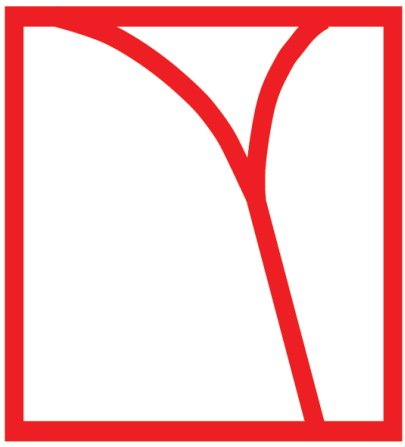
INTERNATIONAL PERMAFROST ASSOCIATION



GTN-P
Global Terrestrial Network for Permafrost

STRATEGY AND IMPLEMENTATION PLAN 2021–2024

for the Global Terrestrial Network for Permafrost (GTN-P)

MAJOR SPONSORS AND SUPPORTERS

Global Climate Observing System
GCOS

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AWI

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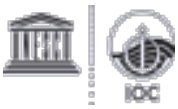
World Meteorological Organization
WMO



United Nations Educational, Scientific and Cultural Organization
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United Nations Environment Programme
UNEP

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ICSU

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The GTN-P success would not have been possible without the substantial monetary investments of critical organizations and work of a large number of motivated people. The progress of GTN-P, from organizing workshops to developing a data management system, was sponsored by numerous organizations and research projects. The EU project PAGE21 and subsequently the EU Horizon2020 project Nunataryuk contributed significantly to creating and maintaining the governance structure and the GTN-P DMS.

The network was created essentially as a bottom-up structure, reflecting the needs in observations conducted by members of the permafrost community. It is now at an advanced stage, with a developed governance structure, including an Office and an established data management system. The success of GTN-P is acknowledged by other terrestrial networks, the WMO and the scientific community.

SUMMARY

Permafrost is recognized as an Essential Climate Variable (ECV) within the Global Climate Observing System (GCOS) of the World Meteorological Organization (WMO). The Global Terrestrial Network for Permafrost (GTN-P) is the primary international programme concerned with the long-term monitoring of permafrost. **The core mission of the GTN-P is a sustained comprehensive long-term monitoring network to provide consistent, representative and high-quality long-term data series of indicator variables (ECV products) at globally distributed key sites and to assess the state and changes of permafrost over time.** The GTN-P Strategy and Implementation Plan (SIP) 2021–2024 describes the governance and management structure of GTN-P, linkages to regional and global observing systems, the management process and reporting strategies. It presents measurement methods and protocols used for field data collection and the GTN-P data management system, which are designed to collect, process, analyse, and visualize permafrost data to feed into (support) synthesize studies from local to global scales and Earth System Models targeting climate feedbacks on the terrestrial cryosphere. The GTN-P SIP concludes by outlining potential future developments of the network, which are needed to sustain and succeed its core missions of providing high-quality permafrost data, serving as a sustainable long-term data archive and remain a forum for the GTN-P community.



1. INTRODUCTION

Permafrost is an Essential Climate Variable (ECV) within the Global Climate Observing System (GOCS) of the World Meteorological Organization (WMO) (GCOS, 2016). ECVs are physical, chemical or biological variables that critically contribute to the characterization of the Earth's climate and may consist of different sub-variables, called ECV products. The ECV Permafrost products are Permafrost Temperature (PT) and Active Layer Thickness (ALT). These are currently (2021) being extended to a third Permafrost ECV product defined as Rock Glacier Velocity (RGV).

The Global Terrestrial Network for Permafrost (GTN-P) is the primary international programme concerned with sustained long-term monitoring of permafrost and thus highly relevant for the observation and evaluation of the Permafrost ECV. Permafrost is soil, rock, and any other subsurface earth material that exists at or below 0°C throughout at least two consecutive years, usually for decades to centuries to millennia and can extend to depths of metres to hundreds of metres. Permafrost can influence many natural processes and human activities in cold regions at high latitudes and high altitudes (Figure 1). Overlying the permafrost is the active layer, which is the layer of ground that is subject to annual thawing and freezing. Permafrost temperature and active layer thickness are robust indicators of the state and changes of the permafrost.

The main task of the GTN-P is to operate a sustained, comprehensive long-term monitoring network to provide consistent, representative and high-quality data series of selected permafrost parameters over long time periods and to assess their state and changes over time.

The GTN-P collects and disseminates essential baseline data to detect changes in the permafrost system. Changes, such as rising inter-annual permafrost temperature or increasing active layer thickness are critical in climate change impact assessments, understanding of ecosystem processes and feedbacks, development and validation of models, and mapping of the present and future permafrost extent. These data are also important to validate permafrost modules in Earth System Models, and to inform

development of climate change adaptation and mitigation strategies under the United Nations Framework Convention on Climate Change (UNFCCC). The GTN-P also aims to provide baseline data that contributes to societal well-being and sustainable development of communities located or dependent on the presence of permafrost. Beyond serving the scientific community, GTN-P data summaries are meant to inform and assist stakeholders and policy makers in developing and implementing strategies to mitigate and/or adapt to the effects of a warming climate in permafrost regions.

The Strategy and Implementation Plan (SIP) 2024 outlines the historical developments, the current status and future directions of the GTN-P. This document replaces the SIP 2016–2020 (Streletskiy et al., 2016).

The specific objectives of the SIP 2024 are:

- to provide a comprehensive strategy and vision for the role, mandate and mission of GTN-P through 2024 and beyond,
- to ensure that the adequate governance and capacity is in place to implement this strategy.

1.1 GTN-P Tasks and Goals

The role of the GTN-P is to provide information on changes in permafrost worldwide to the scientific community, policy makers, stakeholders and the public. Reporting on the extent, state, and evolution of permafrost, relies on the GTNP's extensive and geographically representative network of instrumented field sites and on established measurement protocols. The GTN-P products include global datasets of permafrost temperature and active layer thickness, with the potential to add more permafrost-related data.

The GTN-P focusses on its core products of permafrost temperature and active layer thickness and provides them through the GTN-P Data Management System (DMS). The new third ECV product rock glacier velocity (RGIK 2021) will be added when it is formally integrated. GTN-P remains open to include additional permafrost related data (such as terrain deformation, changes in ground ice content, greenhouse gas

fluxes) as metadata. The possibilities offered by new technologies have to be assessed and integrated when considered robust and informative.

The specific tasks and goals of the GTN-P are:

- to compile standardized data of permafrost temperature, active layer thickness, and rock glacier velocity,
- to maintain and support a publicly accessible GTN-P data portal,
- to report on permafrost temperature, active layer thickness and rock glacier velocity at selected reference sites to support national and international climate assessment reports,
- to coordinate and promote observations from the GTN-P network,
- to develop and approve standards of permafrost, active layer and rock glacier velocity measurements,
- to stimulate the integration of existing and new methods on the measurement of active layer thickness, permafrost temperature and rock glacier velocity,
- to periodically assess changes in active layer thickness, permafrost temperature and rock glacier velocity and contribute this knowledge to relevant assessments, reports and scientific papers
- to expand observations of permafrost into regions lacking sufficient observations, like for example some high latitude or high altitude regions.

Finally, the GTN-P strives to create new partnerships with services monitoring other ECV components (e.g. glaciers, snow, meteorology, soils, hydrology, ecology) by co-locating monitoring sites and expanding existing networks and reducing costs (e.g., as part of the CryoNet sites of the Global Cryosphere Watch). The GTN-P will continue its effort to promote systematic permafrost monitoring, which can be accomplished by its integration as part of official meteorological, hydrometeorological or climate stations located in permafrost regions, establishing

private-governmental partnerships in key resource development areas, securing long-term research funds, and building in-situ network capacity. **Concurrently, the GTN-P will continue to use these synergies to improve the representativeness of its network and encourage researchers and national networks to establish monitoring sites in under-represented ecological environments or geographical areas and regions.**

To address the growing needs for permafrost observations, the GTN-P will continue to develop an effective and sustainable governance structure. An independent supervision should involve key players in global climate monitoring, including the sponsors of the GTN-P, but also international players such as Global Cryosphere Watch (GCW), the Scientific Committee for Antarctic Research (SCAR), the International Arctic Science Committee (IASC) and the International Association of Cryospheric Sciences (IASC). To be able to manage the daily operations of GTN-P, a coordinating office shall be funded to the extent possible; that is, through the provision of at least one Full Time Equivalent (FTE) position for the coordination, reporting and assessment actives and network management of the network (the GTN-P Office) and one FTE position for the related management of the data.

The GTN-P shall continue to rely on a **bottom-up approach concerning data submission, through the involvement of National and Young National Correspondents (NCs and YNCs),** closely associated with the scientific community that manages these observatories. When possible, these NCs should be closely associated with those of major observing systems and UN agencies (e.g., WMO). The NCs should form the backbone of the data submission and reporting process, and be closely associated with the decision-making at the GTN-P coordination level.

1.2 Current State of the GTN-P

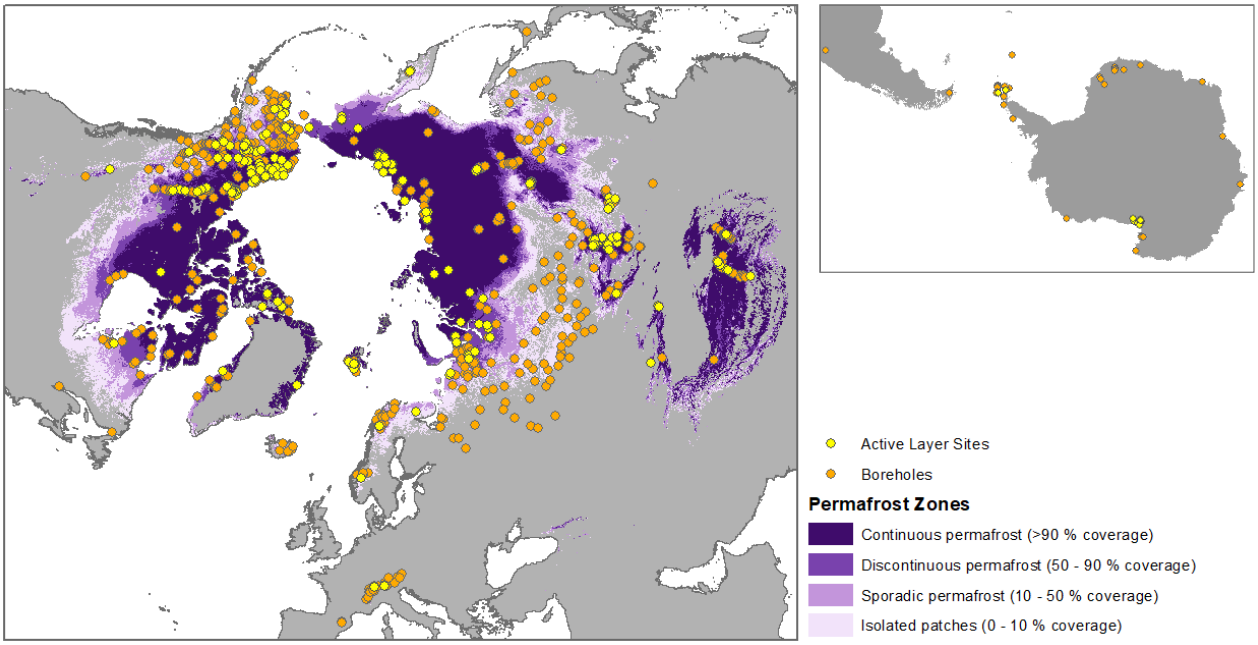

Figure 1: Location of the GTN-P PT (orange dots) and ALT (yellow dots) monitoring sites and permafrost distribution. Permafrost Zones are based on Obu et al. 2019

Presently, the GTN-P involves 40 NCs and 14 Young NCs representing 26 partner countries. These countries contribute permafrost data to the GTN-P data management system (DMS) but do not necessarily have permafrost present in their country; for example Portugal is delivering data for Antarctica. The Arctic Portal (AP) located in Iceland, administers the DMS (gtnp.arcticportal.org). The GTN-P Office is hosted by the Alfred Wegener Institute (AWI, Germany) through at least the end of 2024 and coordinates the network activities. Presently, permafrost monitoring sites registered within the GTN-P database include more than 1380 boreholes and 250 active layer measurement sites, representing over five million individual data units (Figure 1). Permafrost temperature measurements conducted in 21 countries and active layer thickness measurements conducted in 12 countries are registered within the GTN-P database (Figure 2). The large areal extent of permafrost in Russia, Canada and the USA is reflected in the large number of PT and ALT measurements in these countries.

1.3 Main tasks for the period 2021–2024

Measurement standards

Measurement and reporting standards require further development and compliance with international best practices, guidelines and standards. This development is currently being coordinated by the WMO's GCW Permafrost Best Practices Task Team, which consists of a team of experts representing different permafrost regions and methodologies. The results of the Team's work will be implemented in the update of the WMO Guide No. 8 and will mark an important step towards the standardization and operationalization of permafrost measurements. A close collaboration between the GCW Permafrost Best Practice Task Team and the GTN-P Steering Committee ensure that GTN-P measurement standards will comply with the set WMO Permafrost Best Practices.

Spatial coverage of measurements

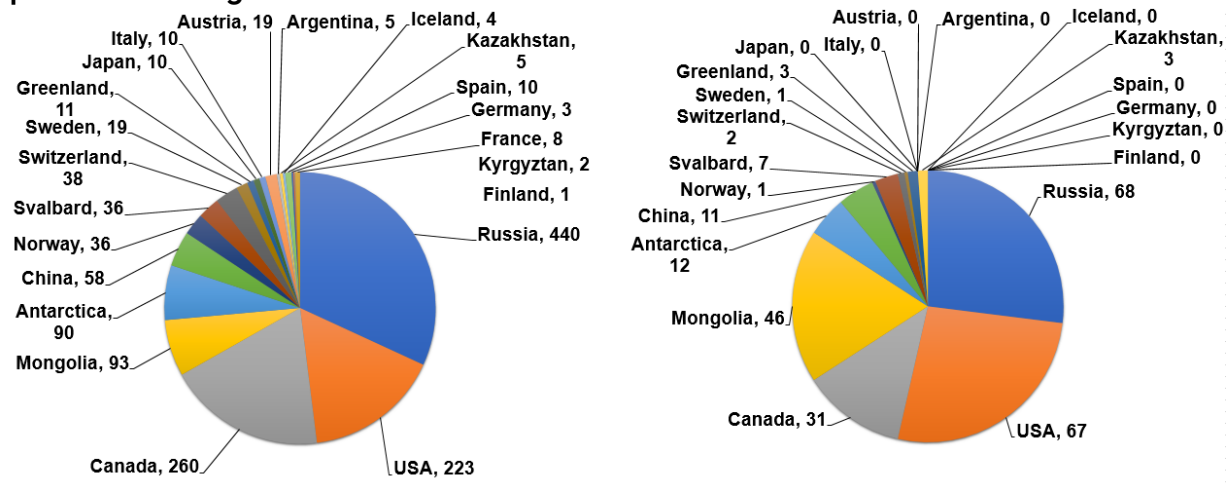

Figure 2: Number of PT (left pie chart) and ALT (right pie chart) sites in the respective countries registered within the GTN-P DMS. Note that measurements in a certain country do not necessarily need to be conducted by the respective country, but can be conducted by teams from different countries.

Many permafrost regions that are relatively easy to access are already very well monitored, as for example the Mackenzie River region in Canada, northern Alaska, or the Swiss Alps (Figure 1). The primary goal is that existing PT and ALT monitoring sites with long records are continued and, as necessary and possible, upgraded in terms of instrumentation. **Further, it is of high importance to increase the site**

coverage in regions that presently reveal a small spatial coverage, such as the Third Pole region including the Hindu Kush Himalaya, (e.g., Mongolia, Kazakhstan, India, Nepal and China), large parts of Siberia (Russia), the central Canadian Arctic, as well as in the Southern Hemisphere (South America, New Zealand, Antarctica) (Figure 1). An expansion of the network with sites in regions with few or no data will close critical data gaps, will contribute increasing our understanding and modelling capabilities of permafrost response to climatic changes. Especially for modelling purposes, the additional acquisition of complementing observations of active geomorphological surface processes (e.g., slope deformation and movement, thermokarst and lake development, coastal erosion, and terrain instability) and their implementation into the GTN-P DMS as additional metadata would be of high value.

Funding

The GTN-P data acquisition operates on a largely voluntary basis with partial funding through private, national and internationally-sponsored programmes. National and international projects support local permafrost observational networks and observatories, including:

- US Geological Survey Alaskan deep borehole network,
- US National Science Foundation-supported Circumpolar Active Layer Monitoring (CALM) programme and Alaskan long-term borehole network,
- former EU projects PAGE21, PACE,
- current EU projects NUNATARYUK and Arctic PASSION,
- German ESKP AWI-Program,
- Russian Academy of Sciences “Evolution of Cryosphere” Program,
- Geological Survey of Canada,
- Swiss Permafrost Monitoring Network (PERMOS),

- French permafrost observation network (PermaFRANCE),
- Norwegian NORPERM database,
- GEF in Mongolia,
- International ANTPAS network in Antarctica (with contributions from Argentina, Brazil, Czech Republic, Italy, New Zealand, South Africa, Russia, USA and from the Portuguese PERMANTAR and the Spanish PERMATHERMAL networks)

are examples of further projects and programs, which provide the foundation of the GTN-P. **Sustaining observations in a climate monitoring context require dedicated long-term funding on the regional, national and international level.** Close collaboration with existing and the establishment of new national or regional permafrost centres to collect, analyse and process data is critical for the continued success of the GTN-P. Such networks are critical for data collection and management as well as assessments at the regional to country levels. **The establishment and support of national and regional permafrost centres to compile and analyse data is a critical step in maintaining and preserving the sites and observations and creating and maintaining a baseline for the future.** However, only a global internationally coordinated permafrost network like GTN-P is capable of ensuring that the state and changes in permafrost are adequately assessed and represented within the framework of UNFCCC.

While the GTN-P continues to collect and deliver publicly available and widely used permafrost data, its capacity to secure long-term funding to sustain network activities and coordination has not yet evolved to meet research and societal needs and still largely relies on the voluntary contribution of individuals and short-term funded national and international research projects. At the same time, expectations of monitoring, reporting, development and maintaining of standardized geospatial datasets in commonly used formats require a continuing and increasing effort for data management. **The establishment of a permanent coordination Office including at**

least an executive director position and a data management position is essential to secure a reliable and long-term functionality of the GTN-P (1.1 GTN-P Tasks and Goals).

2. ORGANISATION OF THE GTN-P

The GTN-P was developed in the 1990s by the Terrestrial Observation Panel for Climate (TOPC) and implemented by the International Permafrost Association (IPA) under the Global Terrestrial Observing System (GTOS) as part of the Global Climate Observing System (GCOS) in support of UNFCCC, with the long-term goal of obtaining a comprehensive view of the spatial structure, trends, and variability of changes in permafrost worldwide (Brown et al., 2000; Burgess et al., 2000). **A robust governance structure was established to foster the development of the GTN-P to be a vital and well-functioning network.** Further, the foundational history of the GTN-P (S. 4. Historical Development) facilitates its integration into the international network of Earth observing systems.

2.1 Governance and management structure

The GTN-P governance structure ensures a professional and efficient coordination of the network's activities. The structure includes a Steering Committee, an Advisory Board, a Office, as well as National and Young National Correspondents (Figure 3).

GTN-P Steering Committee

The Steering Committee (SC) is the governing body of the GTN-P. The SC's major task is to ensure that the overarching goals of the GTN-P (1.1 GTN-P Tasks and Goals) are being pursued. It reports annually on the strategy, decisions and actions of the GTN-P and in collaboration with the Office communicates its report to the sponsors of the network and the IPA, as well as via updates on the GTN-P webpage.

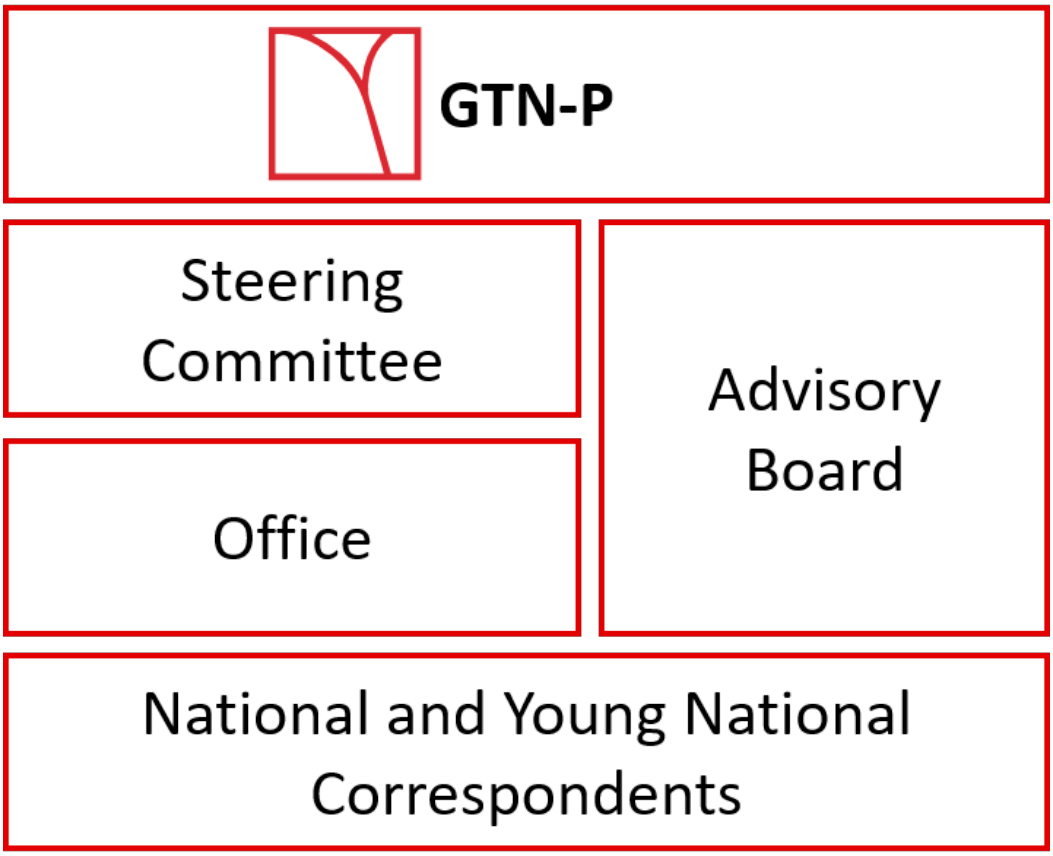

Figure 3: Governance structure of the GTN-P.

The SC meets on a regular basis online and in person during international and regional permafrost conferences. The SC reviews the activities of the network, sets the directions for future GTN-P activities and leads the initiative for new activities in the network. The SC ensures that connections to other international bodies are well established and frequent, especially to GCOS and TOPC. The SC is responsible for finding funding and coordinating with the sponsors of the GTN-P.

The SC shall consist of six to ten members representing a wide range of regions and diversity of backgrounds involved in permafrost research and observations, as well as data science and data management. The IPA will nominate one ex-officio member to the SC. The presence of a young researcher, through the involvement of the Permafrost Young Researchers Network (PYRN) is a requirement. The young researcher is elected from the YNCs. The SC chooses the chair among its members.

The chair is working closely with the GTN-P Office to ensure that the SC meets on a regular basis and actively pursues the network goals.

The members of the SC are elected by the NCs at the GTN-P General Assembly scheduled each year virtually and during each International Conference on Permafrost (ICOP) in person. Any member of the permafrost community at large can be nominated or self-nominate to the SC. However, only NC and YNC are eligible to vote. SC members should commit for at least four years. The GTN-P Office is responsible for soliciting nominations prior to the elections at the GTN-P general assembly. Each nominated member has to attend the general assembly, either in person or virtually, and present a short summary of his/her background and motivation. As needed, the voting process can be made using online voting tools.

GTN-P National (NC) and Young National Correspondents (YNC)

The NCs and YNCs primary task is to foster the implementation of the GTN-P strategy by the scientists who are working in the country they represent. This may include building and improving the structure of a national permafrost monitoring network, interaction with national institutions and funding agencies as well as the coordination of monitoring activities in the country and data submission to the GTN-P DMS. NCs are responsible for stimulating and coordinating the compilation of data and reporting to the GTN-P DMS by the individual investigators or by the national/regional central service. **The major responsibility of the NCs is to provide updates on monitoring data of their country once per year.** NCs shall maintain close contacts with relevant institutions and funding agencies in their country and the IPA, and national focal points of related international entities (IASC, GCOS, GCW etc.). These contacts will enable the emergence of an operational framework for the collection and reporting of permafrost data in the country (in the way e.g. PERMOS is operational in Switzerland) and help in reaching out to the whole community of permafrost researchers in that country.

NCs shall be proposed by the country, either through the IPA National Adhering Body, or by the national network recognized by the IPA adhering body. In general, the

nomination should be based on a consensus among the investigators involved in GTN-P activities in the country. When a structure, such as a national network, is already in place, it should be used to nominate the correspondent. NCs should commit for at least four years. The SC shall take measures if replacement is deemed necessary, for example if data are not being provided, or if the NC advances in his/her career outside of the science sector.

Young National Correspondents (YNCs) shall be nominated either by the IPA adhering bodies or by the national observational networks, if they exist. Alternatively, they can also be proposed by the NCs. YNCs should be members of PYRN at the time of nomination. YNCs should work closely with the NCs to promote GTN-P at the national level, inform peers about the network and be actively involved in the data collection and submission to the GTN-P DMS. YNCs are expected to attend GTN-P workshops and events closely related to the GTN-P mission, such as national and international conferences on permafrost, and contribute to GTN-P reports and publications. YNCs need to attend a higher education institute or work at an organization located in the corresponding country represented, and be closely familiar with GTN-P activities within the corresponding country. When YNCs become senior scientists and are still involved in permafrost monitoring they can become NCs without going through a nomination process. When YNCs advance their career outside of the science sector, it is the NCs and YNCs responsibility to inform the Office and nominate a new YNC.

GTN-P Advisory Board

The Advisory Board (AB) is the body that provides non-binding strategic advice and scientific expertise to the SC and National Correspondents Assembly of GTN-P. The GTN-P SC and the IPA Executive Committee, jointly nominate representatives to the AB. The AB will communicate electronically and meet preferably virtually on an annual basis. The AB advises the GTN-P, GCOS and IPA activities concerning present practice and future developments on the monitoring of permafrost, and on the delivery of datasets to the permafrost community. It evaluates the work of the SC and the GTN-P Office on an annual basis. The Chair of the SC is responsible for ensuring that the assessment is taking place in a transparent and timely manner and ensures

that appropriate actions are taken to improve GTN-P operations based on AB recommendations. Members of the AB are the primary reviewers of Strategy and Implementation Plans produced by the SC in coordination with the GTN-P Office every four years.

GTN-P Office

The **GTN-P Office** is responsible to carry out, under the general direction of the SC, the overall coordination, reporting and daily business of the GTN-P. This includes the coordination and management of the network, the data management including the collection, control and redistribution of data, the periodic reporting and release of GTN-P products, as well as the coordination with other organizations, education and outreach activities.

The GTN-P Office shall annually **report on the activities, decisions and actions of the GTN-P and provide an overview of the GTN-P strategy and goals for the coming year.** As a joint effort with the SC, the GTN-P Office communicates this information to the sponsors of the network and the IPA and informs the public by providing updates on the GTN-P webpage. The GTN-P Office is responsible for publishing the Strategy and Implementation Plan every four years together with the SC.

The GTN-P Office shall ensure that GTN-P is embedded in existing observing activities at the international and national levels and aligns its processes with their activities and frameworks. The GTN-P Office shall also **pursue active linkages with relevant international organisations.** This includes coordination with GCOS/TOPC and harmonisation of GTN-P observing activities with WMO requirements.

The GTN-P Office shall handle **the financial management of GTN-P** and anticipate funding cycles **by conducting an active fundraising strategy together with the SC**. The GTN-P Office shall support the data management efforts of GTN-P by providing a **central platform for communication**, acting as a focal point of contact for national organizations and national contacts and maintaining strong ties to the IPA.

The location and hosting of the GTN-P Office shall be based on recommendations of the SC in coordination with the IPA. The organization hosting the GTN-P Office then requests a formal letter of support from the SC outlining the duration, funding and staff. The GTN-P Office shall be staffed with at least one PostDoc-level position (Executive Director) and at least one FTE data management position (Technical Director). The Executive Director and Technical Director shall be approved and reviewed on a regular basis by the SC. To date, funding for the GTN-P Office has been obtained by being part of international EU-funded projects.

2.2 Linkages to global and regional observing systems

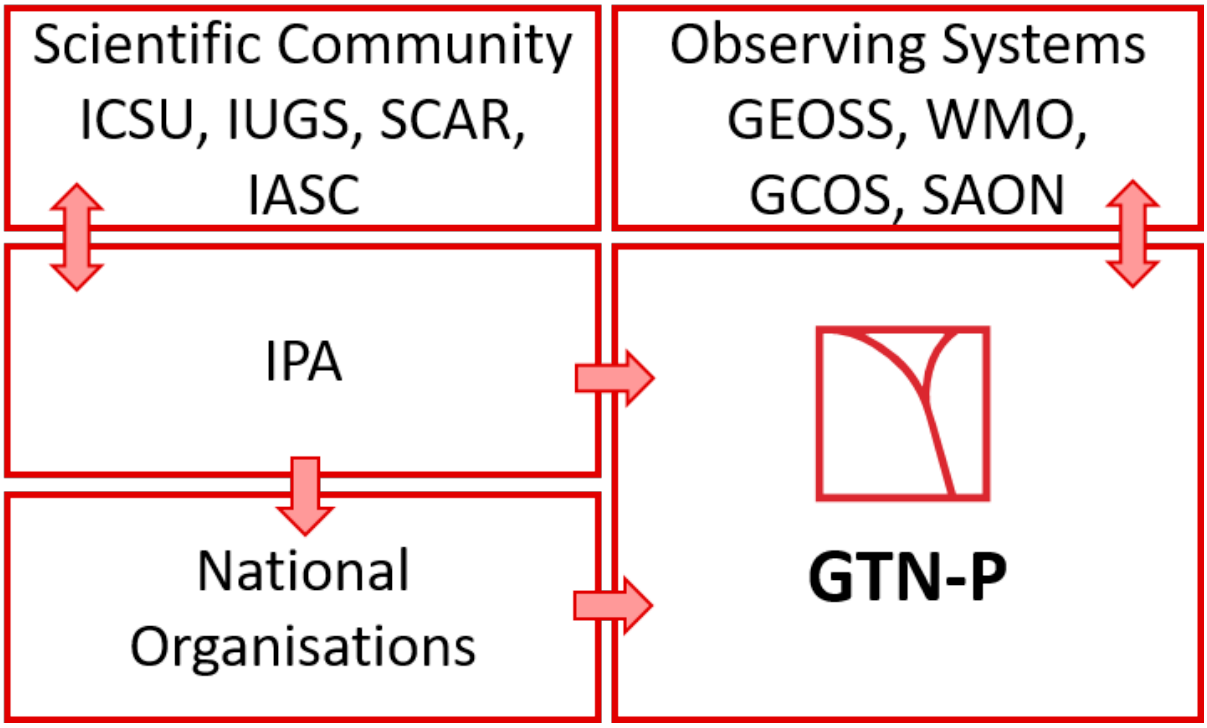

Figure 4: GTN-P involvement in the international Observing Systems network.

Global Climate Observing System and WMO's Global Cryosphere Watch

Within GCOS, the GTN-P is partner of the Terrestrial Observing Panel for Climate (TOPC), where it is represented by an ECV steward for the Permafrost ECV. The GCOS Permafrost ECV steward should be member of the GTN-P SC. GTN-P acts in close collaboration with WMO's Global Climate Observing System (GCOS) and Global

Cryosphere Watch (GCW) to ensure that the framework proposed in this document is implemented and is being carefully embedded in existing observational strategies and systems. **In particular, the GTN-P complies with the definitions and best practices set by the WMO,** which are currently being elaborated by a Permafrost Best Practices Task Team. Further GTN-P advises research projects and local and national monitoring networks, to choose the location of permafrost monitoring sites close to those of existing global systems, wherever possible. GTN-P follows the Global Hierarchical Observing Strategy (GHOST) and the Integrated Global Observing Strategy (IGOS) recommendations to bridge the gap between detailed local investigations and representative global coverage (Harris et al. 2001).

Regional and thematic observing systems

The GTN-P acknowledges the very specific nature of its focus on the cryosphere and shall collaborate actively with the existing initiatives in this realm, such as the Global Terrestrial Network for Glaciers (GTN-G) and the World Glacier Monitoring Service (WGMS). In particular, the GTN-P should seek to encourage the efforts WMO's GCW and the IASC's SAON initiative to coordinate the scientific and operational communities and to provide freely available data. GTN-P shall seek to provide its data products to these activities.

2.3 Process Management, Reporting structure and Publication activity

The goal of the GTN-P is to deliver relevant and understandable products to a wide range of stakeholders, as well as the public. The GTN-P Office also promotes the network through presentations and involvement at scientific conferences and in outreach events. The timely reporting of permafrost data is based on an efficient information flow, relying on the input of field investigators through the activities of the NCs and YNCs (Figure 5).

NCs are requested by the SC to inform national colleagues of the standards, protocols and reporting formats associated with the submission of data. **The NC's primary duty is to annually ensure that local collaborators submit their data either (1) into a national/regional database when applicable, (2) to the NC or (3) directly to the**

GTN-P DMS. To do so, NCs are provided by the GTN-P Office with a database account, documents describing the protocols and reporting formats supported by the GTN-P. These can be also found at the GTN-P website (https://gtnp.arcticportal.org/).

GTN-P shall conduct a proactive publication strategy, including the regular publication of standardized data on permafrost temperature and active layer evolution for all available sites with appropriate data coverage to account for spatial and temporal variability. Examples for such synthesis papers are Biskaborn et al., 2019 who synthesised Permafrost Temperature data from the GTN-P database as a community-driven global study involving 48 co-authors from the GTN-P network, and Nyland (et al., in prep). The latter synthesises Active Layer thickness data obtained by the CALM program which also feeds into the GTN-P database. These comprehensive regional synthesis papers are being complemented by specific regional synthesis papers which analyse data deposited in the GTN-P database, for example for Antarctica (Hrbacek et al. 2017), for the Nordic Arctic Region (Strand et al., 2020), for the Russian Arctic (Romanovsky et al. 2010b, Vasiliev et al., 2020, Kaverin at al., 2021), for Alaska (Urban and Clow, 2021, Nyland et al., 2021), and for the European Mountains (Etzelmüller et al. 2020).

GTN-P data are also being synthesised in periodic climate assessment reports like the annual report on the State of the Climate published in the Bulletin of the American Meteorological Society (BAMS) (e.g., Noetzli et al., 2021; Smith et al., 2021, Romanovsky et al., 2017, 2020, Streletskiy et al., 2017, Christiansen et al., 2012) and the National Oceanic and Atmospheric Administration (NOAA) Arctic Report Card.

Further, the GTN-P contributes to major global or regional climate assessments, such as the International Panel on Climate Change (IPCC) Report and the Snow, Water, Ice and Permafrost in the Arctic (SWIPA) report published by the Arctic Monitoring & Assessment Programme (AMAP). Finally, reports on the GTN-P network activities are being published on an annual basis in the News Bulletin of the IPA Frozen Ground.

GTN-P sessions at the ICOP and the Regional Conference on Permafrost (RCOP) provide a vibrant and popular scientific platform for the GTN-P community to present and discuss their most recent findings.

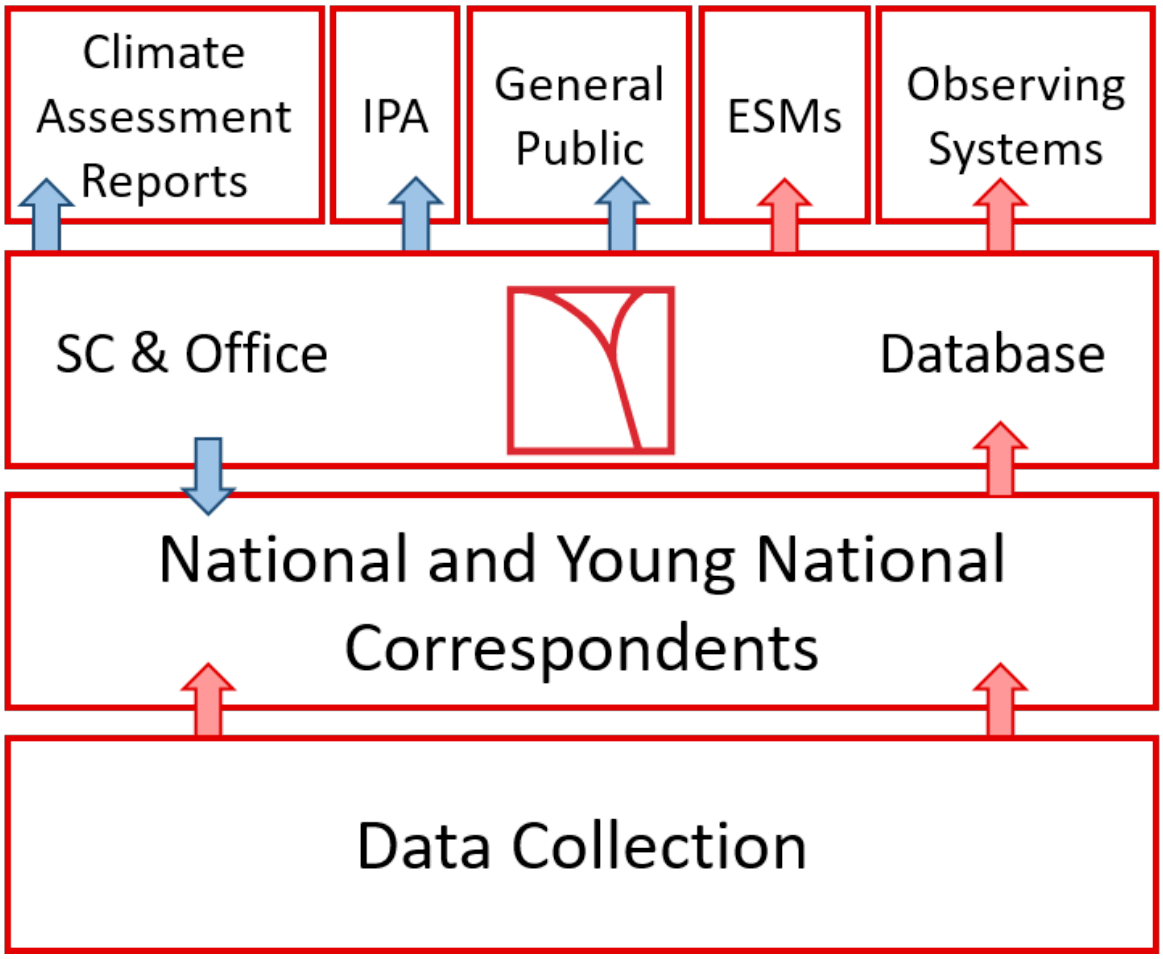

Figure 5: Data flow and reporting structure in the GTN-P. Red arrows are indicating data flow, blue arrows are indicating the reporting structure. Major input is into the database and observing systems, shown with larger arrows.



3 GTN-P DATA

It is GTN-P's highest priority to ensure open access data to permafrost temperature, active layer thickness and in the future on rock glacier velocity. PT and ALT data shall continue to be accessible online through the GTN-P DMS in a user-friendly interface, ensuring compliance with scientific and technical standards. The implementation of rock glacier velocity data is dependent on future funding.

Definitions

The definitions applied by GTN-P are in alignment with the WMO Permafrost Best Practices (WMO, in prep.) and the GCOS Permafrost ECV definitions (GCOS, 2016).

Permafrost: Subsurface material that remains continuously at or below 0°C throughout at least two consecutive years.

Active Layer: The surface layer of ground that is subject to annual thawing and freezing in areas underlain by permafrost.

Rock Glacier: Debris landform generated by the former or current creep of frozen ground, detectable in the landscape with the following morphologies: front lateral margins and optionally ridge-and-furrow surface topography.

ECV Permafrost Products and Units of Measure

To comply with the WMO definitions and best practices, we have adapted the name of the ECV product Thermal State of Permafrost (TSP) to Permafrost Temperature (PT).

Permafrost Temperature (PT): Ground temperatures in permafrost ground measured at specified depths (°C).

Active Layer Thickness (ALT): Thickness of seasonally thawed ground measured in centimetres (cm).

Rock Glacier Velocity (RGV): Surface velocity of a single rock glacier unit in metres per year.

Information about measurement standards and monitoring guidelines were newly compiled in a separate document, which is accessible at the GTN-P website (Streletskiy et al., 2022). These are provisional and will be replaced by the permafrost best practices document when released.

3.3 GTN-P Data Management System (DMS)

Datasets provided to the GTN-P DMS are physically archived at the Arctic Portal in Iceland and mirrored at the Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research in Germany as co-hosting institution. Quality checked (and partly aggregated) data products will be regularly uploaded to the data storage facility PANGAEA Earth Data Publisher, which is a part of the ICSU World Data System. Since metadata of GTN-P measurements are stored in PANGAEA, their relational database system enables linking data author ID's to GTN-P borehole ID's and related datasets.

The GTN-P should continue to work towards sustaining a robust, and accessible information system for permafrost data, compliant with existing international data standards, following open-access policies in line with the IPY data policy (IPY, 2008) and the FAIR guiding principles (Wilkinson et al., 2016). Its major task is to deliver data to permafrost scientists and modellers, but also to the scientific community at large, to policy-makers and the public.

GTN-P Database

The GTN-P Database (GTN-P, 2015) is accessible online at http://gtnpdatabase.org or through the GTN-P website at http://www.gtnp.org. The Data Management System (DMS) was developed within the PAGE21 EU project in cooperation between the Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research (Germany) and the Arctic Portal (Iceland). The GTN-P database structure and statistics on available metadata are published in Biskaborn et al. (2015). More background information about

the GTN-P DMS is provided at: https://gtnp.arcticportal.org/data/database-management-system.

3.4 Data Management System Infrastructure and Data Submission

The implementation of an Information Technology (IT) infrastructure responding to increasingly complex user demands (such as ingesting and serving data efficiently, on-the-fly data processing and analytics, visualisation and web services interoperable within international data infrastructures and standards) requires constant efforts of enhancing stability, robustness, efficiency, modularity, and maintainability. It is a goal of GTN-P to establish and maintain these high requirements and constantly improve the Data Management System (DMS).

The software uses open source technologies and is modular. Independent parts can be improved according to scientific and socio-economic user requirements in order to enhance users experience and lowering maintenance. To assure sustainability, maintaining a detailed DMS documentation is recommended.

To sustain the regular and continuous data acquisition, two different submission mechanisms should be envisaged:

- Data acquisition from PT and ALT annual monitoring campaigns.
- Data rescue from other data repositories in cooperation with the NSIDC and other data archives.

Online data submission mechanisms and data validation rules should regularly be improved as guided by user experiences and requirements.

Data Standards and Quality Control

The definition and adoption of a common international standard for permafrost data is a demanding process. Future GTN-P General Assemblies and participation in international data management proposals will aim at building a momentum for achieving interoperability with overarching and worldwide leading data archives, such as the WMO Observing Systems Capability Analysis and Review Tool (OSCAR).

This will be promoted by participating in different joining efforts, such as in the Research Data Alliance (RDA). The following key points describe targeted topics for the following years until 2024:

- Web Services deployment and standard implementation (WIGOS versus ISO19115-3),
- Data quality and uncertainty assessment,
- Data packages or products which are easy to use for climate modellers,
- Structured Technologies and Permafrost Ontologies.

3.5 Datasets and Products

The GTN-P DMS encompasses the workflow of a modern monitoring network from raw data submission to distribution of data products. Due to their great heterogeneity and spatial variability, *in situ* terrestrial data are difficult to distribute on a gridded basis. Consequently, methodological consensus and metadata standards must be continuously implemented for their management within GTN-P to facilitate data integration into climate research and global modelling programs. Targeted topics for the next four years are:

- Regular analysis and report on metadata,
- The next global report on permafrost temperature change,
- Potential effect of permafrost degradation on permafrost region's infrastructure (GTN-P as the early warning system for permafrost thaw),
- NetCDF products for the Earth System Modelling community.

4. CONCLUSIONS

The role of permafrost in the Earth System and its impact on climate, infrastructure and land management has substantially increased the awareness of the scientific community and the public of the importance of permafrost and permafrost science. The degradation of permafrost, the subsequent release of previously permafrost-bounded greenhouse gases, or the long-term destabilization of icy mountain peaks and infrastructure built on permafrost worldwide are arguably among the most prominent issues in the discussion about climate change impacts. Concurrently, economic developments in the polar and high altitude areas affected by the presence of permafrost raise critical issues related to the terrain instability and the potential natural hazards resulting from the warming and thawing of ice-rich permafrost. In recent years, several countries initiated national coordination networks for monitoring of the permafrost temperature such as the PERMOS network in Switzerland (Vonder Muehll et al. 2008, PERMOS 2016). **However, most observations are still part of academic or other institutional research projects and depend on the involvement and voluntary work of individual researchers and unsteady funding.** To adequately assess the risks associated with changes of the permafrost temperature and subsequent ground subsidence, a permanent permafrost observing network is needed. **While the GTN-P has not yet developed the capacity to independently maintain and support the observations and data management, it has developed the capacity to connect those involved in the observational community, and to provide a platform for meetings, discussions, and dissemination of data.** Coordination amongst individuals within the GTN-P permafrost observational community empowered those connected within the network by allowing their work to be presented to a much broader scientific community, as well as the public.



5. RECOMMENDATIONS

In order to succeed in the future, the GTN-P should continue to develop and strengthen its position as the central storage and access point for reliable, high-quality permafrost data. To sustain and improve its management, the GTN-P should attempt to link data management processes, structures and technologies to existing elaborated networks in the marine and atmospheric science branches. To increase our knowledge gain, a systemized linkage to other networks, such as The Northern Circumpolar Soil Carbon Database (NCSCD) may be beneficial. Further, the GTN-P should be open and actively striving for the integration of new products, such as the implementation of data management for the new Permafrost ECV product Rock Glacier Velocity or remotely sensed permafrost temperatures and inventories of permafrost landforms.

While short-term human and monetary investments can enhance the network and contribute to maintaining its various functions (workshops, data management, publication and dissemination of materials and knowledge transfer), they do not solve the overall need for sustained long-term investments required to sustain and enhance network activities. **To ensure the long-term sustainability of the GTN-P, a permanent hosting institution is required, which will guarantee an Office executive director and data management position, the coverage of operational expenses, as well as operating the DMS.**



REFERENCES

Biskaborn, B.K., Smith, S.L., Noetzli, J., Matthes, H., Vieira, G., Streletskiy, D.A., Schoeneich, P., Romanovsky, V.E., Lewkowicz, A.G., Abramov, A., Allard, M., Boike, J., Cable, W.L., Christiansen, H.H., Delaloye, R., Diekmann, B., Drozdov, D., Etzelmüller, B., Grosse, G., Guglielmin, M., Ingeman-Nielsen, T., Isaksen, K., Ishikawa, M., Johansson, M., Johannsson, H., Joo, A., Kaverin, D., Kholodov, A., Konstantinov, P., Kröger, T., Lambiel, C., Lanckman, J.-P., Luo, D., Malkova, G., Meiklejohn, I., Moskalenko, N., Oliva, M., Phillips, M., Ramos, M., Sannel, A.B.K., Sergeev, D., Seybold, C., Skryabin, P., Vasiliev, A., Wu, Q., Yoshikawa, K., Zheleznyak, M., Lantuit, H. 2019: Permafrost is warming at a global scale. Nature Communications, 10(1), 1–11. DOI: 10.1038/s41467-018-08240-4

Biskaborn, B.K., Lanckman, J.P., Lantuit, H., Elger, K., Streletskiy, D.A., Cable, W.L., Romanovsky, V.E. 2015: The new database of the Global Terrestrial Network for Permafrost (GTN-P). Earth System Science Data 7, 245-259. DOI: 10.5194/essd-7-1-2015.

Brown, J. and H.H. Christiansen, 2011: Permafrost observatory project: A contribution to the Thermal State of Permafrost (PT, IPY no. 50). In: Understanding Earth's Polar Challenges: International Polar Year 2007-2008, Summary by the Joint Committee (I. Krupnik et al. eds), WMO-ICSU, pp. 259-261, plus references, pp. 266-271.

Brown, J. 2010: Report from the International Permafrost Association: The IPY Permafrost Legacy. Permafrost and Periglacial Processes, 21: 215-218.

Brown, J., Hinkel, K.M. and Nelson, F.E. 2000: The Circumpolar Active Layer Monitoring (CALM) program: Research designs and initial results. Polar Geography, 24(3), 165–258

Burgess, M.M., Smith, S.L., Brown, J., Romanovsky, V. and Hinkel, K. 2000: The Global Terrestrial Network for Permafrost (GTNet-P): Permafrost monitoring contributing to global climate observations. In: Current Research 2000E, Geological Survey of Canada.

Circumpolar Active Layer Monitoring (CALM), 2021: www.gwu.edu/~calm (access date: 01. Dec. 2021).

Christiansen, H.H., M. Guglielmin, J. Noetzli, V. Romanovsky, N. Shiklomanov, S. Smith, and L. Zhao, 2012: [Global Climate, Cryosphere] Permafrost Thermal State [in "State of the Climate in 2011"]. Bull. Amer. Meteor. Soc., 93 (7), S19-S21.

Christiansen, H.H., Etzelmüller, B., Isaken, K., Juliussen, H., Farbot, H., Humlum, O., Johansson, M., Ingeman-Neilsen, T., Kristensen, L., Hjort, J., Holmlund, P., Sannel, A.B.K., Sigsgaard, C., Akerman, J., Foged, N., Blikra, L.H., Pernosky, M.A., and Odegard, R. 2010: Thermal state of permafrost in the Nordic area during the IPY 2007-2009. Permafrost and Periglacial Processes, 21: 156-181.

Clow, G.D. 2014: Temperature data acquired from the DOI/GTN-P deep borehole array on the Arctic slope of Alaska, 1973–2013 Earth System Science Data, 6, 201–18.

Etzelmüller, B., Guglielmin, M., Hauck, C., Hilbich, C., Hoelzle, M., Isaksen, K., … Ramos, M. 2020: Twenty years of European mountain permafrost dynamics-the PACE legacy. Environmental Research Letters, 15(10). DOI: 10.1088/1748-9326/abae9d

Global Climate Observing System (GCOS). 2016: Permafrost Essential Climate Variable (ECV) Factsheet. https://ane4bf-datap1.s3.eu-west-1.amazonaws.com/wmod8_climatedata/s3fs-public/permafrost_ecv_factsheet:_201905.pdf?g.E9WybO2xlDJVXmTENgHHExmy7m3XJe (access date: 01. Dec. 2021).

Global Terrestrial Network for Permafrost (GTN-P) 2015: GTN-P metadata for permafrost boreholes (PT) and active layer monitoring (CALM) sites. PANGAEA database. DOI: 10.1594/PANGAEA.842821.

Global Terrestrial Network for Permafrost (GTN-P) 2012: Strategy and Implementation Plan 2012-2016. International Permafrost Association. ISSN: 2410-2385. 36p.

Haeberli, W., Barsch, D., Brown, J., Guodong, C., Corte, A.E., Dramis, F., Evin, M., Gorbunov, A.P., Guglielmin, M., Harris, C., Harris, S.A., Hoelzle, M., Kääb, A., King, L., Lieb, G.K., Matsuoka, N., Ødegaard, R.S., Shroder, J.F., Sollid, J.L., Trombotto, D., Von der Mühll, D., Shaoling, W., Xiufeng, Z. 1998: Mapping, modelling and monitoring of mountain permafrost: a review of ongoing programs. Mountain permafrost working group report. Proceedings of the Seventh International Conference on Permafrost, Yellowknife-Canada, 233-246.

Haeberli, W., Cheng, G., Gorbunov, A.P. and Harris S.A. 1993: Mountain permafrost and climatic change. Permafrost and Periglacial Processes 4/2, 165-174.

Harris, C., Vonder Mühll, D., Isaksen, K., Haeberli, W., Sollid, J.L., King, L., Holmlund, P., Dramis, F., Guglielmin, M. and Palacios D. 2003: Warming permafrost in European mountains. Global and Planetary Change 39, 215-225.

Harris, C., Haeberli, W., Vonder Mühll, D. and King, L. 2001: Permafrost monitoring in the high mountains of Europe: the PACE Project in its global context, edited by C. Harris, Permafrost and Periglacial Processes, 12(1), 3–11, DOI: 10.1002/ppp.377.

IPY, 2008: International Polar Year 2007-2008 Data Policy (version 1.1)

Hrbacek, F., Nývlt, D., and Láska, K. 2017: Active layer thermal dynamics at two lithologically different sites on James Ross Island, Eastern Antarctic Peninsula. CATENA, 149, 592–602. DOI: 10.1016/j.catena.2016.06.020

Kaverin, D., Malkova, G., Zamolodchikov, D., Shiklomanov, N., Pastukhov, A., Novakovskiy, A., Sadurtdinov, M., Skvortsov, A., Tsarev, A., Pochikalov, A. and Malitsky, S., 2021. Long-term active layer monitoring at CALM sites in the Russian European North. Polar Geography, pp.1-14.

Lewkowicz, A., Weege, S., Biskaborn, B., Streletskiy, D., Romanovsky, V., and Fortier, R., 2016: Report from the International Permafrost Association: Permafrost and Periglacial Processes. v. 27, no. 3, p. 316-319.

Mair, V., Zischg, A., Lang, K., Tonidandel, D., Krainer, K., Kellerer-Pirklbauer, A., Deline, P., Schoeneich, P., Cremonese, E., Pogliotti, P., Gruber, S., Böckli, L., (2011): PermaNET - Permafrost Long-term Monitoring Network. Synthesis report.

INTERPRAEVENT Journal series 1, Report 3. Klagenfurt. http://www.permanet-alpinespace.eu/ (access date: 30. Dec. 2021).

National Oceanic and Atmospheric Administration (NOAA): The Arctic Report Card, http://www.arctic.noaa.gov/reportcard/ (access date: 17. Dec. 2021).

Nelson, F.E., Shiklomanov, N.I., Christiansen H.H. and Hinkel, K.M. 2004: The Circumpolar-Active-Layer-Monitoring (CALM) Workshop: introduction. Permafrost and Periglacial Process, 15(2): 99-101.

Noetzli, J., Christiansen, H.H., Hrbacek, F., Isaksen, K., Smith, S.L., Zhao, L., and Streletskiy D.A. 2021: Cryosphere – 1) Permafrost thermal state [in "State of the Climate in 2020"]. Bulletin of the American Meteorological Society 102(8): 42-45. DOI: 10.1175/BAMS-D-21-0086.1.

Nyland, K.E. et al. Global Observation Data Show Variable but Increasing Active-Layer Thickness. In prepapration.

Nyland, K. E., Shiklomanov, N. I., Streletskiy, D. A., Nelson, F. E., Klene, A. E., & Kholodov, A. L. 2021: Long-term Circumpolar Active Layer Monitoring (CALM) program observations in Northern Alaskan tundra. Polar Geography, 1–19. DOI: 10.1080/1088937X.2021.1988000

Obu, J., Westermann, S., Bartsch, A., Berdnikov, N., Christiansen, H. H., Dashtseren, A., Zou, D. 2019: Northern Hemisphere permafrost map based on TTOP modelling for 2000–2016 at 1 km2 scale. Earth-Science Reviews, 193(March), 299–316. DOI: 10.1016/j.earscirev.2019.04.023

PERMOS 2016: Permafrost in Switzerland 2010/2011 to 2013/2014. Noetzli, J., Luethi, R., and Staub, B. (eds.), Glaciological Report (Permafrost) No. 12-15 of the Cryospheric Commission of the Swiss Academy of Sciences, 85 pp.

Rock glacier inventory and kinematics (RGIK) 2021: Rock Glacier Kinematics as an associated parameter of ECV Permafrost (Version 3.0). Barboux C., Delaloye R. and Pellet C. (eds.), IPA Action Group Rock glacier inventories and kinematics, 12 pp.

Romanovsky, V.E., Smith S.L., Isaksen, K., Nyland K.E., Kholodov, A.L., Shiklomanov, N.I., Streletskiy, D.A., Farquharson, L.M., Drozdov, D.S., Malkova, G.V., Christiansen H.H. 2020: Terrestrial Permafrost [in “State of the Climate in 2019”] Bulletin of the American Meteorological Society 101(8):265-269. DOI: 10.1175/2020BAMSStateoftheClimate.1.

Romanovsky V.E., S. L. Smith, I. Shiklomanov, D. A. Streletskiy, K. Isaksen, N. , A. L. Kholodov, H.H. Christiansen, D. S. Drozdov, G. V. Malkova, and S. S. Marchenko. 2017: Terrestrial Permafrost [in "State of the Climate in 2016"]. Bulletin of the American Meteorological Society 98(8):147-149. DOI: 10.1175/2017BAMSStateoftheClimate.1.

Romanovsky, V.E., Smith, S.L., and Christiansen, H.H. 2010a: Permafrost thermal state in the polar Northern Hemisphere during the International Polar Year 2007-2009: a synthesis. Permafrost and Periglacial Processes, 21: 106-116.

Romanovsky, V.E., Drozdov, D.S., Oberman, N.G., Malkova, G.V., Kholodov, A.L., Marchenko, S.S., Moskalenko, N.G., Sergeev, D.O., Ukrainsteva, D.G., Abramov, A.A., and Vasiliev, A.A. 2010b: Thermal state of permafrost in Russia. Permafrost and Periglacial Processes, 21: 106-116.

Shiklomanov N.I., Streletskiy, D.A., Nelson F.E. 2012: Northern Hemisphere Component of the Global Circumpolar Active Layer Monitoring (CALM) Program. Proceedings of the 10th International Conference on Permafrost, Salekhard, Russia, June 25 - 29, 2012, Vol.1, 377-382.

Shiklomanov, N.I., Nelson, F.E., Streletskiy, D.A., Hinkel, K.M., Brown, J. 2008: The Circumpolar Active Layer Monitoring (CALM) Program: Data Collection, Management, and Dissemination Strategies. Proceedings of the 9th International Conference on Permafrost, Fairbanks, Alaska, June 29 - July 3, 2008, Vol. 2, 1647-1652.

Smith, S.L., Romanovsky, V.E., Isaksen, K., Nyland, K.E., Kholodov, A.L., Shiklomanov, N.I., Streletskiy, D.A., Farquharson, L.M., Drozdov, D.S., Malkova, G.V. and Christiansen, H.H. 2021: The Arctic – h. Permafrost [in "State of the Climate in 2020"]. Bulletin of the American Meteorological Society 102(8): 293-297. DOI: 10.1175/BAMS-D-21-0086.1.

Smith, S.L., Romanovsky, V.E., Lewkowicz, A.G., Burn, C.R., Allard, M., G.D., Yoshikawa, K., and Throop, J. 2010: Thermal state of permafrost in North America - A contribution to the International Polar Year. Permafrost and Periglacial Processes, 21: 117-135.

Smith, S. and Brown, J. 2009: Assessment of the status of the development of the standards for the Terrestrial Essential Climate Variables - T7 - Permafrost and seasonally frozen ground.

Streletskiy, D., Smith, S.L., Vieira, G., Schoeneich, P., Hrbacek, F., Noetzli, J. and A.M. Irrgang, (2021): Measurement Recommendations and Guidelines for the Global Terrestrial Network for Permafrost (GTN-P) 2022. DOI: 10.5281/zenodo.5973079.

Streletskiy, D.A., Biskaborn, B.K., Nötzli, J, Lanckman, J-P., Romanovsky, V.E., Schoeneich, P, Shiklomanov, N.I., Smith, S.L, Vieira, G, Zhao, L. 2017: Permafrost thermal state [in "State of the Climate in 2016"]. Bulletin of the American Meteorological Society 98(8):19-21. DOI: 10.1175/2017BAMSStateoftheClimate.1

Streletskiy D., Biskaborn B., Smith S., Noetzli J, Viera G., Schoeneich P. 2017. Strategy and Implementation Plan 2016-2020 for the Global Terrestrial Network for Permafrost (GTN-P). The George Washington University, Washington D.C., 42 pp.

Urban, F.E., and Clow, G.D. 2021: DOI/GTN-P Climate and active-layer data acquired in the National Petroleum Reserve–Alaska and the Arctic National Wildlife Refuge, 1998–2019: U.S. Geological Survey Data Series 1092, 71 p. DOI: 10.3133/ds1092.

Vasiliev, A. A., Drozdov, D. S., Gravis, A. G., Malkova, G. V., Nyland, K. E., & Streletskiy, D. A. 2020: Permafrost degradation in the Western Russian Arctic. Environmental Research Letters, 15(4). DOI: 10.1088/1748-9326/ab6f12

Vieira, G., Bockheim, J., Guglielmin, M., Balks, M.R., Abramov, A.A., Boelhouwers, J., Cannone, N., Ganzert, L., Gilichinsky, D.A., Goryachkin, S., Lopez-Martinez, J., Meiklejohn, I., Raffi, R., Ramos, M., Scaefer, C., Serrano, E., Simas, F., Sletten, R., and Wagner, D. 2010: Thermal state of permafrost and active-layer monitoring in the Antarctic: advances during the International Polar Year 2007-09. Permafrost and Periglacial Processes, 21: 182-197.

Vonder Muehll, D.S., Noetzli, J. and Roer, I. 2008: PERMOS-A comprehensive monitoring network of mountain permafrost in the Swiss Alps. In: Proceedings Ninth International Conference on Permafrost. Edited by D.L. Kane and K.M. Hinkel. Fairbanks. Institute of Northern Engineering, University of Alaska Fairbanks, Vol.2, pp. 1869-1874.

Wilkinson, M. D., Dumontier, M., Aalbersberg, Ij. J., Appleton, G., Axton, M., Baak, A., … Mons, B. 2016: The FAIR Guiding Principles for scientific data management and stewardship. Scientific Data, 3, 160018. DOI: 10.1038/sdata.2016.18

Zhao, L., Wu, Q., Marchenko, S.S., and Sharkhuu, N. 2010: Thermal state of permafrost and active layer in Central Asia during the International Polar Year. Permafrost and Periglacial Processes, 21: 198-20

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SUPPLEMENTARY MATERIAL

S. 1. Historical Development

The GTN-P was developed in the 1990s by the Terrestrial Observation Panel for Climate (TOPC) and implemented by the International Permafrost Association (IPA) under the Global Terrestrial Observing System (GTOS) as part of the Global Climate Observing System (GCOS) in support of the United Nations Framework Convention on Climate Change (UNFCCC). The long-term goal was and is to obtain a comprehensive view of the spatial structure, trends, and variability of changes in permafrost worldwide (Brown et al., 2000; Burgess et al., 2000). Presently, the two main elements observed within GTN-P are: (a) the thermal state of permafrost (TSP) (to be compliant with the WMO from now on referred to as permafrost temperature (PT)) in an extensive borehole network; and (b) the Active-layer thickness (ALT). These components were implemented through partial networks coordinated by the International Permafrost Association (IPA).

The PT database was originally hosted at the Geological Survey of Canada (GSC) in Ottawa. The PT observatories in the United States and Russia were supported by the US National Science Foundation and managed by the Permafrost Laboratory at the University of Alaska Fairbanks. The program description, measurement protocols and data are available at www.permafrostwatch.org. The Circumpolar Active Layer Monitoring (CALM) programme, the largest international programme concerned with monitoring of ALT, was established in 1991 and initially affiliated with the International Tundra Experiment (ITEX). Through funding from the National Science Foundation (NSF), CALM has had operational bases at Rutgers University (1991-1994), the State University of New York (1994-1997) the University of Cincinnati (1998-2003), the University of Delaware (2003-2009), and is currently headquartered at the George Washington University. Long-term support for data collection in Alaska and Russia has been provided by the NSF, and data from all CALM sites are available through a

dedicated CALM website (CALM, 2021). Historical data from PT and CALM are available from the National Snow and Ice Data Center in Boulder, Colorado (NSIDC), and Advanced Cooperative Arctic Data and Information Service (ACADIS), and NSF Arctic Data Center, reflecting efforts from the NSF to provide data archival, preservation and access for all projects funded by the NSF's Arctic Science Program. The U.S. Geological Survey has established an array of climate-monitoring stations in Arctic Alaska as part of the U.S. Department of the Interior/Global Terrestrial Network for Permafrost (DOI/GTN-P) Observing System in 1998 (Urban and Clow, 2021) and continues temperature monitoring of the DOI/GTN-P Deep Borehole Array with some sites dating back to 1973 (Clow, 2014).

During the International Polar Year 2007-2008 (IPY) the IPA coordinated and strengthened the collection of permafrost temperature data in the PT project focusing on a first global snapshot. A database and map of mean annual ground temperatures (snapshot) for 600 boreholes from all permafrost areas, including high-altitude locations outside the polar regions, became available online in an ISO-compliant format at the National Snow and Ice Data Center (NSIDC). This provided a baseline for measuring future changes. Synthesis papers were published at the end of IPY in a special issue of the journal *Permafrost and Periglacial Processes* (e.g., Smith et al. 2010, Romanovsky et al. 2010 a, b, Christiansen et al. 2010, Vieira et al. 2010, and Brown, 2010, Zhao et al., 2010); followed by an IPY legacy permafrost observatory report (Brown and Christiansen, 2012). The progress of the CALM program is summarised in Shiklomanov et al. (2008, 2012) and CALM special issues in *Polar Geography* in 2000 (Brown et al., 2000) and *Permafrost and Periglacial Processes* in 2004 (e.g., Nelson et al., 2004).

From the very beginning, efforts had been made within the IPA to include permafrost in rugged mountain topography at lower latitudes/higher altitudes (Haeberli et al. 1993, 1998). Particularly, the EU Permafrost and Climate in Europe (EU-PACE) project, systematically established a series of 100 m deep boreholes for long-term observation of permafrost thermal conditions along a continental-scale longitudinal transect from Svalbard through Scandinavia and the Alps to the Sierra Nevada in

Spain (Harris et al. 2001, 2003). The EU funded PermaNET project (2007-2011) further supported the development of a comprehensive network of permafrost monitoring sites throughout the European Alps (Mair et al. 2011).

The continued involvement of individual permafrost scientists and relevant stakeholders is assured through their participation in GTN-P meetings and workshops. The first of these workshops took place in the fall of 2011 and was followed by three technical workshops in February, September and November 2012. The workshops, partially funded by the PAGE21 project, focused on the needs and technical requirements of GTN-P data providers and users. These include field scientists, modellers, ecologists, engineers, other scientific communities, observing networks, lecturers, students, the public, and policy-makers. The first workshop focused on the technical needs required for scientists and modellers to form the scientific basis for the data portal.

The first GTN-P Strategy and Implementation Plan was produced in 2012 (GTN-P, 2012). The document outlined the governance structure of the network, defined roles and responsibilities of the National Correspondents (NC), the Executive Committee (later renamed to Steering Committee, SC) and the Advisory Board (AB). The governance structure was put in place in spring 2013. The first meeting of the NCs was held at the WMO Headquarters in Geneva in early May 2013. Of the 25 countries formally included in the GTN-P, 18 countries were represented. The second meeting took place in Quebec in September 2015 and largely focused on developing data standards and protocols. It was attended by 28 participants from 16 countries (Lewkowicz et al., 2016). Major progress was made to establish the GTN-P Office, to improve the data management system, data policy and standards, and to increase sustainability of the GTN-P network by introducing Young National Correspondents (YNC). The YNC were formally elected during the GTN-P meeting held at the Eleventh International Conference on Permafrost (ICOP) in Potsdam, Germany in June 2016.

Over the last decade, GTN-P made considerable progress from a grassroots organization towards a more structured and operational GCOS entity. The GTN-P core group that formed during the EU project PAGE21 (2011-2015) successfully established

a governance structure and a functional body providing the current baseline network of people for the observation of the Permafrost ECV. It is critically important to capitalize on the previous accomplishments and to secure the future and sustainability of the GTN-P network. Close collaboration with existing and the establishment of new national or regional permafrost centres to collect, analyse and process data is critical for the continued success of the GTN-P network, since such networks are essential for data collection and management on a regional to country level.

S.2. GTN-P achievements & timeline

2010

- Publication of IPY snapshot and IPY synthesis papers provide major findings and highlight the need for consistent and standardized permafrost observational data

- Submission of an IPA Strategy Preparation Document to the Council of the IPA, outlining the need to overhaul GTN-P and the initiative to form a task force to compile a strategy and implementation plan.

- Formation of the GTN-P task force by the Executive Committee of the IPA, following the recommendation of the IPA Strategy Preparation Document.

- Validation of the IPA Strategy Preparation Document during the twentieth IPA Council and subsequent validation of the recommendations to strengthen and to make GTN-P operational under the IPA leadership.

- First Meeting of the GTN-P Task force during the Third European Conference on Permafrost and decision on the timeline for the compilation of the strategy and implementation plan.

- Compilation of a first draft of the Strategy and Implementation Plan and internal editing process (circulation in the GTN-P Task Force).

2011

- Finalization of the first draft of the Strategy and Implementation Plan.
- Strategy and Implementation Plan reviewed by IPA Executive Committee, PT and CALM leaders and other targeted reviewers.
- Integration of reviews and editing of Strategy and Implementation Plan.
- Data Management GTN-P Workshop for data providers and users, including potential national correspondents.
- Establishment of GTN-P Interim Executive Committee.
- Establishment of a writing team for the GTN-P Information System user and technical requirements based on the outputs of the stakeholder workshop.
- Establishment of GTN-P Office in Potsdam, Germany.
- Finalization of user and technical requirement document for GTN-P Information System.

2012

- First PAGE21/GTN-P technical workshop on DMS held in Copenhagen, Denmark.
- Preparation of inventory of existing datasets.
- Finalization of GTN-P Information System.
- First GTN-P Executive Committee appointed and met during the Tenth International Conference on Permafrost.
- Second PAGE21/GTN-P technical workshop on DMS held in Akureyri, Iceland.
- Third PAGE21/GTN-P technical workshop on DMS held in Hamburg, Germany.

- GTN-P EC meeting to revise the GTN-P Strategy and Implementation plan.
- Designation of GTN-P National Correspondents by the corresponding countries.

2013

- Strategy and Implementation Plan reviewed and endorsed by GCOS and GTOS
- First call for data reporting.
- Launch of the GTN-P DMS Beta version.
- Second GTN-P workshop at WMO in Geneva.

2014

- GTN-P Workshop in Akureyri.
- GTN-P Meeting in Evora, Portugal during 4th EUCOP.

2015

- Official release of the GTN-P DMS.
- GTN-P in the report of GCOS.
- ESSD GTN-P Metadata publication.
- Third GTN-P Workshop, Quebec, Canada.
- Announcement of the launch of the GTN-P DMS.
- Change in governance structure, introduction of YNC positions.
- Nomination of Young National Correspondents

2016

- GTN-P Meeting and Session at ICOP2016, Potsdam, Germany.
- GTN-P contribution to GCOS Implementation Plan.

- Compilation of the first GTN-P data snapshot using DMS.
- Nomination of representative of YNC to SC.
- Call for data submission to be used in Snapshot.
- Integration of NSIDC datasets into GTN-P DMS.

2017

- Development of the Strategy and Implementation Plan: 2016-2020, editing and external review process.
- Opening of the GTN-P Mirror and establishing AWI (Germany) as co-host partner of Arctic Portal (Iceland).
- Collaboration with Global Cryosphere Watch to advance best practices and protocols for permafrost.

2018

- GTN-P Meeting during IPA Regional Conference at the Fifth European Conference on Permafrost (EUCOP5), Chamonix, France.
- New Office
- Development of standards for permafrost temperature monitoring within GCOS TOPC
- End-user survey and Improvement of our GTN-P webpage and data portal

2019

- GTN-P session during SouthCOP in Queenstown, New Zealand
- Revision of PT and ALT, introducing rock glacier kinematics product
- GTN-P global PT publication in Nature Communications becomes top 50 Nature paper.

2020

- GTN-P National Correspondent Meeting and a corresponding session at ICOP in Lanzhou (postponed to RCOP 2021)
- Call for new extended Steering Committee
- GTN-P contributes to GCOS TOPC
- GTN-P and GCW establish Permafrost Best Practices Team

2021

- Development and approval of the GTN-P Strategy and Implementation Plan 2021-2024
- GTN-P session during RCOP2021, Boulder, USA (virtual conference)
- First virtual GTN-P General Assembly, November 2021

2022

- Publication on global ALT evolution, based on GTN-P / CALM data
- Second virtual GTN-P General Assembly, November 2022

2023

- GTN-P General Assembly and session during EUCOP6, Spain
- Implementation of the ECV product Rock Glacier Velocity
- Release of Permafrost Best Practice Standards as part of the updated WMO Guide no. 8, implementation of the product into the GTN-P
- Third virtual GTN-P General Assembly

2024

- Implementation of the ECV product Rock Glacier Velocity
- GTN-P workshop and session during ICOP2024, Canada

- Establishment of a permanent funding structure, including a permanent GTN-P Office and host institution for the GTN-P DMS
- Forth virtual GTN-P General Assembly

S. 3. List of Staff

A regularly updated list of the GTN-P Steering Committee, the Office and the Advisory Board is available here: https://gtnp.arcticportal.org/about-the-gtnp/staff

List of GTN-P Steering Committee

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List of Advisory Board

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S.4. List of National and Young National Correspondents

A regularly updated list of all National and Young National Correspondents is available here: https://gtnp.arcticportal.org/about-the-gtnp/national-correspondents

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S.5. List of Acronyms and Abbreviations

AB	GTN-P Advisory Board
ACADIS	Advanced Cooperative Arctic Data and Information Service
AMAP	Arctic Monitoring and Assessment Programme
ALT	Active Layer Thickness
AP	Arctic Portal
AWI	Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research
ANTPAS	Antarctic Permafrost, Soils and Periglacial Environments
CALM	Circumpolar Active Layer Monitoring
DMS	Data Management System
DOI	Department of Interior (U.S.)
DUE	Data User Element
ECV	Essential Climate Variable
ESKP	Earth System Knowledge Platform
FAO	Food and Agriculture Organization of the United Nations
FGDC	Frozen Ground Data Center
GCOS	Global Climate Observing System
GCW	Global Cryosphere Watch
GEO	Intergovernmental Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GHOST	Global Hierarchical Observing Strategy
GSC	Geological Survey of Canada

GTN-G	Global Terrestrial Network for Glaciers
GTN-P	Global Terrestrial Network for Permafrost
GTOS	Global Terrestrial Observing System
GWU	George Washington University
IACS	International Association of Cryospheric Sciences
IASC	International Arctic Science Committee
ICOP	International Conference on Permafrost
ICSU	International Council for Science
IGOS	Integrated Global Observing Strategy
IPA	International Permafrost Association
IPCC	Intergovernmental Panel on Climate Change
IPY	International Polar Year
ITEX	The International Tundra Experiment
IUGS	International Union of Geological Sciences
NC	GTN-P National Correspondent
NCSCD	Northern Circumpolar Soil Carbon Database
NOAA	National Oceanic and Atmospheric Administration (U.S.)
NSF	National Science Foundation (U.S.)
NSIDC	National Snow and Ice Data Center
OSCAR	WMO's Observing Systems Capability Analysis and Review Tool
EU-PACE	Permafrost and Climate in Europe
PAGE21	Changing Permafrost in the Arctic and its Global Effects in the 21st Century
PermaFRANCE	The French permafrost observation network
PERMOS	The Swiss Permafrost Monitoring Network
PERMANTAR	Western Antarctic Peninsula Permafrost Observatories (Operated by University of Lisbon)
PERMATHERMAL	Spanish Permafrost Monitoring Network
PT	Permafrost Temperature
PYRN	Permafrost Young Researchers Network
RCOP	Regional Conference on Permafrost
RDA	Research Data Alliance
SAON	Sustaining Arctic Observing Networks
SC	GTN-P Steering Committee
SCAR	Scientific Committee for Antarctic Research

SC	GTN-P Steering Committee
SWIPA	AMAP's Report and the Snow, Water, Ice and Permafrost in the Arctic
TOPC	Terrestrial Observation Panel for Climate
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
WGMS	World Glacier Monitoring Service
WIGOS	WMO Integrated Global Observing System
WMO	World Meteorological Organization
YNC	GTN-P Young National Correspondent
ZAA	Depth of Zero Annual Amplitude

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Strategy and Implementation Plan 2021-2024
for the Global Terrestrial Network for Permafrost (GTN-P)

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