

A new GLOF inventory for the Peruvian and Bolivian Andes

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Introduction and motivation

- Numerous catastrophic GLOFs have occurred in the Tropical Andes
- Unified country-wide GLOF inventory does not exist in either Peru or Bolivia
- The need to understand spatial-temporal patterns of GLOF occurrence and related process chains for:
 - (i) enhanced GLOF hazards and risk identification, assessment and management studies
 - (ii) possible GLOF attribution to climate change (Harrison et al., 2018)

Data and general workflow

- In this work, we integrated:
 - Literature review (scientific literature, grey literature and documentary data sources)
 - Analysis of remote sensing imagery
 - Reconnaissance and field validation
- Study area: glacierized Cordilleras of Peru and Bolivia

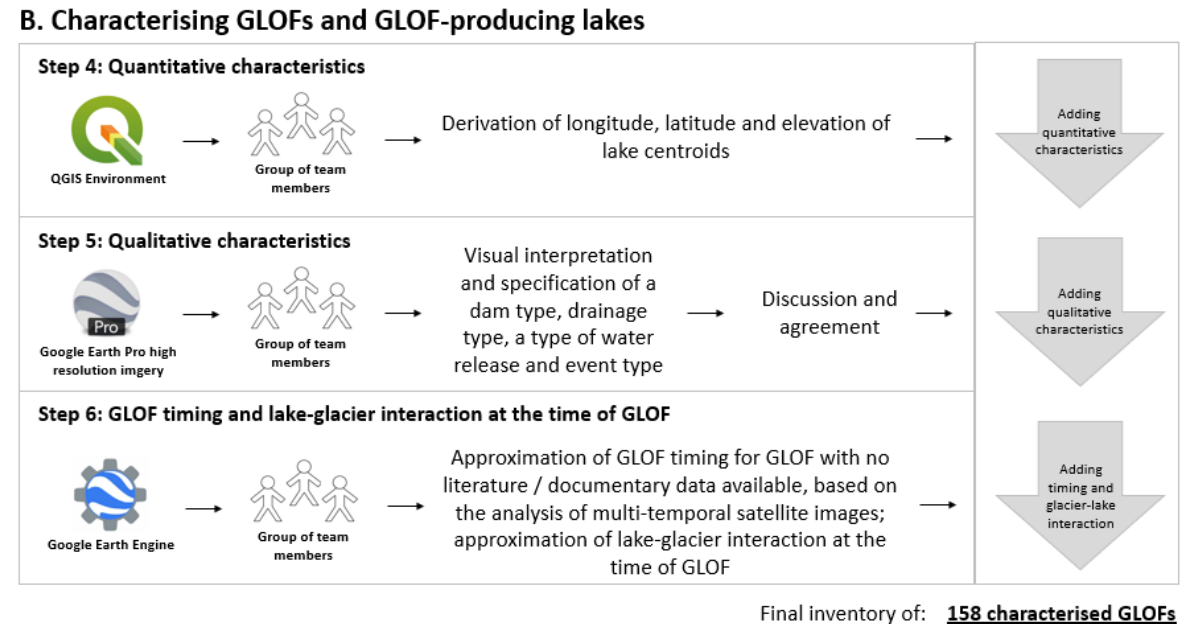
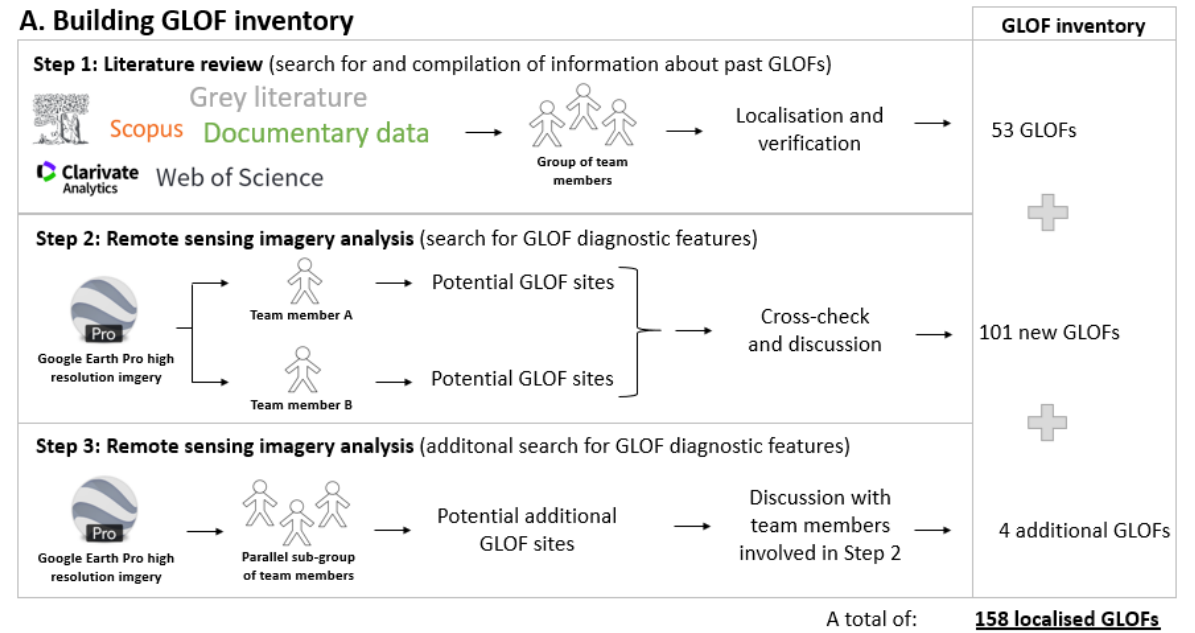


Figure: Workflow of the GLOF inventory building

GLOF diagnostic features

- GLOF diagnostic features were employed to detect previously unreported GLOFs from remote sensing images
- GLOF diagnostic features include (from Emmer, 2017):
 - (i) **Breached dam** (deeply incised outflow channel)
 - (ii) **Outwash fan** located downstream of lake dam (typically formed by material eroded from the dam or stream channel during the GLOF)
 - (iii) Visible **lake level drawdown** associated with permanent or temporary post-GLOF lake level decrease

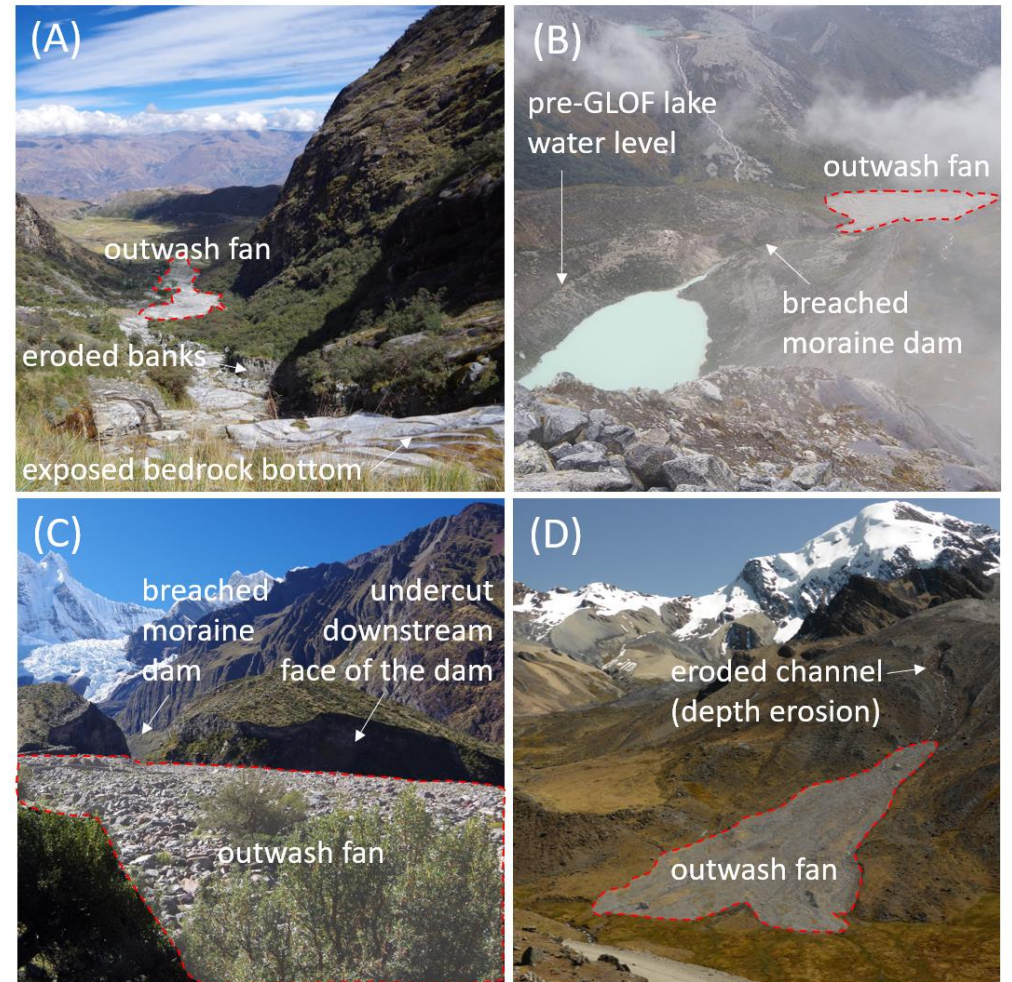


Figure: Examples of GLOF diagnostic features as observed in the field

Characterisation of GLOFs and GLOF sites

- Each GLOF in the inventory was characterised by several quantitative and qualitative attributes
- These characteristics were derived automatically or assigned manually, based on the visual interpretation of remote sensing images

Inventoried characteristics:

- Event (site) ID
- Longitude, latitude, elevation of lake centroid
- Country, mountain range (Cordillera)
- Lake dam type
- Mechanism of water release (dam failure, dam overtopping)
- Drainage type (complete, partial)
- Event type (classification based on magnitude and previous mentioning in literature)
- GLOF timing
- Lake-glacier interaction at the time of GLOF
- Likely trigger
- Reference
- Additional information

Table: A list of characteristics used to describe each GLOF / GLOF site in the inventory

Preliminary results – inventoried GLOFs

- 158 GLOFs from 150 unique sites are inventoried across glacierized Peruvian and Bolivian Cordilleras
- Majority of these GLOFs (66%) were not mentioned previously in the literature
- Spatial hotspots of GLOFs:
 - C. Blanca
 - C. Vilcabamba – C. Urubamba
 - C. Apolobamba

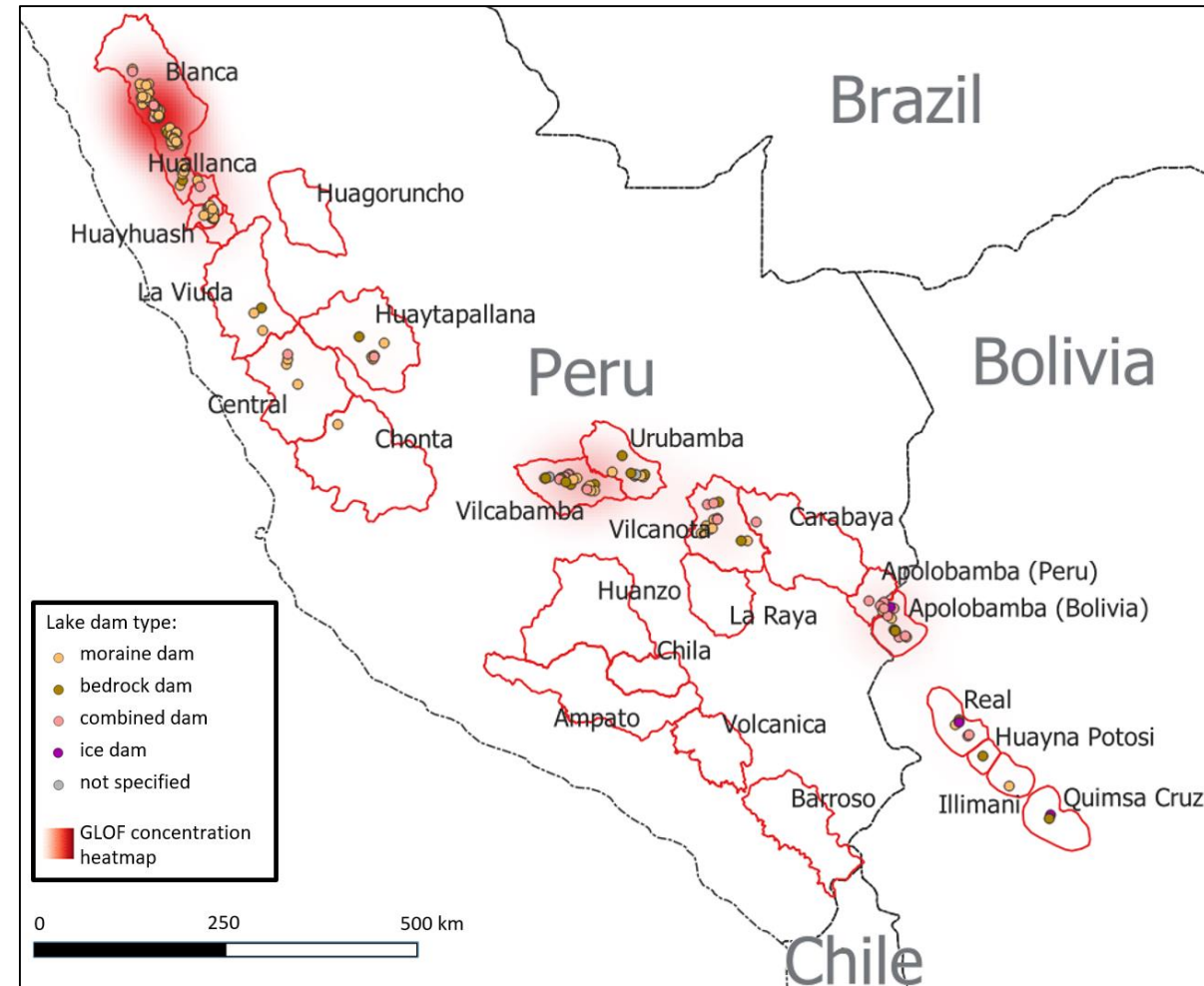


Figure: Spatial distribution of inventoried GLOFs

Preliminary results – GLOF characteristics

- Dominant source of GLOFs were moraine-dammed lakes (n=97; 61.4%), susceptible to both dam overtopping and failure, followed by lakes dammed by combined dams (n=28; 17.7%); and bedrock-dammed lakes (n=26; 16.5%), other lake types are represented only marginally
- Dominant source and mechanisms of high magnitude GLOFs were failures of moraine dams



Figure: Example of complex GLOF process chain

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Preliminary results – GLOF characteristics

- Most of the GLOF-producing lakes persisted (n=143; 90.5%), 8 lakes produced repeated GLOF and only 14 lakes drained completely as a result of the GLOF
- GLOF triggers are only known (or assumed) for a subset of 78 events, revealing a dominant role of mass movement into the lake as the main GLOF trigger in the Tropical Andes

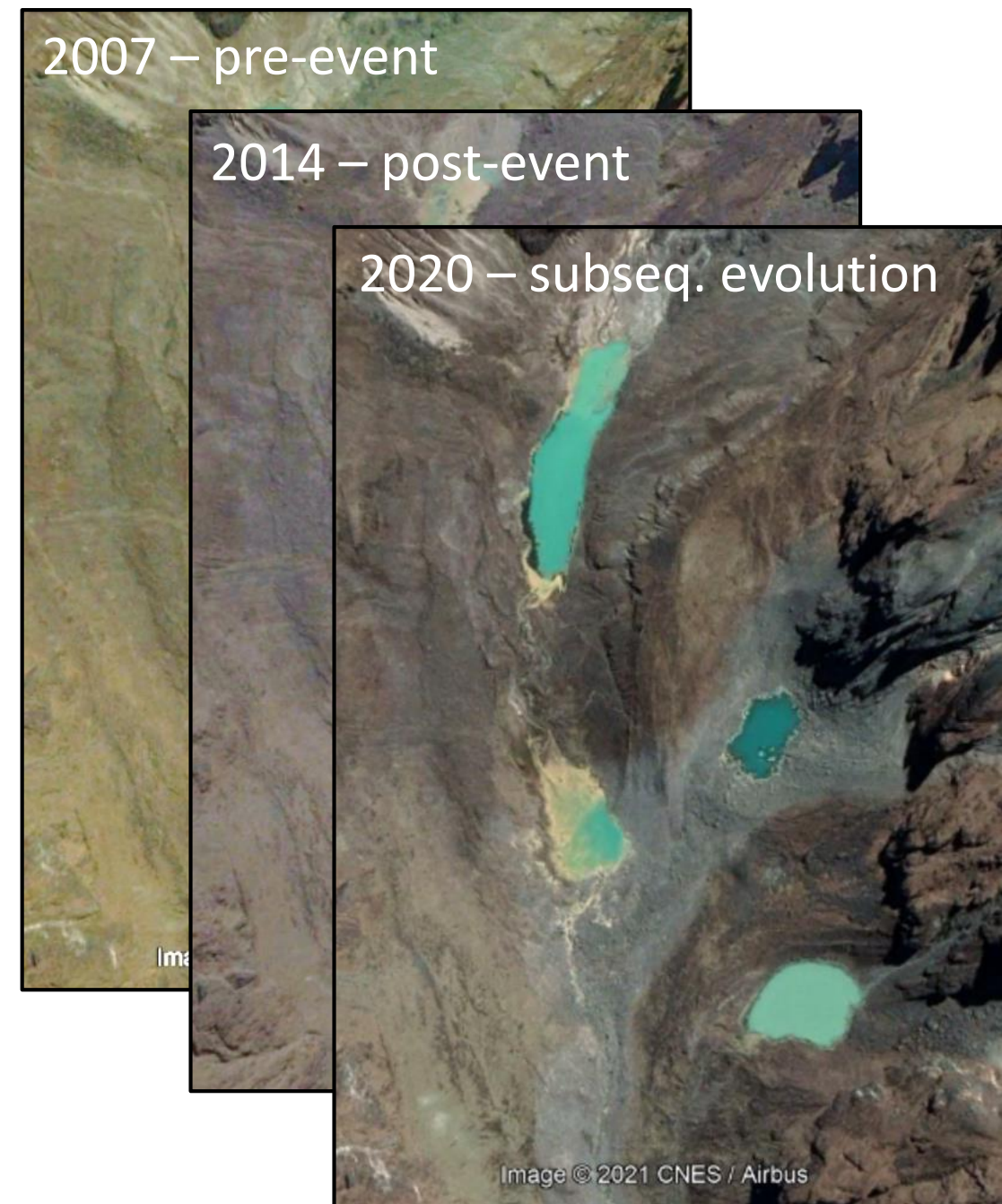


Figure: Example of complex GLOF process chain

Preliminary results – statistical GLOF frequency

- Statistically speaking, GLOFs occur with an average frequency of 0.03 GLOFs per existing lake
- However, differences in order of magnitude exist among the Cordilleras
- The highest GLOF frequencies (GLOFs per existing lakes) are observed in C. Vilcabamba, C. Huayhuash and C. Blanca

Cordillera	No. of inventoried GLOFs	No. of lakes*	GLOFs-per-lake-count ratio	Total lake area [km ²]*	GLOFs per lake area [km ⁻²]
Blanca	59	803	0.0735	38.72	1.5238
Huallanca	2	69	0.0290	1.68	1.1905
Huagoruncho	0	145	0	12.33	0
Huayhuash	14	129	0.1085	6.92	2.0231
Raura	0	245	0	16.36	0
La Viuda	3	442	0.0068	46.56	0.0644
Huaytapallana	6	373	0.0161	18.77	0.3197
Central	4	509	0.0079	37.92	0.1055
Chunta	1	212	0.0047	11.06	0.0904
Urubamba	10	139	0.0719	3.32	3.0120
Vilcabamba	21	183	0.1148	4.81	4.3659
Vilcanota	12	490	0.0245	49.33	0.2433
Carabaya	1	590	0.0017	46.86	0.0213
Apolobamba (P)	5	142	0.0352	30.88	0.1619
Huanzo	0	54	0	1.64	0
Chila	0	13	0	0.97	0
Ampato	0	19	0	0.73	0
Sub-total (Peru):	138	4557	0.0303	328.86	0.4196
Apolobamba (B)	11	203	0.0542	26.24	0.4192
Real	5	175	0.0286	17.43	0.2869
Huayna Potosi	1	81	0.0123	7.57	0.1321
Illimani	1	68	0.0147	3.54	0.2825
Quimsa Cruz	2	125	0.0160	17.42	0.1148
Sub-total (Bolivia)	20	652	0.0307	64.25	0.3113
TOTAL	158	5209	0.0303	393.11	0.4019

* Counts and areas of lakes in Peruvian Cordilleras are derived from Wood et al. (in review), counts and areas of lakes in Bolivian Cordilleras are derived from Cook et al. (2016).

Table: Inventoried GLOFs related to inventoried lakes

Conclusions and the next steps

- Unprecedentedly detailed GLOF inventory for the Tropical Andes is presented, almost tripling the number of GLOFs found in the literature
- Our study helps to understand patterns of GLOF occurrence in space and time and provides a solid basis for future studies (enhanced GLOF hazard assessments, climate change attribution studies)

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- This work will be submitted to the journal soon and the data will be made available once it is published

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THANK YOU FOR YOUR ATTENTION



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