Observed runoff, jökulhlaups and suspended sediment load from the Greenland ice sheet at Kangerlussuaq, West Greenland, 2007 and 2008

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ABSTRACT. This study fills the gap in hydrologic measurements of runoff exiting a part of the Greenland ice sheet (GrIS), the Kangerlussuaq drainage area, West Greenland. The observations are of value for obtaining knowledge about the terrestrial freshwater and sediment output from part of the GrIS and the strip of land between the ice sheet and the ocean, in the context of varying ice-sheet surface melt and influx entering the ocean. High-resolution stage, discharge and suspended sediment load show a decrease in runoff of ~25% and in sediment load of ~40% from 2007 to 2008 in response to a decrease in the summer accumulated number of positive degree-days. During the 2007 and 2008 runoff seasons, jökulhlaups were observed at Kangerlussuaq, drained from an ice-dammed lake at the margin of the GrIS.

INTRODUCTION

The Greenland ice sheet (GrIS) is the Northern Hemisphere's largest terrestrial permanent ice- and snow-covered area, and serves as a water reservoir that is highly vulnerable to ongoing climatic variations and change. Studies have documented GrIS mass loss, with an increasing trend of loss and runoff over the last several decades (e.g. Box and others, 2006; Fettweis, 2007; Hanna and others, 2008; Mernild and others, 2008a) and with ice-sheet melt extent and runoff at a record high in 2007 (Mernild and others, 2009a,b). In spite of the obvious need for information about GrIS freshwater runoff and its related sediment load, only a few observations are available. High-resolution observations are filling the gap in hydrologic measurements of water exiting the GrIS, especially in the context of varying ice-sheet surface melting. Such observations are important for estimating the impact of runoff, erosion and suspended sediment load on the Arctic marine ecosystem, and for obtaining knowledge about the frequency and intensity of, and processes leading to, glacier outbursts (jökulhlaups) (Sugden and others, 1985; Roberts, 2005). High-resolution observations are also important for runoff model validation before upscaling to ungauged GrIS sub-basins to simulate the freshwater contribution to eustatic sea-level rise and changes in ocean salinity.

The goal of this study is to present the observed 2007 and 2008 runoff and suspended sediment load from the GrIS Kangerlussuaq drainage area, West Greenland, including two consecutive yearly jökulhlaup events. This is the first time seasonal hydrologic measurements of water flow exiting the GrIS Kangerlussuaq drainage area have been monitored, filling the information gap between the melting ice sheet and the influx of fresh water entering the ocean.

STUDY AREA

At Kangerlussuaq (Søndre Strømfjord), West Greenland, a gauging station is situated at the Watson River drainage basin outlet (6279 km^2) and provides information on stage, runoff and sediment concentration and load from a GrIS sub-basin into Kangerlussuaq Fiord (Fig. 1). The outlet is located about 30 km downstream from the GrIS margin. This location is one of the best for observing GrIS runoff and sediment, due to well-defined, stable bedrock cross-sections. Braided channels with unstable banks characterize most other river outlets in Greenland, making accurate runoff monitoring almost impossible.

METHODS

Runoff investigations (Fig. 2) were initiated in 2007 at the Watson River outlet (Mernild and others, 2008b). River stage was measured approximately 75 m upstream from the outlet using a pressure transducer for every 20 min in 2007 and for every 5 min in 2008. Discharge was determined 21 times during the 2007 and 2008 runoff seasons by measuring cross-sectional area and velocity using the float method. Due to flow turbulence and the subcritical and supercritical flow regime, it is expected that the measured surface velocity is representative through depth. These discharge measurements were used to develop a stage–discharge relationship ($R^2 = 0.91$) and to convert the stage measurements into a river discharge time series. The relationships are expected to have an accuracy of 10–15%.

Suspended sediment concentration was determined (1) by filtering 17 water samples collected manually (by ISCO peristaltic pump samples) for 2007 and 2008 and (2) by Partech Soli-Tech 20 transmissometer measurements for 2008 only. A discharge–water-sample relationship ($R^2 = 0.81$) was established, with an expected accuracy of 10–15%. Soli-Tech observations were calibrated using simultaneously collected water samples ($R^2 = 0.63$), and converted into suspended-sediment concentration and sediment-load time series. The suspended sediment load represents the total sediment load due to fully mixed water-column conditions. For 2008, the Soli-Tech instrument

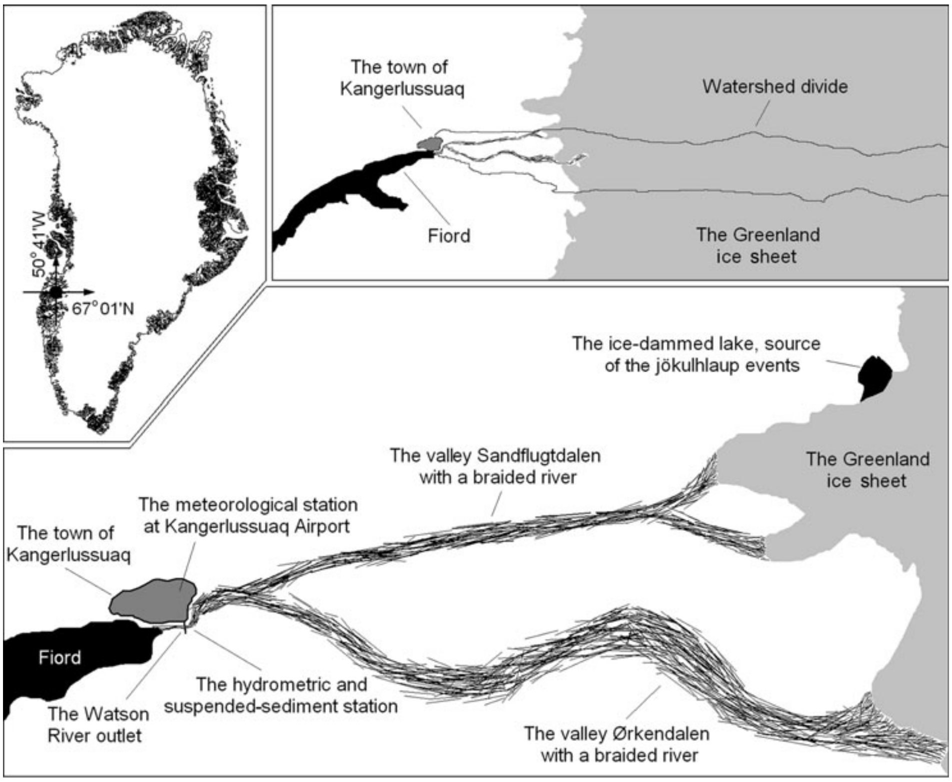

Fig. 1. Kangerlussuaq drainage area (black dot on Greenland inset map), including the GrIS, location of the ice-dammed lake (source of the jökulhlaup events) and the hydrometric and suspended-sediment station at the drainage basin outlet. The watershed divide is estimated based on the surface topography in the program River Tools. The figure is not to scale.

suspended-sediment time series deviate significantly from the water-bottle sample time series at the beginning and end of the runoff season (Fig. 2). During periods of low stage (approximately <13 m; Fig. 2) the Soli-Tech instrument, unfortunately, is situated above the river stage, causing observation errors. However, the difference between water-sample and Soli-Tech estimated cumulative suspended load is only ~1%.

RESULTS

Figure 2 shows the 2007 and 2008 seasonal stage and hydrograph from the end of May through mid-September from the GrIS Kangerlussuaq drainage area. A full year's comparison is impossible due to missing stage measurements at the beginning and end of the runoff season. However, the seasonal water-level range varies by ~9 m in 2007 and 6.5 m in 2008. At the beginning and end of the seasonal stage observations, there is limited diurnal variation, while during summer (July and August) a diurnal variation of approximately 0.5–0.75 m is observed, with the maximum stage at about 0500 h (Fig. 2). This indicates a lag time of 15–16 hours between maximum daily GrIS periphery surface melt and maximum stage at the outlet. During winter (September through April/May), runoff events might occur in relation to hot-spell melt events (föhn winds) and liquid (rain) precipitation events. No observed runoff values through winter periods occurred.

The observed runoff varies from $1.769 \times 10^9\,m^3$ in 2007 to $1.283 \times 10^9\,m^3$ in 2008, indicating a decrease in runoff volume of ~25%. The average discharge is 200–400 $m^3\,s^{-1}$ in 2007, but only 100–200 $m^3\,s^{-1}$ in 2008, with values up to ~540 $m^3\,s^{-1}$ for 2007 and ~310 $m^3\,s^{-1}$ for 2008. Furthermore, record runoff occurred from the GrIS in 2007 (Mernild and others, 2009a,b). For suspended sediment, the load decreased ~40%, from 3.502×10^9 kg in 2007 to 2.006×10^9 kg in 2008, and the maximum concentration decreased from ~3.1 to ~2.1 $g\,L^{-1}$ (Fig. 2).

The variation in meteorological conditions and their melting effect on the GrIS heavily influence the Kangerlussuaq seasonal (June–August) runoff and suspended sediment load. The decrease in the seasonally accumulated number of positive degree-days (PDD; defined as the sum of values of positive mean daily air temperatures), by 19, and in precipitation, 20 mm w.e. from 2007 to 2008, is reflected in decreases in runoff volume of ~25% and in sediment load of ~40%.

Figure 2 also includes short-lived jökulhlaup events in 2007 and 2008, both of which occurred on 31 August. Two consecutive yearly events also occurred in 1983 and 1984 (Sugden and others, 1985). Both the 2007 and 2008 events occurred after 4 days with mean daily air temperature ~11–12°C, and PDD of 45 for 2007 and 28 for 2008. In 2007, the drainage was preceded by a period of high precipitation of 33 mm w.e., whereas it was dry (3 mm w.e.) in 2008 before the drainage took place. The ice-dammed lake was full when drainage occurred in 2007 and only partly full in 2008 (Fig. 1), possibly indicating a different trigger mechanism – probably a different weakness in the sub-GrIS internal drainage system combined with relatively high mean daily air temperature – initiating the jökulhlaup. Based on the stage–discharge relationship, the jökulhlaup peak discharge was ~540 $m^3\,s^{-1}$ in 2007 and ~130 $m^3\,s^{-1}$ in 2008. These discharges indicate runoff volumes during the events of 11.3×10^6 and $4.6 \times 10^6\,m^3$ respectively, a difference mainly caused by a 13–14 m difference in lake

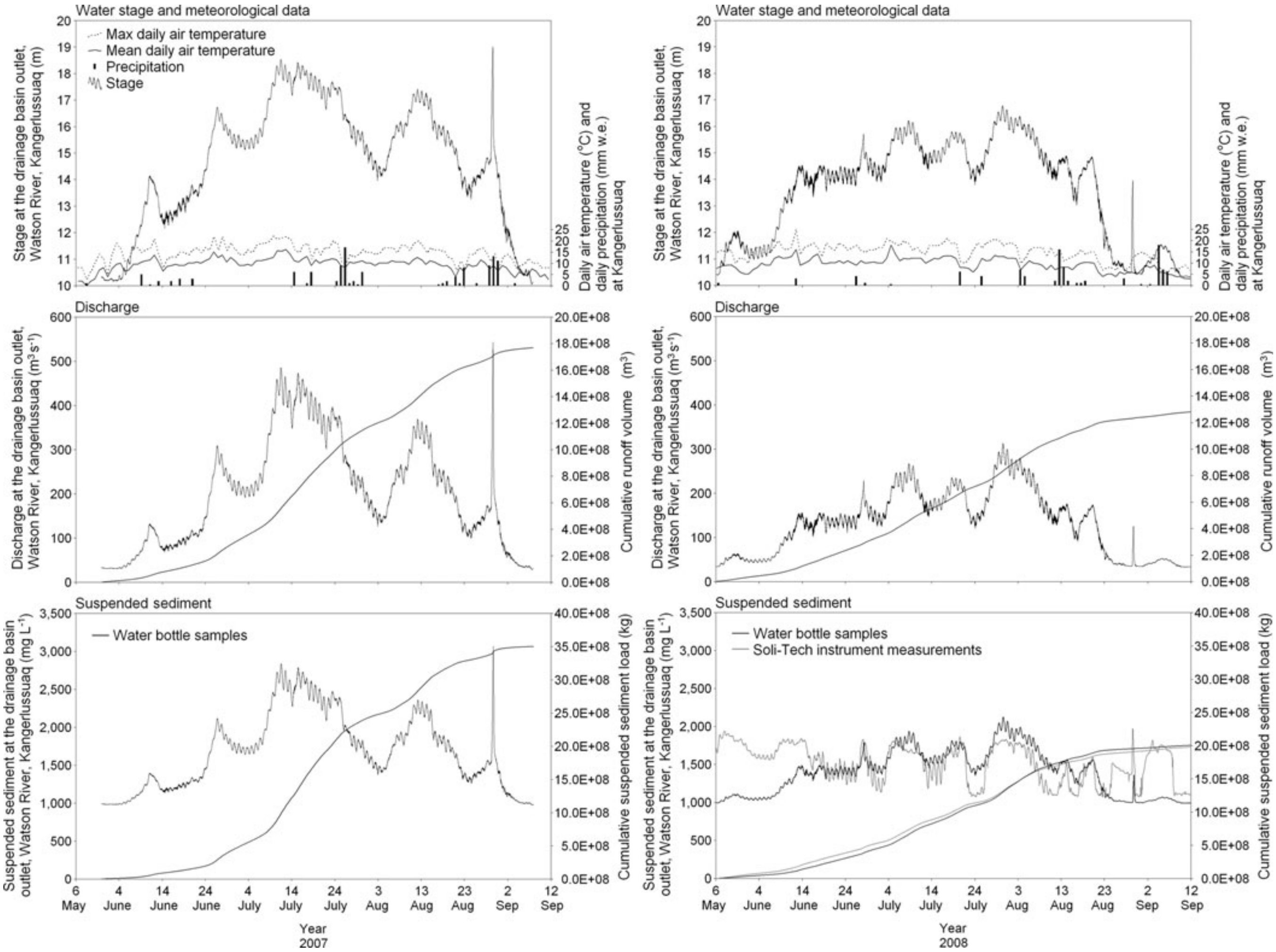

Fig. 2. Variations in stage, discharge and suspended sediment during the 2007 and 2008 summer runoff seasons at the Kangerlussuaq drainage area outlet going into the fiord. The parameters were measured approximately 75 m upstream from the outlet. In 2007 and 2008, each time on 31 August, a short-lived jökulhlaup event occurred. Cumulative runoff volume and suspended sediment load are shown.

water level across the two years. For the 2007 jökulhlaup, the river peak stage was 4.25 m above average for the season, posing a serious risk to the nearby Kangerlussuaq community and infrastructure. For 2008, the peak stage was only 3.4 m above average, posing no risk. Kangerlussuaq, together with many glaciated parts of the world (Sugden and others, 1985) such as areas in Iceland, is likely threatened by the effect of jökulhlaups.

Detailed observations of event and seasonal variations in GrIS runoff and sediment load make it possible to understand the complexity of sub-basin runoff sediment processes. More sediment load during years with higher discharge could be enhanced by remobilization (erosion) of sediments deposited between the GrIS and the drainage basin outlet during years with low discharge. These conditions can be shown by more observations, and demonstrate the necessity of continuing such GrIS runoff and sediment measurements. Additionally, local-scale GrIS investigations are needed, since bank erosion has caused the collapse of old military bunkers approximately 8 km upstream from the outlet. Likewise, sediment deposition rates are needed in the fiord, as it now requires frequent dredging at the harbor. In a global change perspective, a local-to-regional study is needed of the West Greenland terrestrial freshwater and sediment output from the GrIS and from the land strip area between the GrIS and the ocean.

SUMMARY

Since 2007, high-resolution stage, discharge and suspended-sediment observations have been carried out at the river outlet of the GrIS Kangerlussuaq drainage area. These observations yield useful insights into runoff variability during 2007 and 2008, including the occurrence of two jökulhlaups and suspended sediment load. Outputs influenced by meteorological conditions and their melting effect on the GrIS show, from 2007 to 2008, a decrease in runoff volume of ~25% and in sediment load of ~40%.

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