Evolution of the drainage system during a jökulhlaup as revealed by dye tracer experiments on the Gornergletscher.

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Ice-dammed lakes represent the most significant glacier-related hazard, because of the occasional or recurrent release of the water stored within them. They can generate spectacular floods, called jökulhlaup, caused principally by the sudden failure of its natural ice dam. When this unusual amount of water bursts out of the glacier and proceeds into the proglacial area, the created flood wave might combine with the till debris to form a chain reaction, such as catastrophic mud or debris flows. The Gornersee, an ice-marginal lake situated at the Gorner – Grenzgletscher confluence zone (Switzerland), has caused important damages in the village of Zermatt in the past and still comports a potential hazard every year. Therefore, the assessment and prediction of natural hazards related to glacial lakes would be not only of interest for basic research in glaciology, but also for practical reasons, due to its impact on landscape and population.

Prediction of the timing and duration of the lake outburst, as well as the magnitude of the flood, depend on the interaction of the lake with the complex dynamic behaviour of the ice and the water movement through the glacier. The goal of the work reported here was to study the link between hydrological conditions at the bed and the jökulhlaup system.

The subglacial hydraulics were therefore investigated by performing dye tracer injections over a month on three locations near the lake, in order to give insight into the subglacial drainage system prevailing before, during and after the outflow event. Data tracer experiments were interpreted using the concept of two tracer transport models: The classical advection – dispersion model (ADM) was fitted on the rising limb of each dye breakthrough curve in order to infer the advective – dispersive physical process contained in dye return curves. However, tracer return curves were mostly asymmetric, containing a tail on the falling limb of the data curves. Thereby, a mobile – immobile model called CXT, which implements into the classical ADM a storage – release term, was fitted on the entire tracer return curves, in order to assess the transient storage – retardation phenomenon often observed in subglacial water-flow. This model consists of a system of equations that was solved numerically using the CXTFIT 2.1 computer program. Comparison of the transport parameters between the numerical and the theoretical solution has given a very good agreement for the ADM with the CXT model. So the obtained transport parameters have provided a reliable basis to describe the water-flow regime prevailing in the glacier and its evolution through time. The analysis of the estimated transport parameters enabled the observation of different types of subglacial drainage system during the melt season 2005. Injections performed on the lower part of the ablation zone have shown sharp, fast flowthrough peaks, that have suggested an efficient arborescent drainage system before the lake outburst. Tracer tests performed in a moulin near the lake have revealed a well-integrated drainage system, efficiently channelized. However, more inhomogeneity in the dye return curves have suggested a fairly braided water-flow system at the glacier bed, before the lake emptied. Dye experiments performed in a moulin located above the lake have returned broader return curves with slow transit velocities; that have suggested an inefficient, more distributed linked-cavities drainage system until about 10 days after the jökulhlaup. After the outburst, injections were done in the lake outlet as well, which revealed a very efficient drainage system through arborescent flowpaths. In 2005, no strong influence of the jökulhlaup on the subglacial drainage system could be clearly observed. However, the tracer data have revealed that the outburst of the lake coincides with the end of a period of transition, resulting from the adaptation of the drainage system to the summer melting regime. The efficient drainage system observed in the lower part of the ablation area, characterized by a direct and unrestricted water-flow, seems to extend upwards to the whole ablation zone, following the retreat of the snow line. More locally, a readjustment of the hydraulic system after the lake outburst, according to the discharge prevailing normally in the ablation area near the lake, is suggested in this study, but could not be distinctly established. Transport parameters were analysed according to the R-channels mechanism. Velocity – discharge relationships have demonstrated that water flows for a part of its passage through the glacier in an open-channels system. And this happened at high discharge as well. However, it could not be assessed if this open-channels configuration expands to the upper part of its ablation zone. As the drainage system has to adjust to the seasonal change in discharge, the system may consist of combined cavities – channels morphology, where some R-channels of moderate sizes develop in a dominated cavities region.

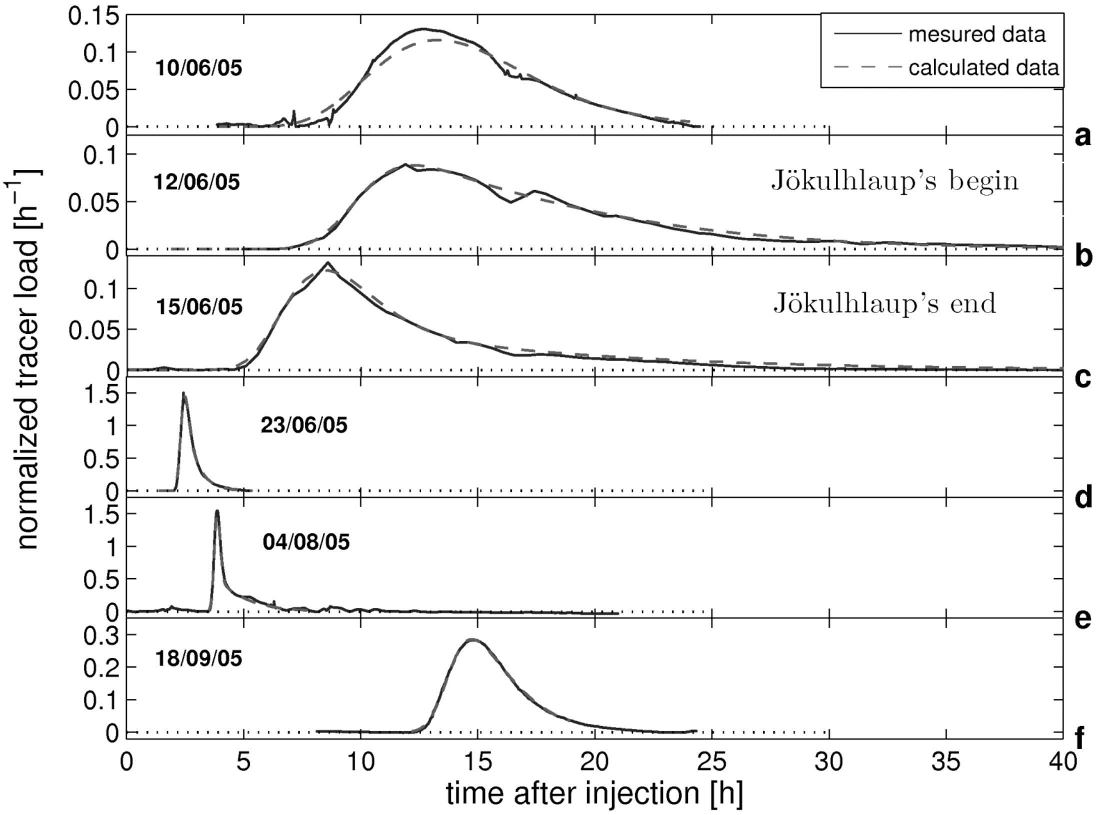

Figure 1: Dye return curves resulting from tracer injections performed in a moulin located above the Gornersee in summer 2005. They show the general evolution of the subglacial drainage system during the melt season. Notice the transition from an

inefficient to an efficient subglacial drainage system prevailing after the jökulhlaup. The dash lines illustrate the results of fitting the CXT model to the observed data.