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WGMS Report 2022 & Program 2023

1. Introduction

Internationally coordinated glacier observation was initiated in 1894 with the foundation of the *Commission Internationale des Glaciers* at the 6th *International Geological Congress* in Zurich, Switzerland. Since 1986, the *World Glacier Monitoring Service* (WGMS) has maintained and continued the collection of standardized information about distribution and ongoing changes of glaciers. Today, the WGMS is a service of the *International Association of Cryospheric Sciences* (IACS) within the *International Union of Geodesy and Geophysics* (IUGG) as well as a member of the *World Data System* (WDS) of the *International Science Council* (ISC), and works under the auspices of the *United Nations Environment Programme* (UNEP), the *United Nations Educational, Scientific and Cultural Organization* (UNESCO), and the *World Meteorological Organization* (WMO). The WGMS maintains a scientific collaboration network of *Principal Investigators* and *National Correspondents* in all the countries involved in glacier monitoring.

Based on a decision in 2009 relating to the participation of Switzerland in the *United Nations Framework Convention on Climate Change* and the *Global Climate Observing System* (GCOS), the *Swiss Federal Council* decided to provide long-term funding through GCOS Switzerland to the *Department of Geography* of the *University of Zurich* (UZH) for the operational lead and coordination of the WGMS. In 2021, the original contract between the UZH and MeteoSwiss was replaced by a long-term framework agreement and a four-year finance agreement (2021–24), to be extended after successful evaluation.

Beside this, WGMS products and projects have recently been supported by national and international organizations such as the *Cryospheric Commission* of the *Swiss Academy of Sciences*, *Swiss Agency for Development and Cooperation* (SDC) and *University of Fribourg*, IACS, and UNESCO. Moreover, the WGMS has strengthened its remote sensing capacities within ESA's *Climate Change Initiative* (CCI) and in the *Copernicus Climate Change Service* (C3S), and has recently started an additional project to reconcile measurements of glacier mass balance within ESA's *Polar Science Cluster*.

Detailed information about the WGMS, its partner organizations, monitoring strategy, and data products are available on the WGMS website: <https://wgms.ch>. In addition, the GTN-G website gives an overview on the overarching structure of international glacier monitoring as well as on the available global datasets: <https://gtn-g.org>.

2. Annual Report for 2022

2.1 Status report

In 2022, the WGMS successfully accomplished all its operational tasks, in spite of the still influencing pandemic. In addition, the WGMS published a new version of the *Fluctuations of Glaciers* (FoG, WGMS, 2022) database, as well as several scientific publications and media reports. The reorganization of the database infrastructure and the *Fluctuations of Glaciers* web browser has been continued and advanced. Moreover, WGMS staff members have been active on numerous international boards, including the GCOS *Steering Committee*, the *Terrestrial Observation Panel on Climate* (TOPC), and several IACS working groups.

2.2 Activities

Core business and special tasks

The operational tasks of the WGMS included the management of its databases and website, the response to data and information requests, and the periodic contact with its scientific collaboration network of *National Correspondents*, *Principal Investigators*, and partner institutions. In addition, the WGMS was present at various national and international conferences, meetings and workshops and was actively involved in selected education and public outreach activities.

In 2022, the core team responded to more than 20 data requests and about 100 information requests as received by email. Due to the facilitated online access to glacier data, the number of data requests by email to the WGMS is decreasing. Nevertheless, the remaining requests often require more effort because of specific demands. The WGMS website registered about 10-20,000 visits per month on average and the GTN-G website about 2-4,000 visits per month, and stayed as high as last year. Besides the *home* (<https://wgms.ch>), the pages on *global glacier state* (<https://wgms.ch/global-glacier-state/>), the *FoG browser* (<https://wgms.ch/fogbrowser>), and the *database versions* (https://wgms.ch/data_databaseversions/) were the most visited.

The *wgms Glacier App* was officially shut down in autumn 2022. Unfortunately, the search for an external partner to start a spin-off was not successful.

Beside these operational tasks, the main efforts in 2022 were the finalization of the application of the WGMS as an official UZH technology platform, the finalization of the integration of geodetic volume change estimates with global coverage from the Nature paper by Hugonnet et al. (2021), the start of the GlaMBIE (Glacier Mass Balance Intercomparison Exercise) project as part of ESA's Polar Science Cluster, and the compilation of the WGMS (and GTN-G) self-evaluation.

In addition, the WGMS completed the following (repeated) tasks in 2022:

- Control and quality check of data from the *Call-for-Data* 2019/20 (including *near-time reporting* for 2020/21) and online publication of the latest database version with the respective *Digital Object Identifier*,
- Organization of glacier monitoring sessions at EGU and AGU conferences,
- Regular updates of online products and minor revision of the WGMS and GTN-G websites,
- Glacier safety training in the Einsiedeln region,
- *Call-for-Data* for the observation periods 2020/21 and 2021/22,
- Lecture series on *Glacier Mass Balance Measurements & Analysis* (GEO851),
- Online publication of mass-balance values for 2020/21 and preliminary values for 2021/22,
- Reporting for 2022 and planning for 2023.

In 2022, several letters of support related to national and international glacier monitoring were provided on request to institutions in Austria, India, and Switzerland.

Revision of database infrastructure

In early 2022, we completed Python software and a JupyterHub interface for validating data submissions against schematic requirements and their consistency with existing data. We used this tool to review and revise 80 submissions received for the 2021 call-for-data, and are now using it (with further refinements) for the 2022 call-for-data. The submissions are subjected to over 500 data quality checks, helping us to systematically identify and correct hundreds of errors in the submissions before the new data is integrated.

In a crucial step towards further automation and centralization, WGMS' flagship Fluctuations of Glaciers (FoG) dataset was migrated from a Microsoft Access database file (proprietary, Windows-only, and limited to 2 GB) to a PostgreSQL database running on a University of Zurich server (open-source, operating-system agnostic, and unlimited in size). WGMS staff is now able to directly query the database and access the latest version of

the data. A new web browser (<https://wgms.ch/data-exploration/>) provides quick access to a metadata layer summarizing the content of the FoG database.

In June, we organized a technical workshop – with national and international partners – to discuss proposed revisions to WGMS data management, storage, and interfaces. The workshop sessions have spurred follow-up conversations with experts from *Global Land Ice Measurements from Space* (GLIMS), *Glacier Monitoring in Switzerland* (GLAMOS), the *World Data System International Technology Office* (WDS ITO), and *MeteoSwiss*, *OSCAR*, and *Global Cryosphere Watch* (GCW).

International and national collaboration

In close collaboration with the *US National Snow and Ice Data Center* (NSIDC) in Boulder and the *Global Land Ice Measurements from Space* (GLIMS) initiative, the WGMS has been in charge of the *Global Terrestrial Network for Glaciers* (GTN-G) since its creation in 1998. In 2008, the three bodies proposed a generic structure and terms of reference for a *GTN-G Steering Committee* (including an *Executive Board* and an *Advisory Board*) to the IACS Bureau. This proposal was approved in 2009 and at the beginning of 2011, the *Advisory Board* (under the lead of IACS) was finally filled with representatives from data user and producer communities, as well as from international organizations (see <https://gtm-g.ch/contact>). Over the past years, periodical meetings of officers from NSIDC, GLIMS, and the WGMS were held to discuss and coordinate key tasks. In 2022, again joint (partly hybrid) conference sessions were set up at EGU in Vienna, Austria, and at AGU in Chicago, United States, dedicated to the monitoring of glaciers from in-situ and remotely sensed observations. In addition, the different GTN-G bodies compiled a joint publication with the title '*Democratizing glacier data – maturity of worldwide data sets and future ambitions*' (Gärtner-Roer et al. 2022). This publication built the basis for the GTN-G self-evaluation prepared, presented, and submitted to the GTN-G Advisory Board in 2022.

In 2022, we started a new phase of the *Copernicus Climate Change Service* (C3S, 2022-24) in which we produce glacier inventories for GLIMS, broker vector and raster versions of the Randolph Glacier Inventory, and produce a new distributed glacier mass-change product combining glaciological and geodetic observations from the FoG database. In parallel, we launched the ESA-funded *Glacier Mass Balance Intercomparison Exercise* (GlaMBIE, 2022-2024), which aims at producing and publishing a consensus estimate of regional and global glacier mass changes from different observational sources.

In addition, we started a joint pilot project with the Euro-Climhist team (University of Bern) to secure historical glacier images for the long term and make them accessible to a broad public. For this purpose, the Euro-Climhist database was conceptually extended to include glacier images, such as drawings, oil painting, prints, photographs and maps. Subsequently, about 300 glacier images from two well documented regions (Grindelwald and Mont Blanc areas) and related metadata were integrated into the Euro-Climhist database.

The capacity-building activities in Central Asia are continued in new projects by the University of Fribourg and other partners: the project '*Cryospheric Observation and Modelling for improved Adaptation in Central Asia*' (CROMO-ADAPT) funded by SDC, the University of Fribourg and WSL started in January 2022 (until 2025 with a possible continuation of another four years) to get full sustainability for cryospheric in situ measurements on permafrost, snow and glaciers for most of the Central Asian countries. In January 2022, the project '*From ice to microorganisms and humans: Toward an interdisciplinary understanding of climate change impacts on the Third Pole*' (PAMIR), funded by the Swiss Polar Institute (SPI) and led by University of Fribourg and WSL, started in the mountain range of the Pamir covering several parts of interdisciplinary research for high mountain areas, where glacier research covers the largest part of research topics. A third project, funded by GEF/UNEP/UNESCO with the title '*Strengthening the resilience of Central Asian countries by enabling regional cooperation to assess cryospheric systems to develop integrated methods for sustainable development and adaptation to climate change*', will start beginning 2023. This project aims to increase new

and modern technology for in situ observations on long-term monitored glaciers in Central Asia. All three projects in Central Asia will use large parts of their funding to increase capacity building and enhance gender balance in science.

In the Andes and in the Himalayas, capacity-building and twinning activities related to glacier monitoring are carried out by partner institutions in Grenoble, France.

Relations with the international umbrella organizations were maintained, for example with the participation of the WGMS in the GCOS *Steering Committee* (M. Zemp). I Gärtner-Roer completed her mandate in the World Data System (ISC-WDS) *Scientific Committee* and has got approved as ex-officio TOPC member representing GTN-G. In addition, the WGMS was actively involved in IACS working groups (*Randolph Glacier Inventory*, *Regional Assessment of Glacier Mass Change*; <https://cryosphericsscience.org/activities/working-groups>).

2.3 Outreach

The WGMS staff was active at numerous project meetings as well as at several national and international conferences, some by virtual attendance:

- 17.02.2022: GCOS-WGMS Annual meeting (virtual)
- 24./25.03.2022: Alpine Glaciology meeting, Munich, DE
- 23.-27.05.2022: European Geosciences Union, Vienna, AT (hybrid)
- 23.-27.05.2022: ESA Living Planet Symposium, Bonn, DE
- 23./24.06.2022: Koni Steffen Symposium, Davos, CH
- 24.06.2022: GLOBE Contest 2021/22 und Schüler*innen-Konferenz, Bern, CH
- 20.-26.08.2022: IGS Cryosphere, Reykjavik, IS
- 11.-15.09.2022: Int. Mountain Conference, Innsbruck, AT
- 17.-19.10.2022: GCOS Climate Conference, Darmstadt, DE
- 23.-25-11.2022: ESA Polar Science Cluster Meeting, Frascati, IT (hybrid)

In addition, the WGMS team was actively involved in a large number of educational and public outreach events. Among other things, the team contributed to the *Copernicus report 2021* and to a documentary on Japanese Television. An overview is given on the WGMS webpage showing a selection of articles, videos, and audio files from newspapers and other media with reference to the WGMS: <https://wgms.ch/media>.

2.4 Publication of data and results

In 2022, the WGMS staff was involved in the following selected publications related to glacier monitoring:

- Azisov, E., Hoelzle, M., Vorogushyn, S., Saks, T., Usulbaliev, R., Esenaman uulu, M. & M. Barandun (2022): **Reconstructed centennial mass balance change for Golubin Glacier, Northern Tien Shan**. *Atmosphere*, 13(954).
- Balasubramanian, S., Hoelzle, M., Lehning, M., Bolibar, J., Wangchuk, S., Oerlemans, J. & F. Keller (2022): **Influence of meteorological conditions on artificial ice reservoir (Icestupa) evolution**. *Frontiers in Earth Science*, 9: 771342.
- Berthier, E., Floricioiu, D., Gardner, A.S., Gourmelen, N., Jakob, L., Paul, F., Treichler, D., Wouters, B., Belart, J., Dehecq, A., Dussaillant, I., Hugonnet, R., Käab, A., Krieger, L., Palsson, F., and Zemp, M. (2023): **Measuring glacier mass changes from space - a review**. *Reports on Progress in Physics*. <https://doi.org/10.1088/1361-6633/acaf8e>
- Cicoira, A., Weber, S., Biri, A., Buchli, B., Delaloye, R., Da Forno, R., Gärtner-Roer, I., Gruber, S., Gsell, T., Hasler, A., Lim, R., Limpach, P., Mayoraz, R., Meyer, M., Noetzli, J., Phillips, M., Pointner, E., Raetzo, H., Scapozza, C., Strozzi, T., Thiele, L., Vieli, A., Vonder Mühll, D., Wirz, V. & J. Beutel (2022): **In situ observations of the Swiss periglacial environment using GNSS instruments**. *Earth System Science Data*, 14(11): 5061-5091.
- Fernández, H., García, J.-L., Nussbaumer, S.U., Geiger, A.J., Gärtner-Roer, I., Pérez, F., Tikhomirov, D., Christl, M. & M. Egli (2022): **De-icing landsystem model for the Universidad Glacier (34° S) in the Central Andes of Chile during the past ~660 years**. *Geomorphology*, 400:108096.
- Gärtner-Roer, I., Nussbaumer, S.U., Raup, B., Paul, F., Welty, E., Windnagel, A.K., Fetterer, F. & M. Zemp (2022): **Democratizing glacier data – maturity of worldwide datasets and future ambitions**. *Frontiers in Climate*, 4:4: 841103.

- Gärtner-Roer, I., Brunner, N., Delaloye, R., Haeblerli, W., Käab, A. & P. Thee (2022): **Glacier–permafrost relations in a high-mountain environment: 5 decades of kinematic monitoring at the Gruben site, Swiss Alps**. *The Cryosphere*, 16(5): 2083-2101.
- GCOS (2022): **GCOS 2022 Implementation Plan**. GCOS-244, WMO, UNESCO, IOC, UNEP, ISC: 85 pp & 261 pp ECVs Requirements Appendix.
- Hegglin, M. and 37 others (2022): **Space-based Earth observations in support of the UNFCCC Paris Agreement**. *Frontiers in Environmental Science*, 10: 941490. doi.org/10.3389/fenvs.2022.941490.
- Hoelzle, M., Hauck, C., Mathys, T., Noetzi, J., Pellet, C. & M. Scherler (2022): **Long-term energy balance measurements at three different mountain permafrost sites in the Swiss Alps**. *Earth System Science Data*, 14: 1531-1547.
- Imfeld, N., P. Stucki, S. Brönnimann, S. Bader, M. Bürgi, P. Calanca, S. Gubler, A. Holzkämper, L. Hövel, F. A. Isotta, C. Kestenholz, S. Kotlarski, A. Mastai, S. U. Nussbaumer, C. C. Raible, M. Röthlisberger, S. C. Scherrer, K. Staub, A. M. Vicedo-Cabrera, M.-M. Vogel, K. Wehrli, T. Wohlgenuth, and H. J. Zumbühl (2022): **Hitze- und Trockensommer in der Schweiz. Ursachen und Folgen der Jahrhundertssommer 1947, 2003 und 2018**. *Geographica Bernensia*, G 98. Geographisches Institut der Universität Bern, 33 pp.
- Imfeld, N., P. Stucki, S. Brönnimann, M. Bürgi, P. Calanca, A. Holzkämper, F. A. Isotta, S. U. Nussbaumer, S. C. Scherrer, K. Staub, A. M. Vicedo-Cabrera, T. Wohlgenuth, and H. J. Zumbühl (2022): **2022: ein ziemlich normaler zukünftiger Sommer**. *Geographica Bernensia*, G 100. Geographisches Institut der Universität Bern, 3 pp.
- Jacquemart, M., Welty, E., Leopold, M., Loso, M., Lajoie, L. & K. Tiampo (2022): **Geomorphic and sedimentary signatures of catastrophic glacier detachments: A first assessment from Flat Creek, Alaska**. *Geomorphology*, 414: 108376.
- Kronenberg, M., van Pelt, W., Machguth, H., Fiddes, J., Hoelzle, M. and Pertziger, F., 2022. **Long-term firn and mass balance modelling for Abramov glacier in the data-scarce Pamir Alay**. *The Cryosphere*, 16: 5001-5022.
- Nussbaumer, S.U. & H.J. Zumbühl (2022): **L'iconographie des fluctuations glaciaires dans les Alpes occidentales et centrales au 18e siècle. Dix-huitième siècle**, 54:63-81.
- Paul, F., Piermattei, L., Treichler, D., Gilbert, L., Girod, L., Käab, A., Libert, L., Nagler, T., Strozzi, T. and Wuite, J. (2022): **Three different glacier surges at a spot: What satellites observe and what not**. *The Cryosphere*, 16 : 2505-2526
- Reynard, E., Gärtner-Roer, I. & M. Hoelzle (2022): **Rockglaciers of the Engadine, Switzerland**. In: International Union of Geological Sciences, IUGS. The First 100 IUGS Geological Heritage Sites. Zumaia (E), 242-243.
- Saks, T., Pohl, E., Machguth, H., Dehecq, A., Barandun, M., Kenzhebaev, R., Kalashnikova, O. & M. Hoelzle (2022): **Glacier runoff variation since 1981 in the upper Naryn river catchments, Central Tien Shan**. *Frontiers in Environmental Science*, 9.
- Tielidze, L. G., Nosenko, G. A., Khromova, T. E., and Paul, F. (2022): **Strong acceleration of glacier area loss in the Greater Caucasus over the past two decades**. *The Cryosphere*, 16: 489-504.
- WGMS (2022): **Fluctuations of Glaciers Database**. World Glacier Monitoring Service, Zurich, Switzerland. <https://doi:10.5904/wgms-fog-2022-059>.
- Windnagel, A., Hock, R., Maussion, F., Paul, F., Rastner, P., Raup, B. & M. Zemp (2022): **Which glaciers are the largest in the world?** *Journal of Glaciology*: 1-10.

2.5 Conclusions

Glacier monitoring has been internationally coordinated by the WGMS and its predecessor organizations for more than 125 years. Thanks to long-term core funding from GCOS Switzerland and support from the University of Zurich, the WGMS successfully transformed from an ad-hoc effort to a professional data service firmly rooted in the international glacier monitoring and research communities. Within the new framework for the budget period (2021–24), we are ready to further consolidate glacier monitoring within the WGMS network for in-situ observations and to tackle new opportunities and challenges of geodetic glacier-change assessments from spaceborne sensors.

3. Annual work plan for 2023

3.1 Activities

As in previous years, WGMS operations consists of annual core business, aligned with the hydrological year (cf. WGMS proposal, Fig. 2), and special tasks (cf. WGMS proposal, Fig. 3).

The special tasks for 2023 are to (i) produce the Global Glacier Change Bulletin No. 5 (2020-21), (ii) finalize the revision of the FoG database schema (version 2), update the server-based database as well as the related quality assurance and control tools, and develop internal and external user interfaces, (iii) finalize the GTN-G evaluation, (iv) prepare the WGMS evaluation report for GCOS Switzerland, (v) prepare a proposal for the

next C3S phase (2024-27), (vi) contribute to publications related to the IACS working groups RAGMAC and RGI/GLIMS and (vii) continue the capacity-building programs in Central Asia. In addition, the WGMS team supervises BSc, MSc and PhD theses, employs interns, and hosts visiting scientists working in the field of glacier monitoring and research. The following schedule lists the main activities for 2023.

1. Quarter (Jan-Mar)

- Annual report and account balance for 2022, program and budget for 2023,
- Check and upload of data for 2021/22 and *addenda* from earlier year,
- Ad hoc estimates of global glacier mass-changes in 2021/22,
- Annual telecons with WGMS NCs and PIs,
- Finalize the GTN-G evaluation and organize recommendation letter from IACS,
- Prepare maps for detailed information section of GGCB No. 5,
- Finalize revision of FoG database scheme (version 2).

2. Quarter (Apr-Jun)

- FoG data quality assurance and quality control,
- Database release (FoG-2023-0X),
- Prepare draft GGCB No. 5 for review by National Correspondents and Principal Investigators,
- Update server-based FoG database.
- Prepare and submit WGMS evaluation report for GCOS Switzerland,
- Contribute to IACS Working Groups.

3. Quarter (Jun-Sep)

- Actualisation of digital online products (FoG-2023-0X),
- Finalize and announce GGCB No. 5 (digital only, no hardcopy production & shipment),
- Develop internal & external interfaces to FoG database,
- Prepare proposal for next C3S phase (2024-27),
- Contribute to IACS Working Groups
- Continue the capacity building in Central Asia including a summer school.

4. Quarter (Oct-Dec)

- Update quality assurance & control tools,
- *Call-for-Data* for observation period 2022/23 and *addenda* from earlier years,
- Draft concept for future WGMS data publication series (replacing GGCB series),
- Contribute to proposals for extension of IACS Working Groups RAGMAC and RGI/GLIMS
- Prepare reporting 2023 and program 2024.

We note that further WGMS-related activities are planned within the following projects:

- Copernicus Climate Change Service (C3S), Glacier Area & Glacier Mass Change Services, 2022-24
- ESA Glacier Mass Balance Intercomparison Exercise (GlaMBIE), 2022-24
- ESA Climate Change Initiative (CCI+), 2023-24
- Central Asia projects (CROMO-ADAPT, PAMIR, GEF/UNEP/UNESCO June to October 2023)

3.2 Outreach

In 2023, several glacier monitoring activities of WGMS, NSIDC, GLIMS, and different IACS working groups are planned. Conference sessions on glacier monitoring are set up for the EGU General Assembly in Vienna (AT) and the IUGG General Assembly in Berlin (DE), and planned for the AGU Fall Meeting (USA), ideally including splinter meetings of the GTN-G *Executive Board* and of the IACS WGs. Additional meetings, e.g., the Alpine Glaciology Meeting in Zurich (CH), International Data Week in Salzburg (AT), and GCOS Steering Committee & TOPC meetings, will be attended by the WGMS staff physically or virtually. In addition, the WGMS organizes an IACS RAGMAC & ESA GlaMBIE workshop in Zurich (CH) in February.