

Dear Dr. Sven Fuchs, dear referees,

Thank you for giving me the chance to revise my manuscript „GLOFs in the WOS: bibliometrics, geographies and global trends of research of glacial lake outburst floods (Web of Science, 1979-2016)“ submitted to NHESSD. I appreciate the comments and suggestions of referees and tried to revise the manuscript accordingly.

Most importantly, following changes have been made:

- (i) Extended discussion on significance of local publications and reports not indexed at WOS, especially in section 2.1 but also in other relevant sections;
- (ii) New section 3.3 *Analysis of the content* providing basic overview on focus of GLOF research items and 4.3 *Challenges ahead and research directions* have been introduced;
- (iii) Sections 3.2.1 and 3.2.3 have been extended by more detailed analysis of GLOF research activities in space and time with special focus on GLOF research hotspots located in developing regions;
- (iv) Section 4.2 has been reworked in line with more detailed findings of extended sections 3.2.1 and 3.2.3;
- (v) New figures 3 and 4 have been produced;
- (vi) The list of references has been updated by recently published literature.

Point-by-point answers to the reviews as well as revised manuscript with all the changes visible in changes-tracking mode are attached below.

Thank you, kind regards

Adam Emmer

Point-by-point reply to reviews:

General response:

I'd like to thank both referees for their time, comments and suggestions. In my general response, I'd like to tackle three major issues:

(1) the choice of the journal

Both reviewers are not sure about the suitability of NHESS for publishing such work. Considering the focus of the manuscript, I fully understand this concern. When I have prepared the manuscript, I've had a hard time deciding where to submit. There were two options in terms of research areas: (i) information science (scientometrics / bibliometrics); or (ii) natural hazard science. As it is shown in Introduction of the manuscript - numerous scientometric / bibliometric studies focusing on various fields of natural hazard science (landslides, tsunamis, ...) already exist, some of them published in scientometric journals and some of them in natural hazard science journals. In the case of my manuscript, I'm convinced that natural hazard science research community might be of higher interest and publishing in journal in natural hazard science area might provide higher visibility, therefore I've decided for NHESS.

(2) scientific content and novelty

I'd like to stress, that this contribution does not primarily aim at providing new information about GLOF and its generic physical processes (as pointed out by Referee #2), but about research on GLOFs, its bibliometrics, trends and geographies (where GLOFs are studied; who studies GLOFs; the export of research on GLOFs; and international collaboration). Compared to other types of natural hazards (e.g., landslides, tsunamis, earthquakes) this topic is not yet addressed and, thus, novel. This study shows how publishing culture and paradigm have changed over time, based on analysis of GLOF research items published at WOS (see also point (3)). From this perspective, I'm convinced that new findings and results which might be of interest for GLOF research community as well as practitioners, are presented.

(3) the use of WOS database

The use of WOS database is justified in Section 2.1. Certainly, I'm aware of local publications (see also Introduction and section 2.1), however analysing local publications and aiming on global perspective at the same time is far beyond objectives, scope and resources available for this study. Moreover, based on my experience from Andes, local publications are often not available online (only available in local libraries). Results of presented work are based on research items indexed in the WOS database and, thus, only valid for WOS data, which is clearly stated in the manuscript. I'm, however, still convinced, that the study provides valuable insights into the GLOF research community and geographies of GLOF research (see above).

In line with the suggestions and recommendations of two referees, following major changes will be done in the revised version of the manuscript:

- (i) deeper discussion on limits of WOS database and potentials of local publications;
- (ii) deeper investigation of trends on regional level in time; and
- (iii) discussion of suggestions for future GLOF research.

Point-by-point replies are shown below (in blue) with recent updates compared to open discussion (in green).

Thank you, kind regards

Adam Emmer

Anonymous Referee #1

Received and published: 5 January 2018

General Comments: The paper analyzes 892 GLOF research items published in the Web of Science database during the period 1979-2016. A change in the publishing paradigm over time is proposed and global geographies of research on GLOFs were studied. The paper is a good analysis of the publication database related to GLOFs and might make a good technical note or editorial in NHESS or in a journal devoted to academic publication trends in the geosciences. It is beyond my expertise to say if this paper deserves publication as a research paper in NHESS. I do not find information in the paper that enhances my research on GLOFs.

- Please see my general comments
- The use of WOS database and the potential of local publications and reports is elaborated in more detail in revised version of the manuscript in section 2.1

In the instructions to reviewers, we are asked to address some specific questions, specific ones that I find relevant to this paper are:

1. Does the paper address relevant scientific and/or technical questions within the scope of NHESS?
2. Does the paper present new data and/or novel concepts, ideas, tools, methods or results?

I cannot respond positively to these questions regarding this paper. In particular, scientific or technical questions related to GLOFs are not presented or discussed. Certainly, Web of Science data related to publications in various journals is presented, but this is not related to the scientific/technical questions of the field.

- I understand this concern, please see my general comments
- The extent of the study has been broadened and new sections introduced in revised version of the manuscript

Specific Comments:

P2-L1: Actually glacial lake outburst flood is in the title of Jackson's 1979 paper: Jackson, L. E.: Catastrophic glacial lake outburst flood (jokulhlaup) mechanism for debris flow generation at the spiral tunnels, Kicking horse River basin

- According to the WOS database and the publisher website <http://www.nrcresearchpress.com/doi/abs/10.1139/t79-087#.W18kYq7ibIU> the author did not use 'lake' in title or abstract, just 'glacial outburst flood'
- Checked, no change

P2-L2: "Clarke and Mathews (1981)" reference missing

- will be added
- is added in revised version of the manuscript

Anonymous Referee #2

Received and published: 16 January 2018

Dear Editor,

Thank you for inviting me to review this manuscript. Author proposed the manuscript "GLOFs in the WOS: bibliometrics, geographies, and global trends of research of glacial lake outburst floods (Web of Science, 1979-2016)". The analysis of this paper is interesting, but some parts should be improved and think more deeply. I do not know that this paper is suitable for this journal, because this paper does not include scientific research and detail discussion. I still do not understand a benefit information which author would like to show in this paper. Readers of NHESS might be more interested in regional differences of GLOF including the characteristics of GLOF, research themes, and research methods. In addition, it is difficult to show the trend using only Web of Science, because author does not treat local publications.

- See also my general comment (3); the potential of local publications will be discussed in more detail

- The use of WOS database and the potential of local publications and reports is elaborated in more detail in revised version of the manuscript in section 2.1 and other relevant parts of the manuscript
- Selected aspects of the content of published GLOF research items are analysed in newly introduced section 3.3
- Challenges ahead and research directions are elaborated in section 4.3

General comments:

1) It is not clear what this paper will be useful for future GLOF research. What is benefit information for GLOF studies? Please indicate what your suggestions in the future GLOF research, because I cannot confirm your opinion in the manuscript based on data.

- Separate section on suggestions for future GLOF research will be introduced in the revised version of the manuscript
- Newly introduced section 4.3 discuss this issue

2) The tendency of the study area where GLOF occurred and the foreigners were active varies each decade and region. Based on analysis each decade (e.g. between 1979-1999 and 2000-2016), author might understand the transition of the region. Although author analyzed about time series is whether it is a single author or co-authorship, readers do not have great interest about this topic.

- More detailed analysis will be included in revised version of the manuscript
- More detailed spatio-temporal analysis especially focusing on GLOF hotspots located in developing regions are presented in sections 3.2.1 and 3.2.3 in revised version of the manuscript

4) In this paper, author used the data of Web of Science, but there are many local papers in local journal. For example, it is often written in the USSR. Tables 3 and 4 do not include Russia or USSR. The paradigm shift is clearly a mistake, because this paper is intended for 1979-2016. In USSR territory, there are overwhelmingly local publications before 2000. Please indicate time series each region and mention regions which foreigners wrote mainly (where no paradigm shift has occurred).

- again, only research items published at WOS database are analysed in presented study; see also my general response
- this part of the section 4.2 has been reworked using more detailed detailed spatio-temporal analysis especially focusing on GLOF hotspots located in developing regions (sections 3.2.1 and 3.2.3)

5) In HKT, as a representative of local researchers, I think that contribution such as local scientist of ICIMOD is very large, but there is no mention on that point about paradigm shift. One sentence is not enough for explanation of paradigm shift in HKT. This topic should be written more deeply in discussion.

- I agree with this point; this part will be elaborated in more detail in revised version of the manuscript
- More detailed spatio-temporal analysis especially focusing on GLOF hotspots located in developing regions are presented in sections 3.2.1 and 3.2.3 in revised version of the manuscript

Specific comments and technical notes:

Page 1 L10-L11: What is GLOF research items? Definition of GLOF paper is not clear. For example, glacier lake research (simply changes of lake area) is included? Although theme of papers is glacier changes, there are the cases which these include term of GLOF. Did you confirm each article?

- „research item“ is WOS term referring to individual record in the WOS database; these are mainly papers / articles, but also book chapters, conference papers and others (see also Section 3.1.1)
- Only those items found using carefully designed searching formulae are analysed; glacier lake research is not analysed if the abstract / title does not explicitly mention glacial lake outburst / GLOF
- GLOF research item is described in section 2.1 and its characteristics in Tab. 1

L12: Paradigm over time: : . Please show the paradigm shift (time series) based on each regional study and activity including local publication, because only data base of Web of Science does not show the correct regional trend.

- I'm aware of local publications (see also section 2.1), however analysing local publications and aiming on global perspective at the same time is far beyond objectives, scope and resources of this study (see also my general comments)
- using the WOS database shows (correct) regional trend among WOS publications, which is stress several times in the manuscript as well as obvious from the title
- this issue will be discussed in more detail in the revised version of the manuscript
- The use of WOS database and the potential of local publications and reports is elaborated in more detail in revised version of the manuscript in section 2.1; the use of WOS database is stress in the several relevant places in the manuscript

L18: dam failure and dam overtopping, or glacial lake sub-type?

- „irrespective of the cause (trigger), mechanism (dam failure or dam overtopping) or glacial lake sub-type involved“
- edited („or“ replaced by „and“)

Page 2 L30: Although articles include term of GLOF, some articles are not theme of GLOF. Did you confirm each article?

- In general, yes. Firstly, the search formulae was carefully defined to select items dealing with GLOFs, using a set of articles for double check; I, honestly, did not go through all the full texts of 892 GLOF research items found, but the abstracts; and I can confirm that each item touches GLOFs, at least partially.
- Even if some of the 892 items considered in the analysis would not dealt with GLOFs, this would not changed the overall figure and trends observed

Page 6 L7-14: Trends are also different each developing country. You should write concretely the regionality. For example, there are no differences about foreigner activities for Central Asia and Karakoram, but Himalaya are the most common in US and Japan. The contribution of these countries is different each decade since 1979. Based on summary of developing country, it is impossible to see individual details and transition.

- This section will be elaborated in more detail in revised version of the manuscript
- More detailed spatio-temporal analysis especially focusing on GLOF hotspots located in developing regions are presented in sections 3.2.1 and 3.2.3 in revised version of the manuscript
- Please see newly introduced Fig. 4

Page 9 L2-10: I cannot agree with your opinion. Central Asia and Caucasus have been active mainly by many local researchers since the USSR. They published many articles about GLOF in Russian journal. There is little description of foreigners. In addition to data base of Web of Science, author should use local publications. An example in Himalaya is not appropriate. In Himalaya, we should state the activities of ICIMOD.

- I agree with the reviewer that the use of local publications might be beneficial, there are, however, numerous obstacles which make it hardly feasible on global level (see also my general comments)
- The use of WOS database and the potential of local publications and reports is elaborated in more detail in revised version of the manuscript in section 2.1 and other relevant parts of the manuscript
- I fully agree that ICIMOD did a lot of work in HKH region as well as USSR researchers in Central Asia and the importance of local publications will be discussed in more details in revised version of the manuscript
- The activities of ICIMOD are also already covered in the analysis (the researchers from ICIMOD have contributed to 9 research items indexed in the WOS database)
- This is discussed in more detail in revised version of the manuscript

L24: Please analyze each region of the developing country.

- This part will be extended as suggested by the referee
- More detailed spatio-temporal analysis especially focusing on GLOF hotspots located in developing regions are presented in sections 3.2.1 and 3.2.3 in revised version of the manuscript

L25: I think recent local researchers are active in HKT.

- Will be checked and eventually rewritten
- More detailed spatio-temporal analysis especially focusing on GLOF hotspots located in developing regions are presented in sections 3.2.1 and 3.2.3 in revised version of the manuscript
- Please see newly introduced Fig. 4

GLOFs in the WOS: bibliometrics, geographies and global trends of research of glacial lake outburst floods (Web of Science, 1979-2016)

Adam Emmer¹

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Abstract. Research of glacial lake outburst floods (GLOFs) - specific low frequency, high magnitude floods originating in glacial lakes, including jokulhlaups - is well justified in the context of glacier ice loss and glacial lake evolution in glacierised areas all over the world. Increasing GLOF research activities, which are documented by the increasing number of published research items, have been observed in the past few decades; however, a comprehensive insight into the GLOF research community, its global bibliometrics, geographies and trends in research is missing. To fill this gap, a set of 892 GLOF research items published in the Web of Science database covering the period 1979-2016 was analysed. General bibliometric characteristics, citations and references were analysed, revealing a certain change in the publishing paradigm over time. Furthermore, the global geographies of research on GLOFs were studied, focusing on: (i) where GLOFs are studied; (ii) who studies GLOFs; (iii) the export of research on GLOFs; and (iv) international collaboration. The observed trends [and the links](#) [to the challenges ahead](#) are discussed and placed in a broader context.

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1 Introduction

Glacial lake outburst flood (GLOF) is a term used to describe a sudden release of (part of) water retained in a glacial lake, irrespective of the cause (trigger), mechanism (dam failure or dam overtopping) ~~or~~ [and](#) glacial lake sub-type involved (e.g., Evans and Clague, 1994; Richardson and Reynolds, 2000). The Icelandic term *jokulhlaup* is also frequently used to refer to GLOFs originating in ice-dammed lakes and often (but not necessarily) induced by volcanic activity (Björnsson and Pálsson, 2008). In Spanish speaking countries, the term *aluvión* is often used to describe flow-type processes of various origins, including GLOFs (Lliboutry et al., 1977). The occurrence of GLOFs is commonly tied to periods of glacier ice loss (Clague and Evans, 2000) and GLOFs are considered among the most significant geomorphological as well as the most hazardous consequences of retreating glaciers (Clague et al., 2012). Facing ongoing and even accelerating climate change and the associated glacier retreat (Huss et al., 2017), research of past as well as potential future GLOFs represents a highly actual topic (O'Connor and Clague, 2015). A complex understanding of GLOFs and their related processes has significant implications for various fields such as risk management and disaster risk reduction (e.g., Hewitt, 2013), hydropower plant design (e.g., Schwanghart et al., 2016), or geomorphology and sediment yield (e.g., Korup and Tweed, 2007).

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According to the Web of Science (WOS) Core Collection database (see 2.1), the term *glacial outburst flood* was firstly used by Jackson (1979), the term *glacial lake outburst flood* was firstly used by Clarke and Mathews (1981) and the acronym *GLOF* was firstly used by Grabs and Hanisch (1993). The history of research on GLOFs is, however, much older, going back to the 19th century in some regions, e.g., the European Alps (e.g., Richter, 1892), Iceland (e.g. Hákonarson, 1860) and the first half of the 20th century in others, e.g., Caucasus (Gerassimow, 1909), the Peruvian Andes (e.g., Broggi, 1942) or the North American Cordillera (e.g., Fryxell and Horberg, 1943).

Numerous studies exist that focus on a scientometric / bibliometric analysis of various research fields and their geographies (e.g., Small and Garfield, 1985), including those in geomorphology (e.g., Dorn, 2002), river research (e.g., Vugteveen et al., 2014), and natural hazard science (e.g., Chiu and Ho, 2007; Liu et al., 2012; Wu et al., 2015). While the amount of research of GLOFs has gradually increased over the past few decades (see Emmer et al., 2016), detailed insight into the GLOF research community, its global bibliometrics and geographies of research is missing. Therefore, the main objective of this study is to map GLOF research and the research community by analysing GLOF research items published in the WOS Core Collection database from the point of view of: (i) general bibliometric and scientometric characteristics (temporal analysis, journals, document types, citations and references); (ii) geographies (where GLOFs are studied and by whom in relation to where the GLOFs occur). This study is expected to provide a comprehensive global overview primarily targeting the GLOF research community, but also a broader audience such as GLOF risk management practitioners and policymakers (see e.g., Carey et al., 2012).

2 Data and methods

2.1 Web of Science and the sSet of analysed items

Focussing on research results published in highly credible scientific journals and proceedings, the search was performed on items published in journals/proceedings indexed in the Clarivate Analytics Web of Science (WOS) Core Collection database (www.webofknowledge.com). This database covers items published as far back as 1900 in 13,000+ journals, contains 100+ million published items and 1.3 billion cited reference connections (Clarivate Analytics, 2017). Numerous books (e.g., Carey, 2010; Haeberli and Whiteman, 2015), book chapters (e.g. Iturrizaga, 2011) and papers not indexed in the WOS Core Collection databases as well as so called grey literature (e.g., Horstmann, 2004) are not taken into consideration in this study. as well as Also, various scientific reports of national and regional authorities such as the of ICIMOD in Hindu Kush-Himalaya region (e.g., Ives et al., 2010), (e.g., USGS in the North American Cordillera (e.g., O'Connor et al., 2001), or the National Water Authority in the Peruvian Andes; (e.g., UGRH 2015) and so-called grey literature (e.g., Horstmann, 2004) are not taken into consideration in this study due to the often limited availability (hardcopies stored in local archives; no electronic versions available) and unbalanced overall amount of these sources among the regions. Moreover, these data are often not easily describable by standardized WOS characteristics and, thus, difficult to analysed as a comprehensive set of items on a global level. Such studies and the employment of documentary data, however, may provide a valuable source of information for

analysing the occurrence, causes and mechanisms of GLOFs on a regional level (e.g., Emmer, 2017) and, in turn, to facilitate the help in attempts to compilation of e-a GLOFs database on a global level (see also 4.3). Nevertheless, an analysis To analyse of these studies is ~~nevertheless~~, out of the scope, extent and ~~the~~ resources of this study. The WOS database was, therefore, used as the only source of data and the ~~presented~~ results are, thus, only valid among the items indexed in the WOS.

5 The proper definition of the search formula is a key presumption for successfully searching for a comprehensive set of items. After several iterations, sighting shots and cross-checks with the control set of 30 papers focusing on diverse aspects of research of GLOFs, a basic searching formula was defined as follows:

TOPIC: (glaci* AND outburst* AND flood* OR jokulhlaup*)

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This formula was defined to cover the terminological variability observed in this field over time and lake types, and simultaneously omit undesirable results such as items focusing on outburst floods from landslide-dammed lakes. The WOS database was analysed between September and October 2017, when all of the major journals regularly publishing GLOF research items have already released their 2016 issues to WOS database. Each item contained in the WOS Core Collection database is described by a number of qualitative and quantitative characteristics, some of which are further analysed in this study (Tab. 1; see Section 3), reflecting the objectives. A total of 892 items were found and used for the building and analysis of the database (see 2.2).

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2.2 Data processing, database building and analysis

The basic analysis was performed in the WOS environment, using the WOS Results Analysis tool. This tool allows the analysis of the entire set of 892 items, including an overview of: (i) authors; (ii) institutions; (iii) source titles; (iv) WOS categories; (v) research areas; (vi) document types (see 3.1). Journals publishing GLOF research items (see 3.1.1) were further analysed using the WOS Journal Citation Reports tool and citations and references (see 3.1.2) were analysed using the WOS Citation Report tool. The set of 892 analysed GLOF research items (see 2.1) was exported from the WOS platform, and subsequently processed and analysed in a Microsoft Excel environment. Some of the data needed to be repaired (e.g., the institutions of all of the authors involved in each research item are not available for 21 (2.4%) research items written by more than one author; ~~i-~~In which case, the country of the affiliation of the reprint author was used).

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In addition to the characteristics assigned from the WOS database, each item was manually described by certain other characteristics, based on the search in the titles, abstracts (available for 843 out of the 892 items; 94.5%), and keywords (available for 517 out of the 892 items; 58.0%), using the content analysis method (e.g., Hsieh and Shannon, 2005). These include geographical characteristics, characteristics of authors (teams) contributing to individual research items and mono-/inter-nationality of the research teams. These characteristics are analysed in Section 3.2, focusing on: (i) geographical focus of GLOF research (see 3.2.1); (ii) geographies of the researchers involved (see 3.2.2); (iii) the “export” of research of GLOFs (see 3.2.3); and (iv) international collaboration (see 3.2.4). The content of GLOF research items is further analysed regarding

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selected aspects of their focus (see 3.3), using the WOS Advanced Search tool. This analysis is based on searching among the titles, abstracts and keywords and, thus, only provides a basic, nonetheless however meaningful view on the given aspect. The Observed trends are discussed and placed into a the broader context in Section 4.

3 Results

5 3.1 General characteristics of published items

3.1.1 Bibliometric characteristics

A total of 892 GLOF research items were published in the WOS Core Collection database as of the end of 2016. At least one GLOF research item was published each year since 1979 with the exception of 1983 and 1987 (see Fig. 1). At least 10 GLOF research items were published every single year since 1993, at least 20 items since 2002 and at least 50 items since 2012. A record number of papers was published in 2015 (n = 81; 9.1%). Nearly 500 items (n = 498; 55.8%) have been published since 2008 (during the past 8 years out of the 38-year long period of the analysis).

GLOF research has been published under 256 diverse *source titles* (journals and proceedings) indexed in the WOS, of which 26 journals / proceedings have published 10+ GLOF research items each (515 items in total; 57.7%) and 10 journals / proceedings have published 20+ items each (297 items in total; 33.3%). The Journal of Glaciology (n = 48; 5.4%), Quaternary Science Reviews (n = 46; 5.2%) and Geomorphology (n = 39; 4.4%) have published 30+ items, in total 133 (14.9%). Twenty of the most popular journals / proceedings have published a total of 449 (50.3%) items. Twenty-two out of the 26 journals that published 10+ items each have a Q1 or Q2 ranking in at least one WOS category. Four of these journals have IF > 4, 11 have IF > 3 and 20 have IF > 2. Eight research items (0.9%) have been published in top ranked journals (Nature, Science).

The analysed GLOF research items have been published in journals indexed in 48 diverse *WOS categories*. The vast majority of published items (n = 558; 62.6%) have been published in journals indexed in the *WOS category* “geoscience multidisciplinary”, followed by “geography physical” (n = 338; 37.9%), “water resources” (n = 149; 16.7%) and “geology” (n = 117; 13.1%). Research of GLOFs is represented in 34 diverse research areas. The most frequently represented *research area* is “geology” (n = 666; 74.7%), followed by “physical geography” (n = 338; 37.9%), “water resources” (n = 149; 16.7%) and “environmental science ecology” (n = 100; 11.2%). ~~In terms of document types, the vast majority of the GLOFs items published in WOS are classified as articles (n = 731; 82.0%), while 149 are classified as proceedings papers (16.7%) and 50 are classified as reviews (5.6%). A few items are also classified as letters, editorial materials or notes.~~

3.1.2 Citations and references

The 892 published GLOF research items have attracted a total of 18,570 citations (as of the end of 2016) and around 13,000 citations without self-citations. The number of citations has gradually increased during the analysed period, from tens of citations per year in the 1980s, hundreds of citations per year in the late 1990s and 2000s, thousands of citations per year in

the 2010s, to up to 2,514 citations in 2016, which basically reflects the increasing number of GLOF research items published (see 3.1). Each item has an average of 51.63 records in the list of references, rarely exceeding 100 references.

Each GLOF research item has obtained an average of 20.82 citations (14.57 without self-citations). The most cited paper (Hemming, 2004) has obtained 581 citations (as of the end of 2016) and the 108 most cited papers (12.1% of all) have obtained more than 50% of all citations. Approximately one quarter ($n = 228$; 25.6%) of all items have two or less citations, of which 107 were published in 2014 or earlier. The H-index of GLOF research items is 62 (October 2017). In terms of citations obtained by individual items per year, 7 items obtained 15+ citations / year, 21 items obtained 10+ citations / year, and 77 items obtained 5+ citations / year during the analysed period. Each item obtained an average of 2.11 citations (1.48 excluding self-citations) per publication–year (8,798 publication-years in total). The ratio of citations in a given year divided by the cumulative number of items published until a given year has gradually increased from 0.28 in the early 1990s to 2.90 in 2015.

3.2 Geographies of GLOFs, GLOF research and researchers

3.2.1 Where are GLOFs studied?

The occurrence of GLOFs is closely tied to the retreating glaciers and is, therefore, geographically clustered. Based on the previous GLOF inventories and overviews (Carrivick and Tweed, 2016; Emmer et al., 2016), eleven non-overlapping hotspots of GLOFs occurrence are distinguished around the globe (see Tab. 2; Fig. 2), of which three are located in Asia (HKH, CAS, KRK), in Europe (ALP, ICL, SCA) and North America (ALA, GRL, NAC) and two are located in South America (CAN, PAN). ICL, NAC and HKH are the most prominent GLOF research hotspots with 180, 144 and 142 research items, respectively. The documented numbers of GLOFs are, however, highly disproportionate (see 4.2). GLOFs have been studied on all of the continents including Africa (e.g. Girard et al., 2012), Australia (e.g., Goodsell et al., 2005) and Antarctica (e.g., Margerison et al., 2005), and extreme outburst floods are also thought to shape the landscape of Mars (e.g., Lapotre et al., 2016).

Three types of studies are distinguished among the GLOF research items in terms of geographical focus: (i) regionally-focused items; (ii) multi-regionally-focused items; and (iii) items with no regional focus (e.g., theoretical or model studies). It was determined that almost three quarters of all GLOF research items ($n = 651$; 73.0%) have their geographical focus in 11 of the pre-defined hotspots of GLOFs occurrence, of which 32 items (3.6%) are characterised as multi-regionally-focused (e.g., Worni et al., 2012; Haeberli et al., 2016). However, the actual number of research items with a certain geographical focus is slightly higher ($> 80\%$), considering items that are geographically focused on regions outside the eleven hotspots of GLOF occurrence, such as Altai / Siberia (21 items, e.g., Margold et al., 2011), Svalbard (5 items; e.g., Schoner and Schoner, 1997), Caucasus (4 items; e.g., Petrakov et al., 2012), Antarctica (21 items, e.g. Margerison et al., 2005) or items focused on Mars (23 items; e.g., Rodriguez et al., 2015). In terms of individual countries, the most prominent country of GLOF research is Iceland (180 research items).

While the total amount of published GLOF research items is gradually increasing ~~in time~~ globally over time (see 3.1.1, Fig. 1), significant differences exist between individual GLOF research hotspots (see Fig. 3). The amount of research preformed in GLOF research hotspots located in developing regions (e.g., CAS, KRK, CAN, PAN) ~~has is~~ generally increased~~ing~~, while the amount of research performed in developed regions ~~has been is~~ stagnant (e.g., SCA, NAC) or ~~has even~~ decreasing (ICL) ~~over in the past few decades~~. ~~The An~~ exceptional position of the HKH region in GLOF research ~~can is~~ also be seen ~~in from the Fig. 3~~. Furthermore, ~~itIt~~ is further clear that GLOFs ~~were have been~~ studied in hotspots located in Europe and North America before 1991, and expanded to Asia in the 1990^s and South America in the 2000^s (not considering local publications not indexed ~~in at~~ the WOS, see 2.1).

From the point of view of ~~the~~ geographical focus on individual lakes, 37 items are focused on repeated Late Pleistocene outbursts from the proglacial Lake Missoula, likely being the most researched glacial lake outburst flood (e.g., Benito and O'Connor, 2003), followed by the 8.2 ka outburst flood from Lake Agassiz, which is mentioned in 28 research items (e.g., Clarke et al., 2004). Various aspects of jokulhlaups on the Katla volcano, Iceland, are elaborated in 27 research items (e.g., Duller et al., 2014). The most famous glacial lakes in GLOF hazard / risk studies nowadays - Imja Tsho, Tsho Rolpa (both Nepal Himalayas) and Palcacocha (Peruvian Andes) have received the attention of 17, 9, and 7 research items, respectively (e.g., Rounce et al., 2016; Klimeš et al., 2016).

3.2.2 Who studies GLOFs?

In total, 1,885 authors from more than 750 institutions in 45 countries have contributed to the 892 analysed GLOF research items. Considering the number of items published by each author, it emerges that a research item on GLOF is written on average by 3.49 authors, indicating generally small teams executing GLOF research. Almost one sixth of the 892 research items (n = 146; 16.4%) have been written by individuals, while 746 items (83.6%) by research teams (two or more co-authors). The share of research items written by individuals, however, is dramatically decreasing over time. While 32.8% of all research items published before 2000 were written by individuals, 20.9% were written in 2000-2004, 17.2% in 2005-2009, 6.0% in 2010-2014 and 7.1% in 2015-2016, revealing a certain change in the publication paradigm (see also 4.1). Slightly more than two thirds of GLOF research items (n = 632; 70.9%) have been published by mononational research teams/individuals, while 260 research items (29.1%) have been published by groups of authors from two or more countries (international research teams; see 3.2.4). Researchers from up to six countries have been involved in one individual GLOF research item (e.g., Benn et al., 2012). The share of GLOF research items written by international research teams is gradually increasing over time from 26.4% in 2000-2004, 30.2% in 2005-2009, 35.6% in 2010-2014 to 36.8% in 2015-2016. However, significant differences exist between individual countries (see also Section 3.2.4).

More than 750 *institutions* have been involved in research of GLOFs, of which 17 institutions have published 20+ GLOF research items (369 items in total; 41.4%). Nine of these 17 institutions are located in Europe (United Kingdom, Iceland, Switzerland and France), seven in North America, and the remaining one in Asia. Overall geographical distribution of GLOF research items by the countries of the authors' institutions suggests a strong dominance of authors from Europe and North

America: 497 items (55.7% of all) were (co-)authored by researchers from Europe; 344 items (38.6% of all) were (co-)authored by researchers from North America (USA + Canada); 179 items (20.1% of all) were (co-)authored by researchers from Asia (including Russia); 29 items (3.3% of all) were (co-)authored by researchers from Latin America; 25 items (2.8% of all) were (co-)authored by researchers from Australia (Australia + NZ); and 7 items (0.8% of all) were (co-)authored by researchers from Africa.

Fourteen out of 1,885 individual researchers (0.7% in all) have published 10+ GLOF research items each (189 items in total; 21.2%) and 90 researchers (4.8% of all) have published 5+ GLOF research items each (436 items in total; 48.9%). Researchers from the USA have contributed to 240 research items (26.9%), followed by 213 items (co)authored by researchers from UK (23.9%) and 115 research items (co)authored by researchers from Canada (12.9%; see Fig. 2). The seven most productive GLOF research countries have published 50+ GLOF research items each (678 items in total; 76.0%) and 16 different countries (England, Scotland and Wales are counted separately) have published 20+ GLOF research items each (802 items in total; 89.9%).

3.2.3 The “export” of research of GLOFs

It is obvious that a certain geographical disproportion exists between the countries where GLOFs are studied (11 hotspots of GLOF occurrence; see 3.2.1) and the top 10 GLOF research countries (see 3.2.2; see Fig. 2), which have contributed to a total of 740 (83.0%) GLOF research items. The “export” of research from the top 10 GLOF research countries to 11 hotspots of GLOF occurrence is described in this section (see Tab. 3 and Tab. 4). Considering the country of the first author only (i.e. each item is counted only once in the country of the first author even if it was written by an international research team; Tab. 3), the following patterns are observed: (i) more than three thirds (78.3%) of research items focusing on 11 hotspots of GLOF occurrence were authored by researchers from the top 10 GLOF research countries; (ii) 43.5% of imported research items were authored by researchers from the 10 GLOF research countries; (iii) researchers from the USA and UK have performed research in all 11 hotspots of GLOFs occurrence; (iv) researchers from Iceland, China and Norway have focused almost exclusively on hotspots overlapping with their countries (ICL; CAS, HKH, KRK; and SCA, respectively); (v) the research in ALA and NAC has almost exclusively been performed by the researchers from overlapping countries (74.5% of research items focusing on ALA has been elaborated by researchers from USA and 84.7% of research items focusing on NAC has been elaborated by researchers from USA and Canada).

Considering the countries of all of the institutions contributing to individual GLOF research items (see Tab. 4), it is seen that: (i) researchers from the USA, UK and Switzerland have contributed to research in all 11 hotspots of GLOF occurrence; (ii) the most prominent GLOF research exporter is UK (154 items), followed by USA (84 items) and Switzerland (53 items); (iii) the researchers from Iceland and China focus almost exclusively on hotspots overlapping with their countries (ICL; CAS, HKH, KRK); (iv) the share of imported research from the top 10 countries is very high in GRL, KRK, CAS and HKH, while it is very low in ALP, ALA and NAC; (v) the research in hotspots located in developing countries is dominated

by researchers from the USA and Japan (HKH); Germany, Switzerland and UK (CAS); Switzerland, Germany and the USA (KRK), Switzerland and the USA (CAN); and UK (PAN).

Local researchers in hotspots located in developing regions have generally become ~~ame generally~~ more active in publishing their research in journals indexed in the WOS over ~~in the~~ past few decades (see Fig. 4), which is in line with the increasing amount of GLOF research items published (see 3.1.1, Fig. 1). The share of items co-authored by local researchers (items written by local and foreign researchers) and authored by local researchers (items written solely by local researchers) varies ~~v~~ significantly among the regions. While the share of items authored or co-authored by local researchers is generally increasing (<40% in period 2007-2011 and >50% in 2012-2016), the share of research items published by foreign authors is only slightly increasing in some regions (Casm PAN). A ~~C~~clear trend is also seen in share of ~~i~~items authored by local researchers, which is increasing in all three regions located in Asia, but stagnant in PAN. No research items indexed ~~at in~~ WOS were ~~was~~ authored by researchers from CAN (see Fig. 4).

3.2.4 International cooperation

Section 3.2.2 shows that items written by international research teams represent 29.1% of all GLOF research items with a gradually increasing trend. However, there are significant differences between individual countries (see Tab. 5). The highest number of international research items was authored (first author) by researchers from the UK (56 items), followed by the researchers from the USA (38). The researchers from the USA contributed to 91 international research items (36.1% of all), followed by researchers from UK who contributed to 84 international research items (33.3% of all). The share of international items on the overall number of items published among the top 10 GLOF research countries varies from 34.8% (Canada) to 71.4% (Norway).

The vast majority of the 45 GLOF research countries (n = 42) have contributed to at least one international GLOF research item (Lebanon, Saudi Arabia and Uzbekistan have not). The intensity of international cooperation between GLOF research countries is illustrated in Fig. 35. An overall number of 468 individual bilateral research ties exist (each tie represents one joint publication between two countries; see Tab. 1). Very strong cooperation (20+ joint research items) exists between researchers from the USA and the UK (24 joint research items), and the UK and Iceland (21), and strong cooperation (10+ joint research items) exists between the USA and Canada (19), the USA and Iceland (13), Switzerland and Germany (12), and the USA and Japan (10). Certain patterns and trends are observed regarding the cooperation between groups of countries and GLOF hotspots located in developing regions (see 4.2).

3.3 The Analysis of the -content-analysis

Selected aspects of the content and focus of GLOF research items published in the WOS Core Collection database are addressed in this section. A total of 823 GLOF research items (92.3%) are indexed as research articles (731 articles, 149 proceeding papers) and 50 items as reviews (5.6%). Additional 20 items contain “review*?” “ within the title or abstract. A few items are also classified as letters, editorial materials or notes. Considering the different lake types that ~~which~~ may be the

source of GLOFs (moraine-dammed, bedrock-dammed, ice-dammed), it is shown that studies focusing on GLOFs originating in ice-dammed lakes (n = 451, 58.8%) dominate over ~~the~~ studies focusing on GLOFs originating in moraine-dammed lakes (n = 195; 21.9%), roughly corresponding to ~~with~~ the share of these lake types over the ~~on~~ total number of GLOFs (see Carrivick and Tweed, 2016; Emmer et al., 2016).

5 In terms of distinguishing between studies focusing on palaeo-GLOFs (Pleistocene and Holocene) and recent ones (i.e. post-Little Ice Age), it is found that 258 GLOF research items (28.9%) ~~are~~ explicitly focus ~~ed~~ on palaeo-events such as Lake Missoula and Lake Agassiz (see also 3.2.1). It is further ~~stated~~ ~~declared~~ in titles, abstracts and keywords, that 39.8% of GLOF research items (n = 355) use some kind of modelling approaches / simulations, while 14.1% items (n = 126) explicitly declare ~~the~~ ~~to~~ use of remotely-sensed data and 30.4% of GLOF research items (n = 271) deal with diverse aspects of GLOF
10 hazard / risk assessment. Individual reviews of ~~on~~ these selected aspects of GLOF research have been elaborated, e.g. by Huggel et al. (2002) or Quincey et al. (2005) focusing on the application of remotely-sensed data, or by Kougkoulos et al. (2018) focusing on GLOF susceptibility assessment, etc. (see also 4.3).

4 Observed trends in GLOF research: A discussion

4.1 Is there a changing publishing paradigm?

15 Research of glacial lake outburst floods (GLOFs) represents a dynamic research field, reflecting the needs and challenges brought by the rapidly changing environment (e.g., Huss et al., 2017). A certain change in the publishing paradigm is observed among the published GLOF research items and documented by the analysed characteristics (see Section 3.1). Firstly, the amount of research of GLOFs had an exponentially increasing trend in the WOS database between 1979 and 2016. From the field of natural hazard science, a similar trend is observed in research on tsunamis (Chiu and Ho, 2007), a more remarkable
20 trend is observed in research on landslides (Xu et al., 2015) and a less remarkable trend in research on earthquakes (Liu et al., 2012). This trend is similar despite the fact that the GLOF research field is an order of magnitude smaller than the other above-mentioned fields and is in concordance with the generally observed trends across the scientific disciplines (e.g., Sandstrom and Van den Besselaar, 2016). Secondly, the increasing amount of published research items within the certain research field is directly tied with the increasing amount of citations obtained by individual items within this field (e.g., geomorphology;
25 Dorn, 2002), which is also valid ~~also~~ in the case of GLOF research (see 3.1.2). Thirdly, the share of GLOF research items written by individuals is observed to have dramatically declined over the few past decades (see 3.2.2). This observation is not surprising considering the general trends in research and science, and may indicate the increasing average extent and, hence, multidisciplinary of the research teams involved (see also Skilton, 2009). Last but not least - the changing paradigm in GLOF research is also seen in the thematical content of GLOF research items. While hazards and risks, geomorphology and hydrology
30 have traditionally dominated in GLOF research, recently other aspects such as climate justice have come to the forefront (e.g., Huggel et al., 2016; [see 4.3](#)).

4.2 Trends in geographies

A significant disproportion is observed between the number of documented GLOFs from specific regions and the number of GLOF research items geographically focused on a given region (see 3.2.1). While 270 GLOFs are documented from ICL (180 research items), only 47 are documented from HKH (142 research items; see Tab. 2). This disproportion can be explained as a result of: (i) differences in the causes and mechanisms of GLOFs (repeated GLOFs from ice-dammed lakes in ICL, one-off GLOFs from moraine-dammed lakes in HKH); (ii) incomplete GLOF inventories in less researched and/or less settled regions such as remote areas of HKH (see [Emmer et al., 2016](#); [Veh et al., 2018](#)); (iii) the expected future increase in GLOF occurrence in HKH (Harrison et al., in review). On the other hand, the highest number of GLOFs are documented from ALP (n = 301), where only 46 studies were performed, which may be related to the late stage of glacier retreat in a post-LIA context (see also Emmer et al., 2015).

It has also been shown that an apparent geographical disproportionateness exists between the hotspots of GLOF occurrence (see 3.2.1) and top countries performing GLOF research (see 3.2.2), leading to the geographical “export” of research (see 3.2.3) - a phenomenon not yet fully captured within the context of the GLOF research field. ~~The~~ Considering the items published in the WOS Core Collection database (see 2.1), the research of GLOFs is traditionally dominated by researchers from Europe and North America (see 3.2.2), while researchers from other countries - especially those overlapping with GLOF ~~occurrence~~ hotspots located in developing regions – have been mostly focused ing on producing local publications and reports (see 2.1) and have come into play more recently, frequently as members of international research teams, but also as the first authors ([Zaginaev et al., 2016](#); [Colonia et al., 2017](#); [Gherardini and Nucciotti, 2017](#); [Prakash and Nagaraja \(2017\)](#)). This trend can be explained by the increasing interest of local researchers in to publishing research items indexed in at WOS, instead of apart from traditionally produced local publications and reports (see 2.1).

A sStrong collaboration ~~cooperation~~ is observed between the local institutions in developing regions and foreign researchers e.g. in Peruvian Andes, where none of the 11 research items (published until 2016) (co)authored by Peruvian ~~researches~~ have has been led by them, but foreigner researchers. A Ssimilar but not so strong trend is also observed ~~also~~ among the research items (co)authored by researchers from Central Asian countries (Kyrgyzstan, Kazakhstan). On the other hand, researchers from Nepal tend to publish their GLOF research items on by their 's own - out of 20 GLOF research items (co)authored, 11 items were authored solely by the authors affiliated with Nepalese institutions (e.g., ICIMOD, Tribhuvan University). A Ssimilar trend is also observed ~~also~~ for researchers in the PAN region (Argentina, Chile). The number of research items (co)authored by local researchers, however, significantly differs considering the a total number of items focused on the given region (see 3.2.3, Fig. 4). A general trend of larger involvement of local authors and the internationalization of GLOF research teams has ~~ve~~ also been observed over in the past few decades (see 3.2.4), which is in line with the general trends observed in among the global environmental change research (e.g., Jappe, 2007).

An example is the research of GLOFs in Kyrgyz Tien-Shan, which was formerly led by foreign researchers with the participation of Kyrgyz researchers (e.g., Janský et al., 2009; Narama et al., 2010), but has been led by Kyrgyz researchers

with the contribution of foreign researchers more recently (Zaginaev et al., 2016), indicating a certain shift in the research paradigm and/or successful knowledge transfer (e.g., Fazey et al., 2014; Gherardini and Nucciotti, 2017). A similar shift is observed in other regions such as CAN (early GLOF works published at WOS by Vilimek et al. (2005) compared to the recent work of Colonia et al. (2017)) or HKH (Watanabe and Rothacher (1996) and the recent work of Prakash and Nagaraja (2017)).

5 A trend in the internationalization of GLOF research teams has also been observed in the past few decades (see 3.2.4), which is in line with the general trends observed (e.g., Jappe, 2007).

4.3 Challenges ahead and research directions

The research of GLOFs struggles with numerous challenges brought by the complexity of generic processes and the general characteristics of these events (low frequency, high magnitude, complicated predictability). One of the greatest challenges in

10 the basic understanding of ~~to the~~ spatio-temporal occurrence of GLOFs is ~~to compile~~ ~~ing~~-comprehensive databases of these events (see Carrivick and Tweed, 2016; Emmer et al., 2016). While past GLOFs are well-described in some of the regions (e.g., Alps; see also 3.2.1), others suffer ~~from with~~ data scarcity (e.g., Veh et al., 2018). This different level of detail makes any assessment of GLOF frequencies among the regions (on global level) a rather challenging task (Harrison et al., in review). Compiling regional databases of GLOFs aiming ~~at a on~~ globally comprehensive database is, thus, considered one of the greatest

15 challenges in GLOF research.

Since GLOFs have claimed thousands of lives ~~and~~ ~~have caused considerable material damages in the past~~ (Carrivick and Tweed, 2016), ~~and further the occurrence of GLOFs are is~~ expected in the future reflecting the trend of retreating glaciers (Huss et al., 2017; Harrison et al., in review), hazard and risk assessment represents another highly challenging task and a recurrent topic among ~~the~~ GLOF research items (see also 3.3). While hazard (susceptibility) assessment ~~is~~ traditionally

20 ~~dominant~~ ~~te in in~~ GLOF risk studies (see the overview of methods by Kougkoulos et al., 2018), vulnerability assessment and adaptation in the broader context of retreating glaciers and water resources still remain brand new topics, which need to be further addressed in ~~most majority of~~ regions ~~and~~ ~~especially~~ those located in developing countries (e.g., Vuille et al., 2018). Moreover, the communication of scientific results with local authorities and integration into the ~~decision making~~ ~~decision-~~ ~~making~~ process ~~es~~ is an extremely challenging task, which is ~~far~~ beyond the scope of geoscientific research ~~itself~~ (e.g., Gagne et al., 2014), promoting the need for broader interdisciplinary ~~collaboration~~ ~~operation~~.

25 Hand in hand with the efforts to reliably assess the impacts of potential future GLOFs, ~~v~~ Various modelling tools are being developed and implemented ~~hand in hand with the efforts to reliably assess the impacts of potential future GLOFs~~ (e.g., Worni et al., 2014; Schaub et al., 2016; Chisolm and McKinney, 2017). ~~e~~ Certain challenges are still seen ahead in this regard (e.g., Mergili et al., 2018). ~~D~~ despite the rapid progress in this direction and ~~improvements to~~ ~~improving~~ technical capabilities

as well as data availability and ~~acquirability~~ ~~sability~~ (e.g., Mallalieu et al., 2017; Wigmore and Mark, 2017).

30 ~~cert~~ain challenges are still seen ahead in this regard (e.g., Mergili et al., 2018).

5 Conclusions

This study shows how research of glacial lake outburst floods (GLOFs) published in the Web of Science Core Collection database has become topical over the past few decades (analysed period 1979-2016); how the publishing culture and paradigm have changed over time and what the trends and disproportions in geographies of research on GLOFs are. A significant exponential increase in the number of GLOF research items published in the WOS database is revealed, with > 50% of the research items being published since 2008. While 1,885 researchers from more than 750 institutions in 45 countries have contributed to 892 of the analysed GLOF research items, a relatively small number of 90 leading researchers (4.8% of all) have published 5+ items each and have together contributed to almost half (48.9%) of all of the GLOF research items. Furthermore, the following trends were revealed among the published items over time: (i) internationalisation (increasing share of research items written by international teams); (ii) geographical disproportionateness (disparity between where GLOFs occurred and the top GLOF research countries). Eleven hotspots of GLOF occurrence and research have been identified, of which five are located in developing regions (South American Andes and high Asia). The export of research especially to these five hotspots has been documented hand in hand with the increasing involvement of local researchers in recent years. It was shown that researchers from the UK, the USA, Canada, Germany and Switzerland are the most active in exporting GLOF research worldwide and also in international cooperation. Despite the increasing amount of GLOF research items published and the undisputable progress in this research field, numerous challenges in enhanced understanding GLOF and advanced risk management still remain ahead. The trend of larger involvement of local researchers is observed among recent studies in hotspots of GLOFs located in developing countries, e.g., Central Asia or Central Andes.

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Tab. 1: Analysed characteristics describing each GLOF item.

Characteristics	Description	Value
WOS database:		
Author(s)	A list of authors contributing to GLOF research items	1,885 authors
Author's affiliation (institution)	A list of institutions contributing to GLOF research items	764 / 787 institutions*
Author's affiliation (country)	A list of countries where the institutions are located	45 countries
Year published	Year of publication in the journal	1979**-2016
Cited references in WOS collection	Number of references cited in one item	0-280***
Cited by	Cumulative number of citations obtained by one item	0-581****
Source title	Name of the journal / proceeding that published the GLOF research item	256 different journals / proceedings
WOS categories	WOS category in which the journal / proceeding is indexed	48 WOS categories
Research area	WOS research areas	34 research areas
Document type	WOS document types	9 document types
Manually assigned characteristics (see 2.2):		
Geographical focus	Manually assigned geographical focus of the individual item, where relevant	11 hotspots of GLOF occurrence; other regions
No. of authors	Items written by individuals are distinguished from items written by two or more authors (research teams)	Items written by an individual researcher; item written by a team
Mono-/internationality	Items written by author(s) from one country (mononational) are distinguished from items written by authors from more than one country (international)	Item written by an individual researcher / mononational team; item written by an international team
International research ties	Manually assigned bilateral research ties (each tie represents one joint publication between two countries)	A matrix of 468 bilateral research ties

* institutions / institutions-enhanced

** the first GLOF research item published in the WOS database (Jackson, 1979)

*** the highest number of references cited by one item (Girard et al., 2015)

5 **** the highest number of citations obtained by one item by the end of 2016 (Hemming, 2004)

Tab. 2: Hotspots of GLOF occurrence, number of documented GLOFs and GLOF research items focusing on a given hotspot.

Hotspot of GLOF occurrence	Hotspot acronym	No. of documented GLOFs from a given region*	No. of GLOF research items geographically focusing on a given region	Examples of recent studies
Asia:				
Central Asia (Pamir, Tien Shan)	CAS	69	37	Zaginaev et al., 2016; Petrov et al., 2017
Hindu Kush - Himalaya (including Tibet)	HKH	47	142	Aggarwal et al., 2017; Nie et al., 2017
Karakoram	KRK	98	20	Round et al., 2017
Europe:				
European Alps	ALP	301	46	Emmer et al., 2015
Iceland	ICL	270	180	Guan et al., 2015
Scandinavia	SCA	121	21	Xu et al., 2015
North America:				
Alaska	ALA	80	34	Wilcox et al., 2014
Greenland	GRL	22	34	Carrivick et al., 2017 ; Grinsted et al., 2017
North American Cordillera	NAC	246	144	Shaw et al., 2017
South America:				
Central Andes	CAN	35	27	Emmer, 2017
Patagonian Andes	PAN	74 <u>92</u>	30	Iribarren Anaconda et al., 2015 Wilson et al., 2018

* based on Carrivick and Tweed (2016); Falátková (2017); Emmer (2017); [Wilson et al., 2018](#); note that the numbers of GLOF documented from less settled regions are likely to be underestimated (see also the text)

Tab. 3. Research exports from the top 10 countries to 11 hotspots of GLOF occurrence. Only the reprint address of the first author is considered in this table (each item is counted only once). The number of items from overlapping countries (OC; e.g., Switzerland and ALP; Norway and SCA) is shown in brackets.

Country	Hotspots of GLOFs occurrence (see also Tab. 2)											Total			
	CAS	HKH	KRK	ALP	ICL	SCA	ALA	GRL	NAC	CAN	PAN	Excl. OC		Incl. OC	
TG	37	142	20	46	180	21	34	34	144	27	30	715			
USA	1	19	1	1	15	1	(26)	8	(61)	5	1	52	2.	139	1.
UK	4	13	1	5	76	4	2	12	9	4	6	136	1.	136	2.
Canada	1	2	2	2	4	0	3	2	(61)	1	0	17	6.	78	3.
Iceland	0	0	0	0	(49)	0	0	0	0	0	0	0	10.	49	4.
Germany	5	15	4	(1)	8	0	0	1	2	1	3	39	3.	40	6.
China	(6)	(16)	(3)	0	0	1	0	0	0	0	0	1	8./9.	26	8.
Switzerland	3	7	2	(19)	1	0	0	0	0	5	2	20	5.	39	5.
Japan	3	21	1	2	0	0	1	0	1	0	0	29	4.	29	7.
France	0	1	0	9	6	0	0	0	0	0	0	16	7.	16	9.
Norway	0	1	0	0	0	(7)	0	0	0	0	0	1	8./9.	8	10.
TI10	17	79	11	19	110	6	6	23	12	16	12	311		560	
TI10/1G	45.9	55.6	55.0	41.3	61.1	28.6	23.1	67.6	8.3	59.3	40.0	43.5		78.3	

TG - Total number of items geographically focused on a given region; TI10 - Total number of items authored by researchers from the top 10 GLOF research countries (excluding overlapping countries)

Tab. 4. Geographical focus of research items of the top 10 GLOF research countries (11 hotspots of GLOF occurrence). All items (co)authored by researchers from the given country are considered in this table (i.e. research items written by international research teams are counted for each country separately). The number of items from overlapping countries (OC; e.g., Switzerland and ALP; Norway and SCA) is shown in brackets.

Country	Hotspots of GLOFs occurrence (see also Tab. 2)											Total			
	CAS	HKH	KRK	ALP	ICL	SCA	ALA	GRL	NAC	CAN	PAN	Excl. OC		Incl. OC	
TG	37	142	20	46	180	21	34	34	144	27	30	715			
USA	3	27	4	1	30	1	(28)	11	(76)	6	1	84	2.	188	1.
UK	6	19	1	7	82	4	3	12	9	4	7	154	1.	154	2.
Canada	2	7	3	3	5	0	4	5	(70)	1	2	32	6.	102	3.
Iceland	0	0	0	0	(78)	0	0	0	0	0	0	0	10.	78	5.
Germany	8	17	4	(2)	10	0	0	3	3	2	4	51	4.	53	6.
China	(11)	(22)	(6)	0	1	1	0	1	0	0	0	3	9.	42	7.
Switzerland	7	15	5	(27)	3	2	2	2	4	9	4	53	3.	80	4.
Japan	3	26	1	3	0	0	1	0	2	0	0	36	5.	36	8.
France	0	2	0	(11)	9	0	0	0	0	0	1	12	8.	23	10.
Norway	3	5	0	1	3	(8)	0	3	3	0	0	18	7.	26	9.

5 TG - Total number of items geographically focusing on a given region

Tab. 5. International research items authored and co-authored by researchers from the top 10 GLOF research countries.

	USA	UK	Canada	Iceland	Germany	China	Switzerland	Japan	France	Norway
Total number of research items (co)authored	240	213	115	85	68	65	60	38	30	28
No. of international items authored	38	56	14	17	22	10	19	13	4	1
No. of international items co-authored	53	28	26	34	17	16	23	10	9	19
No. of international items (authored + co-authored)	91	84	40	51	39	26	42	23	13	20
% share on the total number of research items written by an international team (n = 252)	36.1	33.3	15.9	20.2	15.5	10.3	16.7	9.1	5.2	7.9
% share on the total number of research items of the given country	37.9	39.3	34.8	60.0	57.4	40.0	70.0	60.5	43.3	71.4

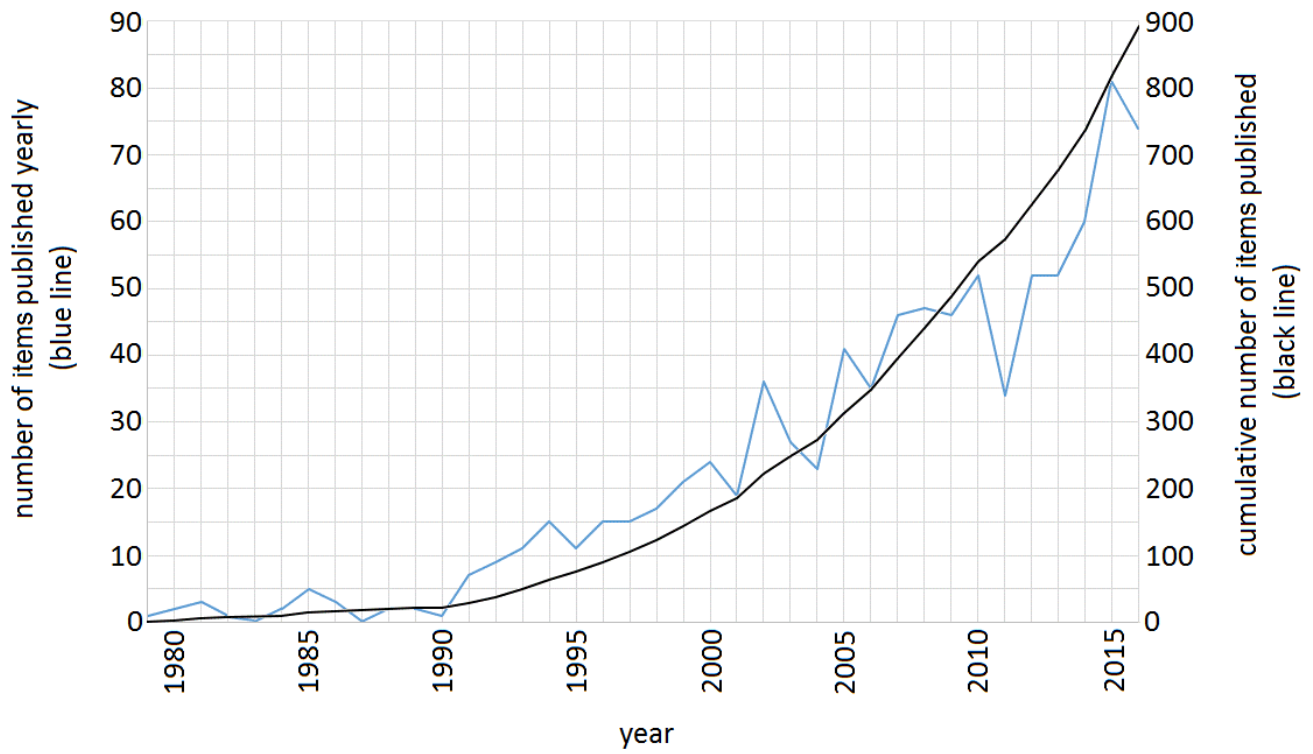


Figure 1: Yearly and cumulative number of GLOF research items published in the WOS Core Collection database (the first item was published in 1979).

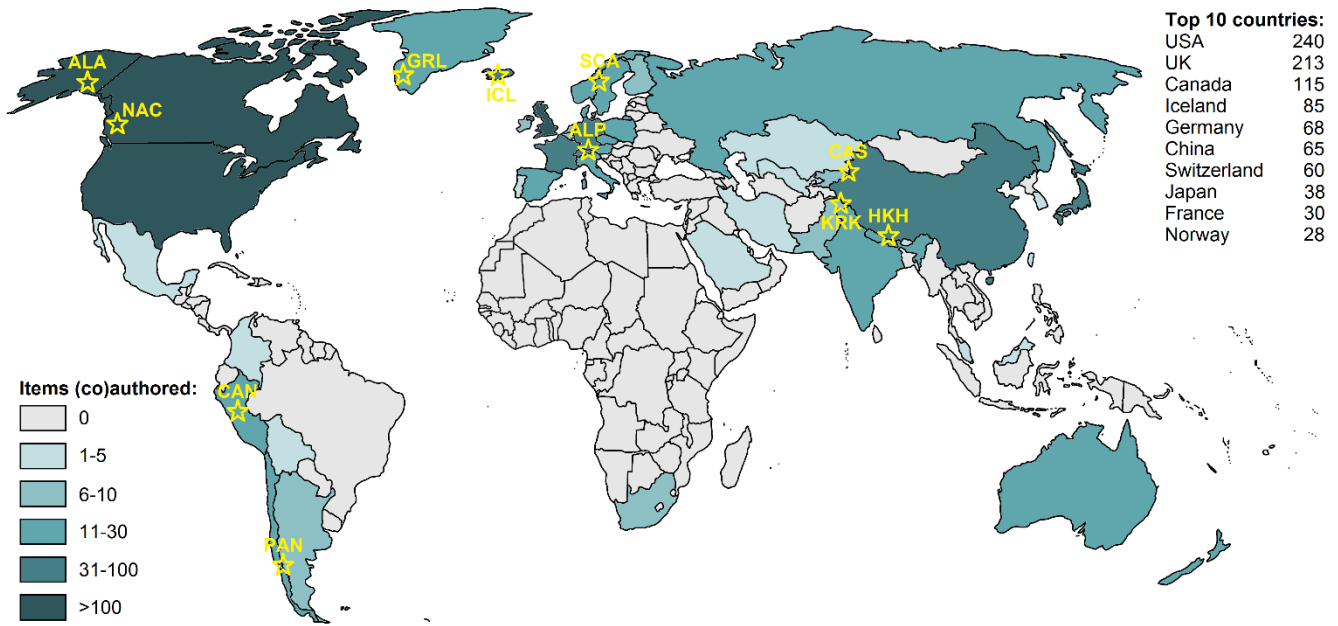


Figure 2: Hotspots of GLOF occurrence (yellow stars; see Tab. 2 for hotspot acronyms) and the geographical distribution of published GLOF research items by country.

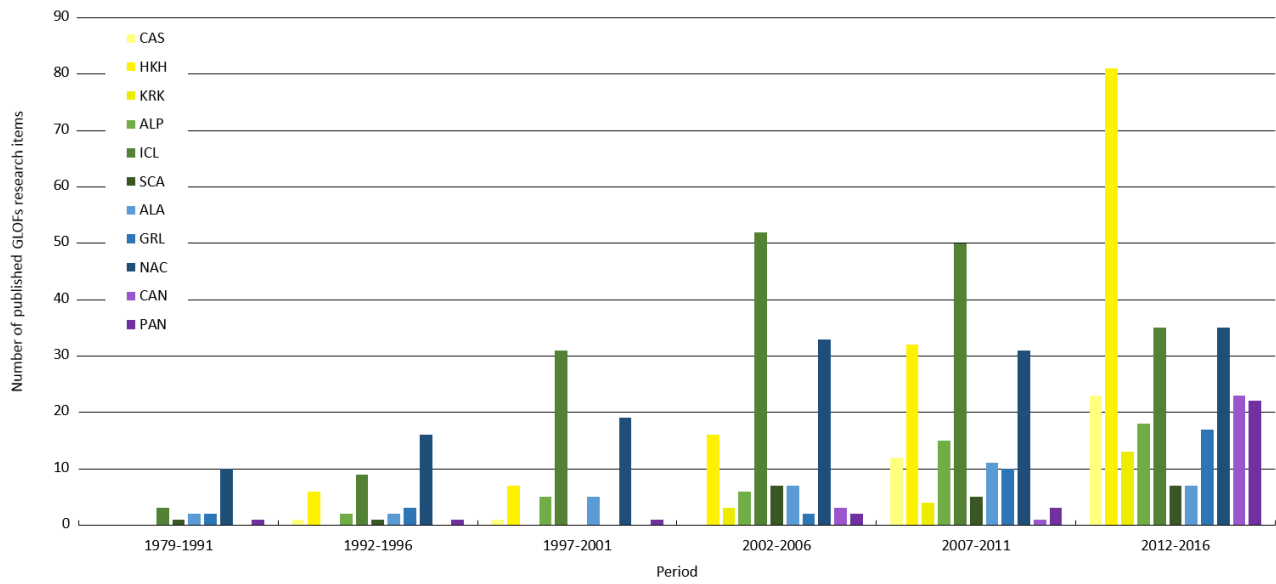


Figure 3: The amount of GLOF research items focusing on individual GLOF research hotspots (see Fig. 2) in over time.

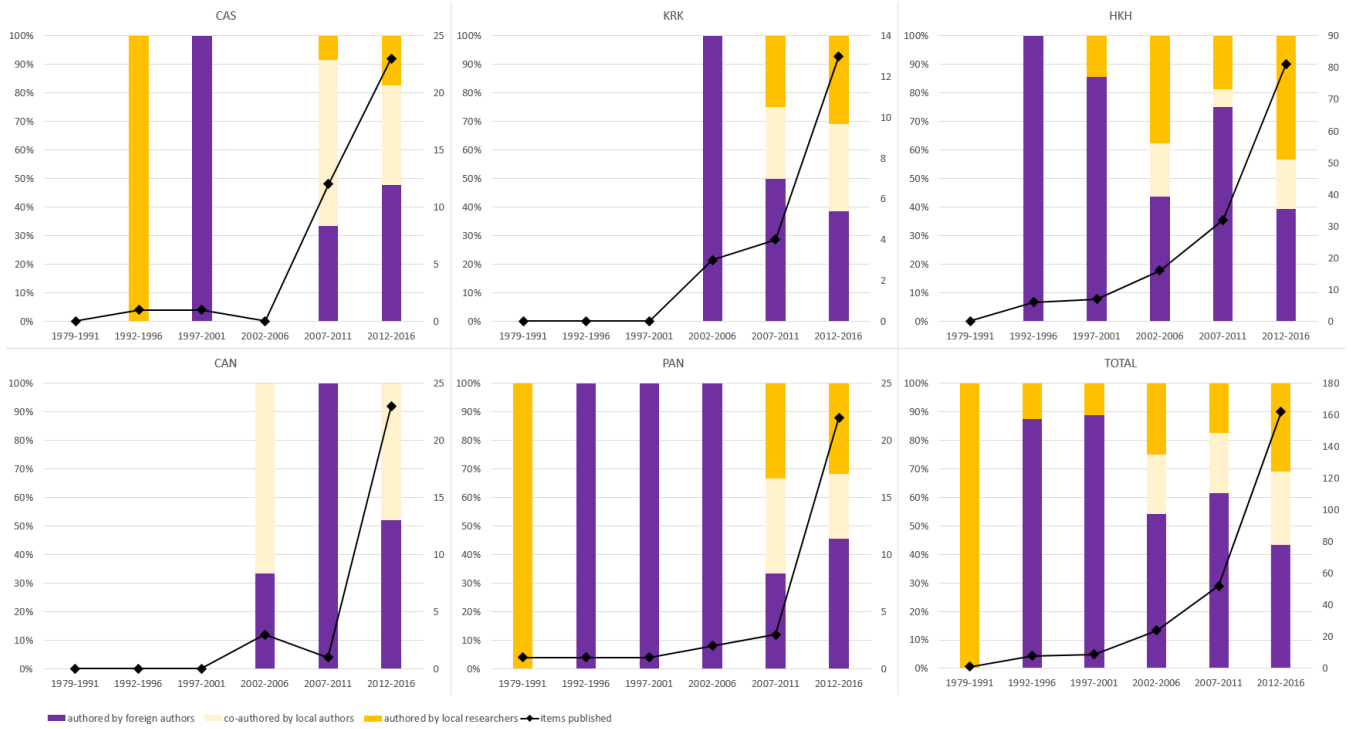


Figure 4: GLOF research items geographically focusing on five research hotspots located in developing regions (see also Figs. 2, 3). The involvement of local researchers is shown. Note the different scales of y axis for the number of GLOF research items published (black line).

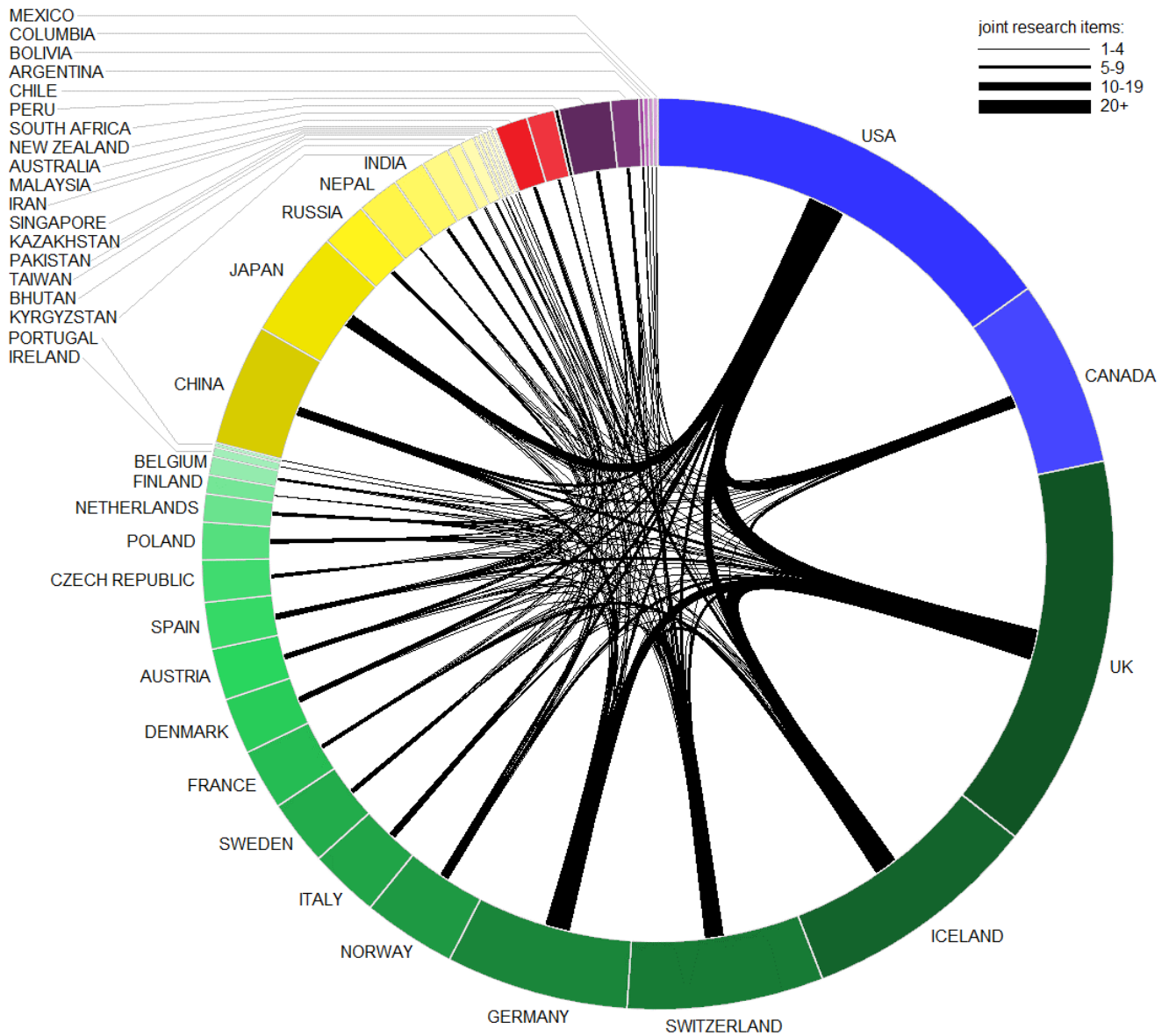


Figure 35: International cooperation between GLOF research countries. The number of international items (co)authored is proportionally indicated by the size of a sector (see also Tab. 5).