Interdisciplinary mountain observations: data standards and sharing

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GEO Mountains is an initiative of the Group on Earth Observations (GEO) that seeks to improve the availability and use of a wide range of data pertaining to global mountain regions

Research Question

To what extent are data measured at global *in situ* mountain observatories, station networks, and experimental basins freely accessible?

Methods

Compile a comprehensive database listing such sites and map them according to whether or not links to freely downloadable datasets can easily be found

Results

- 37% of the ~700 sites/networks provide information/links clearly indicating that at least some data are available for direct download
- There are considerable geographical differences in the extent to which data are shared (Fig. 1)
- Positive recent trends related to i) the establishment of observation networks with common standards/approaches, and ii) better curation and increased sharing of research-derived data (and indeed Open Science more generally) are apparent
- Few sites explicitly state which observational standards / protocols they follow, potentially limiting data intercomparability and reuse

Outlook and Conclusions

- The forthcoming GEO Mountains GEOSS Community Portal could provide one means by which data that is not currently shared might eventually be
- Developing a common, overarching network of interdisciplinary global mountain observatories could also prove fruitful, although many challenges related to the existing heterogeneity in observational and metadata standards, data policies, technological capabilities, etc. are considerable (Shahgedanova et al., under review)
- The definitions of "essential" and "additional" variables required specific consideration in mountainous contexts (Thornton et al., under review)

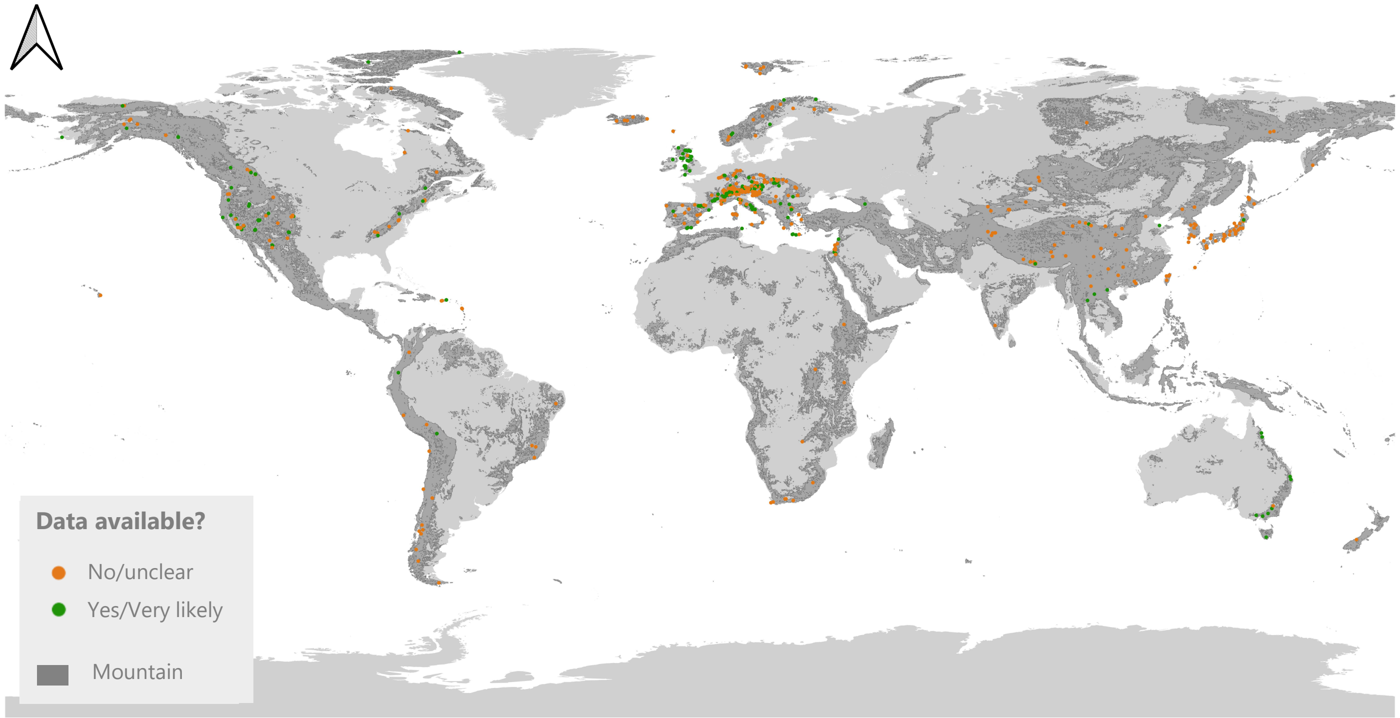

Figure 1. Global distribution of mountain observatories, station networks, experimental basins, and similar infrastructures, colour coded according to whether or not the corresponding data are clearly freely accessible for download. To be included, the coordinates provided/obtained had to fall within at least one of the delineation of global mountain regions presented by Sayre et al. (2018). Note that a site being shaded in orange does not necessarily mean that no data are available, just the data availability is uncertain and/or there are barriers to access (e.g. email contact must be made, a lengthy registration process completed, or a licence agreement made). Likewise, no assurance can be given that all the data measured at sites shown in green are available. The database underlying this map will shortly be shared via GEO Mountains such that the community can add any missing sites, verify and/or update attributed. A "live" version of the table and map will be maintained on the new, dedicated GEO Mountains website (currently in development).

Rationale and Aim

Mountains are some of the most rapidly changing regions on the planet. Because such regions provide numerous crucial resources and services to human populations and hold considerable environmental importance more generally, they must be better understood and monitored. In this way, it should be possible to generate reliable future predictions as a basis for mitigation and adaptation strategies.

The inaccessible and inhospitable nature of many mountain regions, the complex systems they host, and the challenge of obtaining spatio-temporally representative data still complicate mountain observation efforts. That said, the early pioneers of mountain observatories in the late 19th Century faced far greater travails and costs (Figure 2).

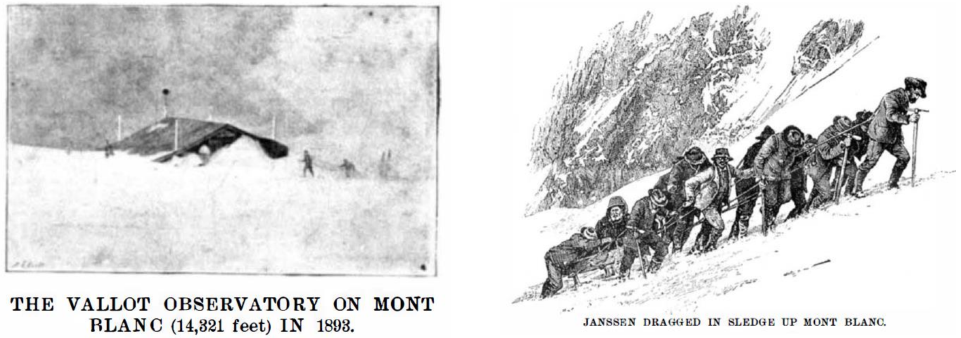

Figure 2. Cuttings from a report on early high mountain observatories (Whymper, 1895)

GEO Mountains is an Initiative of the Group on Earth Observations (GEO) that seeks to increase the availability of a wide range of inter- and transdiciplinary data pertaining to mountain regions globally. In doing so, it hopes to enhance the ease with which the scientific research community, local, national, and regional decision makers, and other interested parties can access and use such data, and thereby help realise the potential societal benefits of doing so. It also intends to ensure that mountains as a context assume and retain a prominent position in all major global policy agendas (e.g. UN 2030 Agenda /Sendai Framework/Paris Agreement, IPCC).

The **new WMO Data Policy** ("Resolution 42") will likely commit the WMO to *"broadening and enhancing the free and unrestricted international exchange of Earth-system data"* (draft text). As such, there is evidently a high degree of complementarity with the ongoing efforts of GEO Mountains.

In this context, we sought to evaluate the extent to which data from the numerous observatories, networks of stations, and experimental basis located in mountainous regions are freely available at present and identify areas of good practice and other ideas that might be further taken up to enhance the availability and use of mountain data.

Method

We compiled a database listing ~700 (predominantly research-oriented) *in situ* mountain observatories/sites. An online search was then undertaken to establish the free availability of corresponding data, and the results mapped (Figure 1). Where a site is marked in orange, this is not to say definitively that data are unavailable at these sites. Rather, it indicates that our search – which had to be quick given the large number of sites involved – failed to discover obvious download links. Data from some such sites may be available by contacting the site/data curators by email (but of course responses cannot be guaranteed), embarking on a lengthy registration process (e.g. to be verified by a representative of the data provider), and/or forming a license agreement, etc. As such, whilst in many cases perhaps unavoidable, these sites appear to diverge current best/ideal practice.

Conversely, a site being marked in green does not necessarily indicate common standards have been adhered to and quality checking undertaken, although this often likely to be the case. Furthermore, it is our impression that few such sites provide data for exchange in near real-time, which could limit the potential that data from these predominantly research-driven stations are able to contribute to include global Numerical Weather Prediction efforts, for instance (if this is an intention of the WMO's new policy). Instead, many stations provide "packaged" data with a fixed end data, i.e. the latest observations not be available on an ongoing basis.

Results, Discussion, and Outlook

At 37%, the proportion of sites at which some data are available is fairly high – perhaps even surprisingly so. Strong regional differences in the extent to which data are available are apparent, although the pattern largely mirrors that of station density. "Positive spots" which a high-concentration of green dots are located over Europe and the mountains of Australia, whilst those in North America are often a product of increasingly well established networks such as the Critical Zone Observatories (CZOs) and National Ecological Observatory Network (NEON). More generally, the large number of sites (~700) identified, a well as their diverse foci, can also be considered rather positive if one takes the view that actually installing the infrastructure and obtaining the data is the "hard"/expensive part, and subsequently preparing and sharing them in a useable format should be fairly "easy"/cheap in comparison. In other words, it seems that considerable scope should exist to increase the amount of data made available.

We additionally found that sites listed on the CryoNet website excepted, mountain observatories rarely specify the data standards / protocols that they follow, which potentially hinders data inter-comparability and re-use. We therefore recommend that mountain observatories pay particular attention to specifically stating this information, where this is not already done.

Looking ahead, one should arguably consider how to improve the availability of data from existing sites, rather than investing in entirely new infrastructure (i.e. how to turn more of the map green). However, many of the sites considered here are operated by Universities and other research organisations. A potential issue, therefore, is that WMO cannot to our understanding "mandate" data sharing except from stations that Member Countries (i.e. are operated by National Meteorological and Hydrological Services; NMHSs). One means by which this could be achieved is the establishment of an overarching network of interdisciplinary mountainous observatories (Shahgedanova et al., under revision). Integrating the diverse existing sites and networks to achieve some degree of uniformity in metadata and data standards, storage, and delivery would be a very substantial task, however.

Moreover, the draft text of "Resolution 42" also implies the need to define "essential" and "additional" data: The variables falling into these categories in mountain regions might well differ from the categorisation elsewhere. Alternatively, the same variables may be considered "essential", but the specific requirements of these observations (e.g. spatial resolution, frequency etc.) in mountain areas may be very different. Hence, a mountain-specific approach is required in this task (Thornton et al., under review).

As the database underpinning this analysis has only recently been compiled, the current version is presently only obtainable from the corresponding author on written request. However, it will shortly be posted online as a "product" of GEO Mountains so that the community can add sites, attributes, and verify and correct the information, with a view to ultimately making more of the valuable corresponding data available. The forthcoming GEO Mountain GEOSS Community Portal could provide an ideal means by which to achieve this objective.

Finally, given the relative inaccessibility of many mountainous regions, and the issue that in areas of complex topography the spatial representativeness of *in situ* observations can be limited, data derived from remote sensing provides extremely useful and highly complementary information. Novel strategies are required to integrate and extract maximal value from all available observations. A detailed assessment of the available remote sensing products and their suitability for mountainous applications fell beyond the scope of the present investigation.

Our analysis has highlighted several examples of good practice that should be harnessed. In particular, trends towards Open Access data (and indeed Open Science more generally) are being strongly driven by:

- Funding agencies (policies setting out the need to develop Data Management Plans; DMPs):

"The aim is that all NERC-funded data are managed and made available for the long-term for anybody to use without restrictions"

"Research funded by the public should be publicly accessible as far as possible and free of charge. The SNSF is committed to this goal"

- Academic publishers (possibilities setting out the need to provide accompanying open data); also growing possibilities to publish data papers, including in dedicated data journals)

Earth System Science Data
The data publishing journal

Special issue | Hydrometeorological data from mountain and alpine research catchments

- A growing realisation amongst scientists themselves of the benefits of such an approach

Developments around The Open Science Framework (OSF), OpenAIRE, FAIR Principles, Creative Commons (open licensing), numerous online data repositories etc. both advocate and help to facilitate such a shift

Finally, national and international networks are becoming increasingly well organised / standardised (e.g. CZOs, (I)LTERs; EU-INTERACT, etc.) (albeit in some cases limited to the provision of metadata and not data)

At some sites, there is also a cost associated with obtaining the data (e.g. Mount Washington Observatory). Data only being available in only non-SI units at some US sites is a practice that could be improved.

Acknowledgements

GEO Mountains is co-lead by the Mountain Research Initiative (MRI) and the Institute of Atmospheric Sciences and Climate, National Research Council of Italy (ISAC-CNR), and receives support from the Swiss Agency for Development and Cooperation (SDC) via the Adaptation at Altitude programme

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