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Variations in suspended and dissolved matter fluxes from glacial and non-glacial catchments during a melt season at Urumqi River, eastern Tianshan, central Asia

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ABSTRACT

The effects of climatic conditions on the delivery patterns of suspended solid and dissolved matter are evaluated by examining their correlation with air temperature, precipitation and runoff from glacial and non-glacial catchments at the headwaters of Urumqi River in eastern Tianshan, central Asia. The results show that the physical and chemical weathering fluxes (168 and 23 t km^{-2} yr^{-1}, respectively) associated with the glacial catchment are higher than those of the non-glacial catchment (34 and 12 t km^{-2} yr^{-1}, respectively). Significant linear correlations are found between river fluxes and air temperature in both catchments. For each degree of temperature increase, the runoff, physical weathering flux and chemical weathering flux from the glacial catchment increase by 12%, 16% and 5%, respectively. On the other hand, in the non-glacial catchment, these values are 9%, 13% and 15%, respectively, if the temperature is below 4 °C; the variations in runoff, physical and chemical weathering fluxes are irregular when the temperature exceeds 4 °C. Such a pattern for the non-glacial catchment during the melt season may be due to the influence of multiple water sources. In contrast, the relation to precipitation is relatively weak in both catchments. Furthermore, although the glacial catchment has a higher increasing rate of physical weathering flux in response to temperature increase than the non-glacial catchment, this is not the case for the chemical weathering flux, suggesting that glaciers play an important role in the effect of air temperature change on physical weathering flux.

1. Introduction

Suspended and dissolved matters in rivers play an important role in material cycling between the atmosphere, lithosphere, biosphere and oceans, and are also critical for the estimate of river material budget or the denudation rate of the catchment. For the last few decades, global warming has resulted in substantial landscape changes and influenced the variation patterns of suspended and dissolved matter fluxes. Many studies have confirmed the impacts of climatic conditions on weathering (Agren et al., 2010; Clow and Mast, 2010; Dupre et al., 2003; Gislason et al., 2009; Kump et al., 2000; Ponge et al., 2011; Riebe et al., 2004; Shin et al., 2011; Tipper et al., 2006; Vebel, 1993; West et al., 2005; White and Blum, 1995; White et al., 1999). Most of the studies on natural weathering are associated with the evaluation of the effects of precipitation, temperature and runoff on the concentrations and fluxes of suspended sediment and solute, especially in large-scale river systems. Few studies (Vebel, 1993) have been carried out to discern the direct link between climatic conditions and weathering intensity in small catchments of <10 km^2 in area. In addition, some studies have indicated that enhanced air temperature and the presence of glacial cover over a watershed can cause increase in suspended sediment load, compared to lower temperature, non-glacial catchments (Anderson, 2005, 2007; Gislason et al., 2009). Other studies have shown that glacial and snowmelt-fed rivers might have opposite runoff responses to climate changes in alpine areas (Lafreniere and Sharp, 2003). These results suggest that the study of the climatic effects on river fluxes in small alpine catchments is quite important. Differences in the climatic effect on weathering may exist between glacial and non-glacial catchments. Hence, a comparative study of the climatic effects on weathering between glacial and non-glacial catchments is required for the evaluation of the relationship between climate and weathering and the impact of glaciers on weathering in small scale alpine catchments.

Located in the eastern Tianshan Mountain, the core area of arid and semiarid central Asia, Urumqi River is the main water supply for Urumqi, the provincial capital city of Xinjiang Uyger Autonomous Region. Glacier meltwater and snow meltwater are both important contributions to the water supply for the city, and significantly influence the discharge of Urumqi River. Meanwhile, water quality at the headwaters of Urumqi River has become an important issue in recent years. Previous researches carried out in this area have focused on solute characteristics and glacier runoff change (Han et al., 2007; Kang et al., 1997; Li et al.,

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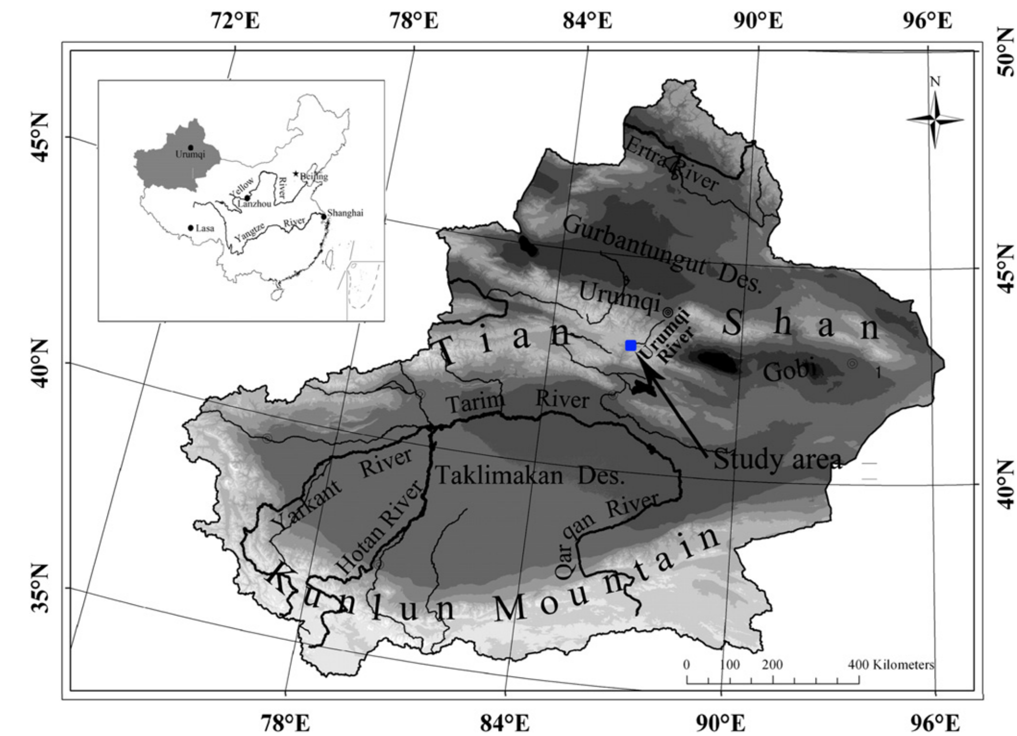

Fig. 1. Location of study site, Tianshan and the surrounding geographic environment.

2003a, 2003b, 2007, 2010; Liu et al., 1999b, 1999c; Luo, 1983; Williams et al., 1995; Woo et al., 1994; Ye et al., 2005). In the present study, we intend to analyze the effects of climatic conditions on weathering in small-scale alpine watersheds at the headwaters of Urumqi River and pay particular attention to the difference between glacial and non-glacial catchments. Chemical and physical weathering processes are quantified by measuring the suspended and dissolved fluxes, respectively.

2. Site description and methods

2.1. Sampling site description

Eastern Tianshan is located in an arid and semi-arid region of central Asia, the source region of Asian dust. Urumqi River is located in this mountain and is bordered by three deserts: the Taklimakan Desert to

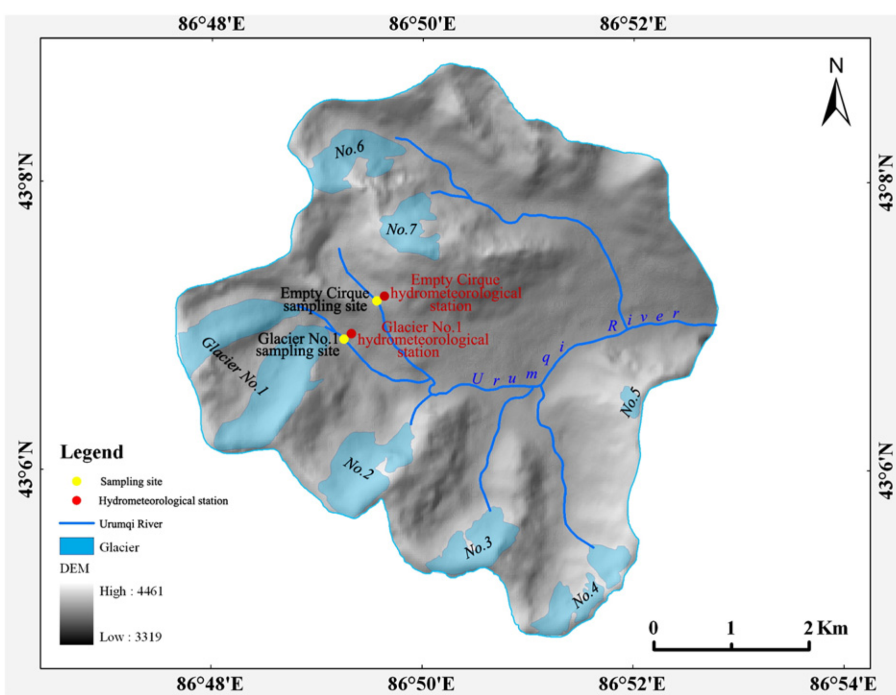

Fig. 2. Locations of the gauging/sampling stations for UG1 and EC at the headwaters of the Urumqi River. The shaded areas designate glaciers.

Table 1
Specific discharge (Q_s), TDS and SPM fluxes, average temperature and precipitation for UG1 and EC during the 2004–2008 melt seasons.

	Q_s (mm day^{-1})	TDS (g m^{-2} day^{-1})	SPM (g m^{-2} day^{-1})	Temperature (°C day^{-1})	Precipitation (mm day^{-1})
UG1					
2004	0.647 to 20.177	0.011 to 0.942	0.008 to 19.075	−1.700 to 9.800	0 to 35.800
2005	2.328 to 23.023	0.039 to 0.634	0.024 to 5.505	−2.900 to 10.000	0 to 46.100
2006	0.259 to 48.374	0.023 to 1.056	0.002 to 30.272	−3.700 to 11.900	0 to 22.700
2007	1.778 to 23.799	0.047 to 0.844	0.031 to 9.590	−3.600 to 10.450	0 to 25.400
2008	1.681 to 23.669	0.001 to 0.587	0.029 to 25.204	−3.535 to 9.900	0 to 38.800
EC					
2004	0.926 to 16.200	0.013 to 0.706	0.012 to 3.669	−3.000 to 8.400	0 to 31.200
2005	1.749 to 42.429	0.013 to 0.498	0.035 to 20.847	−3.100 to 8.100	0 to 44.500
2006	0.926 to 21.600	0.008 to 0.608	0.008 to 1.840	−4.400 to 9.300	0 to 22.200
2007	1.120 to 15.223	0.005 to 0.447	0.023 to 1.917	−5.025 to 9.300	0 to 28.400
2008	1.522 to 12.291	0.005 to 0.268	0.008 to 2.872	−2.975 to 10.000	0 to 18.800

the south, the Gurbantungut Desert to the north and the Gobi Desert to the east (Fig. 1). The river is 214 km long and has a 4684 km^2 drainage basin, of which 1070 km^2 is mountainous terrain (Liu et al., 1999b). There are two catchments at the headwaters of Urumqi River: Urumqi glacier No.1 catchment (UG1), which is largely glaciated, and Empty Cirque catchment (EC), which is virtually non-glaciated (Fig. 2).

The glacial catchment is approximately 3.34 km^2, as measured at the site of the gauging station where the river fluxes were recorded, approximately 200 m below the snout of the No.1 glacier, with a glaciated area of 1.84 km^2 (54% of the basin). In the catchment, the lithology of the moraine is primarily siliceous crystalline schist, with liberal amounts of gneiss, gabbro, granodiorite, granite and quartzite, and occasional deposits of limestone. The minerals consist mainly of breadalbaneite, biotite, dolomite and quartz, with a small amount of carbonate, gypsum and pyrite (Wang and Zhang, 1981).

The non-glacial catchment (1.68 km^2) consists mostly of bare rock and gravel on the steep slopes of the upper valley floor, some vegetation is present on the tundra soil and the peaty bottom land, accounting for less than 10% of the basin area. In the non-glacial catchment, the bedrock is primarily crystalline granite, diorite and gabbro-diabase, with some sedimentary outcrops, most of which are limestone and shale. The surface materials permit much storage, rapid drainage and easy transmission of water in the upper and middle valley floors of the cirque (Woo et al., 1994).

2.2. Collection and analysis of water samples

920 grabbed surface water samples were collected from the glacial and non-glacial catchments (sites UG1 and EC, Fig. 2), generally on a daily basis, during the melt season (i.e., June, July and August) from 2004 to 2008. Water samples were stored using pre-cleaned polyethylene bottles. All water samples were placed in Whirl-Park® bags and transported frozen from the sampling sites and stored at −18 °C until further analysis.

Water temperature, PH, total dissolved solid (TDS) and electrical conductivity were measured at each of the sites. TDS was analyzed by a Conductivity Meter (DDSJ-308A). The TDS concentration was corrected for dissolved TDS originating from precipitation, on the basis of the assumption that all dissolved Cl presented in the water samples is originated from precipitation, and that the TDS/Cl ratio of the high alpine precipitation of Urumqi River can be adopted (Zhao et al., 2008). The flux of dissolved matter was calculated by multiplying the corrected TDS concentration with the measured discharge at the time of sampling.

In addition, suspended particulate matter (SPM) was measured using an Accusizer 780A counter, which is based on the Single Particle Optical Sensing (SPOS) method, equipped with a 120-tm orifice. This particular operation process has been described by Zhu et al. (2006). The relative error for suspended matter is approximately 10% or less. The SPM concentration was calculated by using the raw count data, assuming spherical particles of uniform density $\rho = 2.65$ g cm^{-1}, which is close to that of the average crustal material (Dong et al., 2009; Liu et al., 1999a; Wake et al., 1994). SPM flux was calculated by multiplying the measured SPM concentration with the measured discharge at the time of sampling.

2.3. Measurements of discharge, daily mean air temperature and daily precipitation

Streamflow discharge and meteorological parameters were measured at the No.1 Urumqi glacier hydro-meteorological station (43°06′N, 86°49′E) and the Empty Cirque hydro-meteorological

Table 2
Comparative weathering rates for UG1 and EC at the headwaters of Urumqi River and some major world rivers.

River	Weathering rate (t km^{-2} yr^{-1})			Physical/ chemical ratio	Source
	Physical	Chemical	Total		
UG1 (China)	168	23	191	7.30	Present study
EC (China)	34	12	46	2.83	Present study
Huang He (China)	1402	30	1432	46.70	Milliman and Meade (1983)
Yangtze (China)	246	116	362	2.10	Milliman and Meade (1983)
Amazon (Brazil)	146	46	192	3.10	Milliman and Meade (1983)
Mississippi (U.S.A.)	64	40	104	1.60	Milliman and Meade (1983)
Orinoco (Venezuela)	212	52	264	4.00	Milliman and Meade (1983)
Mekong (Vietnam)	200	74	274	2.70	Milliman and Meade (1983)
Congo (Zaire)	13	10	23	1.30	Milliman and Meade (1983)
Krishna (India)	16	41	57	0.39	Ramesh and Subramanian (1988)
Cauvery (India)	0.5	40	40.5	0.01	Subramanian et al. (1985)
Mahanadi (India)	13.3	67.6	80.9	0.19	Chakrapani and Subramanian (1990)
World average	150	35	185	4.28	Jha et al. (1988)

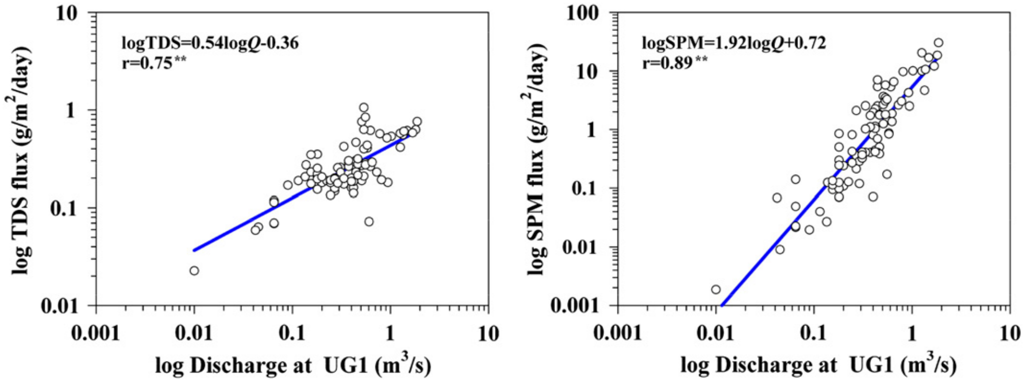

Fig. 3. Fluxes measured at the UG1: dissolved and suspended fluxes versus to discharge at the time of sampling in 2006. The symbols correspond to fluxes and the lines result from a linear regression of the data. Equations of each regression are provided on the figure where Q represents discharge in units of m^3/s and r the coefficient of determination. (**Correlation is significant at the 0.01 level).

station (43°07′N, 86°49′E) at the headwaters of Urumqi River (Fig. 2). The former was established in 1959, in the front of No.1 Urumqi glacier, for the purpose of measuring glacial runoff; the latter was constructed in 1981, in order to measure runoff from the non-glacial permafrost zone. Moreover, the elevations of the ground at these two stations are 3693 m asl and 3804 m asl, respectively. The observations at both gauging stations were carried out from June to August in 2004–2008; the water level records were converted to discharges based on rating curves, and subsequently converted into total daily volumes in cubic meters or daily runoff depths (by dividing the daily volume with the catchment area) in mm (Li et al., 2010). Air temperature and precipitation were recorded at both hydro-meteorological stations during the study periods.

2.4. Statistical analysis

The relationship between the climatic conditions and river fluxes was determined by linear regression analysis. The correlations between air temperature (and precipitation) and runoff, physical weathering flux and chemical weathering flux were derived using Statistical Product and Service Solutions 16.0 (SPSS 16.0). The following procedures are adopted. Firstly, the data were tested for normal distribution: the Shapiro–Wilk and Kolmogorov–Smirnov methods were used to check the normality of the data. Then, the Pearson product moment correlation coefficients, for bivariate correlation, were carried out to establish the correlation between climate and river fluxes. Finally, a two-tailed test of significance was used to examine the statistical significance of these correlations. The correlation was assumed to be significant if the calculated statistical significance (p) was less than 0.05. The linear least square regressions of these relationships, correlation coefficients (r), and standard errors were determined using Sigmaplot 10.0 and SPSS 16.0.

Table 3
Fit equations and correlative coefficients between the logarithm of river fluxes and the logarithm of the discharge (Q) at the UG1 and EC in 2004–2008.

	SPM	r	TDS	r
	$t\,km^{-2}\,day^{-1}$		$t\,km^{-2}\,day^{-1}$	
UG1				
2004	$\log SPM = 1.82 \log Q + 0.86$	0.82**	$\log TDS = 0.56 \log Q - 0.29$	0.67**
2005	$\log SPM = 1.73 \log Q + 0.78$	0.77**	$\log TDS = 0.44 \log Q - 0.54$	0.48**
2006	$\log SPM = 1.92 \log Q + 0.72$	0.89**	$\log TDS = 0.54 \log Q - 0.36$	0.75**
2007	$\log SPM = 2.04 \log Q + 0.92$	0.81**	$\log TDS = 0.37 \log Q - 0.39$	0.40**
2008	$\log SPM = 1.17 \log Q + 0.60$	0.52**	$\log TDS = 0.72 \log Q - 0.38$	0.58**
EC				
2004	$\log SPM = 1.21 \log Q + 0.46$	0.77**	$\log TDS = 1.12 \log Q + 0.28$	0.84**
2005	$\log SPM = 1.02 \log Q + 0.56$	0.66**	$\log TDS = 0.83 \log Q - 0.23$	0.77**
2006	$\log SPM = 0.71 \log Q - 0.12$	0.52**	$\log TDS = 1.01 \log Q + 0.01$	0.79**
2007	$\log SPM = 1.43 \log Q + 0.95$	0.71**	$\log TDS = 1.31 \log Q + 0.32$	0.73**
2008	$\log SPM = 1.21 \log Q + 0.39$	0.49**	$\log TDS = 0.72 \log Q - 0.32$	0.37**

** Correlation is significant at the 0.01 level.

3. Results and discussion

3.1. The variations of climate and river fluxes

The ranges of the average air temperature and precipitation from the UG1 hydro-meteorological station and the EC hydro-meteorological station during the melt season are listed in Table 1. These two parameters varied from −5.025 to 11.900 °C day^{-1} and 0 to 46.1 mm day^{-1}, respectively, during 2004–2008. The water discharge, dissolved and suspended solid fluxes in both catchments were ranged from 0.259 to 48.374 mm day^{-1}, 0.001 to 1.056 g m^{-2} day^{-1} and 0.002 to 30.272 g m^{-2} day^{-1}, respectively, during the study period. Thus, the average air temperature and precipitation of the UG1 catchment are about 1.24 and 1.07 times higher than those of the EC catchment, respectively. Further, the water discharge of UG1 is approximately 1.71 times higher than that of EC. The dissolved and suspended matter fluxes are both higher (by about 2.02 and 6.34 times) in the glacial catchment than in the non-glacial catchment. These observations suggest that there is a well-defined link between climate and fluxes, because enhanced air temperature and precipitation lead to increase in discharge and river fluxes in the study area.

The regional representatives for the rates of physical and chemical weathering in the glacial and non-glacial catchments at the headwaters of Urumqi River, together with other rivers in the world, are listed in Table 2. A comparison of these results reveals that the physical weathering rate in the catchments in consideration is higher than the chemical weathering rate. This phenomenon also occurs in the Yellow, Yangtze, Orinoco, and Mekong rivers, so this may represent a regional characteristic. Furthermore, UG1 has higher physical and chemical weathering fluxes (168 and 23 t km^{-2} yr^{-1}) than EC (34 and 12 t km^{-2} yr^{-1}), i.e., the weathering rates of the glacial catchment are higher than that of the non-glacial catchment, especially in terms of the physical weathering rate. Compared to the world average values, the physical weathering rate in UG1 is slightly higher, but the chemical weathering rate is lower. In the EC catchment, the physical and chemical weathering rates are both lower than the world average. The differences between glacial and non-glacial catchments may be related to the factors such as the climatic conditions, discharge, lithological characteristics of the catchment, vegetation, and glacier cover.

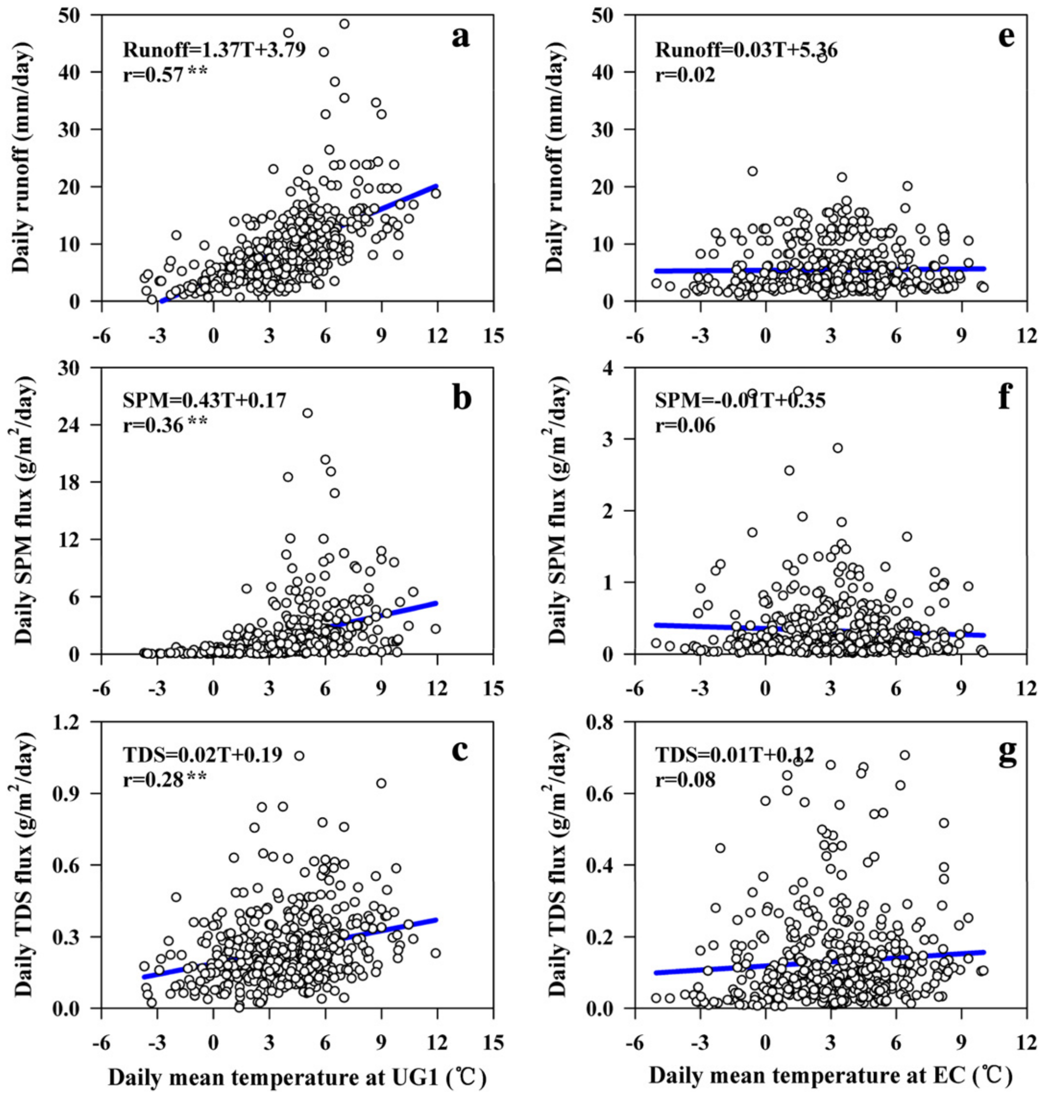

Fig. 4. Daily fluxes from UG1 and EC versus the daily mean temperature: a) and e) daily runoff in mm day^{-1}. b) and f) daily suspended flux in g m^{-2} day^{-1}. c) and g) daily dissolved flux in g m^{-2} day^{-1}. The symbols correspond to measured fluxes and line represents a least square fit of the data. The equation and coefficient of determination (r) of the fit are provided in each plot. (**Correlation is significant at the 0.01 level).

3.2. Relationship between water discharge and material fluxes

Water discharge is an important factor affecting the variation of river material fluxes. A power law relationship between water discharge and material fluxes has been proposed (Agren et al., 2010; Alexsandrov et al., 2003; Clow and Mast, 2010; Gislason et al., 2006, 2009; Godsey et al., 2009; Sinyukovich, 2003):

$$\log F = a \log Q + b \quad (1)$$

where F is the material flux, Q represents the water discharge, and b and a are regression constants. It has been suggested that a is greater than 1 for suspended solid, and it varies between 1 and 0 for dissolved matter (Agren et al., 2010; Clow and Mast, 2010; Gislason et al., 2009; Godsey et al., 2009). Representative relationships between the dissolved/suspended matter fluxes and the water discharge for the UG1 catchment, during the sampling in 2006, together with the linear regression equations and correlation coefficients (r), are presented in Fig. 3. More detailed analytical results for UG1 and EC are listed in Table 3. These results show that all of river fluxes increase to different degrees when the river water discharge increases. The suspended matter flux in UG1 increases more rapidly than the dissolved matter flux, in response to the water discharge change. However, there is no apparent difference for the increasing rate between suspended and dissolved matter fluxes in EC, as demonstrated by the slopes of the best-fit equations presented in Table 3. Moreover, the suspended matter flux in UG1 increases more rapidly with the water discharge increase than in EC, whereas the dissolved matter flux has a different pattern (i.e., in UG1 it has a slower increase than in EC). This observation demonstrates that physical weathering from the glacial catchment is more active than that of the non-glacial catchment, but this is not true for chemical weathering of the catchments in consideration.

3.3. The effects of climate on river fluxes

The effects of climate on discharge and river fluxes have been addressed by many researchers (Dupre et al., 2003; Gislason et al., 2009; Ponge et al., 2011; Shin et al., 2011; Tipper et al., 2006; West et al., 2005; White and Blum, 1995; White et al., 1999). Climatic influences on runoff and fluxes can be evaluated by calculating the correlation matrix between runoff, physical weathering flux, and chemical weathering flux and climate parameters (such as temperature and precipitation). The calculations for the present study areas are presented in Fig. 4. A significant positive correlation (at the level of $p<0.01$) is found between daily mean air temperature and runoff

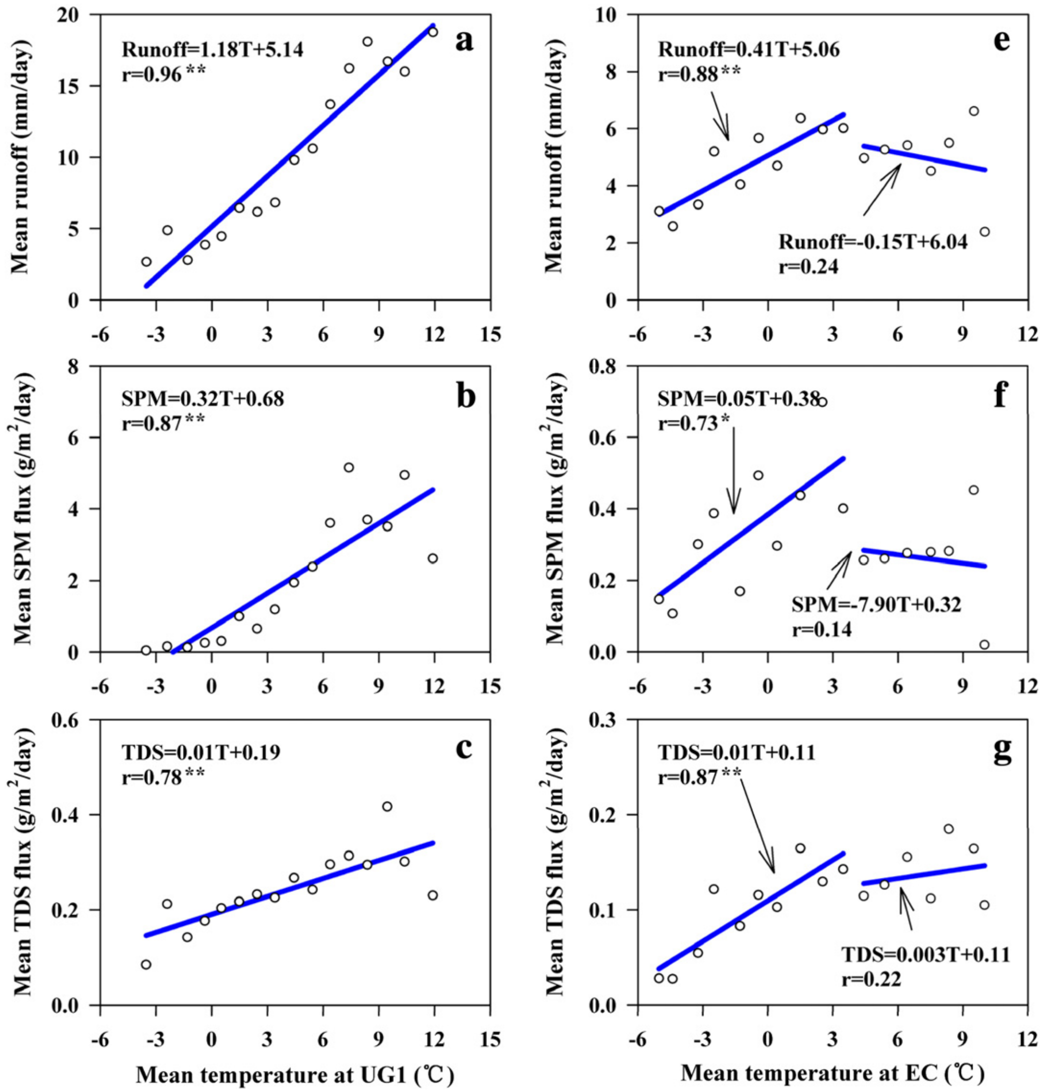

Fig. 5. Mean river fluxes versus mean air temperature in the range of each temperature in UG1 and EC: a) and e) mean runoff in mm day^{-1}. b) and f) mean suspended material flux in g m^{-2} day^{-1}. c) and g) mean dissolved flux in g m^{-2} day^{-1}. The symbols correspond to measured fluxes and line represents a least square fit of the data. The equation and coefficient of determination (r) of the fit are provided in each plot. (**Correlation is significant at the 0.01 level; *correlation is significant at the 0.05 level).

and between river fluxes and air temperature in UG1. The slopes of the regression lines in Fig. 4 yield 15% increase in runoff, 11% increase in SPM flux, and 7% increase in TDS flux for each degree of air temperature increase. However, for the EC catchment, there are poor correlations between daily mean air temperature and runoff and between river fluxes and air temperature. These phenomena may be influenced by a number of factors including 1) the larger diurnal variation of air temperature in the alpine watersheds; 2) a relatively small glacier area; and 3) the hysteresis effect of air temperature on glacier and snow.

To further examine the variation of river fluxes with air temperature change in both catchments, the average values of air temperature, runoff, SPM flux and TDS flux in the range of each degree of temperature are calculated. In terms of the linear regression analysis (Fig. 5), the best-fit equations for UG1 in Fig. 5 indicate 12% increase in runoff, 16% increase in SPM flux, and 5% increase in TDS flux for each degree of air temperature increase. The change rates of the river fluxes with air temperature change based on calculation and measurements are close for UG1. Meanwhile, significant positive correlations (at the level of $p<0.05$) are found between air temperature and the calculated river

Table 4
Correlation coefficients (r) and statistical significance (p) of linear correlations among runoff, suspended and dissolved fluxes versus precipitation in both catchments in 2004–2008.

	Runoff		SPM		TDS	
	r	p	r	p	r	p
UG1	−0.02	0.62	−0.03	0.49	−0.01	0.85
EC	0.36	0.00	0.12	0.01	0.05	0.25

Table 5
Comparative average values of TDS and SPM or Dust of the different samples which include precipitation, surface snow samples, ice core samples, and glacier meltwater samples and river water samples.

Different samples	TDS	SPM or dust	
	Concentration ($mg\ L^{-1}$)	Concentration ($mg\ L^{-1}$)	Average particulate size (μm)
Precipitation	12.77	52.98	1.36
Surface snow	6.38	95.29	1.45
Ice core	2.95	154.36	1.70
Glacier meltwater	38.84	256.29	2.11
UG1	41.04	154.43	2.03
EC	31.24	69.60	1.83

fluxes in EC when mean air temperature is below 4 °C. The slopes of the linear regression equations yield 9% in runoff, 13% increase in SPM flux, and 15% increase in TDS flux for each degree of air temperature increase in EC. However, the correlation coefficients of the calculated values between temperature and river fluxes in EC are not statistically significant when air temperature exceeds 4 °C. Thus, the effects of air temperature on river fluxes in EC are complex. A study about stream processes in present study area has shown that there are multiple streamflow sources for EC, including rainfall, snowfall and active layer ground ice-melt in summer, but the main contributor of runoff in the spring is snowmelt (Woo et al., 1994). The average values of air temperature in June, July and August for EC during the study period are 2.200, 4.068 and 3.378 °C, respectively. Thus, there is an intricate response to air temperature for the runoff which is composed of multiple water sources during the higher temperature period (July) in EC, which in turn causes the complex river flux patterns in the non-glacial catchment.

In contrast to the significant relationships found between fluxes and air temperature summarized in Fig. 5, the correlation between precipitation and fluxes is relatively poor, as demonstrated by the correlation coefficients (r) and statistical significance level (p) listed in Table 4. In UG1, the poor relationships may be due to the strong influence of glacial meltwater on runoff. A previous study has shown that streamflow for UG1 is predominated by new water or instant snowmelt, representing 60.4% of the total discharge (Liu et al., 1999c). The small supply of precipitation to runoff may have also led to the poor influence of precipitation on river fluxes. In EC, multiple streamflow sources and local topography both influence the relationship between precipitation and river fluxes.

3.4. The effect of glaciers on river fluxes

The effects of climate on river fluxes are different between the glacial and the non-glacial catchments, implying that glaciers have an important function in climatic impacts on river fluxes in alpine watersheds. Fig. 5 shows that the effect of air temperature on physical weathering flux is greater in the glacial catchment. Suspended matter flux increases by 16% for each degree of temperature increase in the glacial catchment, but it is only 13% in the non-glacial catchment. However, the presence of glaciers apparently has a different effect on the fluxes associated with chemical weathering. The dissolved matter flux increases by 5% in the glacial catchment and 15% in the non-glacial catchment.

Elsewhere, Anderson (2005) and Gislason et al. (2009) have also shown the influence of glaciers on weathering. As outlined by the data in Table 5, glacier meltwater of the Urumqi glacier No.1 has larger concentrations and average particulate sizes of SPM than UG1 and EC. However, the concentration and average particulate sizes of SPM in precipitation are both smaller than that of UG1 and EC. These comparisons suggest that glacier meltwater can enhance to the concentration of suspended matter in the glacial catchment, but the precipitation will reduce the concentration. Moreover, the main contribution to the runoff in UG1 is glacier meltwater, which is mainly controlled by air temperature, and the second is precipitation. However, the runoff in EC is mainly supplied by precipitation, without glacier meltwater (Liu et al., 1999c; Woo et al., 1994). Consequently, the effect of air temperature on the material flux due to physical weathering in the glacial catchment is larger than that of the non-glacial catchment. In contrast, concentrations of dissolved matter in surface snow, ice core and glacier meltwater are apparently smaller than that of UG1. As a result, glacier meltwater and snow meltwater will dilute the dissolved matter in streamflow. This explains why the presence of glaciers has the different effect on the flux in association with chemical weathering.

In addition, one of the environments with most intense physical erosion on the earth is found in temperate, glacierized basins because the glaciers pluck and grind across the full width of the valley bottom, producing a sediment load characterized by a broad grain-size distribution and sediment yields that are substantially higher than those of other types of environments (Anderson, 2005; Li et al., 2003a, 2003b). For the dissolved matters, Oelkers and Schott (1995, 2001) and Oelkers (2001) have shown that the effect of air temperature on chemical weathering is also influenced by the dissolution rate of the surficial materials.

4. Conclusions

The climatic effects on river fluxes are analyzed by correlating the dissolved and suspended matter fluxes with air temperature, precipitation and runoff in the glacial and non-glacial catchments at the headwaters of Urumqi River. The results reveal that the glacial catchment has higher physical and chemical weathering fluxes (168 and 23 t km^{-2} yr^{-1}, respectively) than the non-glacial catchment (34 and 12 t km^{-2} yr^{-1}, respectively). The average air temperature and precipitation of the glacial catchment are about 1.24 and 1.07 times higher than those of the non-glacial catchment, respectively, resulting in higher dissolved and suspended matter fluxes (i.e., 2.02 and 6.34 times higher) in the glacial catchment. Therefore, there is a correlation between climatic conditions and river fluxes in alpine watersheds.

Significant positive correlations exist between air temperature and river fluxes in both catchments, especially in the glacial catchment. For each degree of air temperature increase, the runoff, physical weathering flux and chemical weathering flux in the glacial catchment increase by 12%, 16% and 5%, respectively, whereas in the non-glacial catchment these values are 9%, 13% and 15%, respectively, when the air temperature is below 4 °C. In the non-glacial catchment poor correlation occurs between air temperature and river fluxes when the temperature exceeds 4 °C, which may be due to the multiple water sources. There is a poor correlation between precipitation and river material fluxes in both catchments.

Glaciers play a critical role in controlling the relationship between air temperature and the material flux related to physical weathering, but they do not have the same function for the chemical weathering flux. The processes that are responsible for these observations may be associated with the fact that, due to glaciers grinding across the full width of the valley bottom, additional suspended matter is supplied to the glacier meltwater, enhancing the concentration of suspended matter in the river flow. On the other hand, the glacier meltwater may dilute the dissolved matter, weakening the influence of glaciers on the chemical weathering flux; the effect of air temperature on the chemical weathering flux is reflected by the dissolution rate of the surficial materials.

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