

## Project Report for the 2015 GEWEX GHP Meeting

**Cross-cut Project Name:** International Network for Alpine Research Catchment Hydrology (INARCH)

**Reporting Period:** November 2014 – October 2015

**Starting date:** January 2015

**End date:** January 2020

**URL:** [www.usask.ca/inarch](http://www.usask.ca/inarch)

**Chair(s) and term dates:** John Pomeroy, University of Saskatchewan. 2015-

### 1) Project activities over the last year

#### Science Issues

There is an international need to improve the understanding and modelling of mountain snow and ice hydrological processes in global hydrological models and land surface schemes. This has prompted 40 scientists, operating 23 mountain research catchments around the world to launch a new GEWEX Hydroclimate Panel Cross-cut Project – INARCH, the International Network for Alpine Research Catchment Hydrology [www.usask.ca/inarch](http://www.usask.ca/inarch). INARCH's alpine catchments are well equipped to measure snow and ice hydrology. Such information can be used to investigate the effects of mountain snowpacks and glaciers on water supply, or to study variations in energy and water exchange amongst different high-altitude regions.

A number of questions were raised in initial discussions at the GEWEX meeting in The Hague that led to INARCH. Examples are: how can snow and ice hydrology best be measured in various alpine regions? How do land surface energy and water exchanges differ in various high mountain regions of the Earth? What improvements to high mountain hydrological predictability are possible in various alpine regions through improved process physics, representation of spatial variability and incorporation of ground and remote observations? From these questions, INARCH's overall objective is to better understand alpine cold regions hydrological processes, improve their prediction and find consistent measurement strategies. To achieve this objective it is necessary to develop transferable and validated model schemes of different complexity that can support research in data sparse mountain areas.

Surface based data requirements for this project will primarily be met by 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, atmospheric model reanalyses and downscaled climate model outputs.

INARCH's methodology includes comparing instrumentation best practices, suggesting improvements in instrumentation, developing reliable alpine datasets for model testing and numerical experiments, conducting process algorithm intercomparisons, conducting model uncertainty and climate sensitivity analyses, demonstrating improvements to model predictability, evaluation of different downscaling schemes, fostering research and development for future observing schemes, and facilitating education and training programmes to build and enhance science capacity and popularize science results with the public. INARCH is engaged with contributing to UNESCO's International Hydrological Programme as one way to build capacity around the world.

#### Science Highlights

INARCH provides mountain snow and ice water security information for UNESCO's International Hydrological Programme and presented on **Addressing Water Security through Better Understanding and Predicting Mountain Snow Water Resources under Climate Change** to the UNESCO IHP Water Security Workshop, Paris, February 2015

INARCH's objective is to better understand alpine cold regions hydrological processes, improve their prediction, diagnose their sensitivities to global change and find consistent measurement strategies.

#### *Statements from the INARCH Inaugural Workshop include*

Observations – INARCH recognises the value of existing mountain observation stations and encourages increased numbers and improved quality of stations on high mountains to provide understanding and warning of the impacts of climate on downstream water resources. INARCH recognises the urgent need to reduce

measurement uncertainty – it will contribute to WMO's SPICE and CRYONET and then implement SPICE and future CRYONET findings in correcting observations at INARCH observatories.

Data – INARCH supports documentation of metadata on observatories and publication of specialised observational data. Our webpage will point where to find specialized data and metadata for sites and include the originator's assessment of the fitness use of the data. INARCH will organize a mountain data publication special issue.

Uncertainty – INARCH notes that uncertainty derives from measurements, scaling and models, and that model uncertainty includes structural, parameterisation and parameter facets. Uncertainty can be identified and reduced via catchment classification, improved physics, appropriate model complexity, model comparisons. Model comparisons need to be informative, multi-year, multi-climate and multi-site and should be expanded to include forests, slopes, glaciers, the alpine basin scale and include ice, streamflow and subsurface processes.

Downscaling & Assimilation. Downscaling atmospheric models appropriately is difficult yet crucial in mountains. INARCH will develop a "mountain downscaling toolbox" of various methods that can be applied in mountains. Comparisons of downscaling methods are needed. New satellite, drone-based and ground-based data assimilation methods need to be evaluated.

Models. INARCH supports the integration of atmospheric, cryospheric and hydrological models in mountains. The headwaters catchment should be recognised as the fundamental modelling unit within which are important horizontal and vertical mass and energy exchanges. Model structure, parameterisation, and parameter identification need multiple year data from a range of sites and environments.

Changing Mountain Hydrology – INARCH notes that mountain snow and ice resources are diminishing rapidly in most regions of the Earth due to rising temperature-driven energy and mass exchange processes including several positive feedback mechanisms such as dust and vegetation change. Streamflow and water storage are impacted by the changing cryosphere, but show a broader range of dampened or enhanced responses depending on the catchment topography, cryospheric state, vegetation and climate.

#### INARCH INAUGURAL WORKSHOP FINAL STATEMENTS

- *GEWEX's INARCH is launched and has broad participation and support from scientists studying mountain regions around the world.*
- *In order to provide warning of the impacts of climate on downstream water resources, INARCH finds an urgent need for enhanced mountain hydrometeorological and cryospheric observations with open availability of data, and reduced measurement uncertainty. INARCH has identified a series of mountain hydrometeorological observatories around the world that address this need, and will promote enhanced mountain observations, and data publication for these observatories.*
- *INARCH notes that despite the substantial predictive skill shown, there is a need to identify and reduce uncertainty in application of mountain atmospheric, cryospheric and hydrological models. The understanding developed using mountain hydrometeorological observatories can help accomplish this by improving the capability and range of downscaling methods to drive models, improving exchange processes with frozen surfaces, and integrating atmospheric, cryospheric and hydrological components to consider impacts of dynamic climate and transient vegetation and hydrological and cryospheric storage at various scales.*
- *INARCH will observe and diagnose mountain climate and resulting cryospheric and hydrological change and explore the changing prospects for mountain water resources through diagnostic modelling experiments using our instrumented catchments from around the world, paying particular attention to the impact of loss of snow and ice on hydrological cycling. This will help quantify and improve the prognostic potential of these models for predicting the water security impacts of global change in mountain regions.*

## Workshops and meetings held

- INARCH was approved as a Cross-cut Project by the GEWEX Hydroclimate Panel at Pasadena, California in December 2014
- AGU 2014 Fall Meeting  
*15-19 December 2014, San Francisco, CA, USA*  
*Session C43E: Snow Hydrology: Flooding, Modeling, and Vegetation Interactions*  
Conveners: John Pomeroy, Tim Link, Tobias Jonas, Mukesh Kumar  
The storage and release of water from seasonal snowpacks has a vast impact on the hydrology of cold regions. Rain-on-snow melt events can generate floods that are highly destructive and often poorly predicted because of their complex method of formation and reliance on the temporal and spatial coincidence of substantial snowpacks and intense rainfall. However, uncertainties and deficiencies in data, and snow and hydrological models are primary challenges to accurate estimation of snow accumulation and melt, and the consequent hydrological response. Vegetation strongly affects snowcover deposition and ablation processes and can consequently affect the amount of water available for runoff. This session seeks to better understand the processes and characteristics of rain-on-snow floods, how snow hydrology observations and models can be improved and how snow interactions with vegetation cover impact snowpacks, energetics, hydrological response and terrestrial ecology.
- AGU 2014 Fall Meeting  
*15-19 December 2014, San Francisco, CA, USA*  
*Session C33B: Advances in High Altitude Glacio-hydrology*  
Conveners: Walter Immerzeel, Joseph Shea and Francesca Pellicciotti  
High-altitude catchments play an important water supplying role, yet the monitoring and modelling of such regions is complex due to poor accessibility, limited data availability and the lack of simulation models that address key glacio-hydrological processes with sufficient detail. Significant progress has been made during the last years and this session brings together studies that focus on integrating field data, remote sensing and simulation models with the aim to understand present day and future glacio-hydrological processes in mountain regions. In particular, this session focuses on recent advances in understanding high altitude meteorology, mass balance studies, glacier surface properties, behavior of debris covered glaciers, feedbacks between the cryosphere and atmosphere and seasonal differences and changes in runoff composition. The session welcomes studies that: i) integrate different data sources into glacio-hydrological simulation models, ii) that quantify multi-source uncertainties, or iii) that present new model parameterizations of high altitude glacio-hydrology.
- INARCH held its inaugural workshop at Kananaskis, Alberta in October 2015, which was attended by 30 scientists from Canada, US, China, Nepal, Chile, UK, Spain, France, Germany, Switzerland and Austria.  
<http://www.usask.ca/inarch/InauguralWorkshop.php>
- INARCH will hold its next scientific activity as Poster Session C33A & Oral Session C43F, "Improved Understanding and Prediction of Mountain Hydrology through Alpine Research Catchments", on 16-17 Dec. 2015 at the American Geophysical Union Fall Meeting in San Francisco, California.
  - <https://agu.confex.com/agu/fm15/meetingapp.cgi/Session/8067>
  - <https://agu.confex.com/agu/fm15/meetingapp.cgi/Session/10888>

## **2) Planned panel activities for next year**

Planned new scientific activities

**Special issue on alpine hydrometeorological/snow/ice/water datasets:** limited to the data we control. Describe it, present it, and discuss it in a data paper format. This is a way for primary investigators to get credit from the data that has been connected and to openly share data. Example is <http://www.earth-syst-sci-data.net/4/13/2012/essd-4-13-2012.pdf>

**Participate in snow model comparisons** at sites where inputs can be measured/defined through links with GLASS (Richard Essery).

**Reduce measurement uncertainty** by implementing WMO SPICE recommendations for solid precipitation measurements at all sites.

**Develop a downscaling toolbox** by putting on one webpage various techniques for statistical, dynamical and medium complexity downscaling.

**Start climate sensitivity comparative analysis** of various alpine basins using “standard virtual basin” modelling to compare the response of snowcover, snowpack, glaciers and hydrology to variations in temperature and precipitation in various climate regimes.

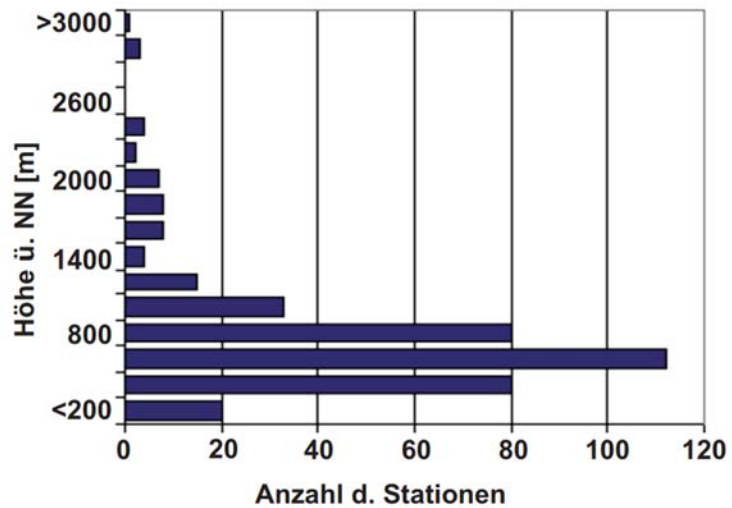
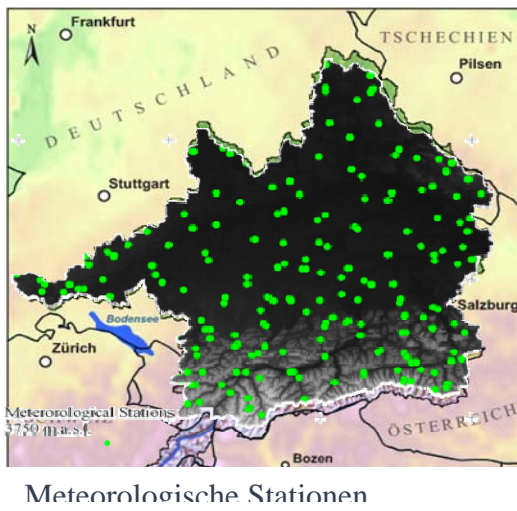
Planned Workshop

**An INARCH workshop** will be held in Europe or Asia in 2016 in collaboration with GEWEX and UNESCO – date and place to be determined.

### 3) Contributions to the GEWEX Science Questions

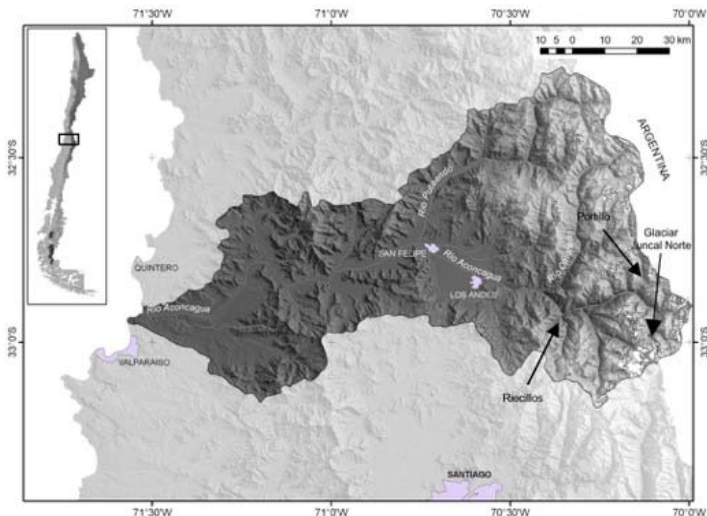
- GSQ1: Observations and Predictions of Precipitation

Alpine precipitation measurements have been quantified and found to be insufficient given the high precipitation, and high variability of precipitation at high elevations. An example is for the Upper Danube River Basin from Matthias Bernhardt where it is noted that some of the highest density of alpine observations in the world are located, but are measurements are biased towards lower elevations creating uncertainty in precipitation over mountain catchments.

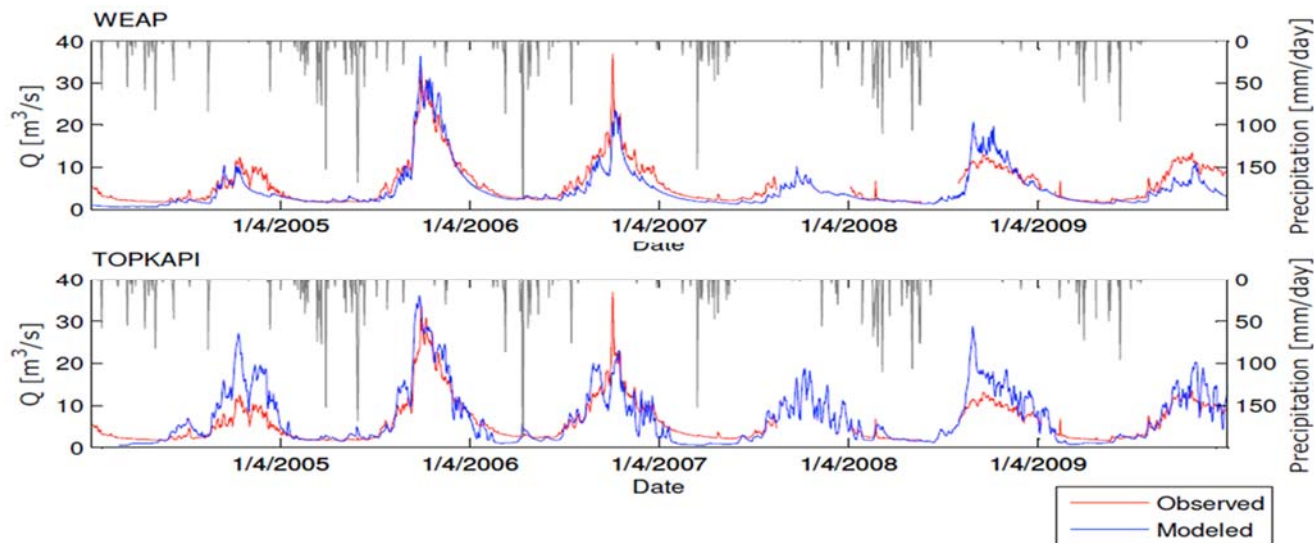


- GSQ2: Global Water Resource Systems

Alpine hydrometeorological systems are being improved in hydrological models for large scale water resource assessments but require improvements in the physical basis of descriptions to reduce predictive uncertainty. An example is the Rio Aconcagua in Chile which receives most of its water from the high elevations of the Andes and flows into semi-arid and arid regions downstream where it provides a critical water resource for irrigation, mining and communities. There is high uncertainty in modelling such catchments.

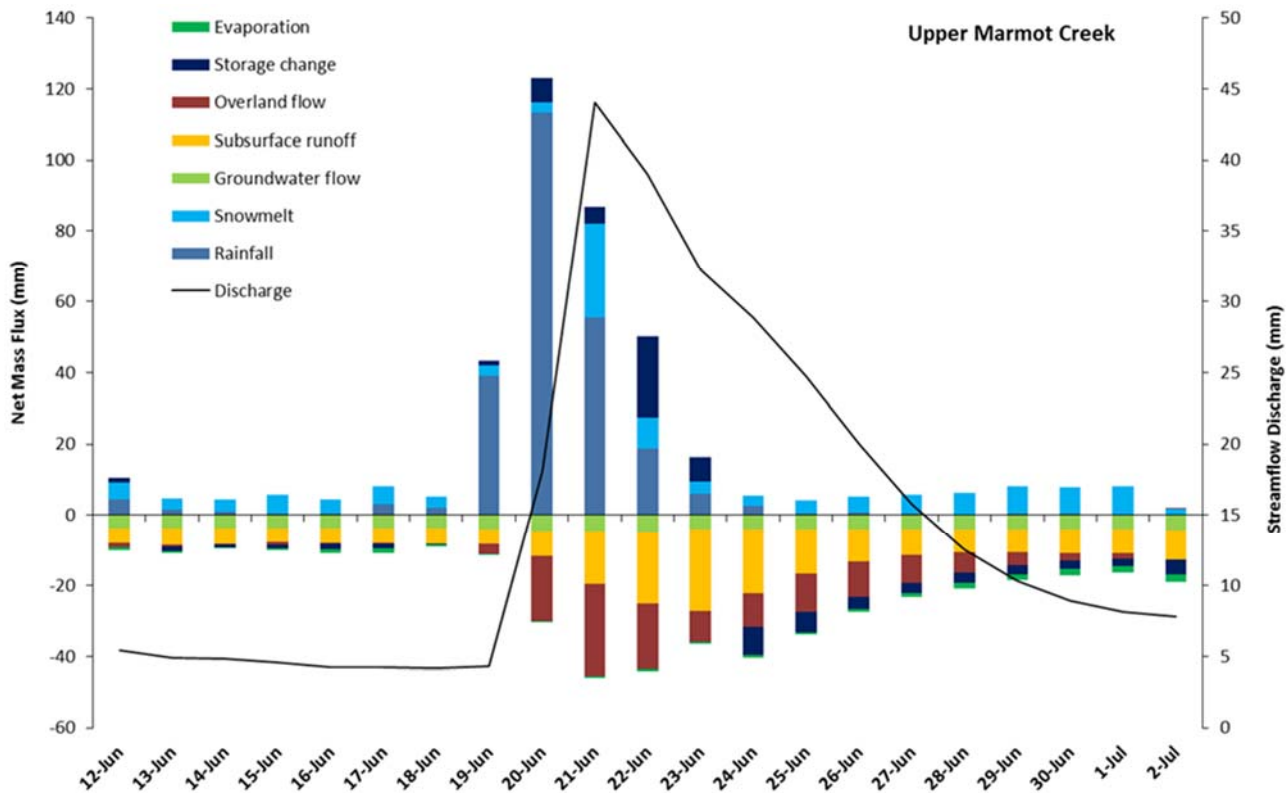


An example of conceptual (WEAP) and process-based (TOPKAPI) modelling of the upper Rio Aconcagua Basin provided by James McPhee.



- GSQ3: Changes in Extremes

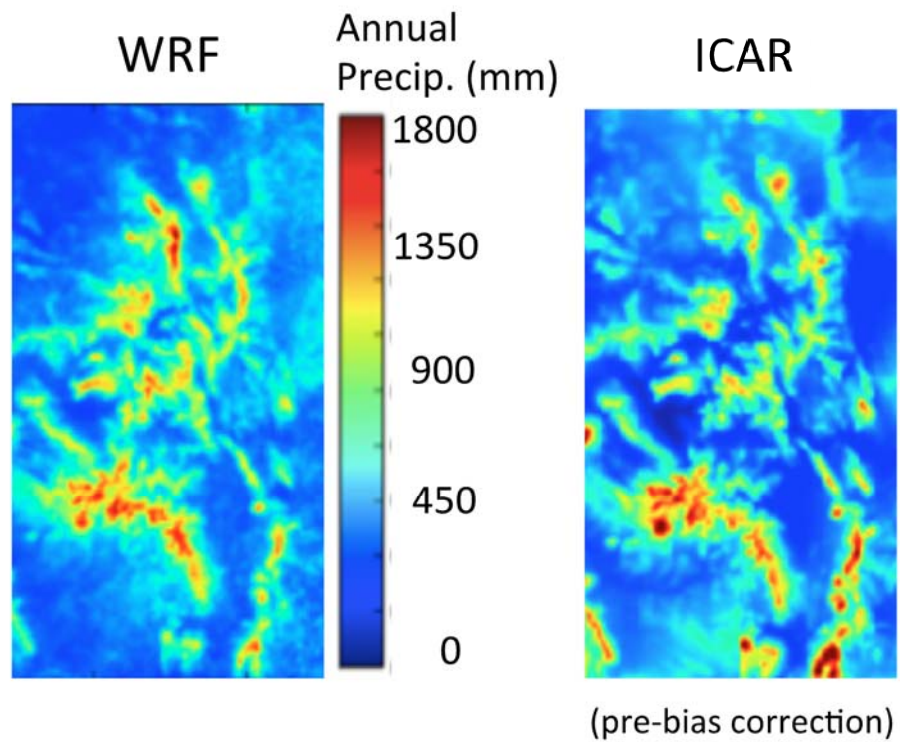
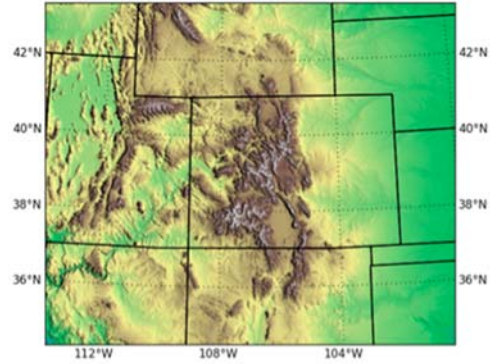
INARCH contributes in studies of mountain flooding and drought. An example of model diagnosed rain-on-snow mass budgets that contributed to record damaging floods in Canada downstream of the Rocky Mountains in June 2013 is provided by John Pomeroy for Upper Marmot Creek, Alberta, Canada.





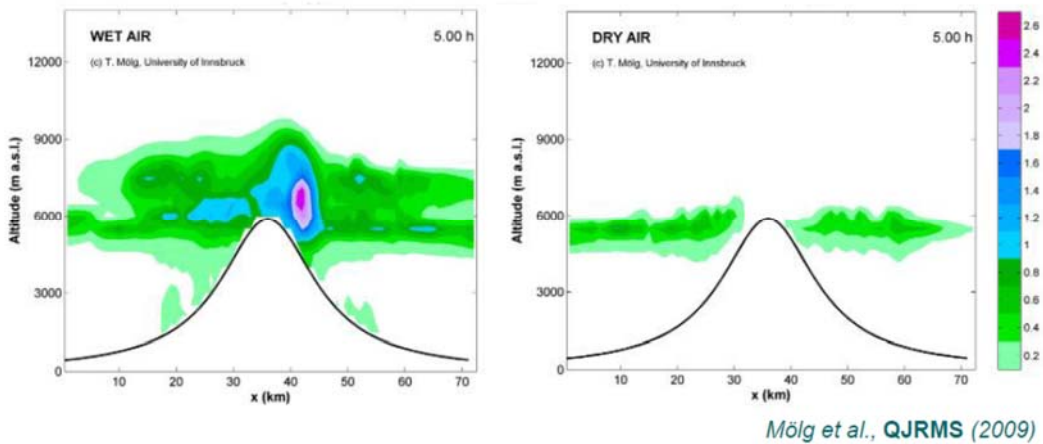
- GSQ4: Water and energy cycles

Downscaling mountain meteorology to produce realistic precipitation fields is a great challenge for GEWEX and has involved either expensive dynamical approaches (e.g. NWP) or uncertain statistical approaches that require calibration. A new Intermediate Complexity Atmospheric Research Model (ICAR) developed at NCAR shows promise at realistic precipitation downscaling at modest computation cost (contributed by Ethan Gutmann)



#### 4) Activities contributing to the WCRP Grand Challenges as identified by the JSC

Clouds, circulation and climate sensitivity are very uncertain over mountain topography which is a challenge for GEWEX (example provided by Georg Kaser)



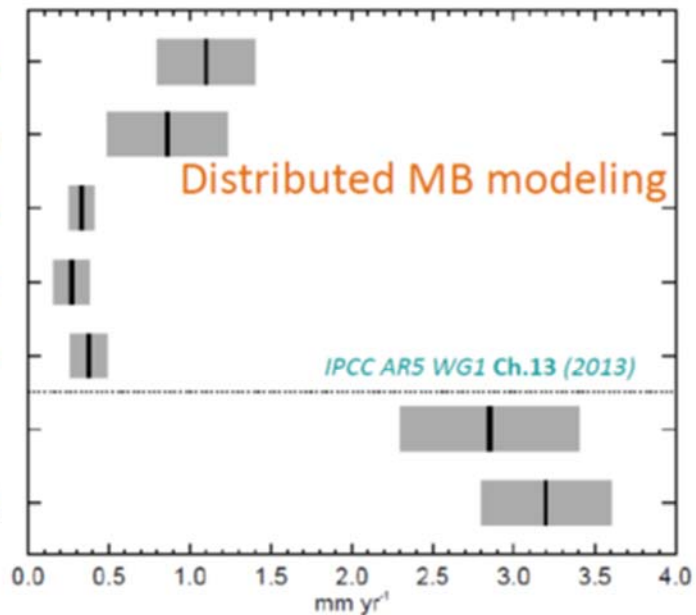
Melting ice and global consequences – melting ice has the major impact on observed sea level rise. The largest ice component is that by mountain glaciers (28% of sea level rise) but this is also a component that contributes great uncertainty to overall sea level rise. This uncertainty needs to be constrained. (example provided by Georg Kaser)

#### Observes sea level rise 1993-2010:

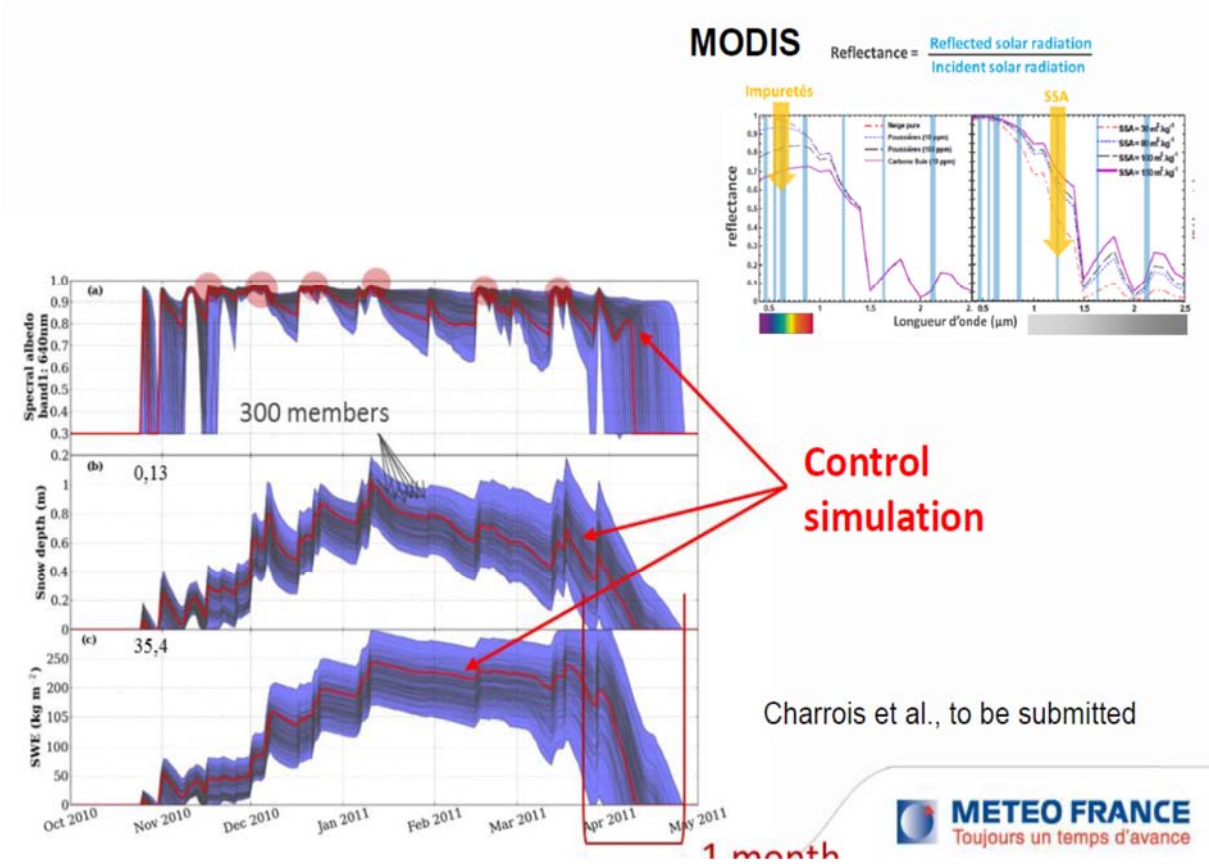
3.2 mm/year



Thermal expansion:	38%
<b>Glaciers:</b>	<b>28%</b>
Greenl. Ice Sheet:	10%
Antarct. Ice Sheet:	10%
Land water stor.:	14%
Total :	100%
Obs. GMSLR:	110%

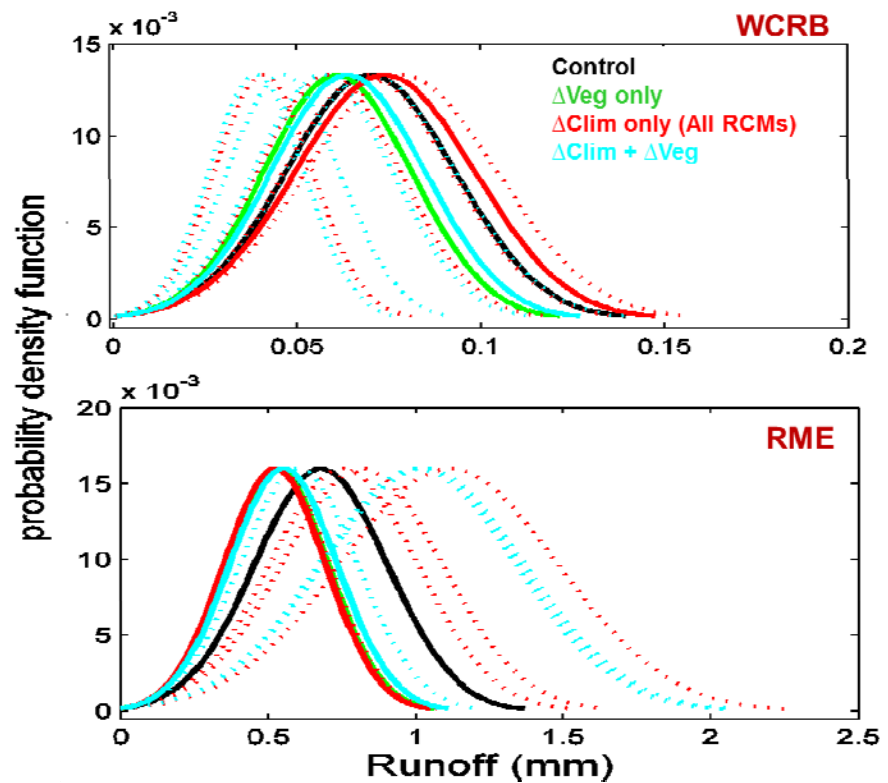


Understanding and predicting weather and climate extremes – example of snow data assimilation into snow forecasting system of Meteo France – example provided by Isabella Zin.





Changes in water availability with rising temperature, changing precipitation and transient changes to vegetation cover in mountains. Example of Cold Regions Hydrological Model of Wolf Creek Research Basin, Yukon, Canada (61 °N) and Reynolds Mountain East Basin, Idaho, USA (43 °N) provided by John Pomeroy. PDF of basin runoff under current climate (black), 2070s climate from various RCM-GCM combinations under RCPs (red), with vegetation change (green and with both changed climate and transient vegetation change (light blue)



### 5) Cooperation with other GHP and WCRP projects (CLIVAR, CliC, SPARC), outside bodies (e.g. iLEAPS) and links to applications

- Collaboration with UNESCO IHP and information collaboration with SPICE and Global Cryosphere Watch (CliC).

### 6) List of key publications

Pomeroy J.W., Bernhardt M. and Marks D. (2015) Water resources: Research Network to Track Alpine Water. *Nature (correspondence)* 521: p. 32 doi:10.1038/521032c [Published online 6 May 2015](#)

Pomeroy J.W (2015) New GEWEX Crosscut Project Addresses Mountain Snow and Ice Hydrology and Atmospheric Interactions. *GEWEX News* 25(2) p. 10 [PDF](#)

Bernhardt M., Schulz K. and Pomeroy J.W. (2015) Das internationale Netzwerk für Alpineinzugsgebietshydrologie: Ein neues GEWEX crosscutting Projekt (The International Network for Alpine Research Catchment Hydrology: a new GEWEX crosscutting project). *Hydrologie und Wasserbewirtschaftung* 59(4), pp. 190-191 [PDF](#)

Rasouli, K., Pomeroy, J.W. and Marks, D.G. 2015. Snowpack sensitivity to perturbed climate in a cool mid-latitude mountain catchment. *Hydrological Processes*, 29(18), 2925-2940.

Kinar N.J. and Pomeroy J.W. 2015. Measurement of the Physical Properties of the Snowpack. *Reviews of Geophysics*: 53, 481-544.

Krogh S.A., Pomeroy J.W., and McPhee J. 2015. Physically Based Mountain Hydrological Modeling Using Reanalysis Data in Patagonia. *Journal of Hydrometeorology*: 16, 172-193.