The Land-Sea Interactions Related to Ecosystems: The Yukon River and Bering Sea

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ABSTRACT

For salmon's going up, the Yukon River in Alaska is known to be the longest river in the world. In order to explore the effects of mass and heat fluxes of the river on the ecosystem in the Bering Sea, discharge, turbidity and water temperature were monitored in the middle and downstream reaches in 2006 to 2007. Results obtained reveal that both the river water temperature and suspended sediment concentration varied hysteretically in response to glacier-melt discharge or rainfall runoffs. Runoff analysis for the time series of discharge indicates that the Yukon river discharge is occupied by the 16.9% glacier-melt discharge. This suggests a significant decrease in discharge by glacial retreat from global warming, which could affect the ecosystem in the river and Bering Sea.

Keywords: Yukon River, Runoff analysis, Bering Sea, Sediment load, Ecosystem

INTRODUCTION

The drainage basins of the subarctic to arctic Yukon River, Alaska, and Mackenzie River, Canada, are composed of spacious permafrost regions and glacierized mountainous regions. The river runoffs in summer occur mainly by glacier-melt and rainfalls [1]. The suspended sediment load in the glacial Tanana River, a tributary of the Yukon River, is controlled by the glacier-melt in the headwater Alaska Range and Wrangell Mts., indicating the 41–58% contribution of glacier-melt discharge to the Tanana river discharge [2]. The discharge, sediment load and heat flux in the Yukon River are important to the ecosystem in summer in the river and Bering Sea, because the water temperature and the organic matters included in suspended sediment could affect the primary production and food chain in the river and coastal regions.

In this study, as a step to clarify the mechanisms of mass and heat fluxes in the Yukon River by modelling and to estimate effects of the river fluxes on the ecosystem in the river basin and sea, the time series of discharge and suspended sediment concentration are simulated by runoff analyses.

STUDY AREA AND METHODS

More than half the Yukon River basin (area, 8.55×10^5 km^2) belongs to the subarctic region south of the Arctic Circle (66°33′N) (Fig. 1; [3]). The glacierized regions in the river basin are located mostly

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Fig. 1 Yukon River basin (gray) and observation sites.

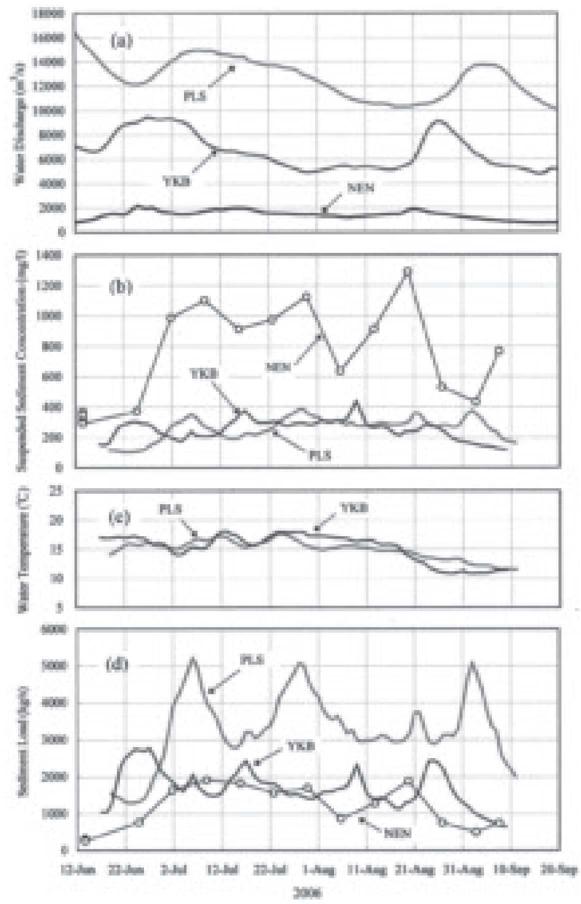


Fig. 2 Time series of daily mean (a) discharge, (b) SSC, (c) water temperature and (d) sediment load obtained at sites PLS, YKB and NEN in 2006.

in the headwater Alaska Range, Wrangell Mts. and St. Elias Mts., occupying 1.1% of the basin area [1]. Using self-recording turbidimeters and temperature data loggers, water turbidity and temperature were monitored at 1 h intervals at two USGS gauging stations, site PLS (Pilot Station) and site YKB (Yukon Bridge) in June to September 1999, 2006 and 2007 [3]. At site PLS, the monitoring was conducted also in the ice-covered season of October 2006 to May 2007. The monitoring of water temperature and turbidity was carried out also at sites NEN and PC in the Tanana river basin in June to September of 2001 to 2007 [2]. The turbidity (ppm) was converted into suspended sediment concentration (SSC; mg/l) by using the significant correlation ($r^2 = 0.748$ to 0.838) between turbidity and SSC obtained simultaneously from the filtration of depth-integrated water samples at mid-channels. The suspended sediment load, L (kg/s), was calculated by $L = Q \bullet C$, where Q is the discharge (m^3/s) and C is the SSC (g/l). The discharge data at sites PLS, YKB, NEN and PC were supplied by U. S. Geological Survey (USGS), and meteorological data in or around the Yukon river basin were downloaded from the web sites of USGS, Western Regional Climate Center (WRCC) and National Oceanic and Atmospheric Administration (NOAA). The discharge data for June to September 2006 are approved by USGS, but those for October 2006 to September 2007 are still provisional.

RESULTS AND DISCUSSION

Figure 2 shows time series of discharge, SSC, water temperature and sediment load at sites PLS, YKB and NEN. The SSC and sediment load at site NEN were obtained from water sampling. As a result, the sediment load appears to fluctuate as being independent of the discharge (Fig. 2a and d). The SSC varies greatly at sites PLS and YKB during the gradually decreasing discharge for early July to late August, due to rainfall and glacier-melt sediment runoffs.

The magnitude of sediment load at site PLS can be explained mostly by the sum of sediment load at sites YKB and NEN, since the Tanana River joins the Yukon River downstream of site YKB (Fig. 1). Time lags of the marked four sediment load peaks between sites YKB and PLS (1097 km distant) range from 8 days 17 hrs to 12 days 10 hrs, thus indicating the propagation speed of 1.02–1.45 m/s (Fig. 2d).

The glacier-melt occurs markedly in late June to July [2, 4]. The decrease of more than 2°C in water temperature, correspond- ing to the SSC peaks on 17 July at site YKB and on 27 July at site PLS, indicates that the sediment runoff occurred as a glacier-melt sediment runoff (Fig. 2c). The other SSC peaks resulted mainly from rainfall sediment runoffs, since water temperature did not then decrease greatly.

Figure 3 shows relations between daily mean discharge and SSC at sites YKB and PLS in 2006. The SSC varies with a temporal pattern quite different from that of discharge (Fig. 2 a and b). Thus, there is no unique sediment rating curve at each site, as described by $C = aQ^b$, where C is the SSC (mg/L), Q is the discharge (m^3/s), and a and b are empirical constants. In June to July, when relatively high temperature or large rainfalls occurred in the headwater glacierized regions (site PC), the sediment ratings likely appeared. The stable sediment supply from glacierized regions thus seems to build up the sediment rating curves. The small variations at high SSC in July and August, accompanied by large discharge variations, suggest that the amount of sediment eroded is proportional to discharge under condition of stable sediment availability. Hence, the sediment source is possibly located in or around the river channels as bed materials or bank deposits.

Figure 4 shows relations between sediment load and water temperature at sites YKB and PLS in 2006. The relations in the glacier-melt season likely appear as clockwise or anticlockwise loops, depending on which of rainfall sediment runoffs (anticlockwise) or glacier-melt sediment runoffs (clockwise) occurred upstream. After 18 or 19 August, the water temperature consistently decreased, being independent of variations in sediment load. This indicates that the cooling from the atmosphere to the river continues toward the winter.

Figure 5 shows temporal variations of daily mean discharge, water temperature and SSC at site PLS for June 2006 to September 2007. As shown by water temperature at 0°C, the ice-covered period continued about six months from about 2300 h, 4 November 2006, and the breakup of covered ice occurred at about 1300 h, 8 May 2007. The SSC fluctuated even in the ice-covered period as in November and December 2006. Actually, the discharge should have then fluctuated under the ice cover. The discharge data are obtained from the river-stage recording, using a rating curve of stage-discharge relations. The variations of discharge would then have led to fluctuation of the flow velocity under the constant stage. The SSC started to increase in mid-March of 2007, and then decreased suddenly before the breakup. This suggests that the slow mass move-

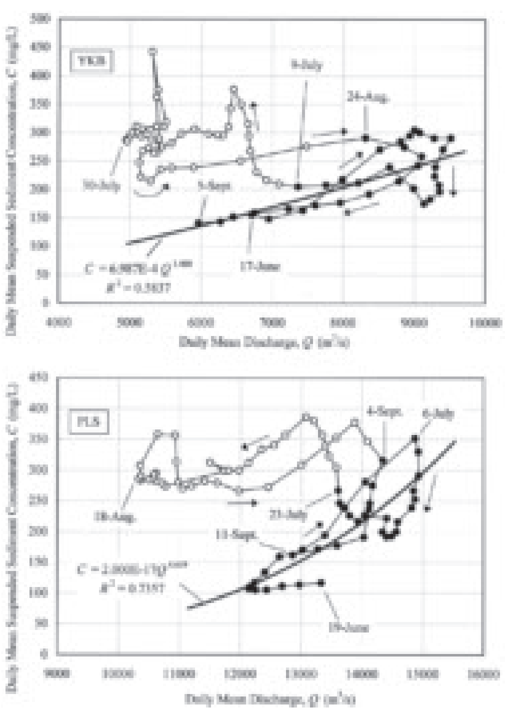


Fig. 3 Relations between discharge and SSC at sites YKB and PLS in 2006.

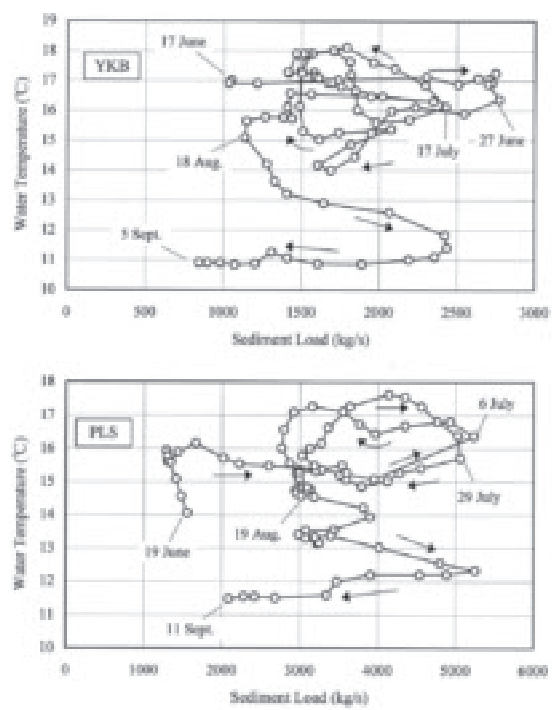


Fig. 4 Relations between sediment load and water temperature at sites YKB and PLS in 2006.

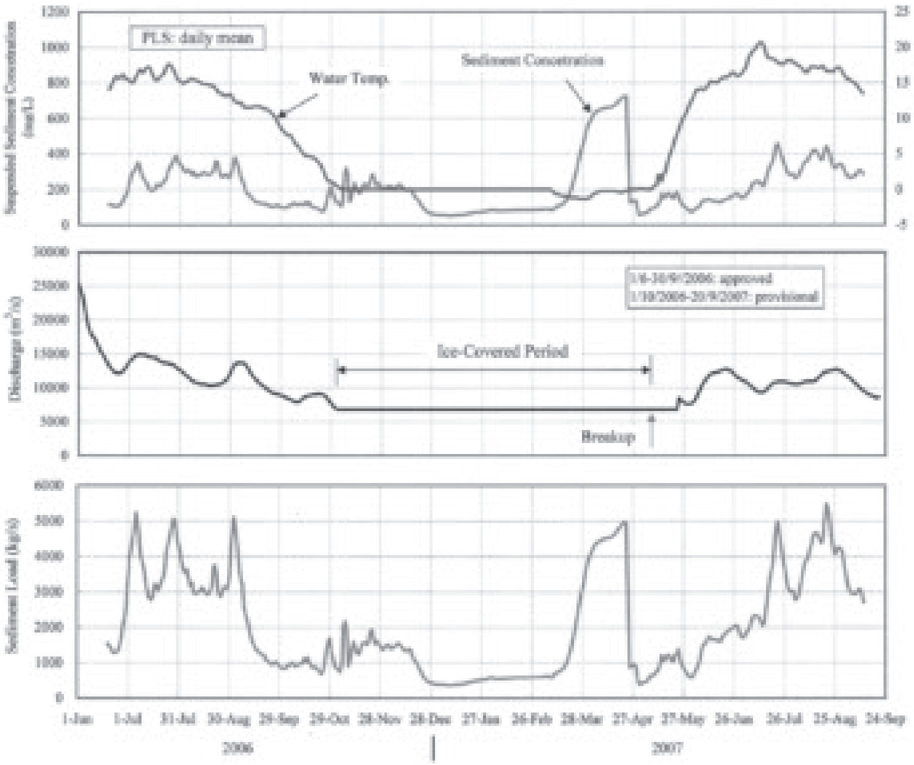


Fig. 5 Time series of daily mean water temperature, SSC, discharge and sediment load obtained at site PLS in June 2006 to September 2007.

ment of covered ice eroded bed materials near the turbidity sensor. It is unknown if or not the high SSC spread in the cross-section.

The snowmelt runoffs, starting after the breakup, were much smaller in 2007 than in 2006 because of relatively small snow depth. Generally, the sediment-load peaks are produced by rainfall runoffs in autumn [3]. More turbidity monitoring is needed, since the sediment erosion from the ice movement could also induce high sediment load

RUNOFF ANALYSES

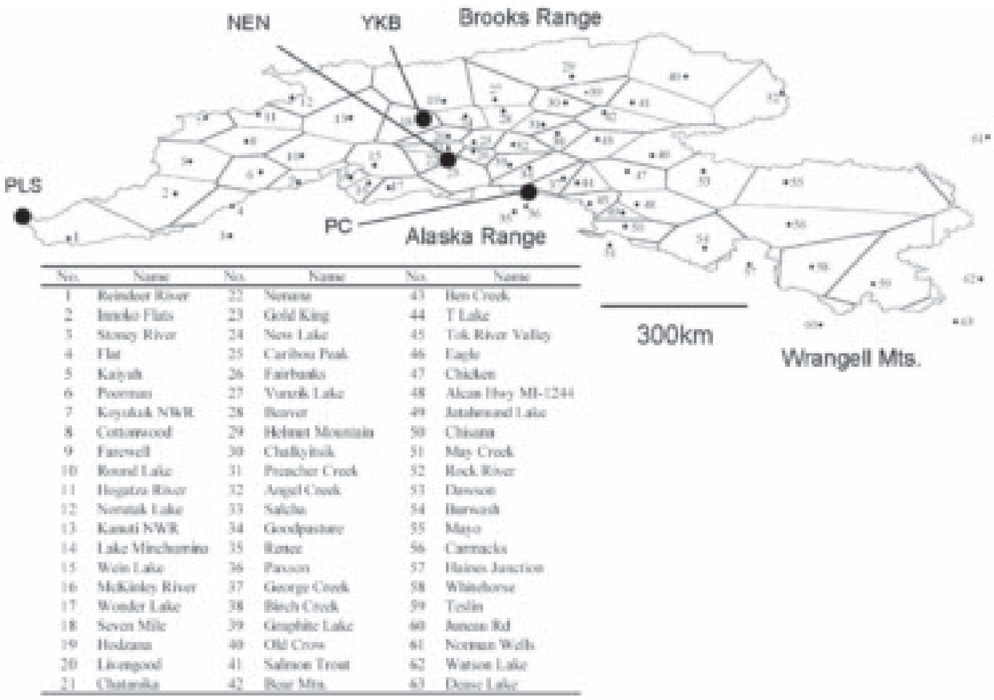
Preparation

According to the locations of 63 weather stations in or around the Yukon river basin, the river basin was separated into 63 sub-areas by the Thiessen method (Fig. 6). The data of daily mean air temperature and daily rainfalls were downloaded from the web sites of WRCC, NOAA and USGS. The air temperature in each sub-area was corrected for elevation by applying the lapse rate of −0.6°C/100 m to a digital elevation model, National Elevation Dataset (NED) (http://seamless.usgs.gov/). By superimposing a Landsat image of 2001 on the NED, the glacierized area was determined as 1.1% of the river basin. An elevation effect on the rainfall in each sub-area was taken into account by the way of Chikita et al. [2]. Using the corrected air temperature, actual evapotranspiration was calculated by the Hamon method and the Pike's equation [2, 4], and glacier-melt amount at the glacier surfaces by the positive degree-day approach (PDDA) [5].

The snowmelt runoffs, starting after the breakup, were much smaller in 2007 than in 2006 because of relatively small snow depth. Generally, the sediment-load peaks are produced by rainfall runoffs in autumn [3]. The monitoring of turbidity is needed more, since the sediment erosion from the ice movement could also induce high sediment load

Model application

In this study, the tank model, developed by Sugawara [6], was applied to simulate time series of the river discharge at site PLS. For simulation, the 63 subareas in Fig. 6 were complied into 5 sections (Fig. 7). Considering the underground structures, three serial permafrost tanks and a glacial tank were assigned to permafrost regions and glacierized regions, respectively [2]. Four glacial tanks and a gla-



No.	Name	No.	Name	No.	Name
1	Reindeer River	22	Nenana	43	Ben Creek
2	Innoko Flats	23	Gold King	44	T Lake
3	Stoney River	24	New Lake	45	Tok River Valley
4	Flat	25	Caribou Peak	46	Eagle
5	Kaiyuh	26	Fairbanks	47	Chicken
6	Poorman	27	Yuruzik Lake	48	Alcan Hwy MI-1244
7	Koyukuk NWR	28	Beaver	49	Jatahmund Lake
8	Cottonwood	29	Helmut Mountain	50	Chisana
9	Farewell	30	Chalkyitsik	51	May Creek
10	Round Lake	31	Preacher Creek	52	Rock River
11	Hogatza River	32	Angel Creek	53	Dawson
12	Norutak Lake	33	Salcha	54	Burwash
13	Kanuti NWR	34	Goodpasture	55	Mayo
14	Lake Minchumina	35	Ronee	56	Carmacks
15	Wein Lake	36	Paxson	57	Haines Junction
16	McKinley River	37	George Creek	58	Whitehorse
17	Wonder Lake	38	Birch Creek	59	Teslin
18	Seven Mile	39	Graphite Lake	60	Jencon Rd
19	Hodzana	40	Old Crow	61	Norman Wells
20	Livengood	41	Salmon Trout	62	Watson Lake
21	Chatanika	42	Bear Mtn.	63	Dease Lake

Fig. 6 Sub-areas separated by the Thiessen method.

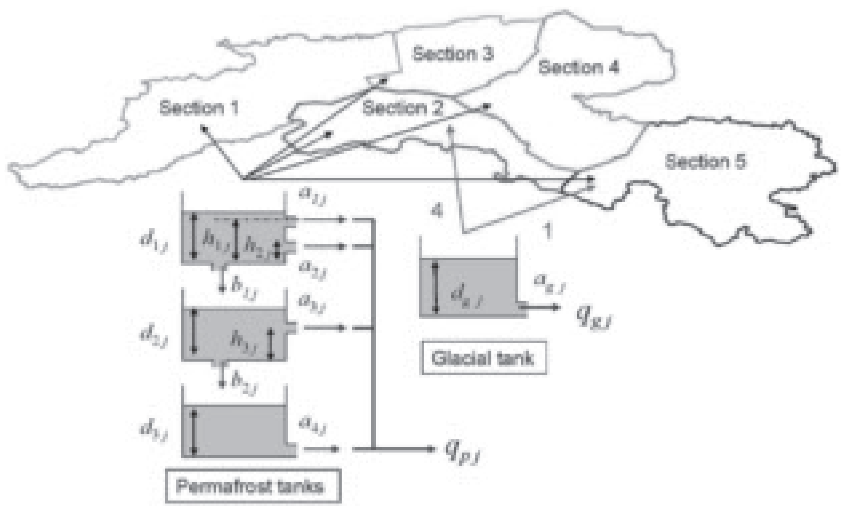


Fig. 7 Yukon River basin compiled into 5 sections and tanks assigned for simulation.

cial tank were assigned to Section 2 and Section 5, respectively, corresponding to the glacierized area in the two sections (Fig. 1). The glacier-melt in Section 3 was neglected. The permafrost tanks were given to all the sections. The rainfall subtracted by actual evapotranspiration was given to the top of the permafrost tanks, and the rainfall and glacier-melt amount by PDDA to the glacial tank. The discharges, q_{1j}, q_{2j}, q_{3j} and q_{4j} (mm/h), from side orifices of permafrost tanks are calculated by $q_{1j} = a_{1j} \times \{d_{1j}\ (t) - h_{1j}\}$, $q_{2j} = a_{2j} \times \{d_{1j}\ (t) - h_{2j}\}$, $q_{3j} = a_{3j} \times \{d_{2j}\ (t) - h_{3j}\}$ and $q_{4j} = a_{4j} \times d_{3j}\ (t)$, and the bottom discharge, q_{b1} and q_{b2} (mm/h), from the upper two permafrost tanks, by $q_{b1} = b_{1j} \times d_{1j}$ and $q_{b2} = b_{2j} \times d_{2j}$ ($j = 1, 2, \ldots, 5$), where a_{ij} is the discharge parameter (/h), d_{ij} is the water storage (mm) in tank, h_{ij} is the height (mm) of side orifice ($i = 1, 2, 3$), and b_{1j} and b_{2j} are the bottom discharge parameter (/h). The tank pa-

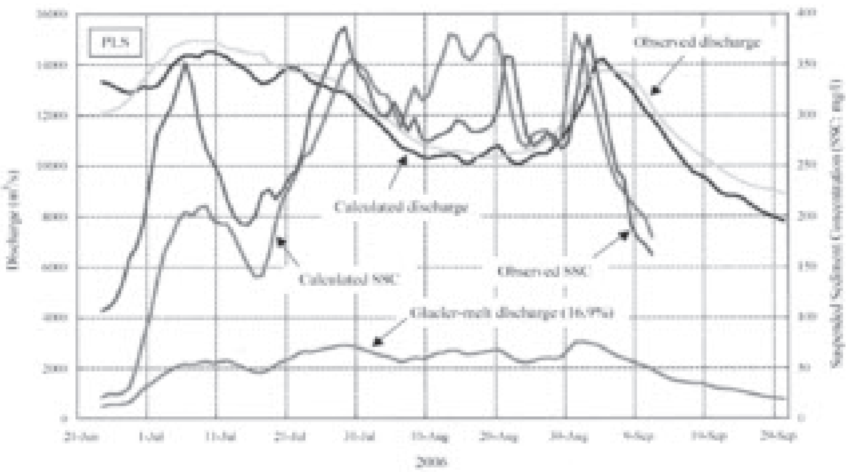


Fig. 8 Comparison between simulated and observed results for the Yukon River discharge and SSC.

rameters, a_{ij}, d_{ij}, h_{ij}, b_{1j} and b_{2j} were determined at values such as giving the best fit to observed discharge series. The total discharge, $q_{p\,j}$, from the permafrost tanks and the discharge, $q_{g\,j}$, from the glacial tank were calculated at a constant time lag (8 to 10 days) from a certain section to the neighboring downstream section.

Supposing that the sediment source is located only in glacierized regions, a sediment rating curve was applied only to discharge from glacial tanks. The sediment rating curve is expressed by $L = a \times (q_g)^b$, where L is the sediment yield per unit area per unit time (kg/m^2 • s), q_g is the discharge (mm/s) from the glacial tanks, and a and b are the empirical coefficients. The coefficients, a and b, were determined to give the best fit to the observed SSC series.

Simulated results

Fig. 8 shows comparisons between observation and simulation for discharge and SSC series. The simulated discharge is very reasonable to the observed one (correlation coefficient, $r = 0.973$), but the simulated SSC cannot sporadically explain the observed SSC with less correlation ($r = 0.773$). The reasonable simulation leads to the conclusion that the Yukon River discharge is occupied by the 16.9% glacier-melt discharge. This suggests that a decrease in the glacierized area, due to global warming, significantly decreases the Yukon River discharge. Then, the glacier-melt sediment load could also decrease by a decrease in glacial sediment yield. The decrease of both discharge and sediment load would seriously affect the ecosystem in the Bering Sea.

The SSC in early July and mid-August is underestimated and overestimated, respectively. The observed high SSC in July is possibly due to snowmelt sediment runoff, which is not considered in this model. The simulated high SSC in August was produced by rainfalls in the upstream regions. At a certain discharge from the glacierized regions, rainfall discharge tends to produce relatively low SSC, compared with glacier-melt discharge [7], which probably gave the overestimation in simulation.

FUTURE WORKS

A physically-based model simulating both discharge and sediment load series have to be developed to elucidate the processes of rainfall and glacial runoffs or sediment runoffs for more detail. The model development could predict glacial or permafrost effects on the ecosystem in the river basin and the Bering Sea and a change of the effects for the future, due to global warming. The river fluxes of water, sediment and heat are possibly related also to the abundance of salmon going up in the Yukon River. To clarify the present relationship between river fluxes and ecosystem in the sea is very important, since the relationship is sensitive to climate change.

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REFERENCES

1. Brabets, T.P., Wang, B. and Meade, R., 2000. Environmental and hydrologic overview of the Yukon river basin, Alaska and Canada. Water-Resources Investigations Report, 99–4204, US Geol. Surv., 106pp.
2. Chikita, K.A., Wada, T., Kudo, I., Kido, D., Narita, Y. and Kim, Y., 2007. Modelling discharge, water chemistry and sediment load from a subarctic river basin: the Tanana River, Alaska. IAHS Publ., 314, 45–56.
3. Chikita K.A., Kemnitz, R. and Kumai, R., 2002. Characteristics of sediment discharge in the subarctic Yukon River, Alaska. Catena, 48, 235–253.
4. Dingman, S.L., 2002. Physical Hydrology, 2nd edn. Prentice-Hall, Englewood Cliffs, New Jersey, USA.
5. Braithwaite, R.J., 1995. Positive degree-day factors for ablation on the Greenland ice sheet studied by energy balance modeling. Jour. Glaciol., 41, 153–160.
6. Sugawara, M., 1972. A method for Runoff Analysis. Kyoritsu Shuppan Press, Tokyo (in Japanese).
7. Kido, D., 2007. Water discharge and sediment load from a glacier-covered drainage basin: observations and modelling. Ph. D. thesis, Hokkaido University, 59pp.