International Network for Alpine Research Catchment Hydrology

Summary and Overview of INARCH
Phase II Activities and Progress

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: Qilian Mountains, China, from near the Yakou snow observation site (C. DeBeer)

About 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. Formed in 2015.
- Phase II, 2021–2026, with refined science questions and activities is approaching its final stage.
- INARCH contributes to the UNESCO Chair in Mountain Water Sustainability, the 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
- International Year for Glaciers' Preservation - 2025

GEWEX

ANDEX

TPE THIRD POLE ENVIRONMENT

WORLD METEOROLOGICAL ORGANIZATION

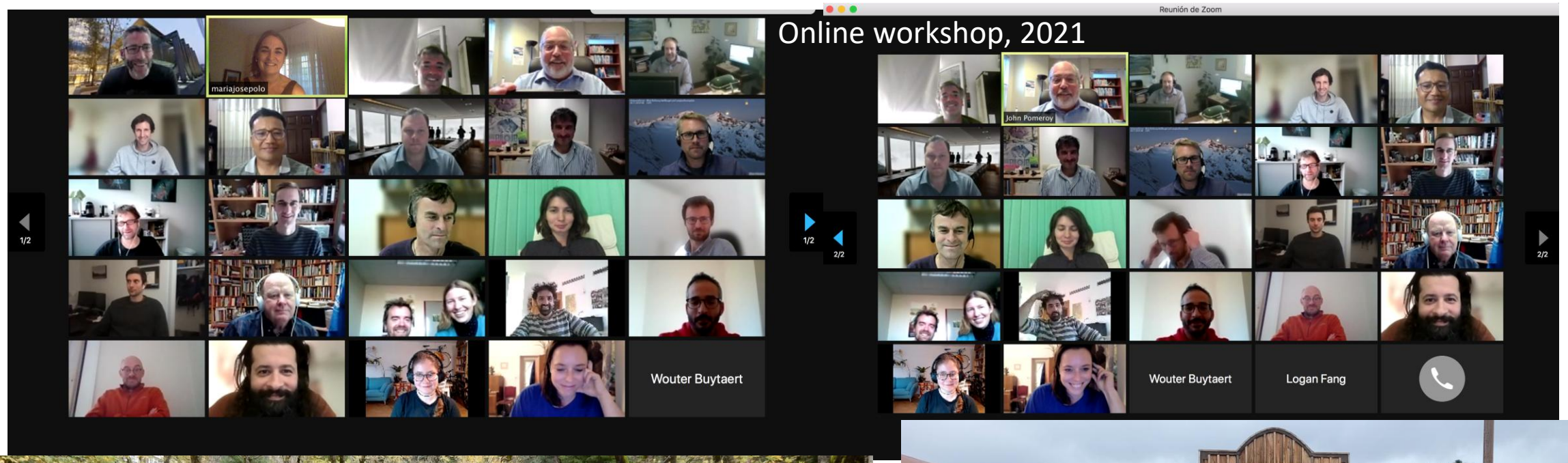
waterfuture Sustainable Water Future Programme

IAHS AISH

UNESCO United Nations Educational, Scientific and Cultural Organization · Intergovernmental Hydrological Programme

Participants

Participants



Participants

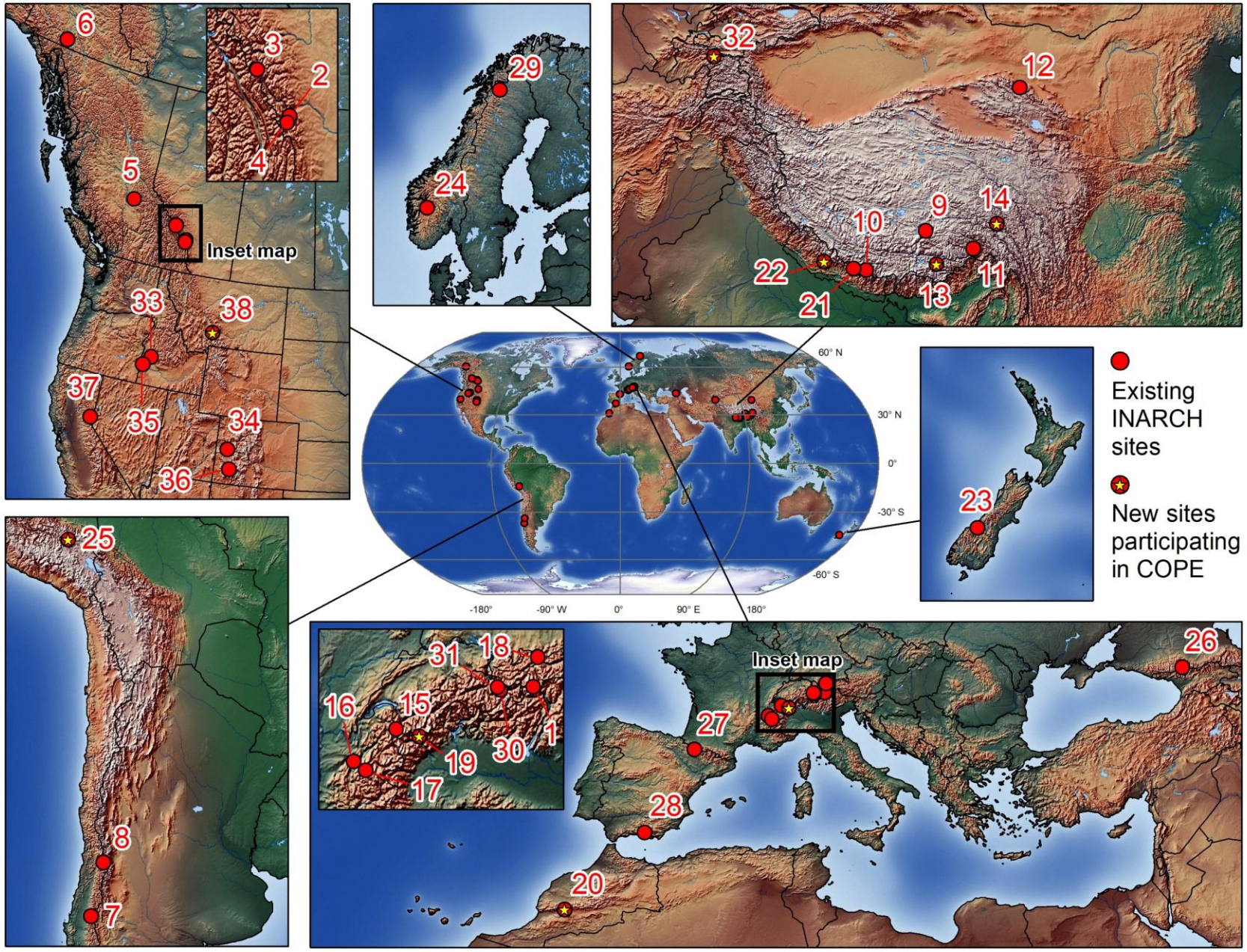
← Participants of the 2024 INARCH workshop at the Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, Lanzhou, China on October 15, 2024.

Participants of the 2024→ INARCH workshop at the snow observation site (Yakou) at 4,120m elevation in the Qilian Mountains, China, on October 17, 2024

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

INARCH Phase II 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? *What do we mean by predictability?*
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)

- INARCH hosted the Common Observing Period Experiment (COPE) over 2022–2024 as a focal network activity to collect high-quality measurements along with supplementary observations and remote sensing campaigns.
- COPE produced a common, coherent, and well-documented and described dataset of mountain meteorology and hydrology from INARCH basins.
- We are now applying 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 emphasize atmospheric, snow, glacier, and water processes in high mountain terrain and include sparse forest, non-needleleaf vegetation, glaciated, and alpine windblown sites.

Common Observing Period Experiment (COPE)
2022–2024

COPE Hydrological, Meteorological, Glaciological Models

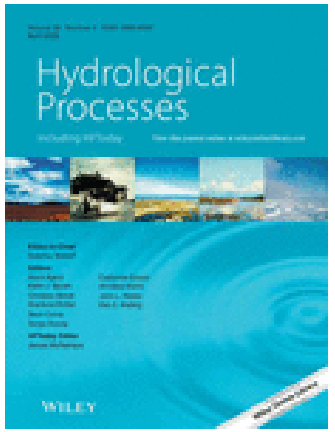
1. CRHM
2. openAMUNDSEN
3. OGGM (open global glacier model)
4. Cosipy
5. WRF\NoaaMP\CLM\LES models
6. FSM2
7. Thethys-Chloris
8. SPHY
9. AMelt
10. SNOWPACK/Alpine3D
11. Canadian Hydrological Model (CHM)
12. SnowModel
13. AWSM/iSnobal
14. FSM-OSHD
15. S3M
16. TopoPyScale
17. SURFEX-Crocus
18. SnowMet

- 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.

Common Observing Period Experiment (COPE)
2022–2024

Next steps

- Publish data in ***Earth System Sciences Data*** **special issue**, “Hydrometeorological data from mountain and alpine research catchments,” https://essd.copernicus.org/articles/special_issue871.html
- Call for papers in ***Hydrological Processes*** **special issue**, “Improving Measurement, Understanding, and Prediction of Alpine Cold Regions Hydrological Processes and Their Sensitivities to Global Change,” https://onlinelibrary.wiley.com/page/journal/10991085/homepage/call-for-papers/si-2024-001778



- **International Mountain Conference 2025:** INARCH convenes the focus session, FS 3.116 on Monday *High mountain hydrology and cryosphere: observations, modelling, prospects* at IMC 2025

IMC Innsbruck 2025
International Mountain Conference

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

INARCH Statement 2024

- INARCH met in Asia for the first time and engaged with many scholars and institutes who are contributing substantially to increasing the capacity and advances of high mountain hydrometeorology and cryospheric science
- Dramatic expansion of high-quality observations in High Mountain Asia and use of this data with sophisticated models to diagnose changing cryosphere and hydrology
- Atmospheric forcing data including reanalysis continues to improve and refine resolution but needs bias correction in high mountains to be useable.
- Risks and hazards in high mountains have been identified and there is a research need for observation, early warning and prediction systems.
- Sub-surface flow and ecological interactions are important areas for development in INARCH with some advances and more needed.
- Black carbon and dust impacts on albedo and melt are a source of uncertainty that needs more attention.
- International teams are testing and applying a suite of models in multiple INARCH basins and show transferability of approaches and algorithms
- INARCH is poised to deliver advances in monitoring, science and application to the International Year of Glaciers' Preservation and UN Decade of Action for the Cryospheric Sciences.

2025
International
Year of Glaciers'
Preservation

The International Year of Glaciers' Preservation – 2025

Secretariat joint between WMO and UNESCO

https://www.un-glaciers.org

The International Year of Glaciers' Preservation - 2025

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.

Raise global awareness of

- **the critical role of glaciers, snow and ice in the climate system and the hydrological cycle, and**
- **economic, social and environmental impacts**

Share best practices and knowledge.

A coordination mechanism to implement activities between WMO and UNESCO, is led by an Advisory Board and 4 Task Forces.

unesco

WORLD METEOROLOGICAL ORGANIZATION

Task Forces

	Task Force	Lead
1	**TF-1: Global Campaign for International Year of Glaciers' Preservation 2025**	FAO Mountain Partnership Secretariat *Contact:* ***Sara Manuelli***
2	**TF-2: International Conference on Glaciers' Preservation, Regional Workshops and Capacity Building**	International Center for Integrated Mountain Development (ICIMOD) *Contact:* ***Neera Shrestha Pradhan***
3	**TF-3: Research and Monitoring Initiatives**	Universidad de Chile *Contact:* ***James McPhee***
4	**TF-4: Policy Advocacy, Partnerships and Resource Mobilization**	International Cryosphere Climate Initiative (ICCI) *Contact:* ***Pam Pearson***

Mountain Partnership

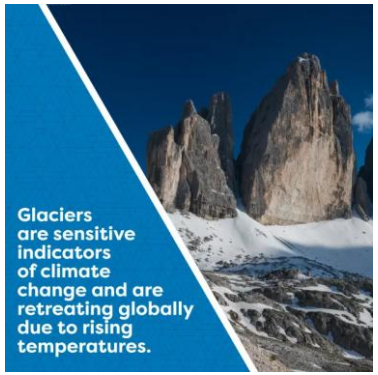
ICIMOD

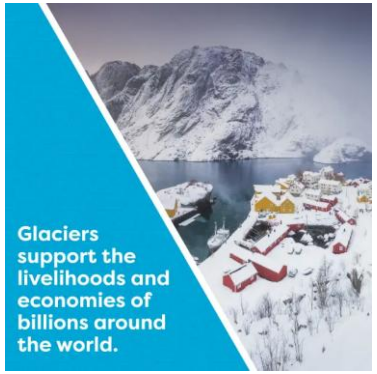
UNIVERSIDAD DE CHILE

INTERNATIONAL CRYOSPHERE CLIMATE INITIATIVE

The open-ended call for Task Force members (via an online form) remains active to welcome applications on a continuous basis.

IYGP 2025 – 13 key messages





Observations, Modelling and Science Needs for the Decade of Action for Cryospheric Sciences

- Comprehensive quantification of the role of snow and ice in global water and ocean resources and impact of global heating on future resources
  - **Global Cryospheric Monitoring, Observation and Prediction System**
  - **Global Cryosphere-Hydrosphere Modelling System**
  - **Digital Cryosphere Twin**
- Integration of climate, cryospheric, oceanic and hydrological sciences with ecological and social systems towards creation of transdisciplinary solutions to cryospheric collapse.
  - **Develop cryospheric deterioration scenarios**
  - **Identify solutions**
  - **Facilitate transformation of communities**
- Develop adaptation and risk management solutions to mitigate cryospheric collapse
  - **Identify cryospheric hazards and impacts**
  - **Strengthen monitoring and early warning systems**
  - **Identify cryospheric risks**
  - **Develop localized adaptation frameworks**
- *Need to build capacity, train scientists and engage communities in order to support these three scientific research milestones*

INARCH Workshop, Innsbruck University Center in Obergurgl, Austria, September 12–14, 2025

- Thank you, Rainer Prinz, Lindsey Nicholson, and Uli Strasser for local organising.

universität innsbruck

Thursday, September 11	**Arrival in Innsbruck**	
7:45 PM	John Pomeroy & Ignacio López Moreno	INARCH 2025 workshop introduction – perspectives of INARCH (accomplishments, current status and activities, future directions);
	Rainer Prinz & Ulrich Strasser	Overview of alpine hydrology and research facilities at Innsbruck University and the Rofental Catchment
	ALL	Discuss Challenges, Opportunities and Prospects in Operating INARCH Catchments.
Saturday, September 13	**Field tour of the Rofental Catchment and surrounding region**	
7:30–8:30 AM	Breakfast	
9:00 AM – 5:00 PM	Participants will tour the Rofental Catchment; this will be weather-dependent and different options will be explored. There will be a bag lunch.	
7:00 PM	Dinner	
Sunday, September 14	**INARCH science updates and discussion**	
7:30–8:30 AM	Breakfast	
8:30–8:45 AM	Chris DeBeer	Overview of the Common Observing Period Experiment (COPE): status, activities, science questions
8:45–9:00 AM	John Pomeroy	Modelling the Impact of Black Carbon on a Nepalese Glacier Catchment using CRHM and Bias-corrected Reanalysis Data
9:99–9:15 AM	Ethan Gutmann	Atmospheric AI Emulators for Downscaling to Catchment and Convection Permitting Scales
9:15–9:30 AM	Thomas Nagler	Extension of the ESA AlpSnow project to INARCH sites
9:30–9:45 AM	Ekaterina Rets	Contrasting energy-balanced based snowmelt runoff estimates with isotopic hydrograph separation for a small arctic mountainous catchment
9:45–10:00 AM	Marc Pons	Contact Leaf area as forest structure indicator to assess the interception and distribution of snow in subalpine mountain environments
10:00–10:30 AM	Coffee break and poster viewing **Posters:**	
	Hamish Pritchard and Federico Covi	Lakes as snowfall sensors: a breakthrough for constraining SWE in satellite and model products
	Carlo Marin	Characterizing Liquid Water Content, Permittivity, Snow Roughness, and Snow Cover Fraction for Improved Understanding of Satellite Observations of Snow at Weissfluejoch and Val Senales
	Achille Jouberton	Snow and glacier at risk: Insights from the Kyzylsu research catchment, Tajikistan
	Jesús Revuelto	High spatial resolution CHM simulations in the Pyrenees: first evaluations with UAV data
	Elizabeth Ramirez	Representation of snow dynamics in a forested area of the Southern Andes using the Factorial Snow Model (FSM)
	Paloma Palma	Estimation of Snow Water Equivalent in the Maipo river basin in central Chile
10:30–10:45 AM	Tim Link	Exploring the Sensitivity of Watershed Hydrology to Land Cover and Climate Change: Results from an Experimental Watershed Spanning the Rain-Snow Transition Zone
10:45–11:00 AM	James McPhee	A modelling study of historical snow droughts in the extratropical Andes Cordillera and their hydrological implications
11:00–11:15 AM	James McNamara	Modelling snow to flow relationship in the Reynolds Creek Experimental Watershed using the Cold Regions Hydrological Model: A work in progress
11:15–11:30 AM	Ignacio López Moreno	Elevation-Dependent Effects of Climate Change on Snowpack in Spanish Mountains
11:30–12:00 PM	Discussion on future INARCH directions and plans (wrap-up of COPE science activities; papers for special issues of ESSD and Hydrological Processes; potential renewal as a GEWEX cross-cutting project) Closing statements	
12:00 PM	Bag lunch and depart by bus for Innsbruck	

Going Forward:
INARCH Renewal as a GEWEX Cross-Cut Project, post 2026