International Network for Alpine Research Catchment Hydrology

Introduction and Current Status of INARCH

John Pomeroy, INARCH Chair

Ignacio López Moreno, INARCH Co-Chair; James McPhee, Scientific Steering Group

Chris DeBeer, INARCH Science Manager

https://inarch.usask.ca

Image: Dry Creek, Idaho, USA (C. DeBeer)

INARCH

- A cross-cut project of the GEWEX Hydroclimatology Panel (GHP) and a contribution to the UNESCO Intergovernmental Hydrological Programme to:
  - measure and understand high mountain atmospheric, hydrological, cryospheric, biological and human-water interaction processes,
  - improve their prediction as coupled systems,
  - diagnose their sensitivities to climate change and propose how they may be managed to promote water sustainability under global change.
- A network of 56 research scientists, 38 experimental research basins in 18 countries and six continents.
- Phase II, 2021–2026, with refined science questions and activities is at mid-point and progressing well.
- INARCH contributes to the UNESCO Chair in Mountain Water Sustainability
- INARCH will contribute to the UN International Year of Glaciers' Preservation, 2025 and the UN Decade for Action on the Cryospheric Sciences, 2025-2034

INARCH Linkages

- GEWEX Hydroclimatology Panel (GHP) Projects
  - TeamX
  - Global Water Futures / GWF Observatories
  - Third Pole Environment-Water Sustainability
  - US RHP – Food, Energy and Water Security
  - ANDEX
- WMO Global Cryosphere Watch
- TPE-WS (Third Pole Environment – Water Sustainability)
- Climate Impacts on Global Mountain Water Security working group of Future Earth's, Sustainable Water Futures Programme (SWFP)
- International Commission for Snow and Ice Hydrology (ICSIH)
- UNESCO-Intergovernmental Hydrological Programme (IHP) and UNESCO Chair in Mountain Water Sustainability
- UN International Year for Glaciers' Preservation - 2025

GEWEX

ANDEX

TPE THIRD POLE ENVIRONMENT

WORLD METEOROLOGICAL ORGANIZATION

waterfuture Sustainable Water Future Programme

IAHS AISH

UNESCO United Nations Educational, Scientific and Cultural Organization

Intergovernmental Hydrological Programme

Participants

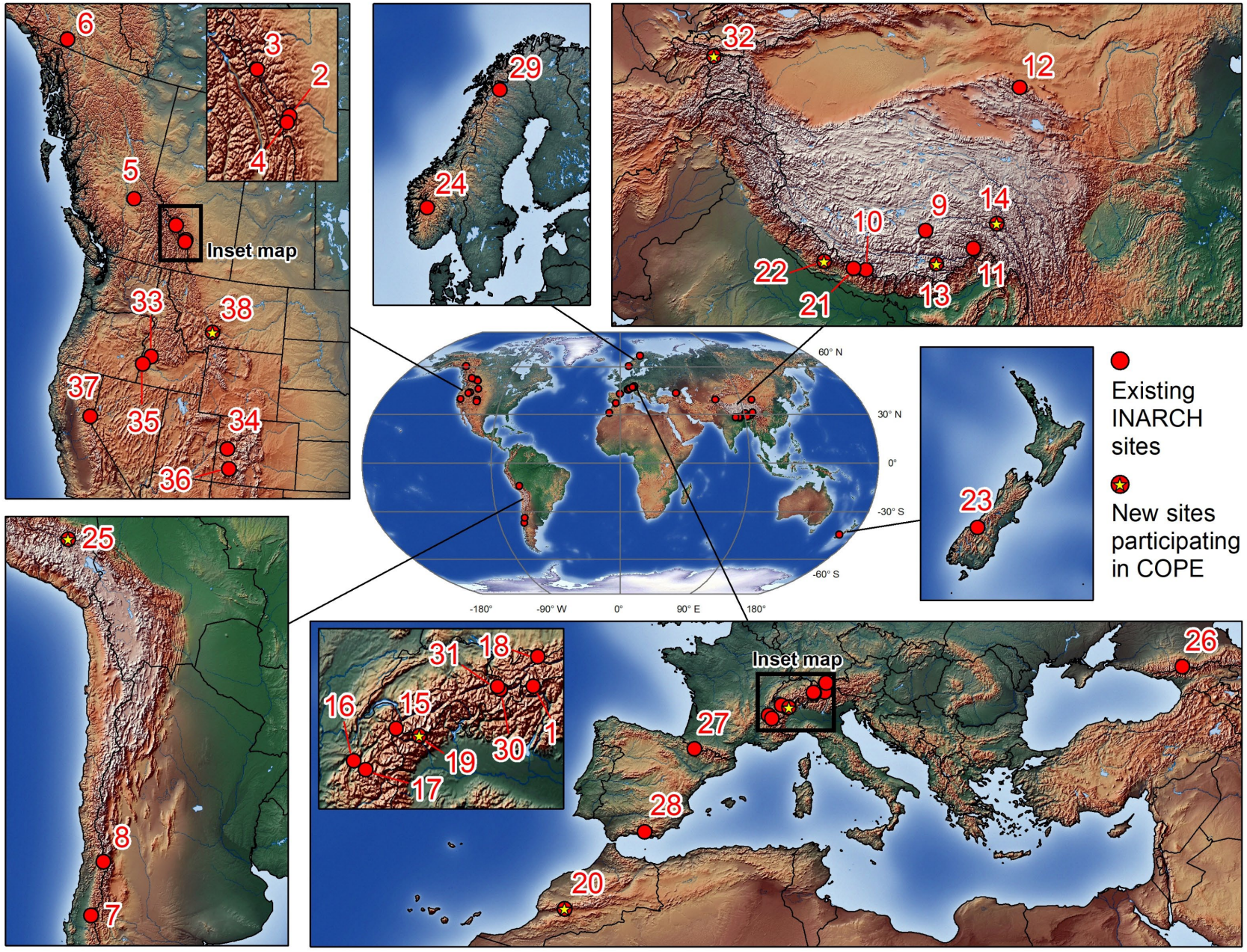
Participant	Location	Participant	Location	Participant	Location
John Burkhart	Oslo, Norway	Franziska Koch	Vienna, Austria	Dhiraj Pradhananga	Kathmandu, Nepal
Wouter Buytaert	London, England	Sebastian Krogh	Concepción, Chile	Rainer Prinz	Innsbruck, Austria
Sean Carey	Hamilton, Canada	Vincenzo Levizzani	Bologna, Italy	Hamish Pritchard	Cambridge, England
Tao Che	Lanzhou, China	Xin Li	Beijing, China	Roy Rasmussen	Boulder, USA
Jono Conway	Lauder, New Zealand	Timothy Link	Moscow, Idaho, USA	Ekaterina Rets	Warsaw, Poland
Nicolas Cullen	Dunedin, New Zealand	Ignacio Lopez Moreno	Zaragoza, Spain	Gunhild Rosqvist	Stockholm, Sweden
Chris DeBeer	Saskatoon, Canada	Yaoming Ma	Beijing, China	Nick Rutter	Newcastle, England
Stephen Dery	Prince George, Canada	Danny Marks	Boise, USA	Robert Sandford	Canmore, Canada
Marie Dumont	Grenoble, France	James McNamara	Boise, USA	Karsten Schulz	Vienna, Austria
Richard Essery	Edinburgh, Scotland	James McPhee	Santiago, Chile	Jean-Emmanuel Sicart	Marseille, France
Simon Gascoin	Toulouse, France	Pablo Mendoza	Santiago, Chile	Delphine Six	Grenoble, France
Alexander Gelfan	Moscow, Russia	Brian Menounos	Prince George, Canada	Sara (McKenzie) Skiles	Salt Lake City, USA
Isabelle Gouttevin	Grenoble, France	Anil Mishra	Paris, France	Ulrich Strasser	Innsbruck, Austria
Ethan Gutmann	Boulder, USA	Samuel Morin	Toulouse, France	Julie Thériault	Montreal, Canada
Adrian Harpold	Reno, USA	Florence Naaim-Bouvet	Grenoble, France	Ernesto Trujillo	Boise, USA
Andrew Hedrick	Boise, USA	Lindsey Nicholson	Innsbruck, Austria	Vincent Vionnet	Dorval, Canada
Walter Immerzeel	Utrecht, Netherlands	Stephen O'Hearn	Saskatoon, Canada	Zhongbo Yu	Nanjing, China
Peter Jansson	Stockholm, Sweden	Francesca Pellicciotti	Birmensdorf, Switzerland	Isabella Zin	Grenoble, France
Tobias Jonas	Davos, Switzerland	María José Polo Gómez	Córdoba, Spain		
Georg Kaser	Innsbruck, Austria	John Pomeroy	Canmore, Canada		

Over one hundred other researchers, graduate students, and post-doctoral fellows involved in field research activities, modelling, remote sensing, and participating in our workshops.

INARCH Basins

Austria **1.** Rofental Open Air Laboratory (OpAL);
Canada **2.** Marmot Creek Research Basin; **3.** Peyto Glacier; **4.** Fortress Mountain Snow Observatory; **5.** Quesnel River Research Basin; **6.** Wolf Creek Research Basin;
Chile **7.** Valle Hermoso, Upper Diguillín River Basin; **8.** Estero Las Bayas, Upper Maipo River Basin;
China **9.** Nam Co Monitoring and Research Station for Multisphere Interactions; **10.** Qomolangma Atmospheric and Environmental Observation and Research Station; **11.** Southeast Tibet Observation and Research Station for the Alpine Environment; **12.** Upper Heihe River Basin; **13.** Yala Shampo Cryosphere Hydro-Ecological Station*; **14.** Changdu Ecological Monitoring Station*;
France **15.** Arve Catchement; **16.** Col de Porte Experimental Site; **17.** Col du Lac Blanc Experimental Site;
Germany **18.** Schneefernerhaus and Research Catchment;
Italy **19.** Torgnon Ecosystem Station*;
Morocco **20.** Rheraya Catchment, High Atlas Mountains*;
Nepal **21.** Langtang Catchment; **22.** Hidden Valley, Himalayas*
New Zealand **23.** Brewster Glacier;
Norway **24.** Finse Alpine Research Centre;
Peru **25.** Salcca-Sibinacocha Catchment*;
Russia **26.** Djankuat Research Basin;
Spain **27.** Izas Research Basin; **28.** Guadalfeo Monitoring Network;
Sweden **29**. Tarfala Research Catchment;
Switzerland **30.** Dischma Research Catchment; **31.** Weissfluhjoch Snow Study Site;
Tajikistan **32.** Kyzylsu Glacier and Monitoring Sites*;
United States of America **33.** Dry Creek Experimental Watershed; **34.** Grand Mesa Study Site; **35.** Reynolds Creek Experimental Watershed; **36.** Senator Beck Basin Study Area; **37.** Sagehen Creek, Sierra Nevada; **38.** Bridger Range*.

*new sites participating in the Common Observing Period Experiment (COPE)



https://inarch.usask.ca/science-basins/research-basins.php

A New INARCH Vision

- Improve mountain hydrometeorological and related observations, understanding and predictions to help adapt to rapid climate change.
- Implement recommendations from the WMO High Mountain Summit—integrated observation and prediction systems. *How can we build up integrated prediction systems around these research basins and apply them to the larger earth systems that derive from mountains, and what does it take to do that?*
- Science for society. *Can we contribute to the development of* ***'fit-for-purpose' hydrological, meteorological and climate information services in high mountain catchments?***
- Mountain systems include human-water interactions and complex ecological interactions – *how can we address this in our models? Can we use these to develop solutions to help achieve water sustainability in high mountain river basins and downstream?*

INARCH Phase II Science Questions

1. How different are the observation and measurement approaches amongst INARCH basins and do we expect distinctive differences in our understanding of basin response and hydrological predictability because of the sampling schemes, and data quality and quantity?
2. How do the predictability, uncertainty and sensitivity of energy and water exchanges vary with changing atmospheric thermodynamics, ecosystem structure and water management in various high mountain regions of the Earth?
3. What improvements to high mountain energy and water exchange predictability are possible through improved physics in, coupling of, and downscaling of models in complex terrain, and improved and expanded approaches to data collection and assimilation?
4. To what extent do existing model routines have global validity, are transferable, and meaningful in different mountain environments for providing service to society?
5. Can mountain systems be predicted and managed to find solutions to help achieve water sustainability in river basins under climate change?

Eventually contribute to answering - How have mountain atmospheric-cryospheric-hydrological-ecosystem-human systems co-evolved to their current states and how will they respond to climate change over the next century?

Common Observing Period Experiment (COPE)
2022–2024

- INARCH is conducting a Common Observing Period Experiment (COPE) over the period 2022–2024 as a focal network activity to collect high-quality measurements along with supplementary observations and remote sensing campaigns.
- The COPE will produce a common, coherent, and well-documented and described dataset of mountain meteorology and hydrology from INARCH basins over the two-year period at a minimum, and longer where possible.
- We will apply 18 different hydrological and atmospheric models over the research basins for diagnostic evaluation using field observations to better understand why models produce various behaviors and to see if models benchmark various known aspects and regimes of the coupled atmospheric-cryospheric-hydrological system.
- Model evaluations will emphasize atmospheric, snow, glacier, and water processes in high mountain terrain and include sparse forest, non-needleleaf vegetation, glaciated, and alpine windblown sites.
- This will have tremendous scientific value in reducing the uncertainty of our understanding and ability to predict global change and water cycling.

Common Observing Period Experiment (COPE)
2022–2024

COPE Hydrological, Meteorological, Glaciological Models

1. CRHM
2. openAMUNDSEN
3. OGGM (open global glacier model)
4. Cosipy
5. WRF\NoaaMP\CLM\LES models
6. FSM2
7. Thethys-Chloris
8. SPHY
9. AMelt
10. SNOWPACK/Alpine3D
11. Canadian Hydrological Model (CHM)
12. SnowModel
13. AWSM/iSnobal
14. FSM-OSHD
15. S3M
16. TopoPyScale
17. SURFEX-Crocus
18. SnowMet

- Details of these models are available at https://inarch.usask.ca/science-basins/cope.php
- Modellers will apply their models in as many places as possible to look at differences in results seen with elevation, vegetation structures, climate, etc.
- Forcing data to be available by Fall 2024, model runs completed by Spring 2025

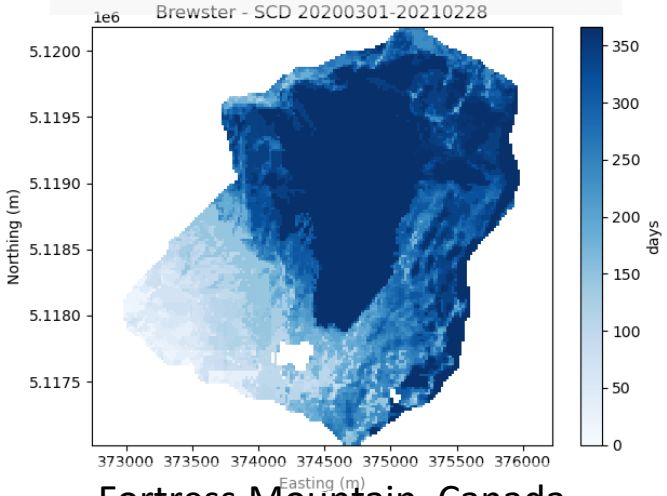
Common Observing Period Experiment (COPE)
2022–2024

Activities at the INARCH basins

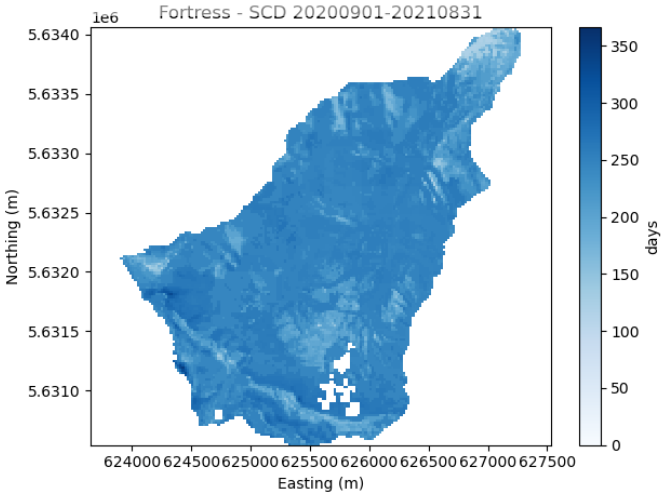
- INARCH participants have frequently met online and in person to review and coordinate activities
- Ongoing intensive observation campaigns at most basins
- Sentinel-2 snow cover analyses by Simon Gascoin at all basins https://sgascoin.github.io/INARCH/
  - Fractional snow cover area, snow onset, disappearance, duration, # snow periods
  - products from July 2017 to Aug 2023 (5 water years in the S. hemisphere, 6 water years in the N. hemisphere).

Snow cover duration 2020-21

Brewster Glacier, New Zealand



Fortress Mountain, Canada



Common Observing Period Experiment (COPE)
2022–2024

Activities at the INARCH basins

- ESA AlpSnow contributions to COPE
  - Remote sensing of snow parameters from multiple missions from all the INARCH sites
  - Snow area extent, albedo, snow water equivalent, depth, grain size, liquid water content (wet snow)
  - Products (from 1 km to 20 m resolution) in a consistent grid for comparing with reference datasets from the sites

Thomas Nagler
Gabriele Schwaizer
Richard Essery
https://alpsnow.enveo.at/

Product	Spatial Resolution	Sensor	Temporal Frequency	Accuracy	Validation
Snow area extent	20 m 300 m	Sentinel-2A/B S3 SLSTR & OLCI	3 days 1 day	< 20% FSC	In situ data of snow depth, Webcams, snow maps from very high resolution satellite images
Snow albedo	300 m	S3 OLCI PRISMA	1-2 days	< 5%	In situ measurements
Snow grain size	300 m	S3 OLCI PRISMA	1-2 days	TBD	In situ measurements during field campaigns
Snow melt area & wetness	100m	Sentinel-1	~3 days	5% of basin area	In situ weather data, numerical weather models (INCA), snow model data
Snow water equivalent	100 m	SnowGrid in synergy with S1, S2 and S3 L-Band SAR (PALSAR, SAOCOM)	3 hourly 14 -28 days	< 10%	In situ SWE measurements at stations and field sites
Snow depth	100 m	SnowGrid TanDEM-X repeat DEMs S1 C-Band PolRatio	3 hours when available ~6 days	< 10%	Snow depth at transects and stations

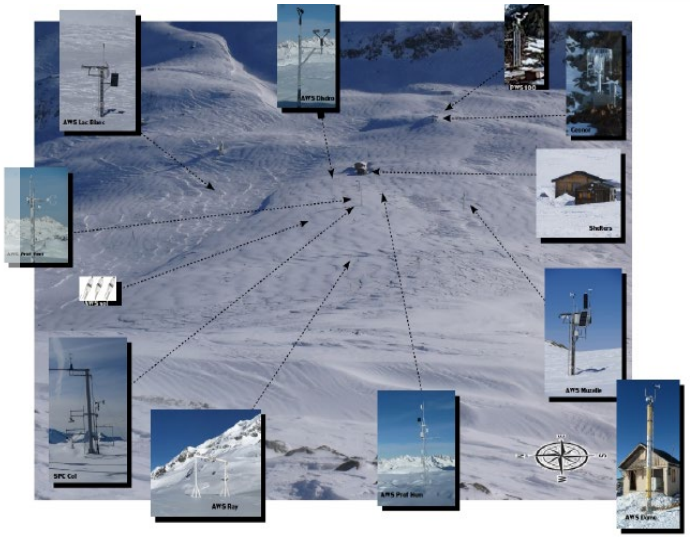
Common Observing Period Experiment (COPE)
2022–2024

Activities at the INARCH basins

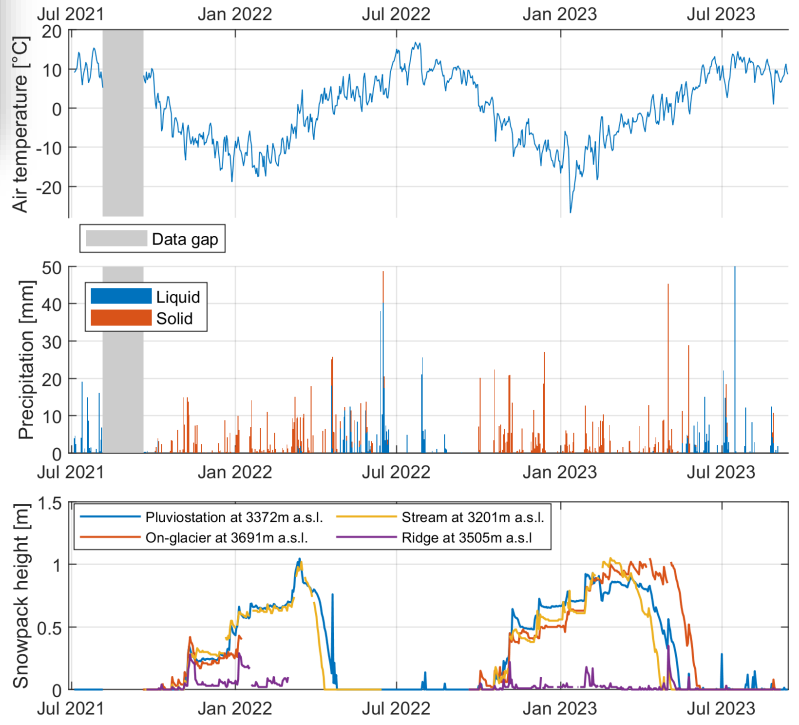
- Many novel experimental activities and intensive observations

SWE and water storage variations measured by super-conducting gravimeter (Franziska Koch et al.: Zugspitze, Germany)

Long-term measurements at Lac Blanc Pass, France (Isabelle Gouttevin et al.) reveal major contrasting years, 2022-23 and 2023-24, seen elsewhere across the Alps



New, high-quality observations in a data-sparse region (Achille Jouberton, Francesca Pellicciotti, et al.; Kyzylsu Glacier, Tajikistan)



INARCH Workshop, Stanley, Idaho, USA, October 9–11, 2023

- 28 scientists in person, 10 more online; tours of Dry Creek and Reynolds Creek, Idaho
- Hosted by James McNamara and Ernesto Trujillo-Gomez of Boise State University, and Dr. Andrew Hedrick of the USDA Agricultural Research Service.
- Topics:
  - Observatories and Measurement Techniques
  - Observations and Modelling
  - Common Observation Period Experiment (COPE) Updates
- Meeting report in GEWEX Quarterly, 2024 Q1: https://gewex.org/gewex-content/uploads/2024/03/Q12024.pdf

INARCH Statement 2023

- INARCH is helping to plan science for and contribute to the UN International Year for Glaciers' Preservation – 2025, including snow, mountain water and frozen ground.
- COPE is running successfully around the world, observations are being made and archived in a data management system and models are being identified and some prepared to analyse the data
- Climate change and extremes continue to strongly affect basin cryosphere and hydrology during the COPE period, including rapid glacier retreat, groundwater destabilisation, drought, fires, and floods.
- A greater appreciation of subsurface storage and flow pathways has emerged in INARCH which is improving the ability to predict and diagnose future hydrology as snow and glacier contributions decline.

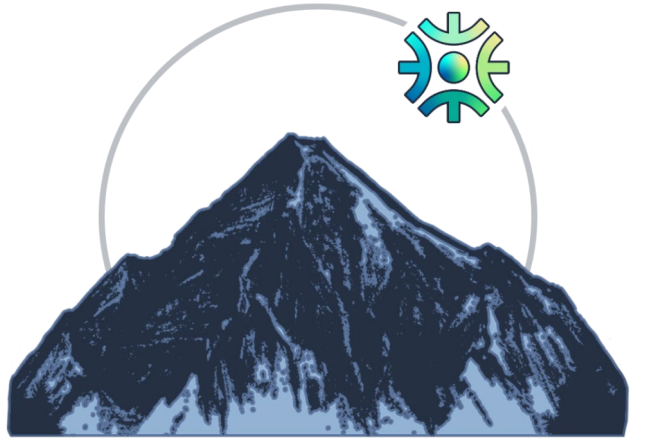
We need to

- Develop detailed science investigations in COPE and ensure that it is used by other groups (WMO, intercomparison projects)
- Apply atmospheric/hydrological/other models to INARCH basins for the COPE period
- Co-develop plans to and share experiences on increase mountain community/regional science and decision-making capacity

WCRP Climate and Cryosphere's IC-MONTC

- Climate and Cryosphere Project of the World Climate Research Programme - new initiative focused on **Impacts of changes in the mountain cryosphere (IC-MONTC).**
- Objectives are to improve our understanding of how changes in climate will affect the mountain cryosphere (snow, ice and permafrost) and downstream geomorphological and hydrological changes.
- Relationship with INARCH?
- Call for Steering Group Members by Oct 31st.

- IC-MONTC will hold **a workshop on high resolution (<3 km) climate modelling of mountain regions**. Goal - to assess the current status of climate modeling applied to such areas of complex terrain, and to identify observational gaps where further data are needed for model validation. September 12-13, 2025, in association with International Mountain Conference, Innsbruck



Background of the International Year of Glaciers' Preservation

In December 2022, the UNGA adopted the resolution to declare 2025 as the International Year of Glaciers' Preservation, accompanied by the proclamation of March 21st of each year as the World Day for Glaciers starting in 2025.

The International Year and World Day for Glaciers aim to raise global awareness about the critical role of glaciers, snow and ice in the climate system and the hydrological cycle, and the economic, social and environmental impacts of the impending changes in the Earth's cryosphere, as well as to share best practices and knowledge in this regard and in addressing issues related to accelerated melting of glaciers and its consequences.

Coordination Mechanism for the IYGP2025

A coordination mechanism has been setup to handle the preparation and implementation of activities of the International Year of Glaciers' Preservation 2025, involving an Advisory Board and 4 Task Forces.

4 Task Forces

TF-1: Global Campaign for International Year of Glaciers' Preservation 2025

Lead by Sara Manuelli,
FAO Mountain Partnership Secretariat

TF-3 Research and Monitoring Initiative

Lead by James McPhee,
Universidad de Chile

4 Task Forces

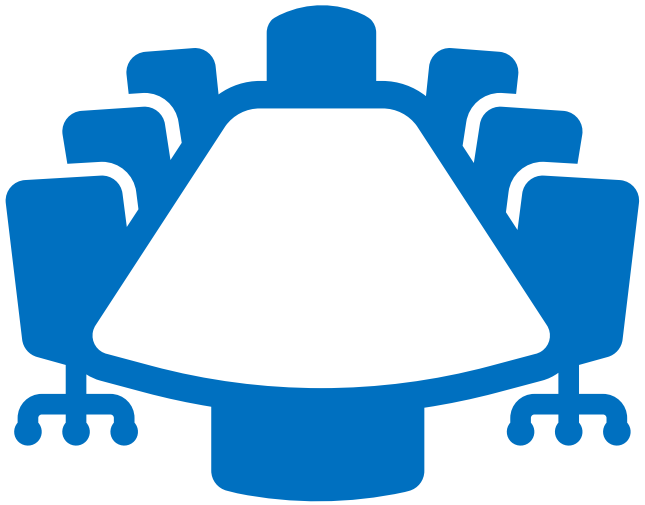
TF-2: International Conferences, Regional Workshops, and Capacity Building

Lead by Neera Shrestha Pradhan,
International Center for Integrated Mountain Development (ICIMOD)

TF-4: Policy Advocacy, Partnerships, and Resource Mobilization

Lead by Pam Pearson,
International Cryosphere Climate Initiative (ICCI)

List of Advisory Board Members of the IYGP 2025

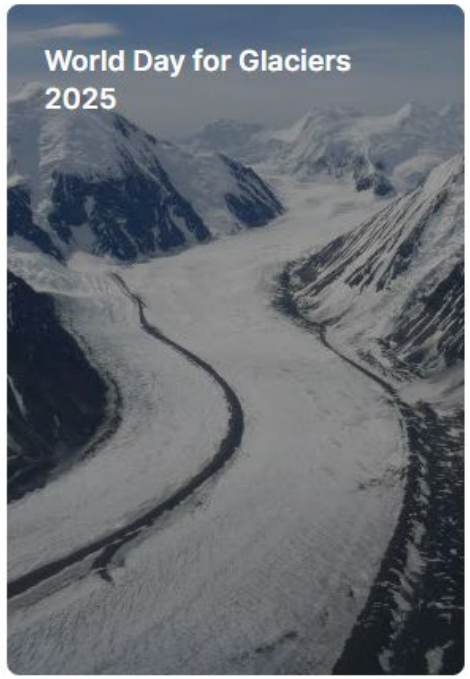


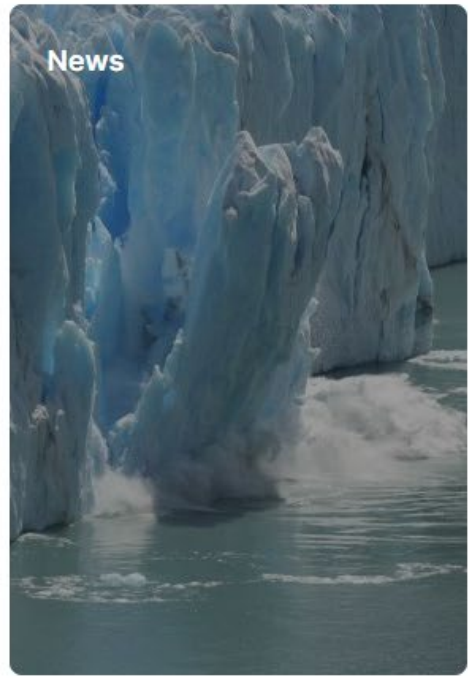
Name	Organization/capacity
Mr John Pomeroy	**UNESCO Co-Chair** -University of Saskatchewan
Ms Carolina Adler	**WMO Co-Chair** -Mountain Research Initiative (MRI)
Ms Sara Manuelli	**TF1 Lead** -FAO Mountain Partnership
Ms Neera Shrestha Pradhan	**TF2 Lead** -International Centre for Integrated Mountain Development (ICIMOD)
Mr James McPhee	**TF3 Lead** - University of Chile in Santiago
Ms Pam Pearson	**TF4 Lead** -International Cryosphere Climate Initiative (ICCI)
Mr Olivier Poivre d'Arvor	HE. Ambassador of France
Ms Heïdi Sevestre	Arctic Monitoring and Assessment Programme (AMAP)
Mr Michael Zemp	University of Zurich; World Glacier Monitoring Service (WGMS)
Mr Gino Casassa	Universidad de Magallanes, Glaciology and Snow Unit; Gaia Antarctica Research Center (CIGA); General Directorate of Water of the Ministry of Public Works of Chile
Mr Thorsteinn Thorsteinsson	Icelandic Meteorological Office; Global Cryosphere Watch (GCW)
Mr Yaoo Tandong	Institute of Planetary Sciences, Chinese Academy of Sciences (CAS)
Mr Raymond Bradley	University of Massachusetts; Climate and Cryosphere World Climate Research Programme (WCRP-CliC)
Ms Liss M. Andreassen	International organization for Cryospheric Sciences (IACS)
Mr Shawn Marshall	University of Calgary, Environment and Climate Change Canada (ECCC); Global Cryosphere Watch (GCW)
Mr Bahodur Sheralizoda	Committee of Environmental Protection of the Government of the Republic of Tajikistan
Mr Jerome Chappellas	Ice Memory Foundation
Mr Thomas Condom	Institut des Géosciences de l'Environnement (IGE-Grenoble)
Mr Mariano Masiokas	Argentine Institute of Nivology, Glaciology and Environmental Sciences (IANIGLA)

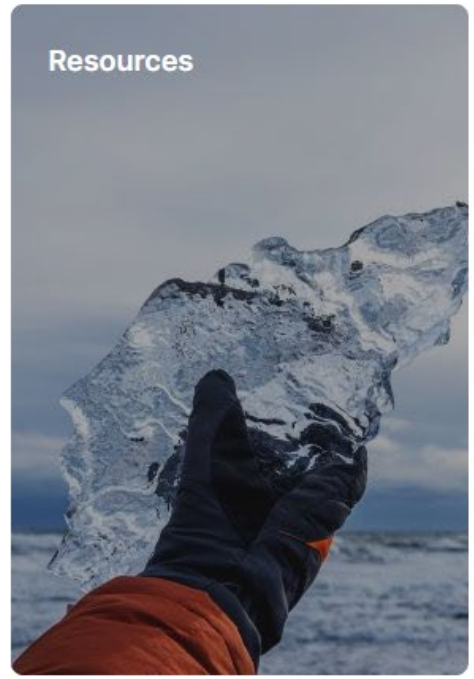
2025 International Year of Glaciers' Preservation

The United Nations declared 2025 as the International Year of Glaciers Preservation, accompanied by the proclamation of the 21st March of each year as the World Day for Glaciers starting in 2025. This is an opportunity to raise global awareness about the critical role of glaciers, snow and ice in the climate system and the hydrological cycle, and the economic, social and environmental impacts of the impending changes in the Earth's cryosphere.

2025
International Year of
Glaciers' Preservation





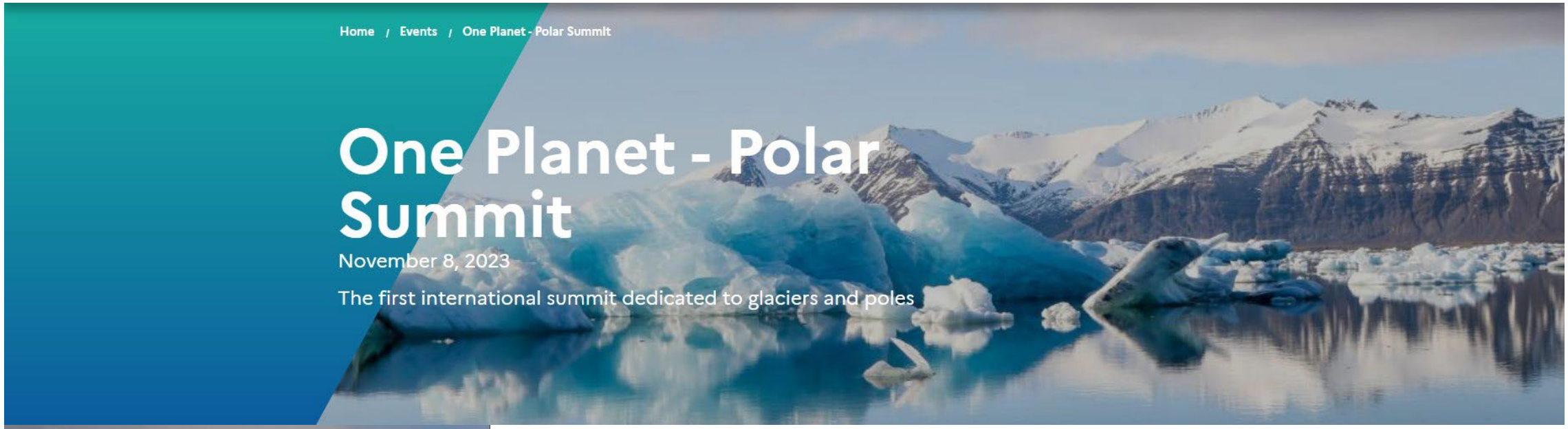


Join us !

You can join us in the implementation of the International Year of Glaciers' preservation

Get involved →

Decade of action for Cryospheric Sciences 2025-2034



UN General Assembly Declares 2025-2034 as the Decade of Action for Cryospheric Sciences

Global News

article written by MRI, United Nations
26.08.24 | 05:08

Also adopted without a vote was a resolution titled "Decade of Action for Cryospheric Sciences, 2025–2034" (document A/78/L.99). By its terms, the Assembly proclaimed the Decade of Action for Cryospheric Sciences to address the challenges associated with melting glaciers and changes to the cryosphere by advancing related scientific research and monitoring.

— United Nations Press Release

unesco

UN GA Resolution

United Nations A/78/L.99

General Assembly

Distr.: Limited
18 July 2024

Original: English

Article 1

… *Decides* to proclaim the period from 2025 to 2034 as the Decade of Action for Cryospheric Sciences, within existing structures, available resources and voluntary contributions, to address the challenges associated with melting glaciers and changes to the cryosphere by advancing related scientific research and monitoring, under the overarching goal of advancing global scientific cooperation and sustainable development efforts as articulated in the International Decade of Sciences for Sustainable Development, 2024–2033;

UN GA Resolution

Article 2

… *Invites* all Member States of the United Nations, all relevant organizations of the United Nations system, other global, regional and subregional organizations and Indigenous Peoples, as well as other relevant stakeholders, including academia, civil society organizations, the private sector and individuals, to observe the Decade of Action as appropriate, at all levels, by promoting activities aimed at raising awareness of the Decade and the importance of glaciers, snow and ice in the climate system and the hydrological cycle, and the economic, social and environmental impacts of the impending changes in the Earth's cryosphere, and to share best practices and knowledge in this regard, including on building resilience to related risks;

Article 3

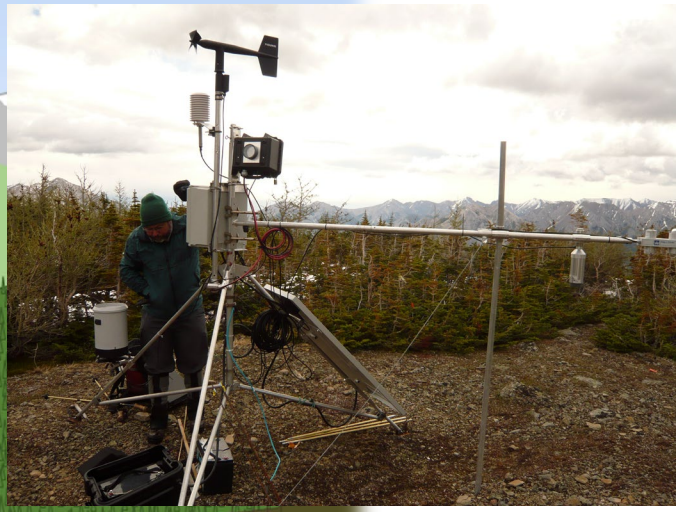
… *Invites* the United Nations Educational, Scientific and Cultural Organization to lead the implementation of the Decade of Action, in collaboration with other relevant organizations of the United Nations system as well as other stakeholders, including those involved in the International Year of Glaciers' Preservation, 2025, identifying and developing activities and programmes within their mandates and using voluntary contributions

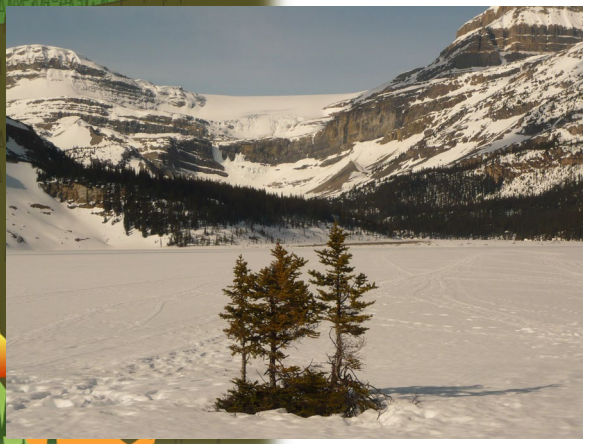
Decade of Action for Cryospheric Sciences 2025-2034

- **The Decade of Action for Cryospheric Sciences (2025-2034) will begin with the International Year of Glaciers' Preservation**
- **Awareness-raising to highlight importance of glaciers, snow and ice in the climate system and the hydrological cycle.**
- **Scientific and research activities on poles and glaciers to better understand their functioning and the consequences of their collapse.**
- **Multidisciplinary studies incorporating economic, social and environmental impacts of the impending changes in the Earths cryosphere.**
- **Collaborative and international efforts in this regard, including on building resilience to related risks.**

Observe, Predict, Protect

Consider INARCH's contributions to the IYGP and DACS





Next steps, activities, and timeline

- COPE completion by Fall 2024, and model runs and analyses by Spring 2025
- Hydrology and Earth System Sciences (HESS) special issue: *Improving measurement, understanding, and prediction of alpine cold regions hydrological processes and their sensitivities to global change*
  - For immediate proposal and start, open to end of 2025
- Ongoing data submissions to ESSD special issue: *Hydrometeorological data from mountain and alpine research catchments*- trying to reactivate this. https://essd.copernicus.org/articles/special_issue871.html
- INARCH-focused scientific sessions at EGU (Apr 2025) and AGU (Dec 2025)
- International Mountain Conference and INARCH Fall workshop (Innsbruck, Austria, Sept 2025)
- Renewal as a GEWEX CC Project, post 2026

INARCH Workshop, Lanzhou and Zhangye, China, October 14–19, 2024

Thank you to Dr. Tao Che, Dr. Shichang Kang, and Dr. Xin Li, Chinese Academy of Sciences