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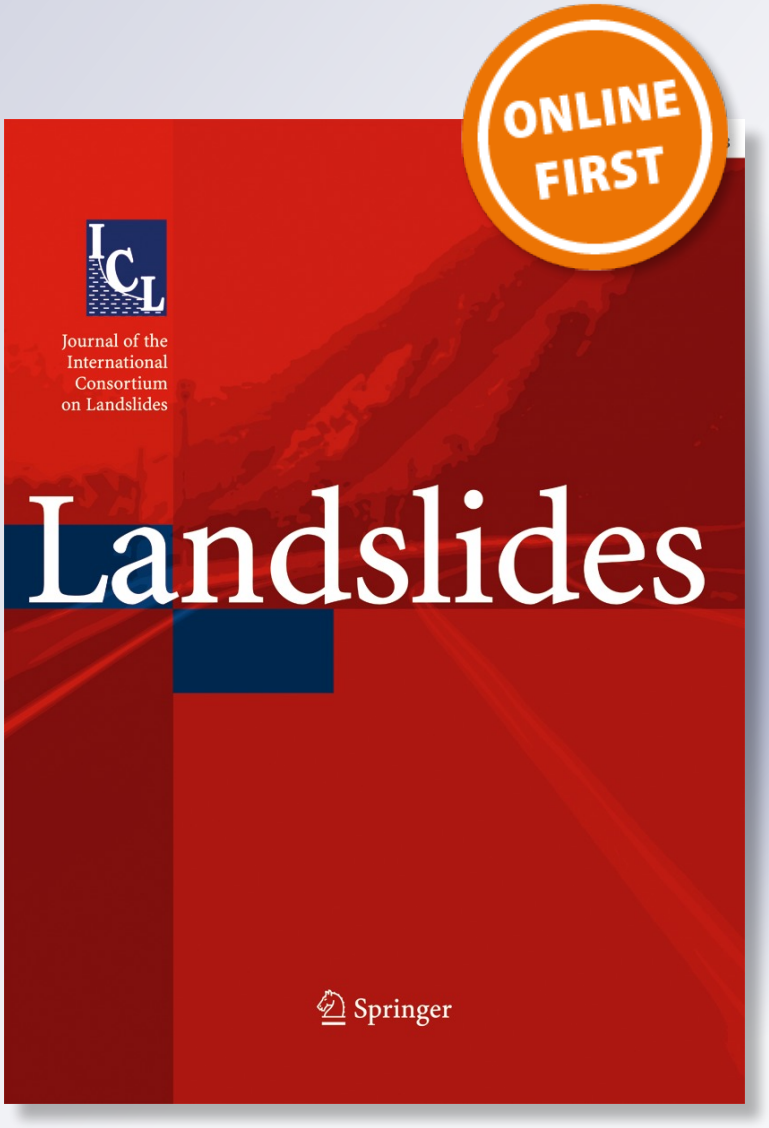

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Abstract This article summarises activities and preliminary results of the International Programme on Landslides Project no. 179 "Database of glacial lake outburst floods (GLOFs)". This project is planned for 3years (2013–2015); the main objectives of the first year are (1) to create an online database and (2) to select collaborating partners. A survey of existing and relevant documents, information and organisations has been initiated along with the creation of a website (www.glofs-database.org) and the establishment of international collaboration. The first preliminary results show regional differences in various attributes of GLOF events (e.g. triggers, chronological distribution). These differences should be taken into consideration in regionally focused methods of hazard assessment, mitigation and consequently risk management.

Keywords GLOFs · Natural hazards · Database · International collaboration · Cordillera Blanca

Introduction

Glacier lake outburst flood ("GLOF") is a term used for a sudden release of water from any type of glacial lake (ice-dammed, bedrock-dammed or moraine-dammed glacial lake), irrespective of its cause (e.g. Clague ad Evans 2000). Because of the high maximum discharge involved, which may exceed tens of thousands cubic meter per second, and the high erosion and transport potential such floods can easily transform into debris flows with volumes of millions of cubic meters (Costa and Schuster 1988; Evans and Clague 1994). Thus, GLOFs involve significant geomorphic processes ranging from floods to debris flows. In many high-mountain regions around the world, they also represent a significant hazard due to their far-reaching destructive potential. GLOFs have claimed thousands of lives in single events and caused destruction of goods and structures (e.g. Vuichard and Zimmermann 1987; Zapata 2002). GLOFs will remain a serious issue in the future as the formation of new lakes in dynamic high-mountain environments will continue in the twenty-first century due to ongoing deglaciation (Fig. 1), and likely increasing instability of steep high-mountain slopes with the potential to produce rock and ice avalanches that impact lakes and trigger lake outburst floods (Carey et al. 2011; Haeberli 2013). GLOFs have been studied in many regions across the world, including the Alps, the Andes, North America, Central Asia and the Himalayas (e.g. O'Connor et al. 2001; Ives et al. 2010), and an initial global summary of events has been compiled (Würmli 2012). This inventory showed that in many cases, important information on the preconditions of lake outbursts is unavailable. As a complete understanding of the process is crucial for hazard assessment, special emphasis should be placed on the description of all of the essential parameters (see the "Website creation and data acquisition" section) when reporting future lake outbursts. A global database could help to close this gap.

The International Programme on Landslides (IPL) Project "Database of Glacial Lake Outburst Floods (GLOFs)" (project no. 179; http://iplhq.org/category/iplhq/ipl-ongoing-project/) was adopted under the International Consortium on Landslides (ICL) at the Board of Representatives in Paris 2012. Root members of the project are Adam Emmer (Project Leader) and Vít Vilímek (Core member of the Project) from Charles University in Prague, Czech Republic. In the framework of the IPL, the project targets some of the main fields of the programme such as vulnerability and risk assessment as well as collaborating and disseminating information/knowledge. The project is coordinated under the World Centre of Excellence dedicated to Charles University in Prague (see also Vilímek et al. 2010). It fits into the global strategy plan of ICL (Sassa 2012). Furthermore, the project is coordinated with other relevant science and high-mountain hazard initiatives and organisations (see "International collaboration" section).

The project aims to create an overview and information basis of GLOFs that is available to a wide range of scientists, technical experts, and authorities. Emphasis is placed on events which have occurred all over the world since the end of the "Little Ice Age". The database can provide regionally differentiated characteristics of GLOFs (e.g. in the representation of each trigger, chronological distribution, etc.) which supports the process of understanding and the creation of optimal, regionally focused methods of GLOF hazard assessment, mitigation, and risk management (e.g. Emmer and Vilímek 2013). For the fieldwork, we focus our attention on glacierized mountainous areas worldwide—the Cordillera Blanca of Peru (e.g. Vilímek et al. 2005; Carey et al. 2011; Klimeš 2012), where this phenomenon has been more intensively studied since the 1950s (e.g. Concha 1952; Lliboutry et al. 1977), the Bolivian Andes, and also the Swiss Alps (e.g. Huggel et al. 2004; Schaub et al. 2013).

Fig. 1 Example of new proglacial bedrock-dammed lakes forming in the upper part of the Ishinca valley (Cordillera Blanca of Peru) at an elevation of 5,170 m above sea level

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Materials and methods

The project will create an online database including information about worldwide GLOFs events since the Little Ice Age based on research of scientific literature, unpublished reports and regional databases (e.g. DesInventar, Glacierhazards.ch, GAPHAZ, Glaciorisk), and on collaboration and communication with international organisations (e.g. ICIMOD) and national services. Creation of the database, as a core activity of the project, is planned for a period of 3 years (2013–2015), although the database itself shall be in operation for a longer period of time. The website shall include a section on "GLOF news" where the international community is invited to share new information. During the first year, the following tasks shall be fulfilled: creation of the structure of the database, evaluation and definition of the appropriate form of documenting the events, selection of partners for future collaboration, creation of the website (www.glofs-database.org). The second year shall mainly be oriented towards filling the database. The third year will be focused on specific improvement of the database, setting of regional differences and evaluation of the database.

Preliminary results

Website creation and data acquisition

During the first year of the IPL project, the structure of the database has been created as well as the website, which is now available at www.glofs-database.org (Fig. 2). The second step of the project is to select the appropriate aspects of GLOF events to be gathered and partners for future collaboration.

More than 500 GLOF events have been summarised based on research in scientific articles, unpublished reports and various regional databases (e.g. glacierhazards.ch). We currently have information on approximately 130 GLOFs from moraine-dammed lakes, 380 GLOFs from ice-dammed lakes and several GLOFs originating from bedrock-dammed lakes or lakes with combined dams (Würmli 2012). The process of uploading data into the database will extend into 2014 and will continue as new information arrives. Primary focus is on the analysis of information about the processes of GLOF triggers, dam failure, flood generation and related downstream processes. Furthermore, impacts on local society and economy are of great importance. Specifically, the main parameters of the database are as follows:

Glacial lakes:

- name
- coordinates (longitude, latitude, altitude)
- location (mountain range, valley)
- lake type (supra-, pro-, peri-, subglacial, etc.)
- dam type (bedrock-dammed, moraine-dammed, ice-dammed, combined dam)

Flood following dam failure or overflow:

- date of occurrence
- probable trigger (icefall/snow avalanche into the lake, rock fall/landslide into the lake, earthquake, intense rainfall/snowmelt, flood wave from a lake situated upstream, blocking of underground outflow channels, buried ice cores melting, dam self-destruction)
- outburst mechanism(s)
- flood volume
- peak discharge
- reach
- flow type/sediment load

Fig. 2 www.glofs-database.org website overview

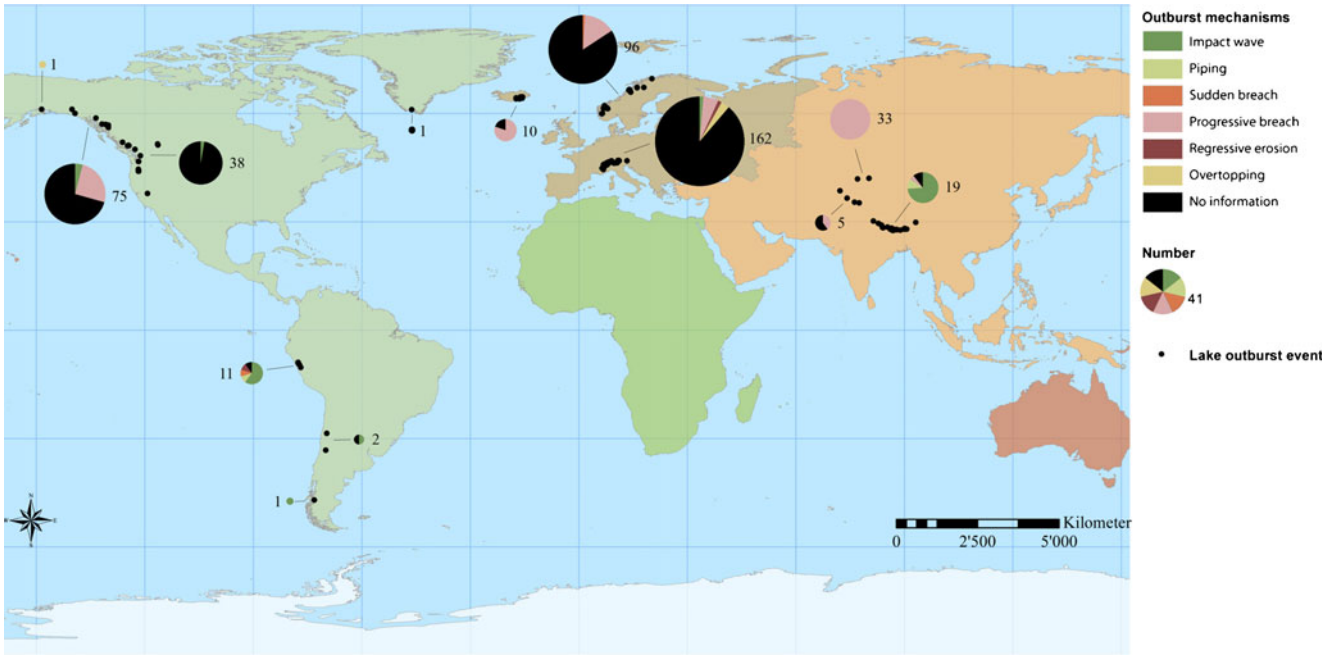

Fig. 3 Outburst mechanisms of GLOFs worldwide (according to Würmli (2012))

Socioeconomic impacts:

- fatalities or missing persons
- affected sectors (homes, industry, agriculture, public infrastructure, others)
- material damage

Of course, there are cases where specific information such as probable trigger, peak discharge or flood volume are not exactly known (or are not known at all), especially in cases of historical GLOFs or GLOFs which occurred in less inhabited regions. For example, the list of all natural hazards in Cordillera Blanca dates back to the beginning of the eighteenth century (Zapata 2002), but we have to consider the poor data quality of the earliest event descriptions. On the other hand, these data are not available for less inhabited regions such as British Columbia. Thus, in some cases, complete information cannot be filled into the database.

International collaboration

The project was first introduced at "Foro International Glaciares 2013", which took place in Huaráz (Peru) between 1 and 4 July 2013. This meeting triggered the start of international collaboration between scientific institutions from South America (Bolivia, Peru), North America (USA) and Europe (Switzerland, Czech Republic). The following departments are currently collaborating on the GLOFs database project: Charles University in Prague, Department of Physical Geography and Geoecology, Czech Republic (A. Emmer

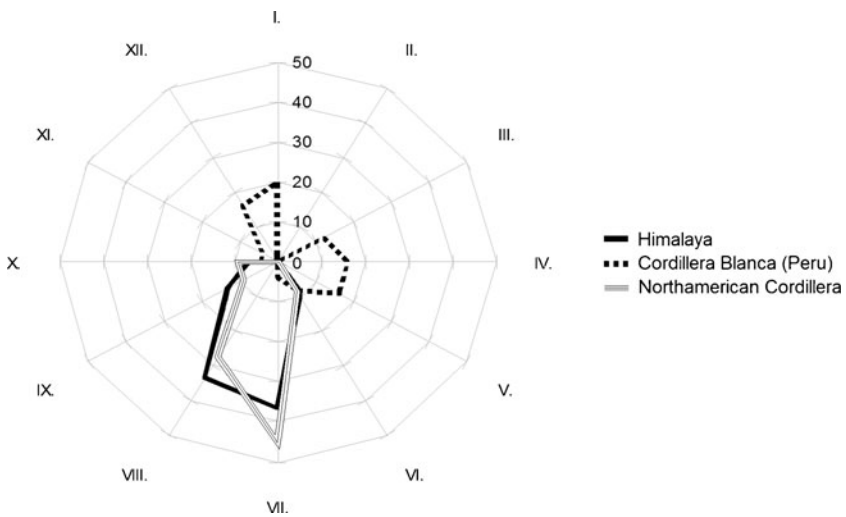

Fig. 4 Chronological distribution of GLOFs originating from moraine-dammed lake failures in three of the studied regions (based on Emmer and Cochachin (2013)). Please note the significant similarities between Himalaya and North American Cordillera regions

and V. Vilímek); Institute of Rock Structure and Mechanics, Academy of Sciences of the Czech Republic (J. Klimeš); University of Zürich, Department of Geography, Zürich, Switzerland (Ch. Huggel and Y. Schaub); BOKU University of Natural Resources and Life Sciences Vienna, Vienna, Austria (M. Mergili); Autoridad Nacional del Agua (ANA), Huaráz, Peru (A. Cochachin); Instituto Boliviano de la Montaña, La Paz, Bolivia (D. Hoffmann), University of Oregon, Eugene, USA (M. Carey), and University of Texas, Austin, USA (R. Chisolm, M. Somos). Furthermore, close collaboration with the joint Standing Group on Glacier and Permafrost Hazards in Mountains (GAPHAZ) of the International Association of Cryospheric Science (IACS) and the International Permafrost Association (IPA).

Regional differences

The GLOF database is now in its first year of operation and we have already presented the preliminary results of our investigation (e.g. conference posters; Würmli et al. 2013; Vilímek et al. 2013). These preliminary results show certain differences and also similarities in GLOF events and characteristics among the various geographic regions. There are differences in the type of trigger events of GLOFs (Fig. 3; Würmli 2012) as well as in the chronological distribution of these events (Fig. 4; Emmer and Cochachin 2013). These differences need to be taken into account in view of GLOF hazard assessment and the related risk reduction for specific regions.

Conclusion and future work

The GLOFs database (IPL project no. 179) is designed to provide information about each GLOF event that has occurred anywhere in the world since the LIA and will be broadly available to the public on the Internet (www.glofs-database.org). Any scientific organisation can use these data; partners working in risk management will directly benefit. The GLOFs database also provides a great opportunity for international collaboration between scientific departments which solve GLOFs related topics.

Work planned in the IPL Project for the following years 2014 and 2015:

- study of literature, unpublished reports and regional databases
- website database filling and maintenance
- search and selection of partners for the database project
- observation and description of new GLOF events filling them into the database
- analysis of regional differences and evaluation of the database

Naturally, we plan to continue the operation of the database project even after the IPL Project is formally completed in 2015.

Acknowledgments

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