INARCH:
International Network for Alpine Research Catchment Hydrology

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University of Saskatchewan, Canada

www.usask.ca/inarch

GHP Annual Meeting, Kathmandu, Nepal, 18 October, 2017

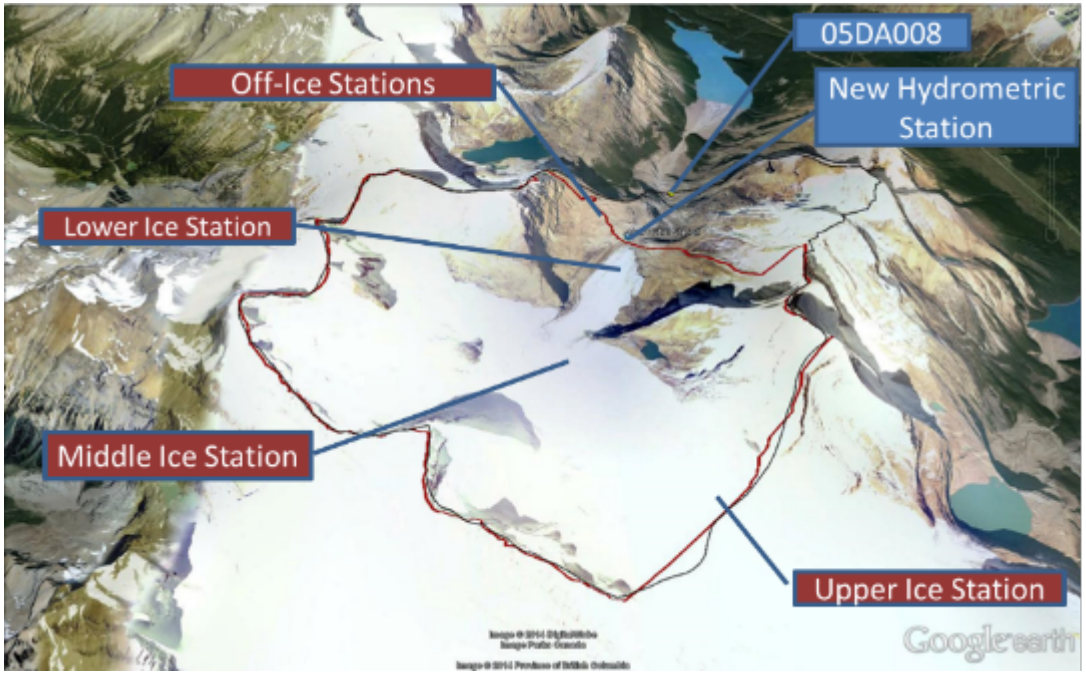
INARCH Objectives

To better

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

and

To find consistent measurement strategies.

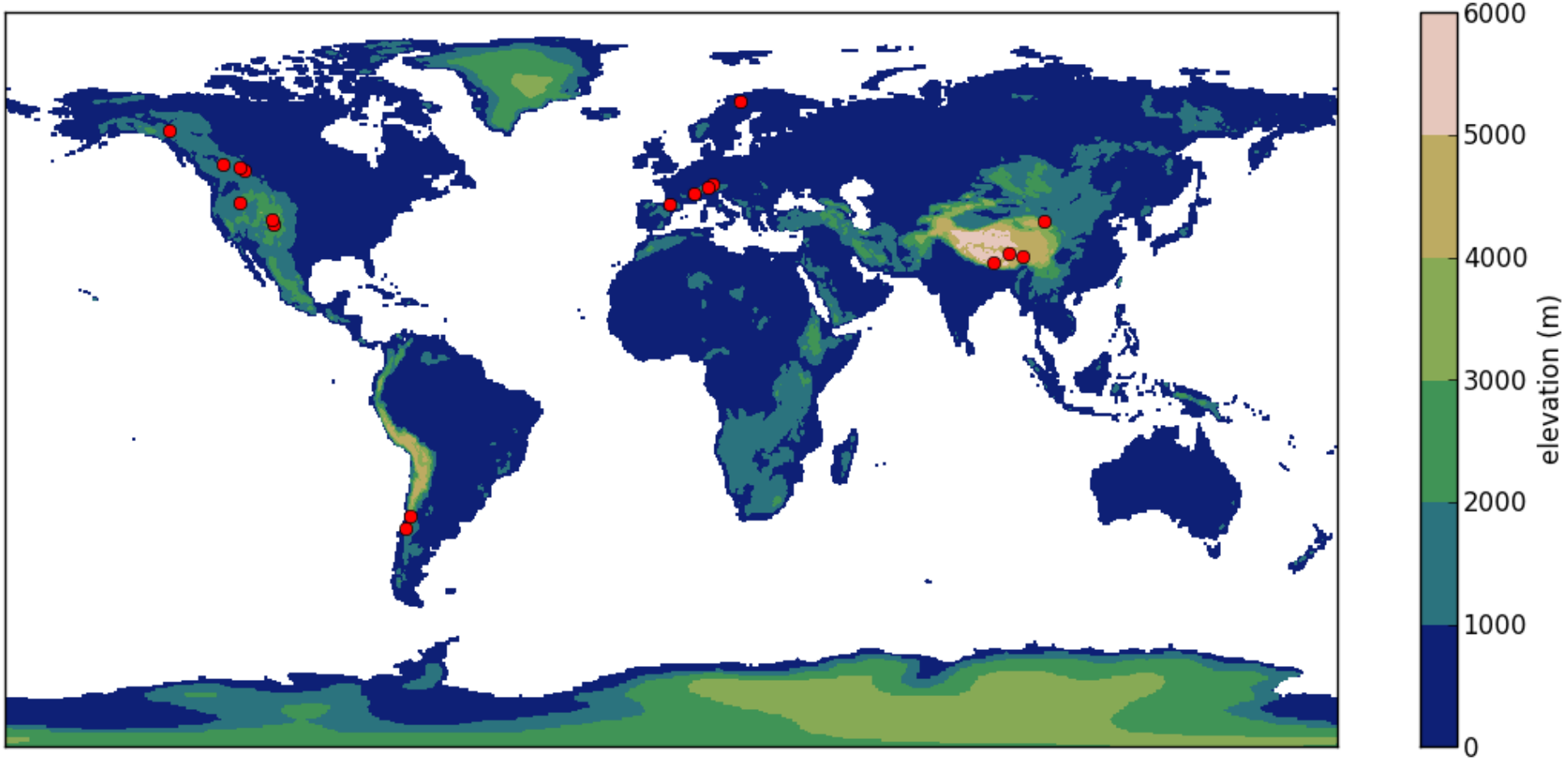


INARCH Questions

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**?

INARCH Research Basins

Canada – Canadian Rockies, BC & Yukon;
USA – Reynolds Creek, ID; Dry Creek, ID; Senator Beck, CO, Niwot Ridge, CO.
Chile - Upper Maipo & Upper Diguillín River Basins, Andes,
Germany – Schneefernerhaus & Zugspitze;
France – Arve Catchement, Col de Porte & Col du Lac Blanc;
Switzerland – Dischma & Weissfluhjoch;
Austria - OpAL Open Air Laboratory, Rofental
Spain – Izas, Pyrenees;
China – Upper Heihe River, Tibetan Plateau,
Nepal – Langtang Catchment, Himalayas
Sweden – Tarfala Research Catchment
Norway - Finse Alpine Research Centre



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 GHP Projects
  - Precipitation phase
  - Mountain precipitation
  - Changing Cold Regions Network
  - Possible North American Network??
- Global Cryosphere Watch
- WMO-SPICE
- TPE (Third Pole Environment)
- UNESCO-International Hydrological Programme efforts on climate change impacts on snow, glacier and water resources within the framework of IHP-VIII (2014-2021) ***'Water Security: Responses to Local Regional and Global Challenges'.***
- International Commission for Snow and Ice Hydrology (IUGG)

Workshops held

- **The 2nd INARCH Workshop** was held at the Institut des Géosciences de l'Environnement (IGE) in Grenoble, France, 17–19, October, 2016

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- Issues:
  - Atmospheric downscaling for mountain snow and ice hydrology modeling;
  - Availability and suitability of observations from mountain observatories and discussion of the INARCH special issue; and
  - Sensitivity of the cryospheric and hydrological response of mountain catchments to various representations of a changing climate

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- 17–19, October, 2016

- Further information and links to presentations: http://www.usask.ca/inarch/wkshp2_report.php

2nd INARCH Workshop

17–19 October 2016
Grenoble, France

John Pomeroy[1], Vincent Vionnet[2] and INARCH Colleagues

[1]Centre for Hydrology and Global Institute for Water Security, University of Saskatchewan, Canada; [2]Snow Research Center, CNRM, Météo France/CNRS, Saint Martin d'Hères, France

The International Network for Alpine Research Catchment Hydrology (INARCH) is a cross-cutting project of the GEWEX Hydroclimatology Panel (GHP) and its objectives are to better understand alpine cold regions hydrological processes, improve their prediction, diagnose their sensitivities to global change and find consistent measurement strategies. INARCH is formulated around addressing five core 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 global validity? (5) How do transient changes in perennial snowpacks, glaciers, ground frost, soil stability and vegetation impact alpine water and energy models?

INARCH has a network of well-instrumented mountain research basins that INARCH members maintain. All of these research basins have hydrometeorological, cryospheric and hydrological observations at multiple scales over multiple years and some have snow, glacier, hydrological and atmospheric models run at various scales. Observations are embedded near the headwaters of larger river basins that supply water for vast downstream populations. The following figure shows a map of INARCH mountain research basins. Mount Lebanon has been proposed as a new research basin.

INARCH has linkages to GHP crosscutting projects on precipitation phases and mountain precipitations, as well as to the Changing Cold Regions Network (CCRN), a Regional Hydroclimate Project. INARCH is seeking stronger connections with the Global Cryosphere Watch and the World Meteorological Organization Solid Precipitation Intercomparison Experiment (WMO-SPICE) and the Third Pole Environment (TPE) initiative. INARCH contributes to the UNESCO-International Hydrological Programme (IHP) efforts to gauge climate change impacts on snow, glaciers and water resources within the framework of the IHP-VIII (2014-2021), and has linkages with the International Commission for Snow and Ice Hydrology (IAHS-IUGG). INARCH also contributes to the Mountain Research Initiative led from Bern, Switzerland.

Over the last two years, INARCH has contributed to several conferences and workshops, such as the 2015 American Geophysical Union Fall Meeting, where INARCH organizers chaired an oral and poster session on Improved Understanding and Prediction of Mountain Hydrology through Alpine Research Catchments. INARCH also participated in the WCRP International Conference on Regional Climate, CORDEX 2016, with a presentation by Richard Essery (UK) on observations and downscaling for alpine hydrological modeling and through several other INARCH participants, including Ethan Gutmun (USA), Kabir Rasouli (Canada) and Deborah Verfaillie (France). John Pomeroy gave a general presentation on INARCH at the 6th Third Pole Environment Workshop and Joseph Shea, Maxime Litt (Nepal) and Walter Immerzeel (The Netherlands) gave talks or poster presentations.

An INARCH special issue in *Journal of Earth System Science China* is now open for submissions until 30 September 2017 on the topic of "hydrometeorological data from mountain and alpine research catchments." Contributions from openly available, detailed meteorological and hydrological observational archives from long-term research catchments at high temporal, well-instrumented mountain regions around the world are being prepared and at least 16 submissions are expected from the INARCH Project by the special issue co-editors, John Pomeroy (Canada) and Danny Marks (USA).

The 2nd INARCH Workshop was held at the Institut des Géosciences de l'Environnement (IGE) in Grenoble, France, and provided an opportunity for scientists to explore and discuss specific issues in mountain snow and ice hydrology highlighted in the first INARCH workshop held in October 2015. Sixty scientists from the USA, Canada, Chile, China, France, UK, Switzerland, Austria, Germany, Italy, Lebanon and Norway attended the workshop. The Local Organizing Committee of Vincent Vionnet (Météo France, Centre National de Recherches Météorologiques-Centre d'Etudes de la Neige (CNRM-CEN)), Isabella Zin (IGE), Jean-Emmanuel Sicart (IGE) and Delphine Six (IGE) arranged the workshop and a field tour to the nearby Mount Blanc area.

INARCH: International Network for Alpine Research Catchment Hydrology

Current INARCH mountain research basins.

The workshop focused on the following topics: (i) atmospheric downscaling for mountain snow and ice hydrology modelling; (ii) availability and suitability of observations from mountain observatories and discussion of the INARCH special issue; and (iii) sensitivity of the cryospheric and hydrological response of mountain catchments to various representations of a changing climate.

The workshop fieldtrip visited research sites in the Aiguille du Midi (3842 m), near Chamonix. Christian Vincent (IGE) described the scientific activities of the CryoWeb-Clim Observing System, Thomas Condom (IGE) outlined the experimental rain gauge network and related scientific activities, and Florence Naaim Bouvet (IRSTEA) presented the Taconnaz avalanche path and associated protection. The group visited the Le Tour hydrometric station and learned about snow measurement techniques and hydrological issues in the Alps (Vincent Vionnet, Samuel Morin and Isabella Zin). At the confluence of the Arve and Arveyron d'Argentière, they were shown flood defenses, saw the sediment transport station at Pont des Favrands and heard about water quality issues.

The 2nd INARCH workshop had 42 oral and poster presentations covering high mountain environments from North and South America, Africa, Europe and Asia. The topics covered downscaling meteorological models for mountain snow and ice hydrology, modelling the cryospheric and hydrological response of mountain catchments under present and future climate and mountain observatories and links between INARCH and other research programs. Discussions on downscaling, observatories and future directions are summarized next.

Downscaling Discussion

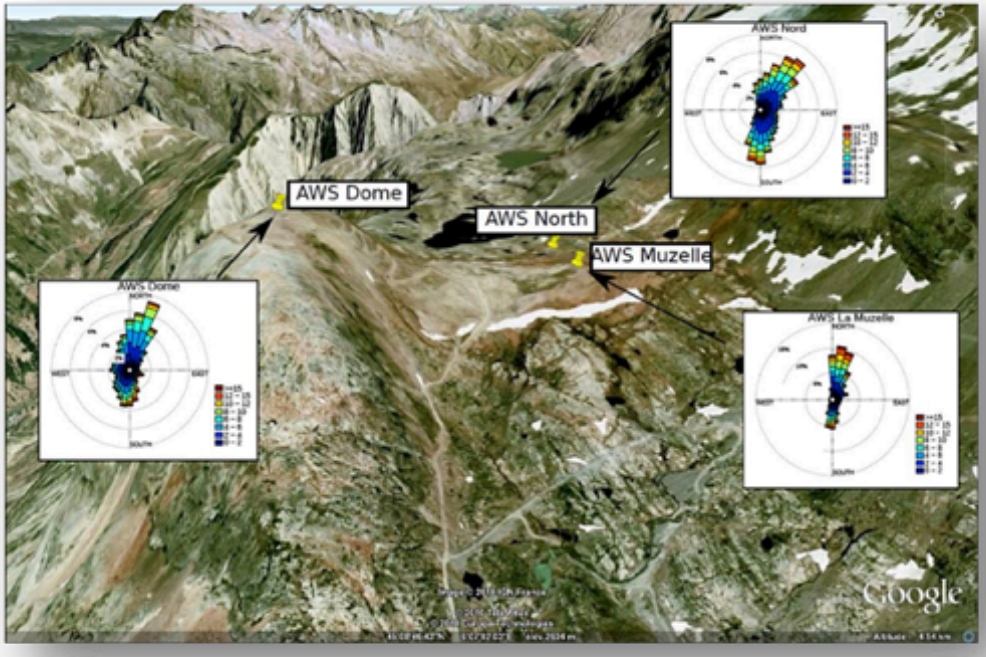
The discussion focused on developing a toolbox or set of guidelines for downscaling. It was agreed that the product should be end user specific (e.g., operational forecasts, 1-3 month water supply forecasts and climate predictions) and the role of statistical versus dynamical methods for various end uses was discussed, including what tools are suitable for each use case. Reoccurring downscaling topics discussed include the following:

- Statistical downscaling of larger-scale regional climate models (RCMs) may be unsuitable for driving physically based snow models where co-occurrence of wind, humidity, temperature and radiation fields with precipitation events control snow regimes, precipitation phase, blowing snow and melt.
- Atmospheric model failure. INARCH recognizes the need for carefully applied bias corrections, but promotes the improved physical representation of atmospheric models in mountain environments. INARCH will interact with the atmospheric modelling community to make its members aware of performance issues in mountain environments. INARCH will promote the assimilation of mountain observations in atmospheric models and the use of mountain data sets in assessing model performance through multi-objective analysis.
- Physical models are never perfect. INARCH can quantify the impact of resolution increase on predicted surface variables (i.e., the diurnal temperature and precipitation cycle). The project will promote dynamical downscaling of atmospheric models but will assist in developing empirical, statistical or simpler dynamical downscaling at scales less than several kilometers.
- Ask questions that Global Climate Model (GCM) and RCM tools can answer. (Just because we want it doesn't mean we can have it.) What is the appropriate scale for evaluation of models given our catchment scales?

Participants at the 2nd INARCH Workshop.

WRFG-CGCM

GSQ1: Observations and Predictions of Precipitation



Automatic weather stations and drifting snow measurement inter-comparison at Col du Lac Blanc, French Alps.

(Credit: Florence Naaim Bouvet.)

GEWEX INARCH

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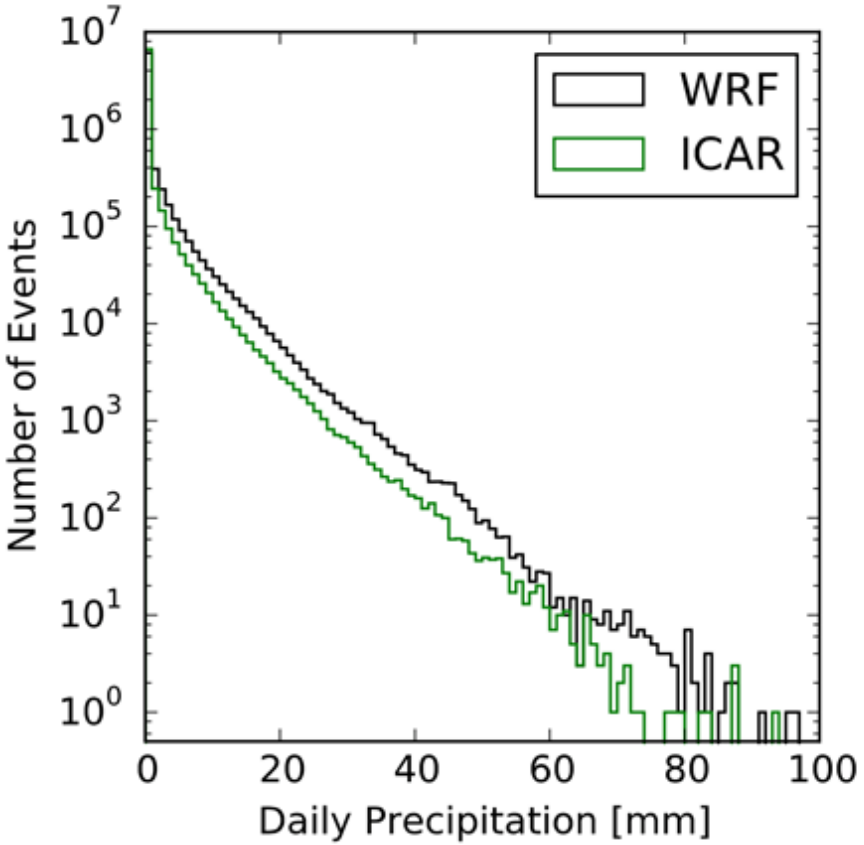
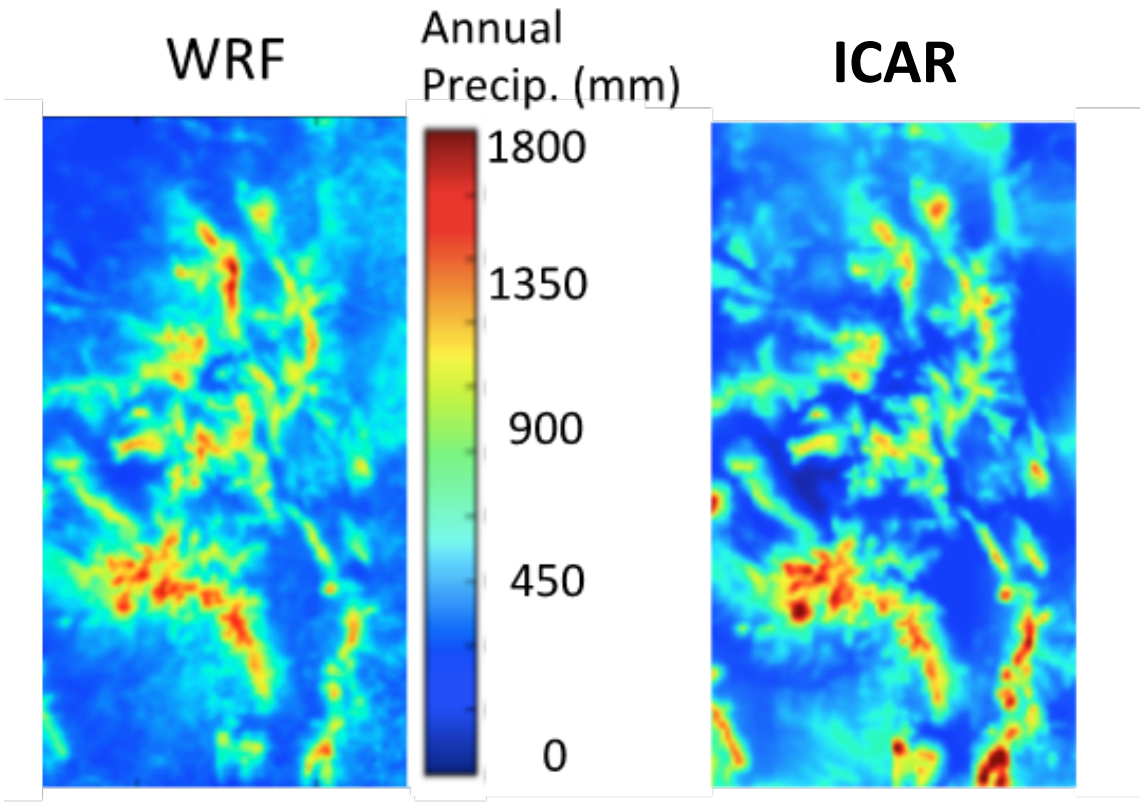
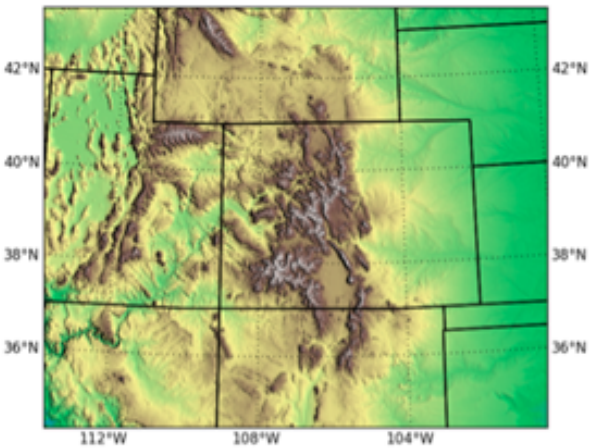


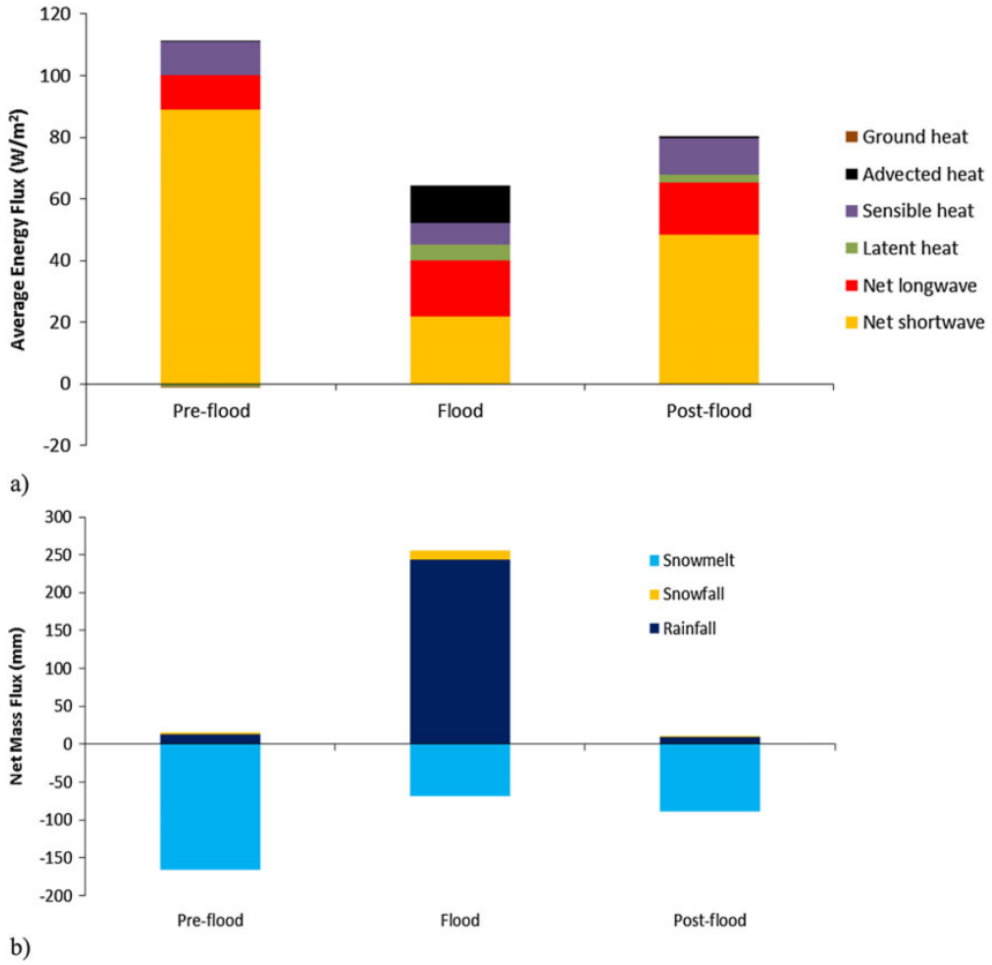




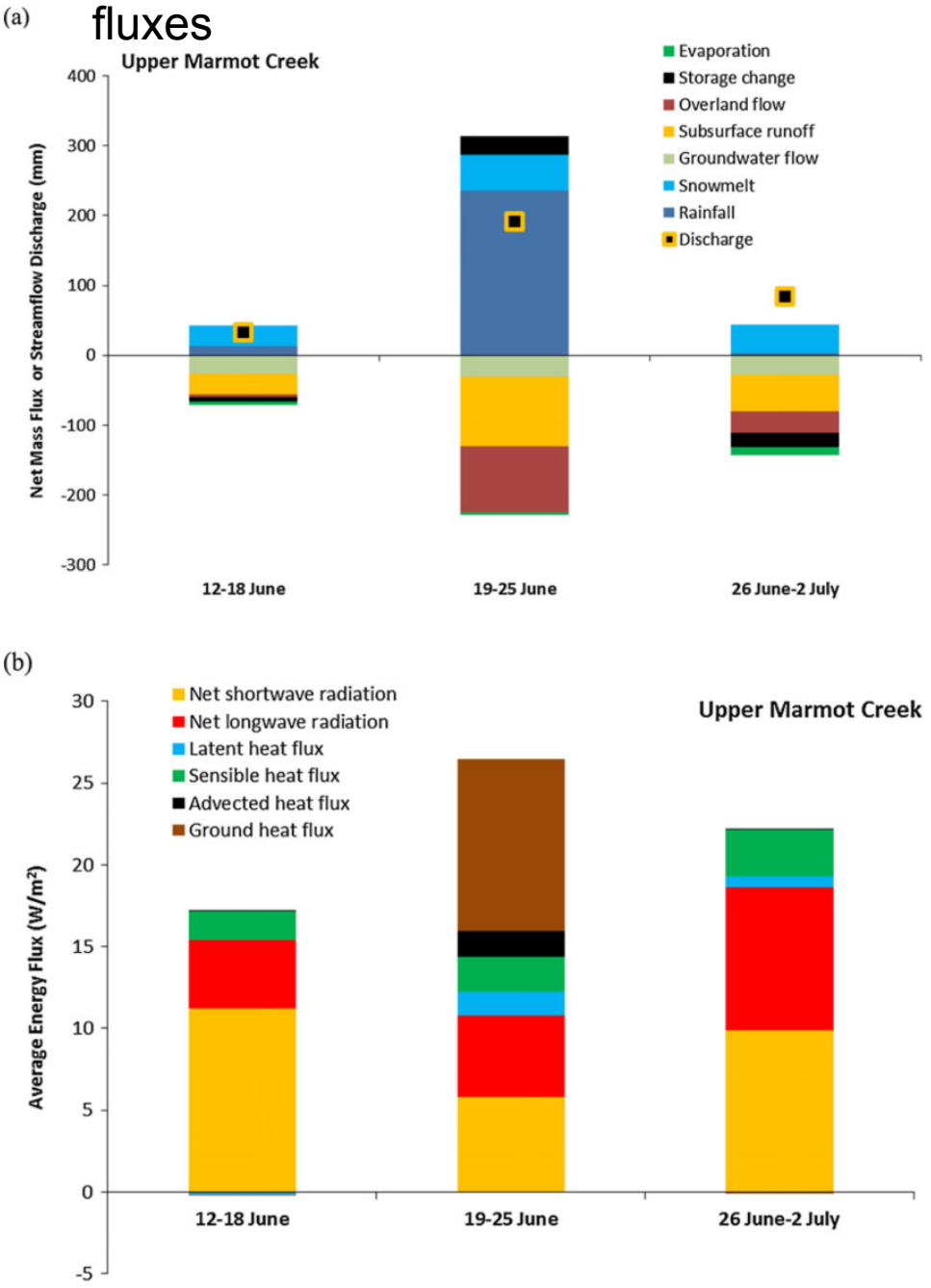
Credit: Ethan Gutmann

GSQ3: Changes in Extremes

Late lying snowpatch – energy & mass fluxes



Upper Marmot Creek – energy and mass fluxes

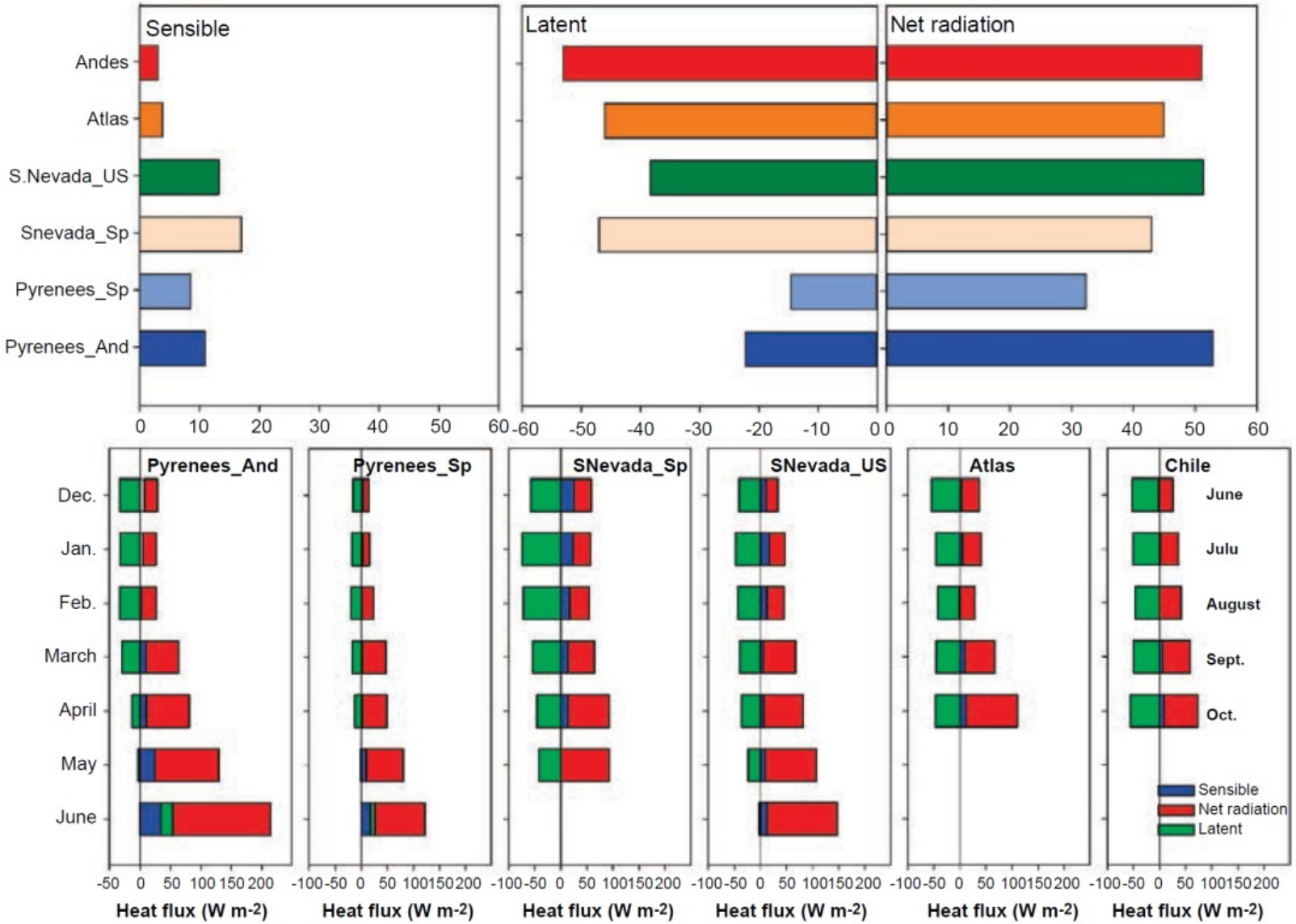


Alberta floods of June 2013 – mountain energy and water budgets – rain-on-snow

Pomeroy et al., 2016 *Hydrol. Proc.*

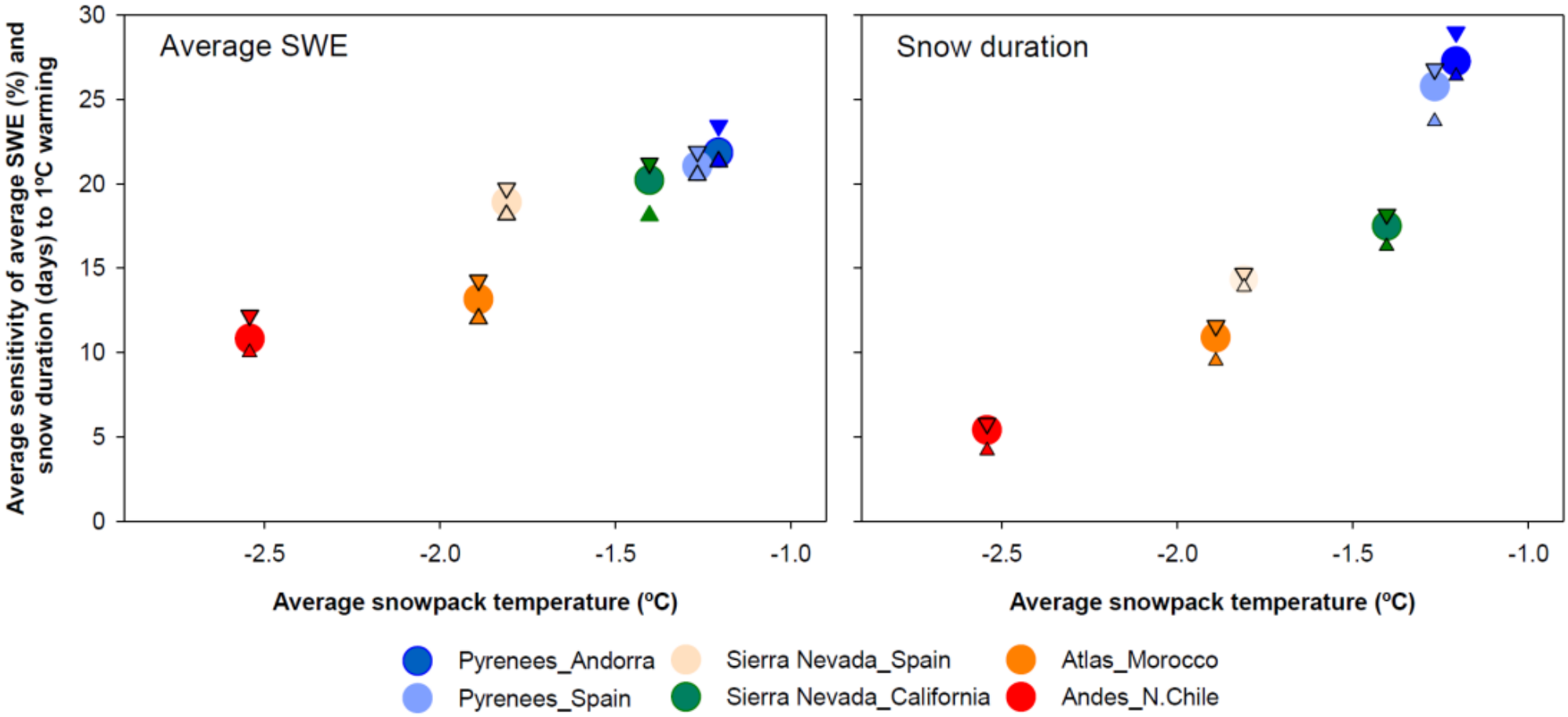
GSQ4: Water and energy cycles

- Mediterranean mountain water and energy fluxes to snow



Lopez Moreno et al., Environ. Res. Letters, 2017

WCRP Grand Challenges:
Melting Ice and Global Consequences



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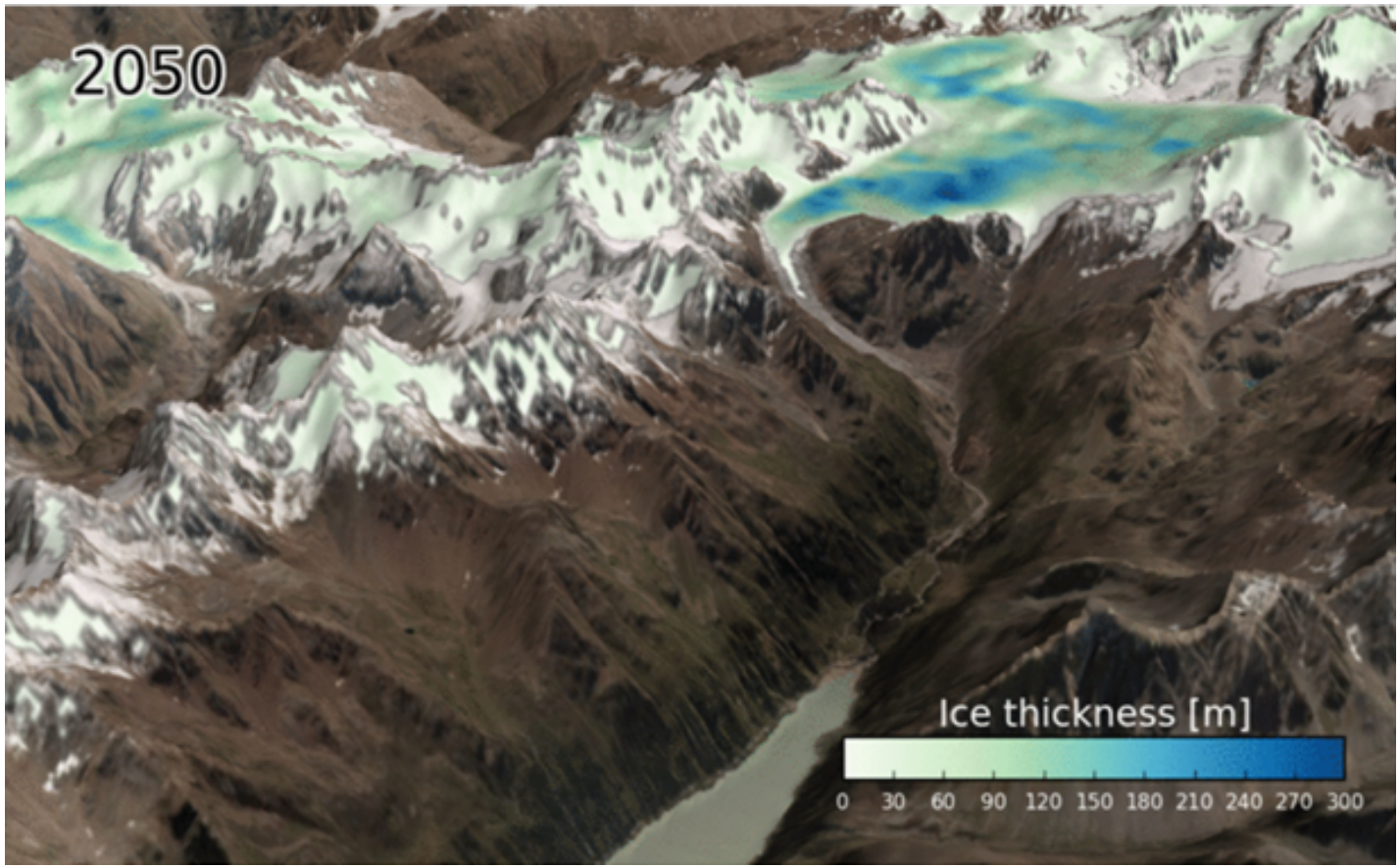
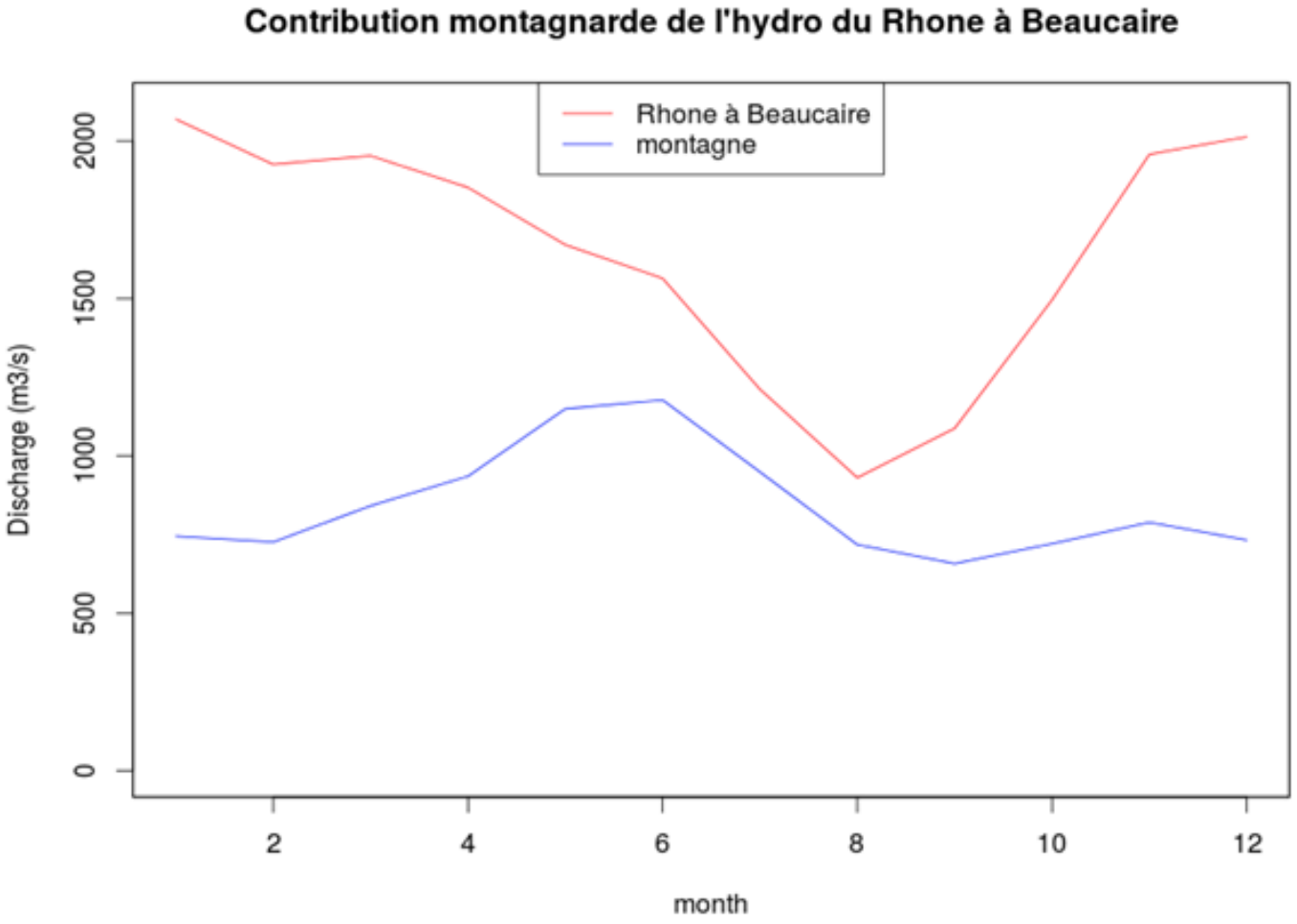
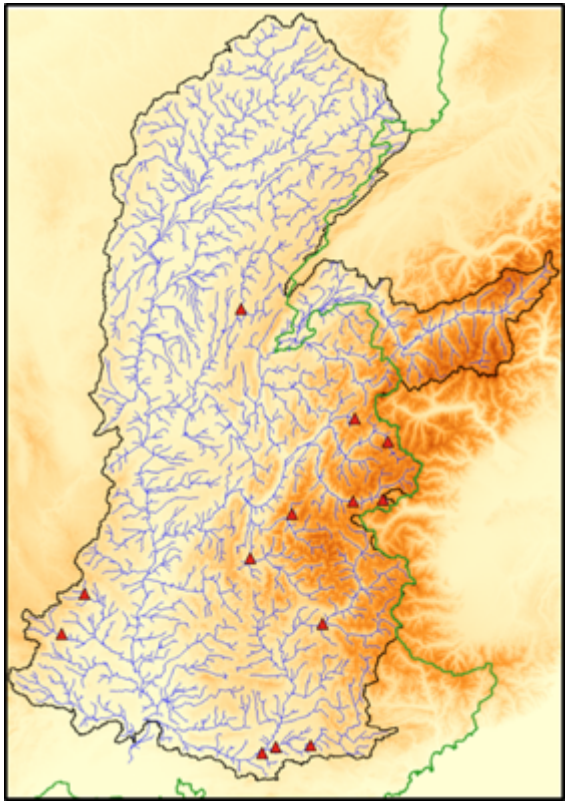


Visualisation of the glacier evolution model: Ice thickness 2000-2050 (Ötztal Alps/Austria), initialized with ice thickness 1997 (Austrian glacier cataster), temperature change (for Austria) 0.048 °C/year. (Credit: Florian Hanzer, Kristian Förster, Thomas Marke, and Ulrich Strasser.)

WCRP Grand Challenges:
Climate extremes and water availability



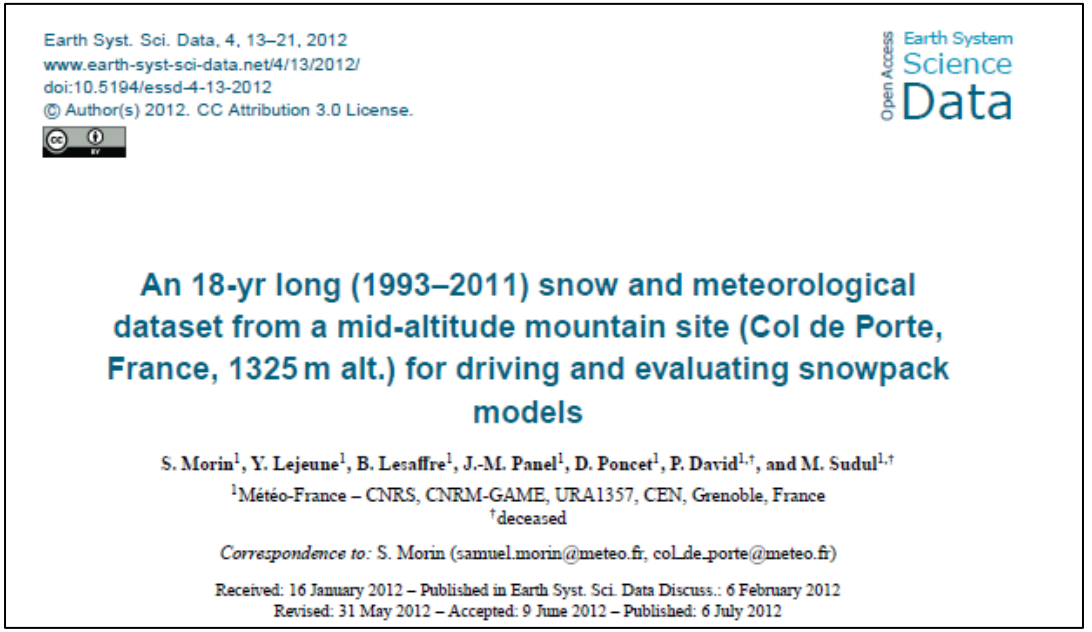


Credit : Isabelle Gouttevin

INARCH and Outreach

INARCH Special Issue

- Special Issue open **in Earth Sytem Science Data** (ESSD)
- Editors: Dr. John Pomeroy, and Dr. Danny Marks (USA)



Earth Syst. Sci. Data, 4, 13–21, 2012
www.earth-syst-sci-data.net/4/13/2012/
doi:10.5194/essd-4-13-2012

Open Access Earth System Science Data

An 18-yr long (1993–2011) snow and meteorological dataset from a mid-altitude mountain site (Col de Porte, France, 1325 m alt.) for driving and evaluating snowpack models

S. Morin[1], Y. Lejeune[1], B. Lesaffre[1], J.-M. Panel[1], D. Poncet[1], P. David[1,†], and M. Sudul[1,†]
[1]Météo-France – CNRS, CNRM-GAME, URA1357, CEN, Grenoble, France
[†]deceased
Correspondence to: S. Morin (samuel.morin@meteo.fr, col_de_porte@meteo.fr)

Received: 16 January 2012 – Published in Earth Syst. Sci. Data Discuss.: 6 February 2012
Revised: 31 May 2012 – Accepted: 9 June 2012 – Published: 6 July 2012

- **Topic:** Hydrometeorological data from mountain and alpine research catchments
- Contributions of openly available detailed meteorological and hydrological observational archives from long-term research catchments at high temporal in well-instrumented mountain regions around the world
- Submission possible until 6 April, 2018. Six submissions and more in prep.!

INARCH and UNESCO

United Nations Educational, Scientific and Cultural Organization

International Hydrological Programme

GEWEX INARCH

Knowledge Forum on Water Security and Climate Change:
Innovative solutions for sustainable water resources management

18 – 20 October 2017
Room IX
UNESCO HQ, Paris, France

Session on "***Water Security and Climate Change Impacts in Mountains"***

3rd INARCH Workshop

Environmental Research Station Schneefernerhaus on Zugspitze, Germany,
8–9 February, 2018

Topics:

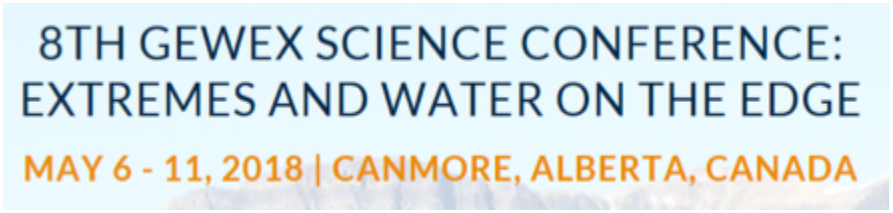
- Snow Hydrology
- Glacier Hydrology
- Alpine Measurements including Remote Sensing
- Climate Models and Downscaling for Mountains

- Each theme will be addressed by a keynote speaker and followed by a moderated discussion, and supplemented with topical poster sessions.
- **Audience:** 50 scientists from USA, Canada, Chile, China, France, UK, Switzerland, Austria, Germany, Italy, Norway

GEWEX INARCH

INARCH session at 2018 GEWEX Open Science Conference

Canmore, AB, Canada
7–10 May, 2018



Title: The Mountain Water Cycle (Session 14)

Topic: Advances in remote sensing, big data techniques and process understanding that are often developed in instrumented alpine research catchments inform mountain water cycling predictions. This session welcomes papers that

-advance mountain water and energy cycle modelling techniques,
-process understanding,
-observations,
-downscaling methods, and
-predicting the impacts of a changing mountain cryosphere on water cycling.

Convenors: R. Rasmussen, J. Pomeroy, C. DeBeer, M. Bernhardt, D. Marks

Next Steps

- Special Issue of *Earth System Science Data.*
- Mountain downscaling toolbox further development
- LSS-H Model comparison and development – link to GLASS
- Comparative analysis of alpine snow and ice hydrological sensitivity to warming – “Mediterranean Climate” and “Continental Climate” snow sensitivity comparison in progress
- Trans-Iberian Snow Hydrology Transect – extend to Morocco
- Multiscale climate change vulnerability analysis of alpine snow, ice and hydrological systems
- Link with Canadian-funded GWF (Global Water Future) Program