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GlacierMap: a virtual opportunity to explore the Andes' vanishing glaciers

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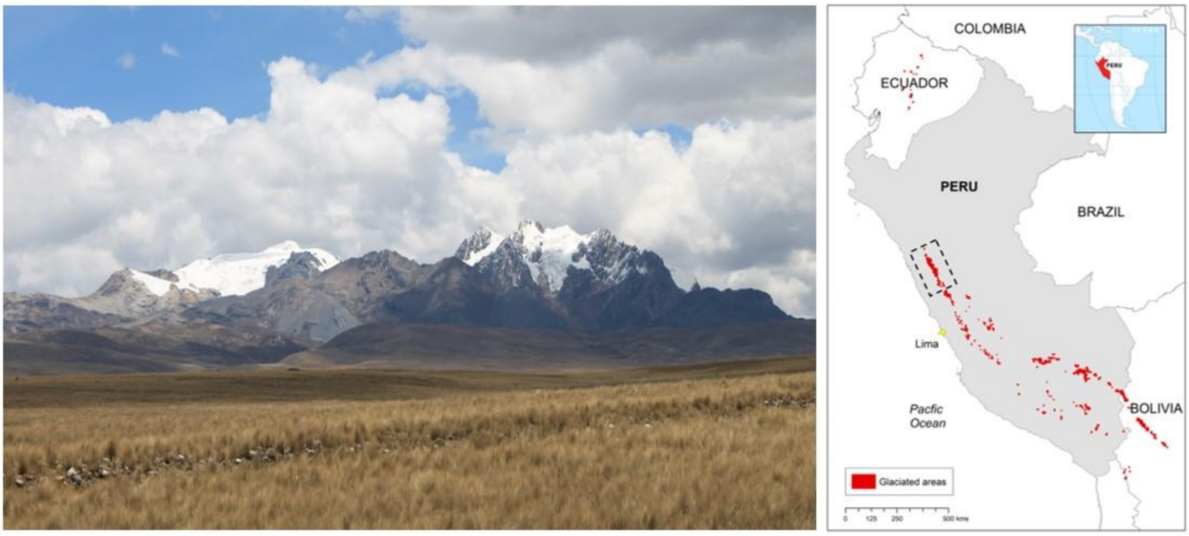

Figure 1: The glaciated Cordillera Blanca in the Peruvian Andes (left); glacier-covered area across Peru in red with the Cordillera Blanca depicted within the dashed black box (right). (Photo: Sally Rangecroft).

Introduction

For many of us, when we think about glaciers, we might imagine cold, icy polar environments such as the Arctic or Antarctica and their associated characteristic fauna. However, the existence of glaciers is not limited to high latitudes, with numerous glaciers also found close to, or even within, the Tropics, where elevation is high enough for snow and ice to persist year-round. Indeed, high mountain regions at lower latitudes, such as the South American Andes and the Asian Himalayas, are home to many hundreds of glaciers and these glaciers provide important water resources for local populations. These mountain glaciers act as "water towers" (Immerzeel et al., 2020), supplying both the environment and millions of people downstream with freshwater. This freshwater supply becomes especially important during the driest times of year when contribution from precipitation is low, yet water demand is high.

As well as being an important water source, glaciers are a key indicator of environmental change, particularly in this new Anthropocene era (Lewis and Maslin, 2015). It is now widely understood that glaciers in all of Earth's currently-glaciated regions are undergoing widespread retreat in response to climate change, including both increasing air temperatures and changing spatio-temporal patterns of precipitation. The tropical glaciers of the Peruvian Andes are no exception, and glacier retreat in this region is posing a threat to the resource security of millions of people (Painter, 2007; Rasul and Modlen, 2019). Tropical glaciers in the Andes are actually retreating quicker than many glaciers elsewhere due to their sensitivity to changes in climate (Bradley et al., 2006; Rangecroft et al., 2013).

The Cordillera Blanca of Peru (which translates as “The White Range” – Figures 1 and 2) is the world’s most glaciated tropical mountain range (Carey et al., 2014); yet, over recent decades, its glacier-covered area has decreased by 25-30% (e.g. Burns and Nolin, 2014). These glaciers are essential to domestic water consumption, agriculture, industry, and hydroelectricity production within this increasingly populated region (Figure 3), and are especially important during the dry season (Kaser et al., 2003). For mountain communities in the Cordillera Blanca, glacial melt provides up to two thirds of dry season water supply (May-October), and up to 91% during droughts (Buytaert et al., 2017). Furthermore, glacier retreat does not only impact the quantity of water available for society and ecosystems, it also can also negatively affect the quality of water available, due to issues such as sedimentation and contaminant transport (Figure 3).

Figure 2: Palcaraju glacier in the Cordillera Blanca (“The White Range”). This glaciated catchment provides important meltwater supplies to communities and ecosystems downstream (photo: Caroline Clason).

The impact of glacier retreat downstream is thus extremely important for water, food, and energy security, yet these issues often remain poorly communicated to the public (Leiserowitz and Barstow, 2010). The direct and indirect impacts of glacier change receive considerably less attention from the media in comparison to other impacts of the changing cryosphere, such as melting polar ice sheets, sea level rise (Milner et al., 2017) and emerging global issues including microplastics. Glacier retreat and its associated impacts are a significant environmental challenge, especially in regions which are more vulnerable to climate change and have lower adaptive capacity (e.g. Latin America, Himalayas). While this issue is not always reported in mainstream media, it has been, and continues to be a focus of many research projects, such as the SIGMA project (https://sigmaperu.wordpress.com/), and is often taught at undergraduate level as an example of a global challenge, particularly within many of the UK’s geography degree programmes.

Figure 3: Key impacts of glacier retreat in the Peruvian Andes for the downstream environment and communities; also illustrated within the GlacierMap tool.

Glaciers in the geography curriculum

There are numerous important geographic concept skills which can be explored and taught through engagement with the topic of glaciation. Students can learn about key physical processes, and the interconnectivity systems including the atmosphere, cryosphere, and hydrosphere, and the carbon and water cycles. There are also possibilities to look at "feedback loops", such as the role of humans for glacier retreat and the impact of that retreat on humans. Engagement with spatial datasets from glaciated environments also provides opportunities to develop skills in analysis of spatio-temporal data, and visualising and mapping of currently glaciated environments can provide an exciting glimpse into polar and mountain regions. Thus, it is perhaps unsurprising that glaciation is included in the national curriculum in the UK where it is offered at GCSE and as an option at A level. However, it is thought that the glaciation option has a much lower take-up at GCSE and A level compared to the alternative topic of coasts (McDougall, 2019). This may be because coastal processes and change can be seen at a more local level and it is more practical to conduct relevant field visits and fieldwork than for the topic of glaciation for some regions in the UK not in close geographic-proximity to previously glaciated topography. Currently glaciated environments are also quite removed from much of the UK population's typical 'sense of place' and can be difficult for individuals to visualise these less familiar places. One could also argue that the focus on coasts is based more on present-day change and issues, whereas glaciation, as it has traditionally been taught with a focus on glacial geomorphology, might be considered somewhat 'stuck in the past'.

Bringing glaciers into the present day through the development of new teaching materials and case studies will help to reinvigorate this optional geography topic, whilst also capitalising on the range of crossovers offered between different aspects of the UK geography curriculum. Glaciology and cryospheric sciences incorporate crucial elements of the physical geography curriculum, including glacial systems and landscapes, hazards, the water cycle, climate change, and ecosystems, whilst providing a platform to introduce interdisciplinary links with human geography, including population and the environment, and resource security.

The mapping and monitoring of glaciers

Glaciers have been monitored, in one way or another, for hundreds of years. During the Little Ice Age (an asynchronous period of colder temperatures spanning the 13^{th} to early 20^{th} Century) the advance of glaciers was captured in drawings, paintings and written accounts (e.g. Nussbaumer and Zumbühl, 2012), while more traditional methods of scientific monitoring at a global scale began in 1894 following the creation of the International Glacier Commission at the 6^{th} International Geological Congress in Zurich (Radok, 1997). The human fascination with glaciers has meant that we have documented evidence, in one form another, of their advance and retreat extending to long before the Industrial Revolution, thus providing a window of understanding into trends of glacier response to human-included climate change. Our understanding of longer-term glacier and environmental change is also underpinned by the proxy climate records extracted from ice cores (e.g. Thompson et al., 2003). In recent decades, in addition to field-based monitoring methods, the use of imagery acquired by satellite or aircraft (remotely sensed data) has allowed for glacier mapping across the global cryosphere at frequent time intervals and for remote regions that have traditionally been difficult to access. While there are efforts to contribute to glacier monitoring in an automated way through machine learning, manual digitisation of glacier-covered area is still central to most glacier inventory research.

Mapping has long been a core skill for geographers, and today this goes hand-in-hand with the use of Geographical Information Systems (GIS) and handling of remotely-sensed data, both of which can contribute to the development of spatial literacy (Williams et al., 2017). When students engage with spatial datasets, they not only learn more about the processes operating on the Earth's surface, and the connectivity of these processes, but they also learn a key employability skill (Seremet et al., 2013). In this regard, "map making" rather than "map reading" can stimulate both interactive and visual learning. In addition to skill development, student familiarity with GIS and analysis of spatial data can also act as a complementary element to fieldwork, or even a virtual field alternative where travel into the field is not possible (Stokes et al., 2012). Many mapping tools that were formerly used only by geographers and other experts are now available to the public and are utilised in citizen science projects (Kerski, 2015). Such projects provide a wealth of learning opportunities, offering benefits for both researchers and participants (Dunkley, 2018). Projects involving mapping specifically, either in the field or via remotely-acquired imagery, can contribute to spatial skills development, while taking part in active research may also help to situate what students are learning in class within a real-world context.

GlacierMap

GlacierMap is a citizen science project that aims to assess glacier retreat in the Cordillera Blanca of the Peruvian Andes, while also assessing the value of citizen science mapping both in terms of educational benefit and mapping accuracy. In creating GlacierMap we hoped to create an educational tool that could help contribute to the upskilling of GIS and satellite image interpretation, particularly for secondary school students, in addition to raising the profile of contemporary glacier systems in education. By contributing to GlacierMap, citizen scientists can improve their understanding of glacier retreat and its downstream impacts, in a region that may be relatively unfamiliar to many UK-based students, creating a useful tool for teachers to help foster global and connective thinking.

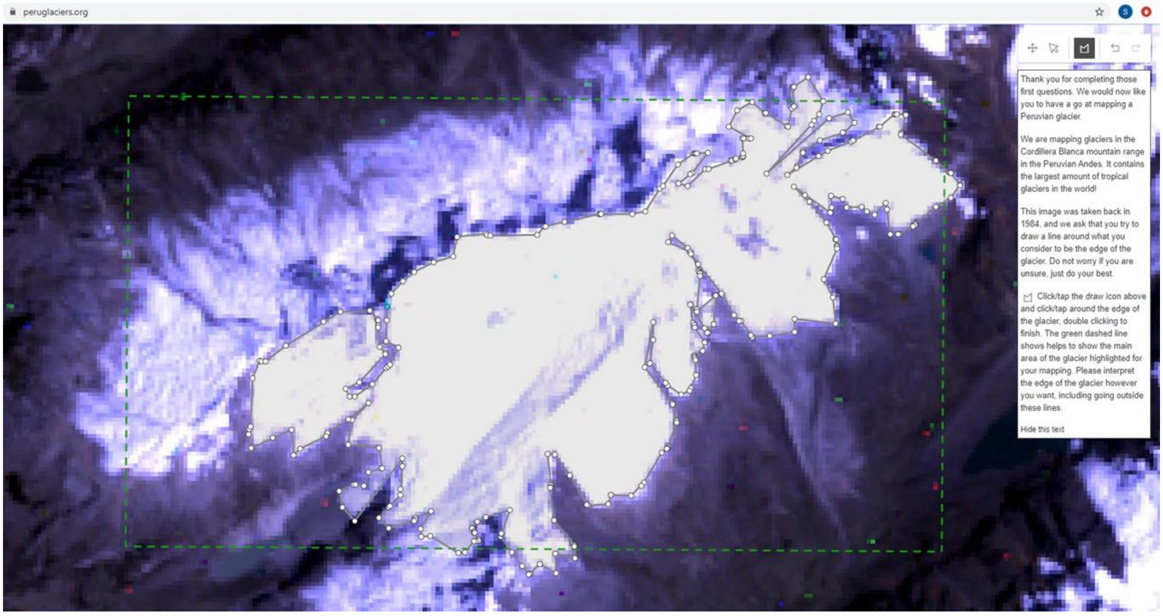

Figure 4. Screenshot of the GlacierMap app and interactive mapping exercise.

The GlacierMap tool is a free, web-based app embedded within the ArcGIS online interface (https://peruglaciers.org). The core activity involves manual digitising of the outlines of a randomly selected glacier from Landsat satellite imagery for both 1984 and 2018 (Figure 4). By digitising the glacier over this 34-year time period, users can witness any change in glacier-covered area through the lens of their own mapping. The glacier mapping element is preceded by a short survey to establish the prior understanding of participants in terms of glacier change and its impacts. On completion of the mapping task participants are provided with information on the downstream impacts of glacier retreat in the Cordillera Blanca region (Figure 3), and are asked some of the same questions again, to gauge the extent to which engagement with the mapping activity and information contributes to development of knowledge. The detailed nature of the mapping means that the exercise is best completed on a PC, laptop, or tablet, and participation from start to finish takes approximately 20 minutes. Participants can contribute to mapping as many glaciers as they like, and the resultant data is being used to assess the difference in mapping effort and accuracy by expert and non-expert groups. As a teaching resource, GlacierMap offers opportunity for inquiry-based learning through participation in an interactive mapping exercise, developing both spatial literacy and skills in interpretation of remotely-sensed imagery (Figure 5). Furthermore, through engagement with materials provided in GlacierMap to promote improved understanding of downstream impacts of glacier change, students can develop their understanding of systems and environment-society interactions.

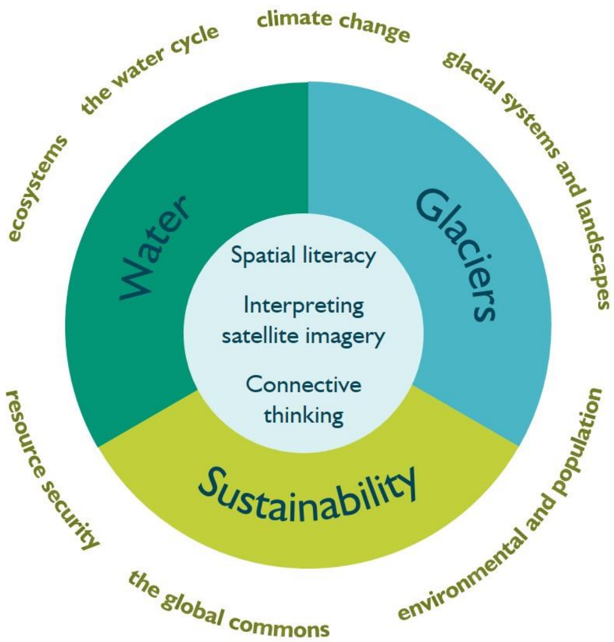

Figure 5. Key themes of GlacierMap with links to the geography curriculum and skills development.

GlacierMap in the classroom

GlacierMap can be used as a teaching resource in a wide variety of ways. For example, students can complete GlacierMap as an independent activity, or as a group class activity to allow for discussion and debate, and as an activity to allow students to actively connect with many other aspects of their learning (metacognition). We also are aware that classroom time can be limited, especially under the restrictions placed on education during the COVID-19 pandemic, and therefore GlacierMap can also be completed independently as homework and perhaps recapped as a lesson starter. Discussions with students stimulated from the GlacierMap resource could include:

- The importance of glaciers worldwide;
- The importance of glacier meltwater for water, food and energy security for different users, at different times and on different geographical scales;
- The importance of glaciers for local communities, both from a water resource and a spiritual/sense of place perspective;
- Physical feedbacks with regards to climate change and glacier retreat;
- Climate change mitigation and adaptation strategies for communities such as those in the Peruvian Andes - for example, Pre-Incan traditional adaptations such as canals, locally known as “amunas”, and the importance of low-tech, low-cost options;
- The concept of climate justice for nations and communities who have much lower contributions to global greenhouse emissions.

In addition to GlacierMap there are also many other free online resources that can be used to support teaching of glaciology in the classroom, for example:

- Virtual Reality Glaciers and Glaciated Landscapes - an online resource providing interactive virtual fieldwork opportunities (McDougall, 2019): https://vrglaciers.wp.worc.ac.uk/wordpress/
- Ice Flows - a game to explore how a simple glacier model reacts to changes in the surrounding environment : http://www.iceflowsgame.com/resources.html
- The Andean Glacier and Water Atlas – maps, figures and infographics: https://www.grida.no/resources/12832

- BRITICE – an interactive map of glacial landforms across Britain and Ireland: https://www.sheffield.ac.uk/geography/research/projects/britice
- AntarcticGlaciers.org - teaching resources and science communication for non-experts: http://www.antarcticglaciers.org/students-3/

Conclusion

We have developed GlacierMap as a citizen science tool to contribute to both research in this crucial region of the changing mountain cryosphere and to contribute towards education around glacier retreat and the downstream impacts of this ongoing climate-driven challenge. Contemporary issues such as resource management and water-food-energy security are pressing challenges for sustainable development, especially in more vulnerable countries with limited adaptive capacity. We believe that engagement with current real-world examples focussed on contemporary glaciated landscapes *and* their relationship with the wider environment and population, can make a significant contribution towards the reinvigoration of glaciology learning in the UK geography curriculum. In producing students who are climate- and spatially-literate, and who possess connected, global perspectives, we can contribute towards a new generation of geographers, equipped to meet the long-term challenges of the climate and nature emergencies and who are passionate about research and innovation.

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