International Network for Alpine Research Catchment Hydrology

Summary and Overview of INARCH

Phase I Achievements and Phase II Ambitions

John Pomeroy, INARCH Chair

Juan Ignacio López Moreno, INARCH Co-Chair

James McPhee, Scientific Steering Group

Chris DeBeer, Science Manager

INARCH 2021 Online Workshop

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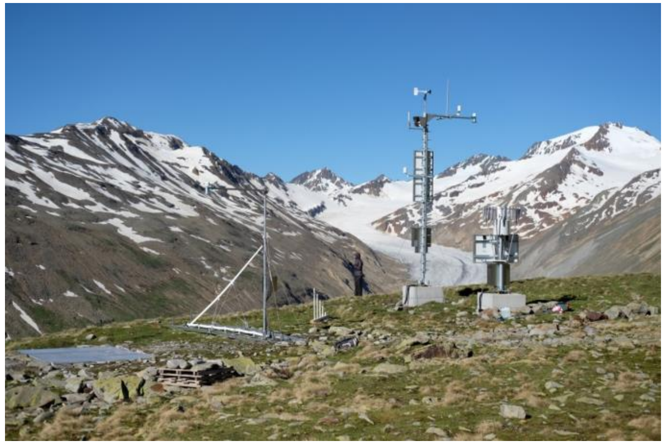
https://inarch.usask.ca

INARCH Objectives

To better

- understand mountain cold regions hydrological processes,
- improve their prediction,
- diagnose their sensitivities to global change



and

- To find consistent measurement strategies.

INARCH Science Questions

1. How do varying mountain measurement standards affect scientific findings around the world?
2. What control does changing atmospheric dynamics have on the predictability, uncertainty and sensitivity of alpine catchment energy and water exchanges?
3. What improvements to alpine energy and water exchange predictability are possible through improved physics, downscaling, data collection and assimilation in models?
4. Do existing mountain model routines have a global validity?
5. How do transient changes in perennial snowpacks, glaciers, ground frost, soil stability, and vegetation impact alpine water and energy models?

Participants

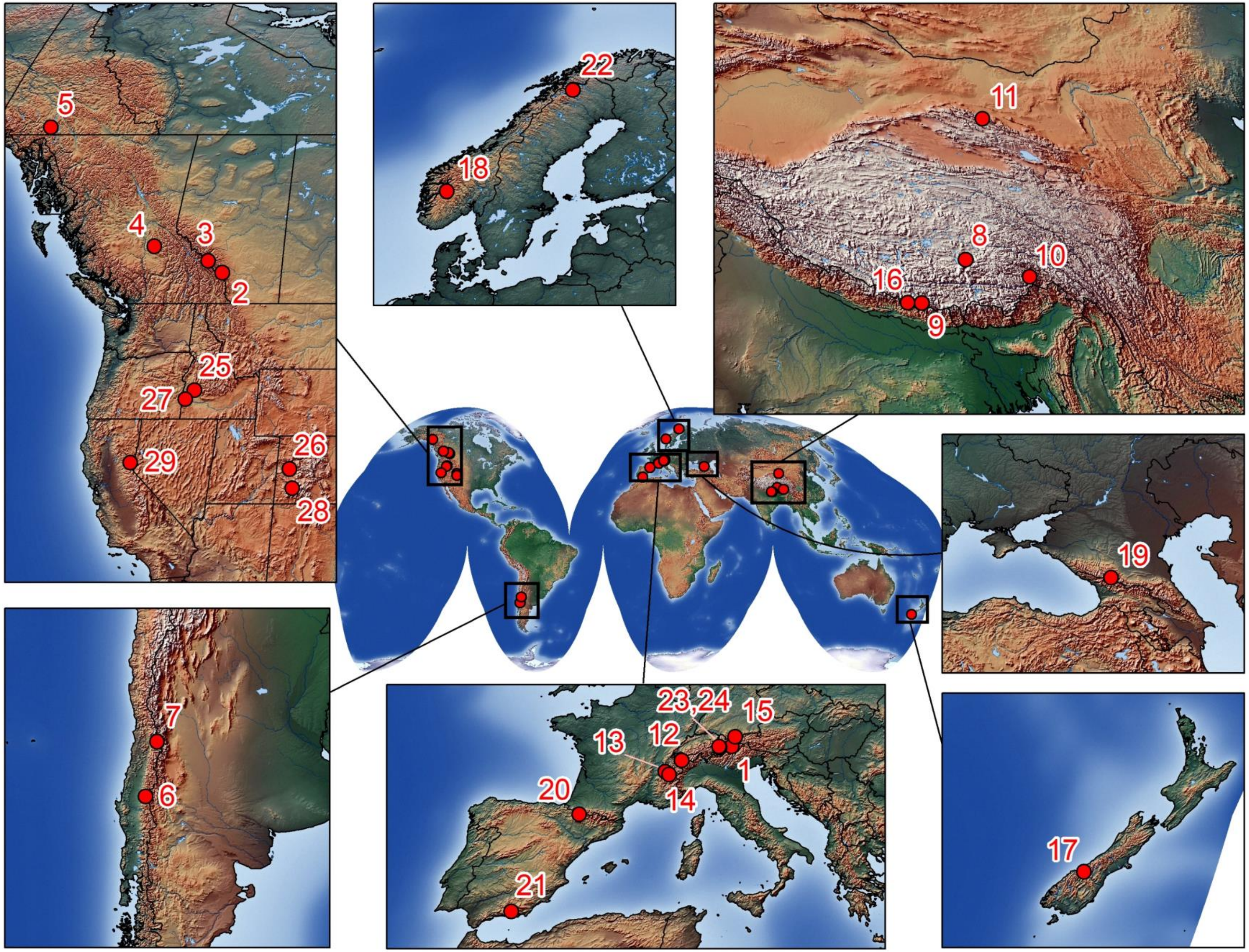
Participants

https://inarch.usask.ca/org-people/participants.php

- John Burkhart, University of Oslo, Norway
- Wouter Buytaert, Imperial College London, England
- Sean Carey, McMaster University, Canada
- Jono Conway, National Institute of Water & Atmospheric Research, New Zealand
- Nicolas Cullen, University of Otago, New Zealand
- Chris DeBeer, University of Saskatchewan, Canada
- Stephen Dery, University of Northern British Columbia, Canada
- Marie Dumont, Centre National de Recherches Météorologiques (UMR CNRS & Météo-France), Centre d'Etudes de la Neige, France
- Richard Essery, University of Edinburgh, Scotland
- Simon Gascoin, Université de Toulouse, France
- Alexander Gelfan, Water Problems Institute, Russian Academy of Sciences, Russia
- Isabelle Gouttevin, Centre National de Recherches Météorologiques, Météo-France, France
- Ethan Gutmann, National Center for Atmospheric Research, USA
- Adrian Harpold, University of Nevada, Reno, USA
- Walter Immerzeel, Utrecht University, Netherlands
- Peter Jansson, Stockholm University, Sweden
- Tobia Jonas, WSL Institute for Snow and Avalanche Research SLF, Switzerland
- Georg Kaser, University of Innsbruck, Austria
- Franziska Koch, University of Natural Resources and Life Sciences Vienna, Austria
- Sebastian Krogh, Universidad de Concepción, Chile
- Vincenzo Levizzani, National Research Council of Italy (CNR-ISAC), Italy
- Xin Li, Chinese Academy of Sciences (CAS), China
- Ignacio Lopez Moreno, Spanish National Research Council (CSIC), Spain
- Yaoming Ma, Chinese Academy of Sciences (CAS), China
- Danny Marks, US Department of Agriculture, USA
- James McPhee, University of Chile, Chile
- Pablo Mendoza, Universidad de Chile, Chile
- Brian Menounos, University of Northern British Columbia, Canada
- Anil Mishra, International Hydrological Programme, UNESCO, France
- Samuel Morin, Centre National de Recherches Météorologiques, Météo-France, France
- Florence Naaim-Bouvet, Institut National de Recherche en Sciences et Technologies pour l'Environnement et l'Agriculture (IRSTEA), France
- Francesca Pellicciotti, Eidgenössische Technische Hochschule (ETH), Switzerland
- María José Polo Gómez, University of Córdoba, Spain
- John Pomeroy, University of Saskatchewan, Canada
- Dhiraj Pradhananga, Tribhuvan University, Nepal
- Rainer Prinz, Universität Innsbruck, Austria
- Roy Rasmussen, US National Center for Atmospheric Research, USA
- Ekaterina Rets, Institute of Water Problems, Russian Academy of Science, Russia
- Gunhild Rosqvist, Stockholm University, Sweden
- Nick Rutter, University of Northumbria, England
- Robert Sandford, United Nations University Institute for Water, Environment and Health, Canada
- Karsten Schulz, University of Natural Resources and Life Sciences (BOKU), Austria
- Jean-Emmanuel Sicart, Institut de Recherche pour le Développement, France
- Delphine Six, Université Joseph Fourier, France
- Sara (McKenzie) Skiles, University of Utah, USA
- Ulrich Strasser, University of Innsbruck, Austria
- Julie Thériault, Université du Québec à Montréal, Canada
- Vincent Vionnet, Environment and Climate Change Canada, Canada
- Isabella Zin, Laboratoire d'étude des Transferts en Hydrologie et Environnement (LTHE), France

INARCH Basins

Austria 1. Rofental Open Air Laboratory (OpAL);
Canada 2. Marmot Creek Research Basin; 3. Peyto Glacier; 4. Quesnel River Research Basin; 5. Wolf Creek Research Basin;
Chile 6. Upper Diguillín; 7. Upper Maipo;
China 8. Nam Co Monitoring and Research Station for Multisphere Interactions; 9. Qomolangma Atmospheric and Environmental Observation and Research Station; 10. Southeast Tibet Observation and Research Station for the Alpine Environment; 11. Upper Heihe River Basin;
France 12. Arve Catchement; 13. Col de Porte Experimental Site; 14. Col du Lac Blanc Experimental Site;
Germany 15. Schneefernerhaus and Research Catchment;
Nepal 16. Langtang Catchment;
New Zealand 17. Brewster Glacier;
Norway 18. Finse Alpine Research Centre;
Russia 19. Djankuat Research Basin;
Spain 20. Izas Research Basin; 21. Guadalfeo Monitoring Network;
Sweden 22. Tarfala Research Catchment;
Switzerland 23. Dischma Research Catchment; 24. Weissfluhjoch Snow Study Site;
United States of America 25. Dry Creek Experimental Watershed; 26. Grand Mesa Study Site; 27. Reynolds Creek Experimental Watershed; 28. Senator Beck Basin Study Area; 29. Sagehen Creek, Sierra Nevada.



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

Data Requirements

Surface based data requirements for this project will primarily be met by:

1. openly-available detailed meteorological and hydrological observational archives from long-term research catchments at high temporal resolution (at least 5 years of continuous data with hourly sampling intervals for meteorological data, daily precipitation and streamflow, and regular snow and/or glacier mass balance surveys) in selected heavily instrumented alpine regions
2. atmospheric model reanalyses
3. downscaled climate model as well as regional climate model outputs

Data Requirements

The ideal is for sites to be Integrated Alpine Observing and Predicting Systems (IAOPS). A provisional classification scheme for IAOPS is:

CLASS A: sites receiving technology transfer and developing towards CLASS B to E

CLASS B: Single measurement points with highly accurate driving data and snow or glacier data

CLASS C: gauged catchments that contain Class B sites and detailed vegetation coverage, soils, topography, snowcovered area, glacier mass balance or permafrost information

CLASS D: domains for which high resolution gridded meteorological data is available that includes CLASS C sites
CLASS E: the same as CLASS D but gridded meteorological data is also available as climate change scenarios.

Linkages

- GEWEX Hydroclimatology Panel (GHP) Projects
  - Cold/Shoulder Season Precipitation Near 0ºC project
  - Changing Cold Regions Network and Global Water Futures
  - Western US RHP & Water for Foodbaskets
  - ANDEX RHP Initiative for the Andes
- Global Cryosphere Watch
- WMO-SPICE and WMO High Mountain Summit
- TPE (Third Pole Environment)
- Future Earth, Sustainable Water Futures Programme (SWFP) and the Climate Impacts on Global Mountain Water Security working group
- International Commission for Snow and Ice Hydrology (ICSIH)
- UNESCO-Intergovernmental Hydrological Programme (IHP)

INARCH Phase I Achievements

- INARCH has grown to a network of 50 research scientists with wide-ranging expertise from around the world
- 29 experimental research basins in 14 countries covering most continents and mountain regions of the world
- significant advances in understanding and predictive modelling of the high mountain water cycle, contributing significantly to multiple international science initiatives, organizations, and other stakeholders
- adopted a philosophy and commitment to open data, with major efforts to compile these data, e.g., ESSD special issue "Hydrometeorological data from mountain and alpine research catchments" with 23 datasets.

Earth System Science Data Special Issue

- Hydrometeorological data from mountain and alpine research catchments
- https://www.earth-syst-sci-data.net/special_issue871.html
- Guest Editors: J.W. Pomeroy, D.G. Marks
- 23 data papers contributed and more coming in

“Data sets contributed to the special issue should support and promote research on the effects of mountain snowpacks and glaciers on water supply as well as study of variations in energy and water exchange amongst different high-altitude regions. …The guest editors invite contributions of openly available detailed meteorological and hydrological observational archives from long-term research catchments at high temporal resolution (at least 5 years of continuous data with hourly sampling intervals for meteorological data, daily precipitation and streamflow, and regular snow and/or glacier mass balance surveys) in well-instrumented mountain regions around the world.”

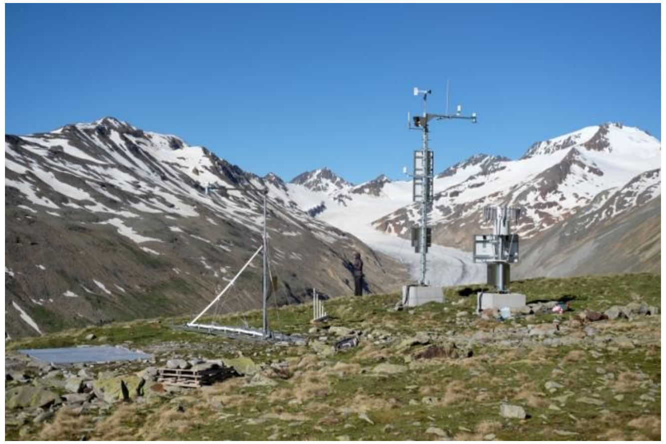
GEWEX INARCH

INARCH Phase II Ambitions and Possibilities

INARCH Objectives

To better

- Measure and understand high mountain hydrometeorological, 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



WORLD METEOROLOGICAL ORGANIZATION

WEATHER CLIMATE WATER

High Mountain Summit

Call for Action, Geneva, October 2019

- Climate change and development are creating an **unprecedented crisis in our high mountain earth system** that threatens the sustainability of the planet.
- **People living in mountains and those living downstream shall have open access to and use of 'fit-for-purpose' hydrological, meteorological and climate information services** that address their need to adapt to and manage the threats caused by unprecedented anthropogenic climate change, recognizing the importance of mountain regions as home of the cryosphere and source of global freshwater.
- **Integrated High Mountain Observation, Prediction and Services Initiative**, organized as collective, intensive campaigns of analysis and forecasting demonstration projects in key high mountains and headwaters around the world. Needs to improve observations, forecasts and data exchange in mountain ranges and headwaters around the world.

A New INARCH Vision

- Improve mountain hydrometeorological 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 **'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 mountains?

Possible Science Questions

We have made progress on the five main science questions, and we can restart from these recast questions:

1. How different are the measurement standards and the standards for field sampling and do we expect distinctive differences in model results and hydrological predictability because of the sampling schemes, data quality and data quantity?
   - Measurement standards and field sampling are always core, and this objective is still relevant
2. How do the predictability, uncertainty and sensitivity of catchment energy and water exchanges vary with changing atmospheric dynamics in various high mountain regions of the Earth?
   - This point is almost the essence of INARCH, we can continue in this line and we have longer observational records now. Maybe we can now make comparison experiments forced by observations instead of reanalysis data.

Possible Science Questions

3. What improvements to high mountain energy and water exchange predictability are possible through improved physics in land surface hydrological models, improved downscaling of atmospheric models in complex terrain, and improved approaches to data collection and assimilation of both in-situ and remotely sensed data?
    - We have seen major advances since 2015 but new models, satellite and atmospheric products are still showing up. Assimilation techniques have been more and more widely used. Perhaps a question would be how can our observational sites may contribute to improve and validate these products.
4. Do existing model routines have global validity, are they transferable and are they meaningful in different mountain environments?
    - We have demonstrated that flexible platforms can work well in contrasting environments, but still we still need good *a priori* knowledge on process manifestation in each environment. Can flexible platforms also work well in regions where there remains no clear idea of how hydrological processes work? What are the implications for global modelling or continental-scale operational models? There are still some questions to improve in models: Interaction with shrubs, representation of processes in patchy snowpacks..

Possible Science Questions

5. How have mountain hydrometeorological systems involving snowpacks, glaciers, frozen ground, lakes/ponds, soils/groundwater, vegetation and humans co-evolved to their current states and how will they respond to climate change over the next century. Are there tipping points and stable states for these systems? Can these systems be predicted and possibly managed to find solutions to help achieve water sustainability in mountain headwaters under climate change?

INARCH Workshop Statement 2018-19

- INARCH has identified the importance of the changing High Mountain Water Cycle to global water and climate initiatives.
- INARCH has published invaluable mountain catchment hydrometeorological datasets from around the world.
- INARCH has identified dramatic snowpack decline and glacial retreat in the Andes and Patagonia as issues of global concern.
- The performance of high resolution atmospheric models needs to be assessed at point and areal scales and spatial datasets for such assessments and for bias-correction need to be assembled. Global application of these products to mountains is needed. High resolution snow and ice hydrology models need development to take advantage of the more accurate alpine precipitation products that will result.
- There is tremendous potential to assimilate high resolution remote sensing products into advanced snow hydrology prediction models. Efforts are needed to demonstrate how the outputs can be used to improve snow prediction models.
- INARCH has quantified the sensitivity of mountain snow hydrology regimes around the world. This should be extended to examine the sensitivity of mountain glacier hydrology to global warming.
- INARCH continues to examine the performance of alpine snow models in simple alpine environments by comparison of model outputs to diagnostic measurements. The next step should be to examine model performance in extreme alpine environments that are more typical of alpine landscapes.

Outline and goals for this workshop

Monday, October 18, 2021

-present initial cut at INARCH science objectives

1. State of INARCH research basins and regional activities
   - Instrumentation/Observations: what is new, what works, what doesn't?
   - What are the observations telling us?
   - Possibilities for common experimental designs?

Tuesday, October 19, 2021

2. Modelling advances and intercomparison studies
   - Look at different models that are up and running, and how they are being evaluated.
   - Survey the bias corrected, gridded products that are available. What exists and how has it been tested so far?

Wednesday, October 20, 2021

3. Using modelling and observations to find solutions to mountain water sustainability under climate change?
   - Evaluation of gridded meteorological products at INARCH basins
   - Advances in high resolution hydrometeorological modelling and observations.
   - Global changes to high mountain hydrometeorology
   - What INARCH basin data exist to test models? What tests have occurred?
   - What next should we do to obtain the data to test these models? Common model correction period and common observing period experiment (COPE)?

-Discussion of INARCH science objectives.

-Synthesis paper(s) on key INARCH science topics and questions*

Online presentations and other materials are at: https://inarch.usask.ca/news-events/inarch-2021-online-workshop.php

INARCH will carry on in spite of COVID-19, and when meetings are again possible, we will reconvene at an alpine research site