburst is thus only determined by temperature of the current year, but also by temperature of the preceding years.

CONCLUSIONS AND DISCUSSIONS

This paper explores the influence of annual temperature on glacier-lake outbursts in Tibet, using data from 16 outburst events in southern Tibet and the relevant temperature from 14 meteorological stations nearby.

Glacier-lake outburst is the response to volatility in annual temperature. A great fluctuation of temperature is more likely to induce the outburst. It is found that multiyear-data other than one-year data is more relevant to determine an outburst. In a year of abrupt climate change, particularly when a cold year turn into a warm year, the probability of outburst increases rapidly only if the average temperature rises by more than 0.5°C.

Apparently, glacier-lake outburst is concerned with many factors, including the features of the lake and the environment. Temperature as an indicator for glacier change may dominate in influencing the potential of outburst, but it is not sufficient to predict a special event. For accurate prediction of outburst, more data is needed both of the outburst process and the related information of weather, such as the daily and monthly variation of the temperature prior to the outburst.

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REFERENCE

AMES A. (1998) - *A documentation of glacier tongue variations and lake development in the Cordillera Blanca, Peru.* Zeitschrift fur Gletscherkunde und Glazialgeologie **34:** 1–36.

BISHOP M.P., SHRODER JR. J.F., HICKMAN B.L. & COPLAND L. (1998) - *Scale-depterminalent analysis of satellite imagery for characterization of glacier surfaces in the Karakoram Himalaya.* Geomorphology **21** (3-4)**:** 217-232.

CHINESE ACADEMY COMPREHENSIVE SCIENTIFIC EXPEDITION TO QINGHAI-TIBET PLATEAU (SEQTP, CAS) (1986) - *Glaciers in Tibet.* Beijing Science Press: 32-37 (in Chinese).

CHINESE ACADEMY OF SCIENCES - MINISTRY OF WATER RESOURCES CHENGDU INSTITUTE OF MOUNTAIN HAZARDS AND ENVIRONMENT (IMHE, CAS) (1999) - Department of the Tibet Autonomous Region Institute of Science. *Mud-rock flow in Tibet and the environment Chengdu.* Science and Technology University Press: 106-136 (in Chinese)

CLAGUE J.J. & EVANS S.G. (1993) - *Historic catastrophic retreat of Grand Pacific and Melbern glaciers, St. Elias Mountains; an analogue for the late Pleistocene decay of the Cordilleran Ice Sheet?* Journal of Glaciology, **39:** 619–624.

CLAGUE J.J. (2003) - *Catastrophic floods caused by sudden draining of lakes in high mountains.* In Martin K. and Hik, D. S. The state of ecological and earth sciences in mountain areas. Science highlights from Symposium on Ecological and Earth Sciences in Mountain Areas, September 2002, Banff, Alberta, Canada, 46 pp

CLAGUE J.J. & EVANS S.G. (2000) - *A review of catastrophic drainage of moraine-dammed lakes in British Columbia.* Quaternary Science Reviews, **19:**1763-1783.

DING Y. & LIU J. (1992) - *Glacier lake outburst flood disasters in China*. Annals of Glaciology, **16:** 180-184.

DODSON R. & MARKS D. (1997) - *Daily air temperature interpolated at high spatial resolution over a large mountainous region[J]* . Clim Res., **8** (1)**:** 1-20

HAMBREY M. & ALEAN J. (2004) - *Glaciers*. 2nd ed. Cambridge University Press, Cambridge, United Kingdom. 376 pp.

HE Y., THEAKSTONE W.H., YAO T. *et alii* (2002a9 - *The irregular pattern of isotopic and ionic signals in the typical monsoon temperate-glacier area, Yulong mountain, China.* Annals of Glaciology, **35:** 167–174.

HE Y., YAO, T., THEAKSTONE W.H. *et alii* (2002b) - *Recent climatic significance of chemical signals in a shallow firn core from an alpine glacier in the South-Asia monsoon region.* Journal of Asian Earth Sciences, **20:** 289–296.

HULME M., CONWAY D., JONES P.D. *et alii* (1995) - *Construction of a 1961 -1990 European climatology for climate change modeling and impact applications.* Inter J Clim., **15** (12)**:** 1333-1363.

LI D. & YOU Y. (1992) - *Bursting of the MiDui moraine lake in Bomi,Xizang.* Journal of Mountain Research, **10**(4)**:** 219-224. (in Chinese)

LI Q.-Y., XIE Z. (2006) - *Analyses on the Characteristics of the Vertical Lapse Rates of Temperature. Taking Tibetan Plateau and Its Adjacent Area as an Example[J]*. Journal of Shihezi University(Natural Science), **24** (6)**:** 719-723 (in Chinese)

LI X.,CHENG G. & LU L. (2003) - *Comparison Study of Spatial Interpolation Methods of AirTemperature over Qinghai-Xizang Plateau.* Plateau Meteorology, **22**(6): 565-573 (in Chinese).

LI C. & KANG S. (2006) - *Review of studies in climate change over the Tibetan Plateau.* Acta Geographica Sinica, **61**(3)**:** 327-335.

LIU C. & SHARMA C.K. (EDS.) (1988) - *Report on the "rst expedition toglaciers and glacier lakes in the Pumqu (Arun) and Poiqu (Bhote-Sun-Kosi) River basins, Xizang (Tibet), China: Sino-Nepalese investigation of glacier lake outburst #oods in the Himalaya.* Science Press, Beijing, China, 192 pp. plus maps.

LIU C. & KANG E. (1999) - *The research about glaciers change and runoff effect in the northwestern region of China.* Science in China, Series D 29 (Suppl. 1), 55-62. (in Chinese).

LU R. & LI D. (1989) - *Ice-Snow-Melt Water Debris Flows in the Dongru Longba (Gully) Bomi County, Xizang (Tibet) 1989* (2)**:** 148-160 (in Chinese)

MOOL P.K. (1995) - *Glacier lake outburst floods in Nepal.* Journal of Nepal Geological Society, **11:** 173-280.

PU J. & YAO T. (2004) - *Fluctuations of the glaciers on the Qinghai–Tibetan plateau during the past century.* Journal of Glaciology and Geocryology, **5** (26)**:** 517-522. (in Chinese).

REYNOLDS GEO-SCIENCES LTD. (2003) - *Development of glacial hazard and risk minimization protocols in rural environments -* Guidelines for the management of glacial hazards and risks. RGSL, Mold, United Kingdom.

REYNOLDS J.M. (1995) - *Glacial-lake outburst floods (GLOFs) in the Himalayas: an example of hazard mitigation from Nepal.* Geoscience and Development, **2:** 6-8.

ROBESON S.M. & JANIS M.J. (1998) - *Comparison of temporal and unresolved spatial variability in multiyear time2averages of air temperature.* Clim Res., **10** (1): 15-26

RUDOY A.N. (2002) - *Glacier-dammed lakes and geological work of glacial superfloods in the Late Pleistocene, Southern Siberia, Altai Mountains.* Quaternary International, **87:** 119-140.

SCOT DAHMS H.(2006) - *Moraine Dam Failure and Glacial Lake Outburst Floods*. Quaternary Geology, **72**.

SHAUN D.R. & JOHN M.R. (2000) - *An overview of glacial hazards in the Himalayas.* Quaternary Internationa **65/66**: 31-47.

SHEN Y. (2004) - *An Overview of Glaciers, Glacier Retreating and Its Impact in the Tibetan Plateau.* A consultative report for Climate Impact and Adaptation Project in the Tibetan Plateau submitted to the World Wide Fund for Nature - China Programme Office (WWF-China), 50 pp.

SHI Y. (2001) - *Estimation of the water resources affected by climatic warming and glacier shrinkage before 2050 in west China.* Journal of Glaciology and Geocryology, **23** (4)**:** 333–341 (in Chinese).

SHI Y., HUANG M. & YAO T. (2000) - *Glaciers and Their Environments in China – the Present, Past and Future.* Science Press, Beijing. (in Chinese).

SHI Y. & LIU S. (2000) - *Estimation of the response of glaciers in China to the global warming in the 21st century*. Chinese Science Bulletin, **45** (4): 668-672. (in Chinese).

THOMPSON L.G., MOSLEY-THOMPSON E., DAVIS M.E., BOLZAN J.F.,DAI J., YAO T.,WU X., XIE Z. & GUNDESTRUP N. (1989) - *Holocene–Late Pleistocene climatic ice core records from Qinghai–Tibetan plateau.* Science, **246** (4929)**:** 474–477.

TUFNELL L. (1984) - *Glacier Hazards*. Topics in Applied Geography, Longman Group Limited, London (1984).

WALDER J.S. & COSTA, J.E. (1996) - *Outburst floods from glacier-dammed lakes: the effect of mode of lake drainage on flood magnitude*. Earth Surface and Process, **21**: 701–723.

WALDER J.S. & DRIEDGER C.L. (1994) - *Frequent outburst floods from South Tahoma Glacier, Mount Rainier, USA: relation to debris flow, meteorological origin and implications for subglacial hydrology.* Journal of Glaciology **41** (137)**:** 1–10.

YAO T., LIU S. & PU J. (2004) - *Recent glaciers retreating in High Asia and their impact on the water resources of Northwest China.* Science in China, Series D **34** (6)**:**535–543. (in Chinese).

ZHANG X. (1992) - *Investigation of glacier bursts of the Yarkant River in Xinjiang.* China. Annals of Glaciology, **16:** 135–139. (in Chinese).

ZHANG Y. & YAO T. (1998) - *The response of continental-type glaciers to climate change in China.* Journal of Glaciology and Geocryology, **20**(1)**:** 3-8 (in Chinese).

