The International Network For Alpine Research Catchment Hydrology

A summary of the proceedings of the 3rd INARCH Meeting
Schneefernerhaus, Germany
February 7th – 9th

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Schneefernerhaus

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As someone who cares about changes that are taking place in the global cryosphere but works principally not directly in science but in translating scientific research outcomes into language decision-makers can use to craft timely and durable public policy, I am grateful to be invited to attend this most important conference. What I would like to offer is what a non-scientist observed during these proceedings.

First I would like to comment on the location of this conference. I have never in my life seen anything like Schneefernerhaus. Schneefernerhaus is as unlikely as Shangri-La. Plastered like a barnacle against an impossibly steep rock wall just below the summit of Germany's highest mountain it seems, like the world, to be just hanging on.

Schneefernerhaus is perched so precariously on such a vertical slope that it has to be protected by avalanche defenses which include alarmed doors that automatically lock when sensors deep in the snowpack pick up heightened avalanche risk on the walls above. That is the hazardous part; the exciting part is that Schneefernerhaus is one of the most comprehensively instrumented high altitude snow and ice research facilities in the world. Canada wants its own Schneefernerhaus; but a coffee maker like the one here has to come with it.

I would, if I may, also like to make an observation on the participants of this conference as a group. I noticed that whenever you find yourselves together there is a sudden, relentless, unstoppable chain-reaction of information exchange. Pouring beer and wine on this dialogue is like pouring gasoline on one of John Pomeroy's Canmore backyard fires: spectacular. Your conversation is iterative, generative, on-going and our hope for the future.

Dr. John Pomeroy

John Pomeroy opened Wednesday night's welcoming reception by offering a presentation on the Global Water Futures Program which is centred at the University of Saskatchewan in Canada. The creation of the Global Water Futures program, he noted, was prompted by rapid hydro-climatic change in Canada. The $77.8 million program is comprised of three pillars: diagnosing and predicting changes in cold regions; a goal of improved disaster warning and prediction of water futures; and a desire for research outcomes that will inform adaptation to change and risk management. What Dr. Pomeroy didn't say, however, is that is it widely held that the Global Water Futures Program is pursuing the Holy Grail of hydrology: the perfection of integrated flood and drought prediction and forecasting. In the conversations I overhead at this conference, it was easy to see the extent to which all of you figure into that vision.

The Global Water Futures program is funded for seven years until 2023. Some $2 million in its budget is committed to international cold regions research, which is to say INARCH. From this we see that INARCH is the international expression of Global Water Futures.

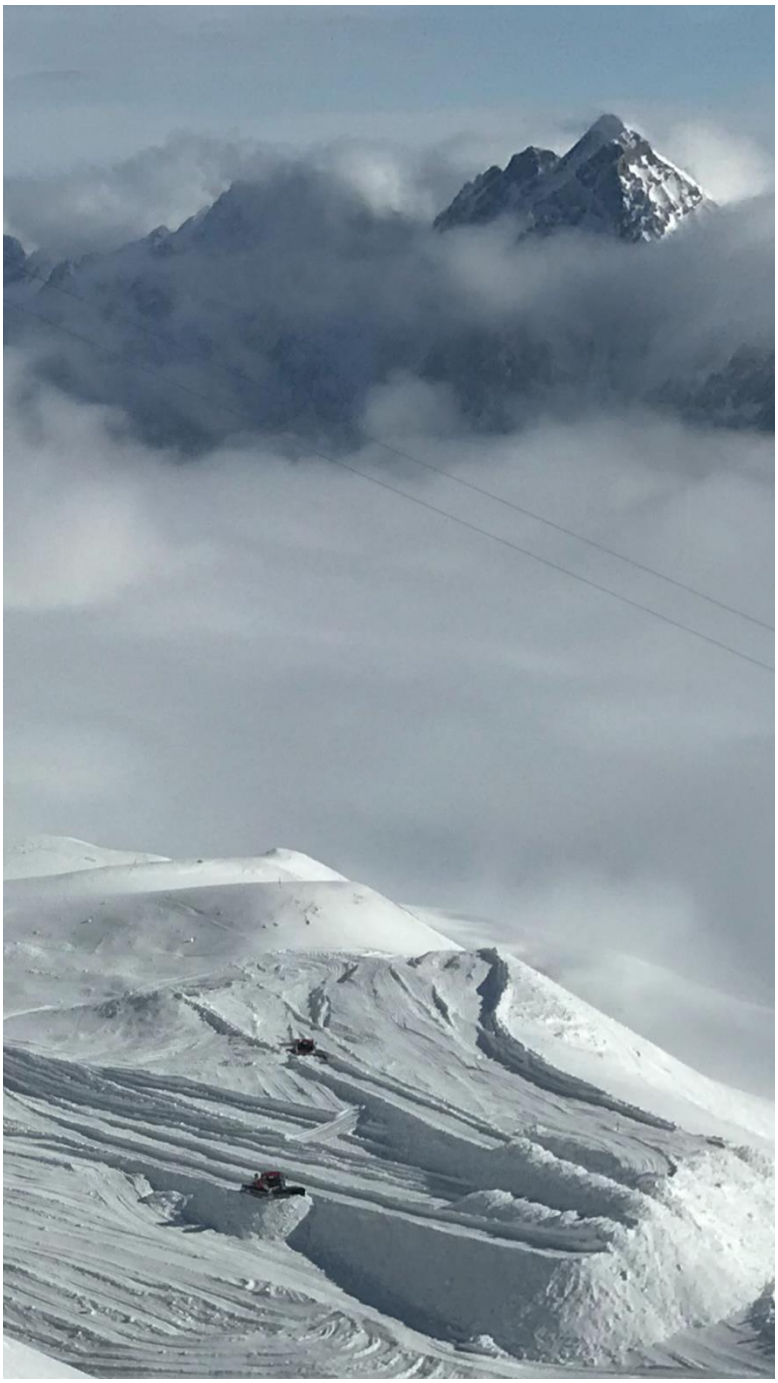
The view from Schneefernerhaus

Thursday, February 8th, 2018

At 9:00 sharp, Karsten Schulz welcomed participants and thanked the organizers and sponsors. Dr. Schulz then noted that the proceedings of this conference would be different from the previous two INARCH meetings held in Canada and in France in that it would be more discussion-oriented. The goal is to have different groups organizing further research synergistically together.

Matthias Bernhardt was then invited to define the alpine catchment in which the meeting was being held. He noted that the site was once occupied by a hotel which was situated on the margin of a major glacier, the Schneeferner Gletcher, which has all but completely disappeared. The hotel itself disappeared also following a disastrous avalanche which put into question the wisdom of locating it on such a steep mountain wall. The hydrology of this catchment, Dr. Berhardt explained, was defined by a karst system which was now being studied. One of the interesting elements of this research is that continuous measurements of cryospheric

parameters have be on-going at this site and later in ski area beneath it since 1900. More sophisticated LANDSAT and other measurements, Bernhardt noted, were now being employed. Expanded monitoring, he observed, revealed the differential of both glacial loss and ski area snow management in the catchment.



The extent of snow management practiced in the ski area below was clearly evident by just looking out the windows of the Schneefernerhaus board room where the meeting was held. The ski area appears to be literally mining snow.

A history of the institute that operated Schneefernerhaus was then offered by Till Rhem. Rhem noted that ten different research institutes had been conducting experiments at Schneefernerhaus for a period of ten years, but researchers often came only for long enough periods to conduct specific experiments. The facility, Rhem wanted participants to know, was open for business if your business was science.

John Pomeroy then offered his formal welcoming address. John began by outlining the urgency of the work in which INARCH is engaged. He then outlined INARCH research questions which related to mountain measurement standards; changing atmospheric dynamics; improved physics, downscaling, data collection and assimilation in models, and the global relevance and validity of research outcomes. He then showed the coverage globally of INARCH research basins. John then showed INARCH linkages to other research networks globally, in North and South America and in the Third Pole region in Asia. John then tracked the advancements INARCH has made since the network's inception. In so doing, he showed how completely INARCH fit into larger research frameworks like GEWEX, the Global Energy and Water Experiment. He then presented the Workshop Statement from the founding 2015 INARCH meeting in Canada and outlined progress toward its goals. He then did the same for the Workshop Statement from the 2016 meeting in Grenoble, France, pointing out what participants at this conference may wish to advance or follow up upon. Finally, he noted the next steps as they were stated at the last meeting. Discussion on progress toward those steps followed. In conclusion, John urged further collaboration between the partners in INARCH and Global Water Futures.

Tobias Jonas then offered a keynote lecture on advances and challenges in snow hydrology. Tobias used a rain on snow event that took place in January of 2018 in Switzerland to illustrate the advances and challenges in contemporary snow hydrology. Tobias noted that we need models that accurately represent key physical processes. But even the best models, he noted, are not helpful if input data requirements cannot be met. This is not news, Tobias observed, in that these same concerns had been brought up in the INARCH meeting in Grenoble in 2016. He then showed that improvements in input data were possible noting that higher spatial resolution and spatiotemporal synchronicity in run-off excess is key.

The presentation venue

The solution, he offered, resided in the introduction of a new 250 meter resolution model covering all of Switzerland, which had only been in operation in the two weeks prior to this workshop. “Then here comes the problem,” he said. Higher resolution creates its own challenges with parameterization and validation. Tobias then foreshadowed later conversations during the workshop by noting the need to provide products for clients while at the same time dealing with uncertainties. In conclusion, Tobias outlined the structure of a data assimilation experiment which demonstrated how improved data assimilation can improve the accuracy of modelling results. Comments and questions followed.

Poster presentations followed. While this observer made extensive notes on the poster sessions they were largely specific to my own policy work. All these sessions were helpful but in the interests of brevity, these observations have been omitted from this brief summary. I cannot resist one comment, however, on the opening poster session by Joe Shea who titillatingly entitled his presentation “50 Shades of Basin Hypsometry,” a title that aroused the immediate interest of participants.

Following the poster session John Pomeroy then moderated a panel discussion on questions posed and challenges identified in the morning session. Matthias Bernhardt noted that we need not just more pixels but more meaningful pixels in

models to which Roy Rasmussen responded that computer speeds were increasing but increased resolution is expensive. Roy wondered, however, if higher resolution was necessary or if, instead, the same results could be achieved through improved parameterization. It was noted that high resolution may not be necessary for all areas being modelled or for all parameterizations. The question was put forward of how participants and partners might benefit from the experience of the larger INARCH community as everyone moved to higher resolution or variable resolution models. John Pomeroy explained the complexity of such considerations at the landscape level using as an example a comparison of prairie and mountain regions, underscoring the value of comparing experiences at meeting such as this.

The comparative value of certain models was discussed. The point was made that it was not reasonable for the INARCH community to condemn certain models as inadequate. It was clear this was a delicate matter. It was inescapably clear, however, that there is tension between research models and practically applied models. Many applied models are clearly outdated and inadequate. There are many questionable older models still in use that have been packaged in new wrappers and strongly defended by those who know and have invested in their evolution and application. While it wasn't said in as many words, it was clear that commercial proprietary models in many instances need to be far more rigorous to be of value especially in changing hydro-climatic circumstances.

The conversation then moved to the content of the morning's poster sessions. It was noted that you can't measure everything, everywhere. Extrapolation is necessary. Users, such as utilities, however, want to extrapolate precisely on to their basins. Experimental catchments can be helpful in these cases. It was noted we use chains of models in which data cascades from one to the other but not always with full coupling which can lead to errors and biases. Huge challenges, it was noted, exist especially when components in more complex models are not employed – or essentially turned off – resulting in imperfect outcomes. Progress is being made but this still means we need to model identify failures when they occur. The INARCH community and the atmospheric land surface modelling community, it was noted, have to work more closely together. It appeared to this observer that this entire conversation was highly relevant not just to INARCH, but to the Global Water Futures goal of integrated flood and drought protection.

It was impossible to ignore the breathtaking and highly relevant backdrop to the meeting during any of the presentations.

Roy Rasmussen then offered the afternoon keynote on the subject of whether properly configured weather and climate models produce reasonable simulations of orographic precipitation. Roy began by outlining some of the work he did as a post-doc in Hawaii. There Roy examined mesoscale flow over complex terrain and concluded that the Hawaiian Islands controlled the behaviour of clouds. He then applied this to annual precipitation under trade wind conditions. This allowed Roy to demonstrate that the models he was developing could be used for orographic precipitation. The next step was to look at the U.S. west in both summer and winter to see if the model applied there also. Model simulations of Colorado headwaters, snowfall, snow pack and run-off followed and were conducted every three hours over eight years. The model was then verified with SNOTEL data over a winter season at two levels of resolution. The model, Rasmussen noted, gained a great deal of agreement with actual observations at higher resolutions particularly in winter. The over-riding take-away was this: getting to higher resolution is very

helpful in configuring models that do simulate what happens in nature. The next step was to run the model over the entire U.S. for 13 years. This demonstrated that climate model simulations are possible. Challenges, however, remain including accounting for blowing snow; improved snow pack representation; verifying evapotranspiration; the coupling of convective parameters and accounting for uncertainty.

Discussion followed. It was noted that the climate community expects that 21 RCM model runs be conducted to constitute a policy run – that is to say a run that could represent results upon which governments could establish climate policy. The question was asked about how the current status of models fit in with this expectation. Roy Rasmussen offered that within 10 years it will be possible to do 20 model runs in preparation for a policy run. Roy also noted that his ICAR group is now expanding their models to include, not just the U.S., but all of Canada. The agenda then turned to the next series of poster presentations. In the final poster session Stefan Harer linked Roy Rasmussen's keynote to what is presently being done in Europe. The ICAR intermediate complexity model, he noted, is now being run in the Zugspitze region. This, Stefan noted, could be a game changer.

Participants did not have to look far to be reminded of the object of their research.

Next on the agenda was a Skype presentation by Rainer Prinz of Global Cryosphere Watch who explained how INARCH and their Cyronet system were and could be linked. It was noted that the Global Cryosphere Watch data portal is an open access marketplace for cryospheric data created by linking to existing data bases. Challenges, it was noted, still exist in terms of interoperability, data exchange protocols, gaps in data and differences in standards. That said, it was also noted that linkages between Global Cryospheric Watch and INARCH may be mutually advantageous. It was suggested that INARCH research sites would qualify as Cryonet stations and in so doing expand the Cryonet system. In conclusion, all INARCH partners were encouraged to register with the Cryonet website. In the meantime, dialogue on how to harmonize efforts will be continued.

A panel moderated by Ethan Gutman followed during which topics presented in the afternoon were discussed. During that conversation it occurred to this observer that rocket science is simple compared to atmospheric physics. I found the amount and nature of the information exchanged during this session dizzying. I found myself still back in Hawaii with Roy Rasmussen. I was watching his clouds rise from orographic uplift. It was 70˚F and I was on a beach. One remark, however, did surface from this reverie. I recall Roy noting that everyone is on their way down to three to four kilometer resolution and that he didn't see a benefit in going down to one kilometer resolution as modelling processes currently stood. Dinner followed after which participants engaged in the First Alpine Team Table Soccer Championship – and further fierce conversation.

The First Alpine Team Table Soccer Championship. Note the flashing alarm light warning of high avalanche risk outside.

Friday, February 9th, 2018

The second day of the conference began with a team keynote by Tom Painter and Mackenzie Skiles who spoke on remote sensing of mountain snow. Tom began by suggesting that what he had to show should be exciting to the INARCH community. It clearly was. Tom then outlined the objectives for satellite-based cryosphere research missions. He noted challenges the remained in terms of measuring snow-water equivalent and changes in glacial mass balance. He explained that even the best remote sensing of global snow-water equivalent entirely omitted mountains which are the source of 60% of annual water supplies globally. Tom then noted that research indicated that impurities as well as warming are driving cryospheric change. Tom then noted that evidence now existed that suggests that the end of the Little Ice Age may have been forced by black carbon from industrialization in Europe. Even today, he noted, the black carbon signal in the Alps is important with respect to negative glacial mass balance. This, he noted, was true also in the high mountains in Asia as a consequence again of the presence of high levels dust and black carbon. He then noted challenges with remotely measuring albedo especially with respect to the grain size and effects of impurities on the surface of snow and ice. We need, he said, better modelling of melt uncertainties as they relate to dust and black carbon.

Tom then showed the Jet Propulsion Lab's Airborne Snow Observatory, or ASO, and outlined its instrumental capabilities with a focus on more accurately capturing snow-water equivalent. A full range of snowpack types from drought to near record snowpack have been recorded in parts of California through the use of this airborne observatory. The region of study is now being expanded to other parts of California. It was noted that Airborne Snow Observatory has also been expanded to the Alps.

Tom then outlined the goals of the Snow-Ex campaign in the Grand Mesa and Senator Beck basin in the western United States. Tom then enthused over what he called "the most awesome snow near-surface water data retrieval ever" which was done on Mount Rainier with an imaging spectrometer. Tom then outlined the NASA-JPL decadal strategy for Earth Observation from space and outlined the mission priorities. It was noted that this strategy includes observations from the

International Space Station. It includes also a pending Earth surface mineral dust source investigation on a global scale which harkens back, Tom noted, to what we need to know about the effects of impurities on changing atmospheric dynamics. In conclusion, Tom excitedly noted that INARCH will be an increasingly important part of all of these advancements and will be explicitly integrated into future missions. We then moved on to the next round of poster sessions and a break while the views outside became ever more spectacular.

As time passed the experience of the peaks outside the windows of the conference room became almost surreal.

A keynote address followed by Georg Kaser on comparative aspects of research on glacial hydrology. Georg began with a comparison between a lorry and a Formula 1 race car. In his analogy, the lorry represented collective scientific knowledge and application, and the race car individual research network advancements. He then quickly illustrated how glacial discharge models based on degree-days worked and how they fit into glacial inventories before introducing the limited influence of climate change mitigation on short-term glacial loss. He then illustrated how the same models were being used to project the future of glaciers in Austria. From this he showed how calculation of natural versus anthropogenic impacts on glacial diminishment could be derived.

Georg then made the point that there was an increasing split between the operational exigencies represented by the lorry and the rapid developments in understanding that are being advanced at race car speeds by the scientific community. He noted – and this was discussed at some length – that the split between the hydrologic sciences and engineering practice has become an inter-disciplinary problem. The important question was this: how do we adequately transfer gains in cryospheric system knowledge from the scientific level to the operational level to address unsolved cryospheric problems? This, it was noted, was an important question in that what was being advanced and discussed at this conference bears little resemblance to what often continues to be applied as science at the practical level of application in many political jurisdictions and major utilities and consulting firms around the world. After vigorous discussion we then had the final poster session which was followed by a break.

The views became more spectacular as the final day advanced.

As the conclusion to the conference neared, Mackenzie Skiles led a final panel discussion on the morning presentations. This conversation returned to Tobias Jonas' question of how to validate models and remote sensing products. The subject then turned to the cost of LIDAR and the frequency required to optimize the value of the data LIDAR generates. The subject then moved to satellite data capture. The conversation then returned again to what the research community can do to break down defenses surrounding outdated or inadequate operational models or, in other words, how do you convince lorry drivers in big utilities or government agencies who are risk averse to take advantage of improved processes. It was noted that capacity is often an issue as are costs. Institution paralysis is also an issue. Disasters, it was noted, can be opportunities to introduce new models especially when old ones have failed and lives are lost as a result. It was also pointed out that value must be demonstrated to motivate change. It was further pointed out that pressure can be applied through the insurance industry. It was also noted that the more complex these products become, the easier they are to misuse. In conclusion, the conversation then turned to modelling soil parameters.

Before John Pomeroy offered a final summary this observer concluded this summary with the following observations. What this observer witnessed over the course of the three days of the conference appeared to be nothing less than a revolution. The growing accuracy of data, expanded understanding of Earth system function, greater knowledge and emerging common urgency are driving a revolution in the Earth sciences. Multi-spectral space-based remote sensing is making the invisible visible. Combined with careful terrestrial ground-truthing the impossible may soon be possible. The Holy Grail of the hydrological sciences to which John Pomeroy alluded in his remarks at the opening reception of the conference is within your grasp. Integrated flood and drought prediction and forecasting and much, much more will soon be possible. This conference underscores the fact that the work and importance of INARCH needs to be conveyed through political channels to leaders.

John Pomeroy's Summary Observations

Snow and Glacier Hydrology 2018

There is a need for procedures to generate model input data at appropriate scales for the model application – links between atmospheric and surface models

There is continued need for detailed validation of individual processes at the process scale.

There is a need for mechanisms to inform large scale and operational models from small scale and process advances - advection, vegetation interactions, snow redistribution, human impacts, albedo dynamics, variable model resolution.

Scaling of process representations and model structure is needed in models. The same processes and process representations are not applicable to all scales.

Variations in basin configuration, hypsometry, glacier coverage, ice exposure, and vegetation need to be considered in climate sensitivity studies
There needs to be support for physical realism, not necessarily complexity, in models.

TI methods – not considered an scientifically appropriate, physically realistic approach to snow and ice hydrology – there may be niche/legacy applications

More climate sensitivity and vulnerability studies are needed in INARCH – we need to focus on a concerted effort using a selection of models driven by perturbed or downscaled climate on this using INARCH basins and data.
-INARCH will continue to encourage scientifically appropriate, physically realistic approaches to snow and ice hydrology.

Climate Models and Downscaling 2018

We must keep Roy Rasmussen's famous quote in mind: "you cannot statistically correct nothing"

Dynamical downscaling using nested, multi-scale atmospheric models is strongly preferred over statistical downscaling for mountain snow, ice and hydrology model applications because of its ability to predict precipitation and wind in mountain environments

Possibility of "mountain policy runs" – long term high resolution climate models – there is an opportunity to use ICAR nested in climate models for this – this needs exploration and testing.

Downscaling wind flow over complex terrain can and should employ physically based approaches.

Dynamical downscaling is needed to create INARCH mountain policy runs for future climate at scales appropriate for snow and glacier hydrology models

Observations including Remote Sensing 2018

There is value in observations from well-instrumented observatories and from remote sensing, model reanalysis and other coupled products.

Remote sensing advances are providing improved albedo/radiative transfer information for snowpacks and accurate, large area estimates of snow and ice surface elevations – DSM from airplanes, drones and satellites.

Snow-water equivalent still cannot be remotely sensed in mountains at scales relevant to INARCH

There is value in extending LiDAR or SfM estimates of DEM with and without peak snowpacks for INARCH and other basins

There is need to co-locate remote sensing initiatives and INARCH basins for joint verification, upscaling, parameter identification, modelling and assimilation advances.

Data quality needs to be identified and documented before it can be used in atmospheric or surface models. Metadata is of high value in interpreting observations

INARCH research basin observational datasets will be proposed to GCW for inclusion in their global data portal. INARCH will provide input to GCW to inform their development of observational guidelines using current science. INARCH will continue to publish datasets and metadata in the ESSD special issue.

INARCH basins will contribute to future coupled surface and remote sensing observational studies including multispectral missions.

INARCH Workshop Statement 2018

INARCH's global mountain observatories are providing a unique set of published, archived, high quality, surface, model and remote sensing datasets that will be made available to WMO-GCW and other global initiatives including remote sensing.

INARCH encourages process validation and description to inform large scale and operational model advances, acknowledging the need to demonstrate improved predictions of the water security impacts of global change in mountain regions.

INARCH is implementing hybrid downscaling with moderate (km) scale dynamical downscaling from atmospheric models followed by fine (<100s m) scale downscaling (dynamical, empirical) to *snowdrift resolving* scales for improved snow and ice hydrology prediction in support of mountain climate change policy runs.

INARCH will use these model runs to predict the response of mountain snow, ice and hydrology to climate change, taking into account transient vegetation cover, basin geometry and hydrological and cryospheric storage.

Next Steps

Complete Special Issue of *Earth System Science Data*.

Mountain downscaling toolbox portal completion and posting to INARCH website

LSS-H Model comparison and development – ongoing project linked to GEWEX-GLASS

Multiscale climate change vulnerability analysis of alpine snow, ice and hydrological systems GWF PDFs to use CRHM at INARCH basins and provide data to GLASS comparison

Pre-assessment synthesis article from INARCH for IPCC mountain report May 2019

Link with Global Water Futures Program – international strategy

GEWEX RHPs – US Water for Foodbaskets, Canada - GWF, ANDEX

Next Meetings

GEWEX convection permitting Sept 4-6 USA
Oct 20, 2018 in Chile.