GHP Working Group (Project) Reports for the 35th GEWEX SSG Meeting 2023

Full Panel Name (Acronym) : The International Network for Alpine Catchment Hydrology (INARCH), Phase 2
Reporting Period : 01 January - 31 December 2023
Starting Date : 2021
End Date (where appropriate) : 2026
URL : https://inarch.usask.ca/

Membership

Lead(s) & Contact(s) : John Pomeroy (Chair)
Juan Ignacio López Moreno (Co-Chair)
Chris DeBeer (Science Manager)

Working Group (Project) Objectives, Goals and Accomplishments during Reporting Period

Overall Working Group (Project) Objective(s)

To better:

- 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.

List of Panel Goals

Adjust yearly

Our phase II proposal to GEWEX contains details on our vision, objectives, and science questions.
A major goal for 2022 – 2024 is to carry out a common observing period experiment (COPE), focusing on obtaining high-quality measurements, to the extent possible, across most of the INARCH basins (https://inarch.usask.ca/science-basins/cope.php).

List of 2 to 3 Key Results

Adjust yearly with respect to goals

The COPE effort has begun and is underway with active fieldwork, observation campaigns, modelling initiatives, and data management planning. This will allow us to address INARCH Phase II Science Questions #1 and #4, and indirectly address the others. There have been a series of web-based meetings to discuss activities and this will be followed up in-person at our next workshop.

Other Science Highlights

Not part of the 2-3 key results

Contributions to the INARCH ESSD special issue continue, with a recent submission:
Sicart, J. E., Ramseyer, V., Picard, G., Arnaud, L., Coulaud, C., Freche, G., Soubeyrand, D., Lejeune, Y., Dumont, M., Gouttevin, I., Le Gac, E., Berger, F., Monnet, J. M., Borgniet, L., Mermin, E., Rutter, N., Webster, C., and Essery, R.: Snow accumulation and ablation measurements in a mid-latitude mountain coniferous forest (Col de Porte, France, 1325 m alt.): The Snow Under Forest field campaigns dataset, Earth Syst. Sci. Data Discuss. [preprint], https://doi.org/10.5194/essd-2023-174, in review, 2023.

AlpSnow (https://alpsnow.enveo.at/) intends to contribute to INARCH by providing a full portfolio of high resolution satellite products (albedo, grain size, wet snow area) for the COPE in the INARCH Alps basins.

Panel Activities during Reporting Period

List of Panel Activities and Main Result

Initialization of COPE and ongoing fieldwork activities at most INARCH basins.

Continuation of model develop, application, and testing across INARCH research basins

List of New Projects and Activities in Place and Main Objective(s)

The COPE initiative is our latest new project/activity. This is a major effort, is globally unique and novel, and will produce a world-class set of new observations and data, model application and comparisons, and new insights that will have tremendous scientific value.

List of New Projects and Activities Being Planned, including Main Objective(s) and Timeline, Lead(s)

COPE and the follow-on model testing and evaluation, sensitivity analyses, and diagnostic and predictive modelling will be a major endeavor over the next several years of INARCH.

Science Issues and Collaboration during Reporting Period

Contributions to Developing GEWEX Science and the GEWEX Imperatives.

a. *Data Sets*

https://inarch.usask.ca/datasets-outputs/mountain-hydrometeorological-data.php

b. *Analysis*

INARCH members have carried out many analyses at the mountain research basins and mountain regions more broadly. INARCH has quantified the sensitivity of mountain snow hydrology regimes around the world. INARCH continues to examine the performance of alpine snow models in simple alpine environments by comparison of model outputs to diagnostic measurements.

https://inarch.usask.ca/science-basins/cope.php#Modellingsoftwaretools.

c. *Processes*

Significant advancement in alpine hydro-meteorological process understanding and representation in models has been achieved by INARCH.

d. *Modeling*

The network has developed and advanced the next generation of alpine meteorological and hydrological models, conducted earth system model intercomparisons, proposed new algorithms for modelling and has applied its models to examine sensitivity and responses to climate and landcover change.

https://inarch.usask.ca/science-basins/models-downscaling-tools.php

e. *Application*

We have used the Integrated High Mountain Observation and Prediction Systems (IHMOPS) to improve our scientific understanding, and evaluate observed changes, data and models around the world. The models are being used to estimate the sensitivity of the high mountain cryosphere and hydrology to climate change.

f. *Technology Transfer*

INARCH will work with mountain communities and regions and national governments to develop plans to predict future water scenarios, build capacity, enhance forecasting systems, answer questions on water futures and evaluate the sustainability of proposed water management solutions

g. *Capacity Building*

INARCH will work with communities and regions to develop plans to predict future water scenarios, build capacity, enhance forecasting systems, answer questions on water futures and evaluate the sustainability of proposed water management solutions.

List contributions to the GEWEX Science Goals and plans to include these.

Goal # 1 (GS1): Determine the extent to which Earth's water cycle can be predicted. This Goal is framed around making quantitative progress on three related areas posed in terms of the following questions:

1. **Reservoirs:**

What is the rate of expansion of the fast reservoirs (atmosphere and land surfaces), what is its spatial character, what factors determine this and to what extent are these changes predictable?

INARCH makes valuable contributions to this goal through its work on mountain snowpacks and glaciers and their changes, and to a lesser extent, mountain groundwater and lakes.

2. **Flux exchanges:**

To what extent are the fluxes of water between Earth's main reservoirs changing and can these changes be predicted and if so on what time/space scale?

INARCH is focused on quantifying the sensitivity and changes in the mountain water cycle, including water vapour fluxes driven by sublimation and evapotranspiration, solid fluxes via blowing snow, snow avalanches and glacier ice dynamics and liquid fluxes from meltwater movement through snow and ice, infiltration to frozen and unfrozen soils and mountain runoff generation and streamflow synthesis. Important progress has been made and many scientific publications have resulted.

3. **Precipitation Extremes*:***

How will local rainfall and its extremes change under climate change across the regions of the world?

We presume you include snowfall in this question. This is a fundamental aspect of INARCH with respect to mountain precipitation with a fundamental question being what is the phase of precipitation and how is it changing from snowfall to rainfall and how are rainfall extremes changing in high mountains.

Goal # 2 (GS2): Quantify the inter-relationships between Earth's energy, water and carbon cycles to advance our understanding of the system and our ability to predict it across scales:

1. **Forcing-feedback understanding:**

How can we improve the understanding of climate forcings and feedbacks formed by energy, water and carbon exchanges?

INARCH contributes through its work at understanding, modelling, and predicting changes in mountain snowcover, glaciers, and landcover, which all have critical importance on surface energy balance and climate feedbacks. Examination of ecosystem fluxes and how they are responding to longer snow-free seasons, declining frozen soils and warmer summers and the upward migration of alpine treelines is fundamental to INARCH.

2. **ABL process representation:**

To what extent are the properties of the atmospheric boundary layer (ABL) defined by sensible and latent energy and water exchanges at the Earth's surface versus within the atmosphere (i.e., horizontal advection and ABL-free atmosphere exchanges)?

INARCH mountain research basins provide exemplary datasets for characterizing mountain boundary layer meteorology in otherwise data-sparse regions of the world.

3. **Understanding Circulation controls:**

To what extent are exchanges between water, energy and carbon determined by the large-scale circulations of the atmosphere and oceans?

Regional and continental-scale atmospheric modelling (i.e. through collaborations with US National Center for Atmospheric Research and Global Water Futures for high-resolution WRF simulations) sheds insight on the controls of circulation patterns on mountain hydro-meteorology.

4. **Land-atmosphere interactions:**

How can we improve the understanding of the role of land surface-atmospheric interactions in the water, energy and carbon budgets across spatiotemporal scales?

Improved computational capacity, geospatial intelligence and new and improved modelling tools developed in INARCH are helping to bridge scales from site, to headwater basin, river basin, regional and continental, but there remains a critical need for the mountain research observatories and the INARCH hydrometeorological, hydrological and hydroglaciological process studies that are conducted there.

Goal # 3 (GS3): Quantify anthropogenic influences on the water cycle and our ability to understand and predict changes to Earth's water cycle.

1. **Anthropogenic forcing of continental scale water availability:**

To what extent has the changing greenhouse effect modified the water cycle over different regions and continents?

This is a focus for rivers that have mountain headwaters where snow and ice reserves are directly impacted by rising temperatures - these are about 50% of human water supplies around the world.

2. **Water management influences:**

To what extent do water management practices and land use change (e.g., deforestation) modify the water cycle on regional to global scales?

INARCH focusses on landcover change (i.e. glacier loss, forest and vegetation change) in mountain regions, which impact the mountain water cycle and the management and flow of rivers originating in mountain regions.

3. **Variability and trends of water availability:**

How do water & land use and climate change affect the variability (including extremes) of the regional and continental water cycle?

The coupled water and energy cycle is intrinsic to cold regions hydrology that is the core of INARCH. As climate warms, there is further decoupling of snow and hydrological regimes, resulting in increased variability in streamflow.

Other Key Science Questions

List 1 – 3 suggestion that you anticipate your community would want to tackle in the next 5-10 years within the context of a land-atmosphere project

See our proposal for a second phase of INARCH, 2021-2026, for details

Contributions to WCRP including the WCRP Light House Activities

Briefly list any specific areas of your panel's activities in particular to the WCRP Light House Activities (Digital Earth, Explaining and Predicting Earth System Change, My Climate Risk, Safe Landing Cimates and WCRP Academy) https://www.wcrp-climate.org/lha-overview.

INARCH's science goals are directly aligned with the Light House Activity, Explaining and Predicting Earth System Change and its overarching objective to design, and take major steps toward delivery of, an integrated capability for quantitative observation, explanation, early warning, and prediction of Earth System change on global and regional scales, with a focus on multi-annual to decadal timescales. Our focus is on high mountain regions as headwaters for major river systems of the world.

Cooperation with other WCRP Projects, Outside Bodies and links to applications

e.g. CLIVAR, CliC, SPARC, Future Earth, etc.

- INARCH leads a working group under Future Earth - the Climate Impacts on Global Mountain Water Security working group of the Future Earth, Sustainable Water Futures Programme (SWFP) (https://water-future.org/working_groups/climate-impacts-on-global-mountain-water-security/)
- INARCH contributes to UNESCO Intergovernmental Hydrological Programme efforts on climate change impacts on snow, glacier and water resources within the framework IHP-IX (2022–2029), "Science for a Water Secure World in a Changing Environment"
- Several INARCH members are now co-chairholders of the UNESCO Chair in Mountain Water Sustainability https://research.ucalgary.ca/unesco-chair-mountain-water-sustainability.
- INARCH co-chaired the WMO High Mountain Summit and is contributing to addressing its call for action, in particular, the observation and prediction aspects of the Integrated High Mountain Observation, Prediction and Services Initiative. It will be imperative for INARCH to show leadership and provide guidance for governments to implement this.
- INARCH is poised to make major contributions and guide the UN International Year for Glaciers' Preservation.
- The Global Water Futures (GWF; www.globalwaterfutures.ca) Program is an expanded follow-on initiative from CCRN. As GWF ends, it will transition to GWF Observatories, maintaining key instrumented observation sites, deployable systems, and water laboratories. INARCH strongly links with the mountain research components of GWF and GWFO. Distinguished Professor John Pomeroy leads and directs INARCH, GWF and GWFO.

Workshops and Meetings

List of Workshops and Meetings Held in 2022

Meeting title, dates and location.

INARCH Workshop, Baños de Panticosa, Spain, October 18-20, 2022. See: https://inarch.usask.ca/news-events/inarch-workshop-2022.php. Also see the article in GEWEX Quarterly: https://www.gewex.org/gewex-content/files_mf/1677625320Q12023.pdf.

List of Workshops and Meetings Planned in 2022 and 2023

Meeting title, dates and location and anticipated travel support needs.

INARCH Workshop, Stanley, Idaho, USA, October 9–11, 2023 https://inarch.usask.ca/news-events/inarch-workshop-2023.php. We would be extremely grateful for any support that can be offered by GEWEX to facilitate travel, meeting logistics, or food and beverages. INARCH is itself, unfunded.

Other Meetings Attended On Behalf of GEWEX or Panel in 2022-23

WMO Oslo Meetings: INARCH (John Pomeroy attending) represented global academia at the World Meteorological Organisation's INFCOM Workshop on Coupling of Cryosphere in Numerical and Earth System Models and First Meeting of the Global Cryosphere Watch Advisory Group in Oslo, Norway in March 2023. INARCH's advances in cold regions modelling were highlighted and recommendations were included in WMO's new plans for snow and hydrology services to member states.

UN International Year for Glaciers' Preservation - 2025: A GWF & INARCH proposal for an international year for snow and ice developed into a resolution to the UN General Assembly from Tajikistan for 2025 to be the International Year for Glaciers' Preservation and each March 20th to be International Glacier Day. The resolution passed a vote in the General Assembly in December. Pomeroy was asked to present the keynote talk on the International Year at a session hosted by the President of Tajikistan, King of the Netherlands, President of Bolivia, Secretary General of the United Nations, Secretary-General of WMO, Head of UNESCO and other organisations (World Bank, World Economic Forum, IAEA) at the UN Water Conference at UN Headquarters in March 2023 and at a planning meeting for the International Year at UNESCO Headquarters in April 2023. He will give a keynote talk on the science plan for the International Glacier Year to UNESCO delegates in July 2023. Canada will host an event celebrating the year in late 2024 or early 2025 in the Canadian Rockies UNESCO World Heritage Site.

UN Water Conference: To evaluate progress of the UN Water Decade at its mid-point, the United Nations held its first major water conference in 47 years at its headquarters in NYC during World Water Week, March 2023. INARCH science was represented here.

Publications during Reporting Period

List of Key Publications

https://inarch.usask.ca/datasets-outputs/key-publications.php