International Network for Alpine Research Catchment Hydrology

INARCH 2023 Closing

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https://inarch.usask.ca

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?

INARCH Workshop Statement 2021

- We have completed our Phase 1 Science Plan and have a suite of well-instrumented research basins, high-resolution forcing meteorological datasets, and advanced snowdrift-permitting and glacier-resolving hydrological models that are exemplars of **Integrated High Mountain Observation and Prediction Systems (IHMOPS)**.
- We have used the 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.
- We need to
  - provide common and archived observations for basin diagnosis and modelling through a Common Observation Period Experiment (COPE),
  - enhance basin observations with novel and more sensors,
  - Improve, downscale and correct atmospheric forcing datasets using basin observations,
  - develop, improve, compare, and apply multiscale high-fidelity cryosphere-hydrological-water management models to river basins originating in high mountains
  - work with communities 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.

INARCH Statement 2022

We have

- begun Phase 2, started COPE,
- expanded investigators, observations, basins, mountain ranges, and models,
- implemented a data cataloguing system, snowdrift-resolving models continentally,
- explored new measurement techniques, data assimilation, parameter uncertainty and machine learning,
- started linking to ecosystems and downstream water resources;
- informed a proposed UN Year of Glacier Preservation and contributed to WMO, UNESCO, WCRP, UN Water Decade

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

Summary of Observatories and Measurement Techniques

- Snow depth from UAVs (Structure from Motion, LiDAR) is expanding and replacing snow surveys, this and new sensors (gamma, cosmic ray, terrestrial lidar, GPS, gravity meters) are adding to valuable snow and glacier records.
- Sublimation and transport of blowing snow can be large components of the alpine water balance being quantified along with overwinter snowpack ablation and redistribution.
- Scale effects on snow distribution are crucial in mountain basin hydrology….
- Frozen ground, snow and land surface fluxes need to be understood together in High Mountain Asia
- Rapid disappearance of glaciers in many mountain ranges including Pyrenees and Canadian Rockies.
- The importance of groundwater to mountain glaciated and non-glaciated basin hydrology is increasingly understood but more needs to be done to quantify this
- Isotopes and other tracers are useful tools for understanding the water balance, glacier mass balance, and the hydrological functioning of alpine sites. Possibility to create working group in INARCH to improve their usability and link to models.
- There is a challenge in dealing with precipitation and snow redistribution as they affect glacier mass balance
- The link between snow hydrology and ET is tight and shifting in many mountain basins – linked to phase change, which also affects glacier hydrology very strongly
- Downstream droughts and water management problems affected by climate change and strongly affected by extremes, including destabilisation of groundwater regimes and impacts on baseflow.
- Isotopes are showing the stability of or changing flow pathways in linking snowpacks, glaciers, subsurface and streamflow
- Ecosystem sustainability through snow refugia that are only partially understood, but link to forest structure and complex terrain drainage.
- New understandings of forest snow interception processes including unloading and entrainment are being developed

Summary of Observations and Modelling

- Fully coupled snow atmospheric and hydrology models including redistribution are being applied operationally for snow hydrology forecasting in mountain regions and informed by research basin observations.
- Coupled glacier and snow hydrology with groundwater models are being developed and applied but with great uncertainty for groundwater parameterisations.
- Isotopes are being integrated into physically based glacier and snow hydrology models and need regular isotopic measurements for further development
- Integration of airborne LiDAR shows promise to set initial boundary conditions or parameterisations for snow and other hydrological models – where available.
- Improvements to convective permitting atmospheric models will permit more reliable forcing in complex terrain.
- Snow interception modelling is progressing in non-needleleaf forests and is promising
- Snow-drift permitting (<100 m), hyper-resolution modelling of snow redistribution and melt in complex terrain is now possible and is being deployed at continental scales with credible results.
- Coupled hydrological land surface schemes that account for glaciers, slope-aspect, elevation and snow processes have global applicability for river basin hydrology for rivers with mountain headwaters.
- New, object oriented and flexible models are available and tested for snow and glacier hydrology processes.
- Remarkable datasets have been collected in the Tibetan Plateau region for hydrometeorological, snow and glaciological systems that are being examined for trends, change and to support model development.
- Sentinel 2 and Pleaides high resolution satellite data are available for some INARCH basins and more are coming.

Summary of COPE Updates

- Compare at elasticity of response of COPE basins to T and P changes
- Compare for trends and change points in basin cryosphere and hydrology
- Compare ecological changes occurring and their impact on basins – treeline, shrubs, wildfire
- Model intercomparisons should emphasize processes in complex terrain and include sparse forests, non-needleleaf vegetation, glaciated and alpine windblown sites
- What models are going to be run at which COPE basins? Who? Training?
- What forcing fields are needed and what outputs will be developed from these models, including atmospheric models and products (ERA5, WRF/COSMOS, EM Earth).
- No book, rather a Special Issue in addition to the ESSD data special issue.

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.

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INARCH 2024

- The INARCH bid selection committee met over cigars and whiskey and after careful consideration of imponderable factors selected……

- China – Lanzhou and Qilian Mountains !

Observe, Predict, Protect