GEWEX NEWS

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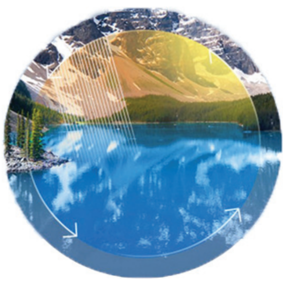
2018 GEWEX Open Science Conference



Extremes and Water on the Edge

6–11 May 2018 | Canmore, Alberta, Canada

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and

YESS community

Towards Regional Information to Improve Our Understanding of Weather and Climate Extreme Events

Young Hydrologic Society

Joint YESS-YHS Early Career Researcher Workshop

3–5 May 2018 | Canmore, Alberta, Canada

See Program at: https://www.gewexevents.org/events/2018conference/ecr/agenda/

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Commentary

Extremes and Water on the Edge

Peter van Oevelen
Director, International GEWEX Project Office

The title of this commentary is the theme of the 2018 GEWEX Open Science Conference. It was chosen to express the need for cutting-edge research with the conviction that GEWEX and the World Climate Research Program (WCRP) contribute to and enable world-class science, but that in doing so, we are often walking on the edge of what is scientifically possible. Many scientists have to face a plethora of constraints and challenges to conduct their research and that requires not only perseverance and creativity, but also quite often personal sacrifice to succeed. Hence, being on the edge can be both exciting and frightening. In particular, our colleagues in lesser-developed countries have to deal with much more than just a lack of funding or sub-optimal working environments. I am grateful that we have been able to support quite a few of these scientists to attend this conference. For that I have to thank all of our sponsors (*https://www.gewex-events.org/events/2018conference/sponsors/*), who have been so gracious and generous! Special mention is needed for our local Canadian hosts from the Global Institute for Water Security of the University of Saskatchewan, particularly Chris DeBeer, John Pomeroy and Howard Wheater. Many thanks to you for making this happen!

In planning the conference, we worked to ensure that early career researchers would not only feel welcome and get exposure to cutting edge science, but also be able to actively engage with the research community. To that purpose, both the Young Earth System Researchers (YESS: *http://www.yess-community.org/*) and the Young Hydrologic Society (YHS: *http://younghs.com*) have played an important role in this conference and it has been a delightful experience working with their representatives. Thank you! If you are an early career researcher and are not aware of the activities of YESS and YHS, please check out their websites. They are responsible for coordinating the Joint YESS-YHS Early Career Researcher Workshop taking place before the GEWEX Conference and have done an excellent job in creating a stimulating and exciting program.

The GEWEX Conference will provide a broad overview of the science performed in both GEWEX and WCRP, as well as related topics. To showcase some of the science within GEWEX and give a forward-looking perspective, we have collected a few interesting articles in this newsletter. Graeme Stephens highlights one of the successes of GEWEX and WCRP in the stewardship of climate data records (page 6). What I would personally like to note is that the need for that stewardship was not always as obvious as it is these days. It is through the perseverance of a few individuals that many of these things have been accomplished.

Over the last few years we have seen a much stronger focus on hydrological science within GEWEX. Although GEWEX has a very robust history in land-atmosphere research that is unique, it was lacking in subsurface hydrology and the human dimension in our modeling. That is rapidly changing. Martyn Clark wrote a stimulating short paper (page 8) highlighting the five areas he thinks could use more focus to make significant progress in Earth system prediction. If anyone is looking for some interesting challenges to work on, he provides a couple of very enticing ideas!

Another hot topic in climate and weather research, due to its obvious relevance and increasing worldwide importance, is extremes. Sonia Seneviratne and co-authors give a succinct overview of the extremes research happening now and how many of these activities are within GEWEX and WCRP (page 3). The GEWEX Conference is the first within our project and WCRP that provides such an extensive platform for extremes research.

Sonia Seneviratne

Sonia Seneviratne has been Co-Chair of the GEWEX Scientific Steering Group (SSG) since 2014, and in almost four years has been a tremendous stimulus to GEWEX activities and has put extremes research front and center in WCRP research with great success. Within GEWEX, she has always been very active in land-atmosphere research, and in particular, in the Global Land/Atmosphere System Study (GLASS) Panel. This year Sonia will step down as Co-Chair and I take this opportunity to thank her for her relentless energy and extensive efforts on behalf of GEWEX and its community. The task of being a SSG Co-Chair is not something to be taken lightly if it is to be done well. Sonia did extremely well, and for that, our community owes her much gratitude. I hope that we can continue to enjoy her participation in GEWEX, albeit in a different role, for many years to come.

On that note I conclude by saying that I am looking forward to welcoming many of you to Canmore, Alberta to enjoy not only great science and stimulating company, but also the stunning environment. I hope that many of you are able to participate in the excursion on the Sunday prior to the conference to the Columbia Icefield. This tour showcases the beauty and the fascinating natural history of the region. Furthermore, I hope that you will meet old friends, make many new ones, and in that process get inspired to do more international collaborative science, as that is what GEWEX is truly about.

Extremes: A Grand Challenge

Sonia I. Seneviratne[1], Lisa Alexander[2], Gabriele Hegerl[3] and Xuebin Zhang[4]

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The 2018 GEWEX Open Science Conference (OSC) will feature leading-edge research on climate and weather extremes. The investigation of extreme events, their relation to climate and weather variability, and their modification under enhanced greenhouse gas forcing, constitutes one of the most challenging areas of current climate research. Accordingly, the World Climate Research Programme (WCRP) has chosen this theme as one of their Grand Challenges (Zhang et al., 2013, Alexander et al., 2016; *https://www.wcrp-climate.org/grand-challenges/gc-extreme-events*). GEWEX co-leads this Grand Challenge (GC) with the WCRP Climate and Ocean–Variability, Predictability and Change (CLIVAR) Project.

While extreme weather and climate events are an inherent part of the climate system, there is overwhelming evidence that extreme events are changing as a result of increasing greenhouse gas concentrations (Seneviratne et al., 2012; Bindoff et al., 2013; Hartmann et al., 2013). Hence, society needs to adapt and prepare for these changes. A better understanding and prediction of these events is thus of critical importance. The impacts of weather and climate extremes, were, for instance, recently illustrated by the devastating California drought in 2012–2016 (Figure 1a), flooding in Houston, Texas associated with Hurricane Harvey in the summer of 2017 (Figure 1b), and the drought and heatwave in Central Europe in 2015 (Figure 1c). A summary of extreme events that occurred in the year 2016 is published as a special supplement of the *Bulletin of the American Meteorological Society (BAMS)* on "Explaining extreme events from the climate perspective" (Herring et al., 2018), which provides more examples of the variety of extremes affecting humans and ecosystems in any given year (Figure 2). While some of these events may occur as a result of natural climate variability, the majority of 2016 events investigated by Herring et al. (2018) were shown to have been exacerbated by enhanced greenhouse gas forcing.

The Extremes Grand Challenge has identified four overarching themes (Document, Understand, Simulate, and Attribute) and four core extremes types (Heavy Precipitation, Heatwaves, Droughts, and Storms) requiring the most intense focus of

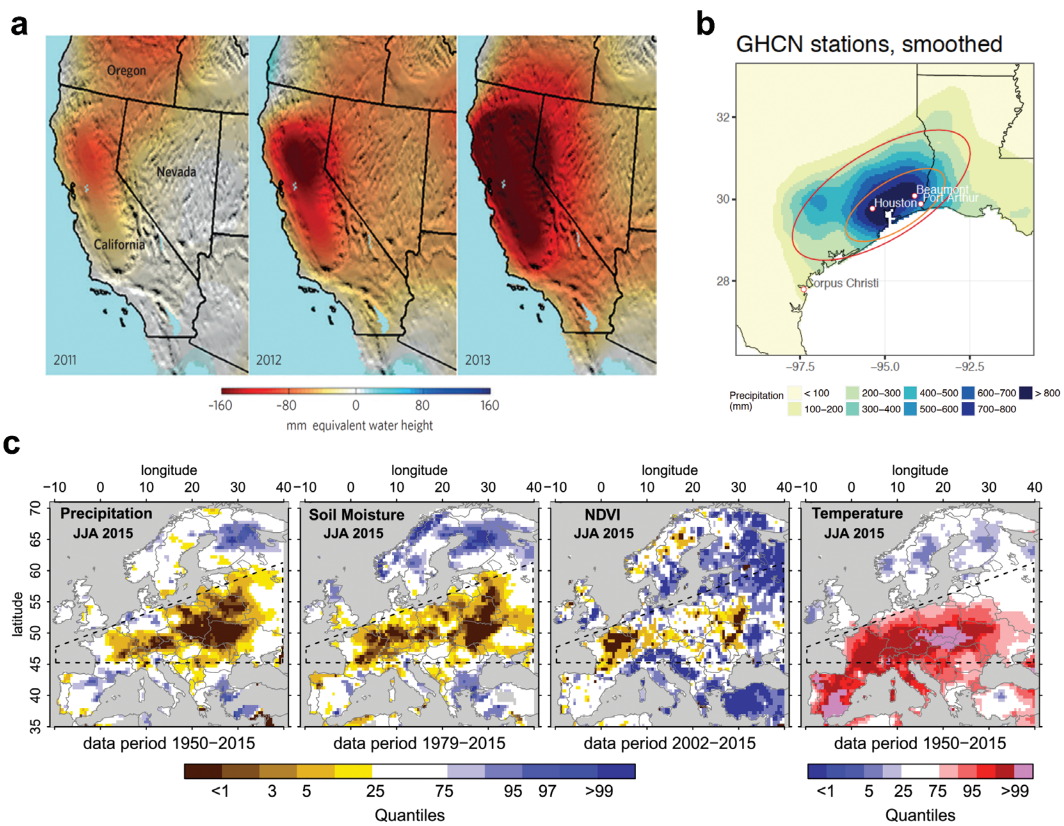

Figure 1. Recent extreme events. (a) The 2012–2016 drought in California: dry-season (September-November) anomalies of total water storage in California in 2011, 2012 and 2013, based upon NASA's Gravity Recovery and Climate Experiment (GRACE) satellite measurements (Famiglietti, 2014). (b) Precipitation totals (mm) caused by Hurricane Harvey for Houston, Texas, from 25–31 August 2017 based upon smoothed estimates of weather station totals (Risser and Wehner, 2017). (c) Mean summer (June, July, August) anomalies (expressed as quantiles) for precipitation, soil moisture, normalized difference vegetation index (NDVI), and temperature during the 2015 European drought and heatwave. The event was the driest and one of the hottest in Central Europe since 1900 (Orth et al., 2016).

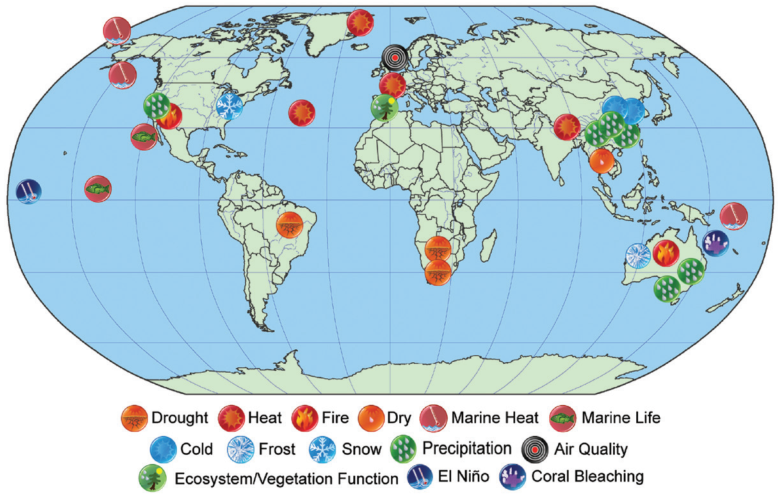

Figure 2. Location and types of events analyzed in the BAMS supplement on "Explaining extreme events of 2016 from a climate perspective" (Herring et al., 2018). A majority of these events was attributed to enhanced greenhouse forcing. Evidence shows that enhanced greenhouse gas forcing has influenced the probability of occurrence of a majority of these events.

current research (Figure 3). The following 2018 GEWEX OSC sessions on Extremes are organized around the four themes and extremes types:

- Documenting extremes
- Modeling for extremes
- Detection and attribution of climate extremes
- Subdaily rainfall extremes
- Changes in rainfall intensity
- Heatwaves in present and future climate
- Droughts in present and future climate
- Storms and high-impact weather

One of the four main GEWEX Science Questions (GEWEX, 2012) is related to extremes research. Hence, several of the addressed themes are joint to the Extremes GC and GEWEX foci, in particular those addressing the observation and documentation of extremes, the analysis of water cycle extremes, and the investigation of changes in extremes in a warmer climate. New developments of the GEWEX community in the areas of high-resolution modeling and land-atmosphere interactions are also of strong relevance for the simulation and understanding of climate and weather extremes and will be a focus of the OSC. Sessions in these fields of particular relevance to extremes research include "**High-resolution modeling and resolved/permitted convection**" and "**Land-atmosphere interactions and climate predictability**." One research field where extremes research is still less developed is the satellite research community. To foster interaction and new developments between the satellite and extremes research communities, one OSC session will be dedicated to the theme "**Satellite observations for extremes, water cycle, and land-atmosphere interactions.**"

Extremes research is also addressed by partner programs within the World Weather Research Programme (WWRP) as part of the "High-Impact Weather" (HIWeather) research project (Jones and Golding, 2014). Another international activity on extremes research is the initiative "Extreme events and environments—from climate to society" (E3S) in the Future Earth Program (*http://www.futureearth.org/extreme-events-and-environments-climate-society-e3s*).

The 2018 GEWEX OSC will provide a stronger interaction between the Extremes GC and these related initiatives. Links with WWRP research will be addressed as part of the session on "**Storms and high-impact weather**" (see above), as well as within the plenary session on "**Extreme weather in a changing climate.**" The session "**Climate extremes, ecosystems, and society**" will address themes related to the E3S initiative. In addition, the Extremes Knowledge Action Network coordinated by the E3S project in collaboration with the Extremes GC and GEWEX will be presented at the OSC and will organize a half-day workshop on the last day of the conference.

An emerging new field in climate extremes research is the investigation of compound events resulting from multivariate extremes. Indeed, the joint occurrence of two extremes (e.g., droughts and heatwaves leading to increased fire risk or heavy precipitation and storm surges leading to coastal inundation) may lead to disproportionate impacts, an area still understudied at the moment. This may happen by chance, but also because the two extreme types are correlated (e.g., due to droughts and heatwaves enhancing one another, or because the two types of events are both exacerbated under climate change). A workshop on this topic was organized by the Extremes GC in 2017 (Zscheischler et al., 2017). This new research area will be addressed at the 2018 GEWEX OSC in the sub-session "**Compound events**" as well as in a parallel event.

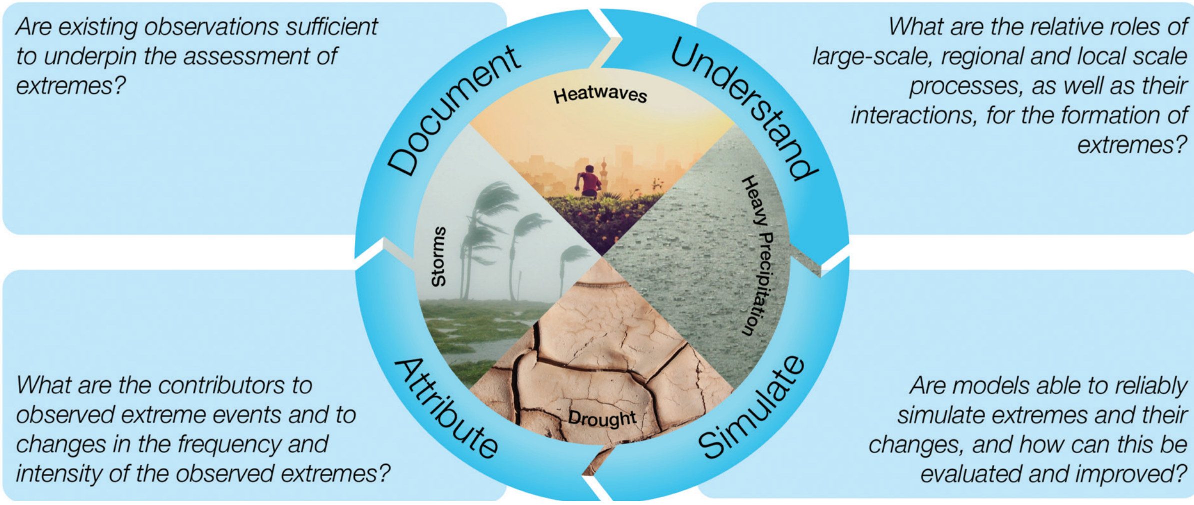

Figure 3. Four overarching themes (Document, Understand, Simulate, Attribute) and four core extremes types (Heavy Precipitation, Heatwaves, Droughts, Storms) addressed by the Extremes Grand, Challenge (Alexander et al., 2016).

The GEWEX OSC will allow for the first time an extensive meeting on themes related to climate extremes research within GEWEX and the overall climate research community. We expect major outcomes from the interactions between the research communities meeting at this event. This is particularly critical for this research field, which is still in its early stages and of direct relevance to society. We thus look forward to exciting sessions and exchanges on extremes research at the 2018 GEWEX OSC!

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GEWEX Stewardship of Global Climate Data Records

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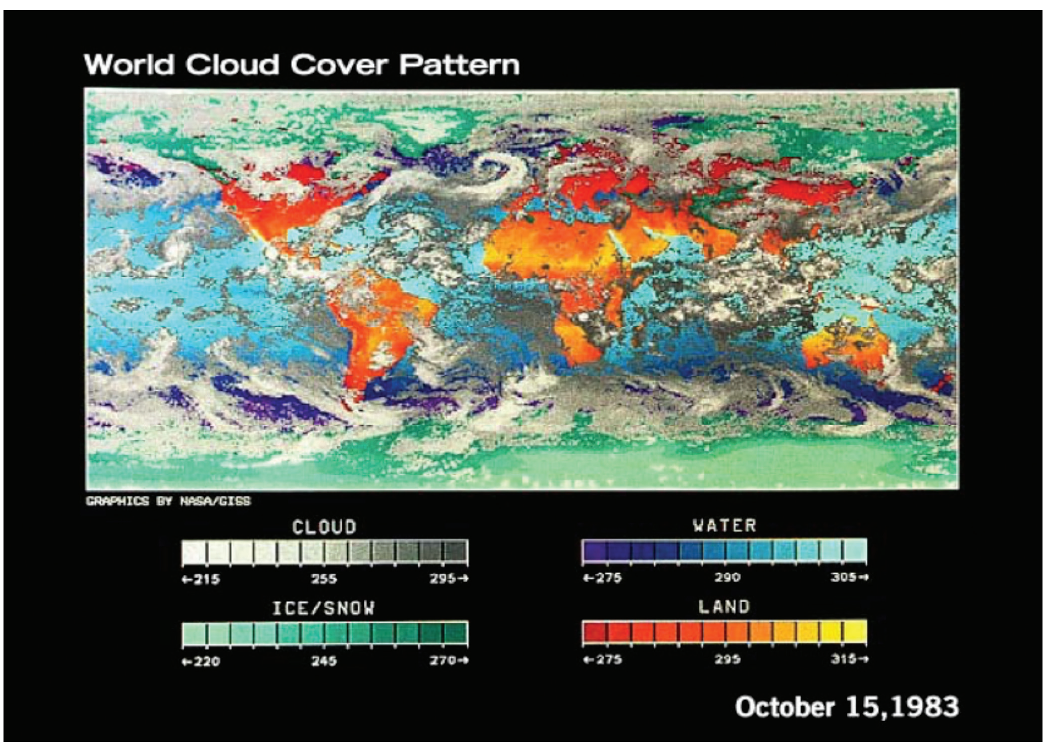
Since its inception, and well before the topic of climate data records became an important effort in Earth sciences, GEWEX has been the steward of many important climate data records. During the earlier part of the decade of the 1980s, and before GEWEX was formalized as a core project of the World Climate Research Programme (WCRP,) it became increasingly apparent that satellite observations would play an important role in climate sciences. The monitoring of the Earth's radiation budget, for example, was well under way (e.g., House et al., 1986) and derivative information, such as the surface radiation balance, was being developed. This led to related activities involving the oversight of surface networks of radiation flux measurements as a calibration source for this new information, laying the foundation for the Baseline Surface Radiation Network (BSRN), which formally began in 1992. The early data efforts were overseen by a working group of the WCRP Joint Scientific Committee, and the maintenance of these supporting data efforts has been a major success of WCRP over the years. This working group transitioned into the GEWEX Radiation Panel, which today is the GEWEX Data and Analysis Panel (GDAP).

The International Satellite Cloud Climatology Project (ISCCP) is perhaps the hallmark example of the successful development of a global climate data record, providing a roadmap for addressing the challenges faced in the creation of such a data record (see figure below). ISCCP was the first project to assimilate data from multiple geostationary satellite platforms into a global and time-resolved view of clouds. Beginning in 1983 (Schiffer and Rossow, 1983), ISCCP has produced a continuous data record and has transitioned from research to an operational data record activity. In developing the climatology, ISCCP had to address a number of issues that are often taken for granted today. Strategies for cross-calibrating the different satellite sensors of operational systems had to be developed and approaches to detect clouds from radiance data were pioneered, as were elementary retrievals of cloud properties. Other multi-satellite global data activities, such as the Global Precipitation Climatology Project (GPCP) and the GEWEX Water Vapor Project (GVaP), followed ISCCP.

Detailed, independent, peer-based data record assessment is another important function of the data stewardship provided by GEWEX. These assessment activities document the quality and limitations of data products by peer groups who are, by and large, independent of the data producers. Over the years GEWEX has provided assessments on the status of the Earth radiation budget, clouds, water vapor, and aerosol observations, and is now performing an assessment of the available global precipitation data products. These assessments involve significant community participation as described, for example,

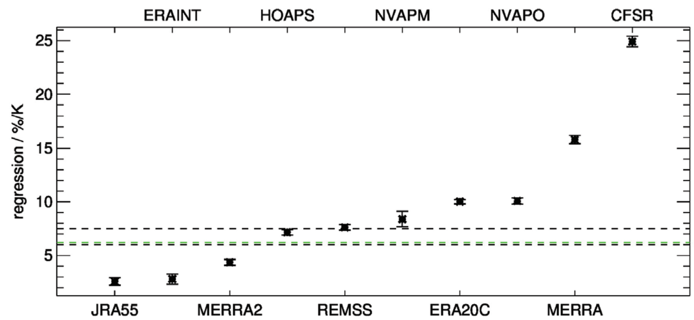


One of the first views of global cloudiness provided by ISCCP. Many challenges had to be surmounted to provide this critial perspective; the sustained gathering of data, the need to cross-calibrate multi-satellite data, the development of techniques to discriminate clouds from snow and ice and other surface conditions, and the need to provide data in a physically meaningful but compressed way (https://isccp.giss.nasa.gov).

in the cloud assessment of Stubenrauch et al. (2013). Another example of a GEWEX assessment is highlighted in the figure on the right taken from Schroeder et al., 2017. It presents an assessment of various sources of global column integrated water vapor over oceans expressed in the form of trends over a 30-year period. The data are given as a percentage change in column water vapor per degree of sea surface temperature warming over the period considered. This sensitivity is thought to be a fundamental metric of the water vapor feedback that contributes the majority of the warming to forced changes of climate. Four independent observational records are shown being close to the guidance of the Clausius-Clapeyron theory ranging between 6-7.5%/K (horizontal dashed lines). This same trend is derived from six different reanalysis data records that are widely used in Earth science research. The trends in these reanalysis data vary over an order of magnitude from 2.5%/K to 25%/K.

The approach toward both developing and using data records for advancing Earth science is evolving and has changed since the earlier days of GEWEX. We are now more interested in integrating multiple sources of data to provide wider insights on the Earth system and in using data in different ways to probe more specifically critical Earth science processes. In many respects, the hallmark of such an effort is exemplified in the GEWEX integrated view of water and energy. The studies of L'Ecuyer et al. (2015) and Rodell et al. (2015) are examples of how large volumes of data from varying sources can be integrated to provide an optimal depiction of the global energy and water balances. A central aspect of this integration is the need to provide defensible estimates of uncertainty on all information which itself is an important function of the data stewardship provided by GEWEX. The next step in this endeavor is to provide a more regional depiction of water and energy balances that requires integration of even more and different data. For example, in the case of energy balance alone, information about heat transported into and out of regions by the oceans and atmosphere is required to constrain balances that become more uncertain as the scale of focus increases.

GEWEX has also championed a more process-oriented use of data. Many activities of the GEWEX panels are framed around using data and models of varying complexity to probe process understanding. Both the Global Land/Atmosphere Study (GLASS) Panel and Global Atmosphere Systems Study (GASS) Panel focus on critical couplings between the surface and atmosphere and the GEWEX Hydroclimatology Panel (GHP) focus on those processes, including human influences that affect hydrology and water resources. The GEWEX Process Evaluation Study (PROES) activity is a cross panel effort that focuses on use of observations to examine the representation of selected processes in global research and weather prediction models. PROES efforts are aimed at bringing data developers and modeling developers together to focus on specific challenges (Stephens et al., 2015). One example of this activity has been the examination of the influence of surface mass and energy balance on the ice mass loss of Greenland, which involved the bringing the water and energy communities of GEWEX together with the ice sheet modeling community within the Climate and Cryosphere (CliC). The basis of this process-based research was used as justification for a new satellite measurement effort within the National Aeronautics and Space Administration (NASA) to monitor previously unmeasured components of Earth's energy balance.



The trends in column-integrated oceanic water vapor from the Japanese Meteorological Agency Reanalysis (JRA-55), the European Centre for Medium-Range Weather Forecasts Reanalysis (ERA interim), the Modern-Era Retrospective analysis for Research and Applications, Version 2 Reanalyses (MERRA-2), ECMWF 20th Century Reanalysis (ERA-20C), MERRA, and the Climate Forecast System Reanalysis (CFSR, Schroeder et al., 2017) contrasted against satellite products and the expectation of Clausius Clayeron theory (horizontal lines).

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Future Challenges in Land Modeling

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Land models have undergone a remarkable transformation over the past 50 years. From very humble beginnings, when they simply provided the lower boundary conditions to the atmosphere, land models have evolved to produce detailed mechanistic simulations of water, energy and carbon (Sellers et al., 1997; Pitman et al., 2003). The earlier focus of land models was to simulate short-term fluxes using the available global information on topography, vegetation, and soils. Over the past two decades, the land modeling community has eagerly embraced the paradigm of Earth System prediction (Bonan and Doney, 2018) and today's land models now simulate the dynamics of change in the Earth System, requiring the capability to simulate interactions and feedbacks both among processes and across time scales.

The challenge of Earth System prediction motivated the land modeling community to act in two important ways. First, the community has quietly risen to meet the wicked interdisciplinary challenge of Earth System prediction. Land modeling naturally requires expertise across multiple fields, including ecology, hydrology, chemistry, meteorology, engineering, soil physics, agronomy, geomorphology and social science. Modelers integrate these fields to incorporate state-of-the-art science solutions from traditional disciplines into complex Earth System models. Second, and a critical role for GEWEX, the community has been able to substantially advance model analysis. Building upon the model intercomparison experiments of earlier years, land model intercomparison experiments have evolved to understand the behavior of complex models (e.g., van den Hurk et al., 2011), including land-atmosphere coupling (Koster et al., 2006; 2011), the dynamics of land use change (Lawrence et al., 2016), and benchmarking studies to evaluate the extent to which land models use the information that is available to them (Best et al., 2015). This multi-decadal effort to advance land models has resulted in a vibrant interdisciplinary community that is effectively answering fundamental questions on the dynamics of Earth System change.

Areas for Improvement in Land Models

Such progress notwithstanding, there are a number of areas that need improvement to meet society's expectations for Earth System prediction:

1. **Better data and stronger theory.** Field experiments are clearly critical to advance our understanding of water and energy cycles. While we are already reaping the benefits from the Critical Zone Observatory Network in the US (Grant and Dietrich, 2017) and other similar efforts worldwide (Tetzlaff et al., 2017), these field experiments, in themselves, are insufficient. More synthesis is needed across scales and locations in order to strengthen the body of theory that is necessary to support global model development (Clark et al., 2015a). Our age-old core challenge still remains—we need to advance our understanding of how the dominant processes in different environments shape energy and water fluxes across a hierarchy of spatial scales.

2. **Improved theoretical underpinnings of land models**. Many modeling groups follow a pragmatic approach to model development, borrowing spatial discretizations, process parameterizations, and time stepping schemes from other extant models (e.g., reliance on the 1-dimensional moisture-based form of Richards' equation in land models). Such a pragmatic approach tends to sever the link between models and the body of theory (Clark et al., 2016). Specifically, the pragmatic approach focuses attention on a model's predictive competence rather than its explanatory power, limiting our ability to generalize, and increasing the need for theoretically unsatisfying model "tuning" exercises. Improving the theoretical underpinnings of land models requires greater engagement of field scientists in model development and greater collaboration across diverse modeling groups.

3. **Improved simulations of the temporal dynamics of environmental change**. Key challenges include predicting how energy gradients dictate landscape evolution, how natural selection favors plants that make optimal use of the available resources, and how the dynamic interaction between humans and the environment shapes the storage and transmission of water across the landscape (Clark et al., 2017). This last challenge is perhaps the most difficult as it requires shifting away from scenario-driven approaches (e.g., scenarios of urban development, without the feedbacks that are key to producing realistic long-term predictions), and shifting towards representing human activities as an endogenous component of the Earth System. Modeling human-environment interactions requires simulating coupled human-natural interactions and feedbacks, in order to understand how the Earth System evolves in the emergent Anthropocene (Sivapalan et al., 2012; Clark et al., 2015a). The simulations of the temporal dynamics of environmental change really define the interdisciplinary nature of land modeling, underscoring the critical importance of community modeling.

4. **Advanced methods for model analysis.** The growing complexity of land models increases the opportunities for compensatory errors, making it quite easy to get the right answers for the wrong reasons. Our model analysis methods must hence keep pace with the bewilderingly large increases in model complexity. We are already seeing more comprehensive model analysis frameworks to evaluate individual processes and process interactions (e.g., Luo et al., 2012), along with

applications of information theory to quantify how effectively models use the available information (e.g., Nearing et al., 2016). It is crucial now to shift away from the "what" questions that have dominated community model analysis projects (e.g., what is the performance of land models) and move toward the "why" questions (e.g., why do models behave badly and what can be done to address model inadequacies).

5. **Expand our prominence in community land modeling.** The growing complexity of land models dictates that we need to focus more attention on community land modeling. Specifically, we need to be much more effective and efficient in sharing data and model source code. This goes beyond just making models and data publicly available, but critically, it requires that we integrate models and data in widely used analysis frameworks and develop model standards to simplify the sharing of source code in models developed by different groups (Clark et al., 2015b; 2016; 2017). This is indeed a key role for GEWEX—to enable the interdisciplinary and international collaboration that is necessary to advance the science of Earth System prediction.

It is an exciting time for land modelers as we make progress in each of these areas. The modeling advances on the horizon will not only improve climate models, they will also substantially improve the skill of drought monitoring and prediction, flood and water supply forecasting, coupled environmental prediction and a broad variety of hydrological and ecological impact assessments. As such, the community of land modelers will continue to grow, and, as a community, land modelers will rapidly transform what science can offer to society.

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ANDEX: A Prospective GEWEX Regional Hydroclimate Project in the Andes

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Plans for a comprehensive hydroclimate research program for the Andes of South America (ANDEX) were developed at a workshop held at the Universidad Nacional de Colombia in Medellín, Colombia on 4–6 December 2017. The goals of ANDEX, which is a prospective GEWEX Regional Hydroclimate Project (RHP), are to understand, model and predict the dynamics of water and energy cycles over the Andes, from north to south and west to east at a wide range of temporal and spatial scales (including their linkages with the surrounding oceans and major river basins).

The Andes constitute the world's longest mountain range, extending 7242 km from the northern Caribbean coast (12°N) to the southern tip of South America (53°S). The region is about 200–700 km wide with an average height of 4000 m and extends through seven South American countries: Venezuela, Colombia, Ecuador, Peru, Bolivia, Argentina and Chile. Due to its long meridional extent, the Andes exhibit equatorial, subtropical and midlatitude hydroclimates that are further diversified by factors such as aspect, slope and elevation. The Andes have glaciers, volcanoes, deserts, high plateaus, lakes, cloud forests, wet forests, tropical rainforests, dry forests, savannas, and intra-mountainous valleys. The region also contains some of the wettest areas on Earth (the Colombian western Andean slope, the eastern topical Andes slope and western Patagonia), as well as some of the driest climates (the Atacama Desert and eastern Patagonia). The retreat and disappearance of tropical glaciers have important implications for water supply, biodiversity, and the sustainability of cloud forests and other ecosystems.

More than 85 million people inhabit the Andes and will be impacted by climate and global environmental change. The mountainous areas of the Andes contain major cities and hundreds of medium and small-sized towns that demand an ever-increasing supply of environmental services and socio-economic resources. The extreme geography and climate set the stage for hydro-meteorological hazards that include flooding, landslides and debris flows that have taken thousands of lives in recent decades. Extreme climate and weather events, combined with a degraded environment will likely affect the well being of communities within the Andes in terms of failure to provide enough natural resources, such as fresh drinking water. Poverty in the Andean region, the disappearance of native and ancestral cultures, human encroachment, large-scale deforestation, erosion and land degradation, accelerated loss of biodiversity and soils, large-scale pollution of water sources owing to mining activities, oil industry activities, agriculture, cattle dwellers and coca growers make it all the more urgent that basic studies and applied research be conducted in this region. At the same time the natural biodiversity and the breadth of current and potential environmental services provided by these ecosystems may provide solutions for sustainable development of this vast region. Therefore, a thorough assessment and understanding of the Andes system is necessary, including the interactions between natural ecosystems and social systems.

The Medellín workshop participants recognized that there is an urgent need to link the physical scientific understanding of the Andes with societal needs (e.g., water, food security, human health, hydropower and navigation). More than 40 research questions were identified and grouped into four major science themes regarding Andes hydroclimatology: (1) Climate Patterns and Drivers, (2) Climate and Environmental Changes, (3) High Impact Events and (4) Andean Cryosphere. In addition, diverse crosscutting themes were considered, including observations, data and modeling, and the science underpinning sustainable development. A "white paper" will be prepared that addresses these issues and emphasizes in each of the four themes the actions and challenges that are necessary to bridge the current gaps in knowledge and applications. The ANDEX white paper will serve as a basis for the Science and Implementation Plan that is planned after the second ANDEX workshop in Santiago, Chile in October 2018. The workshop agenda will include: (i) fostering regional cooperation among researchers and research programs; (ii) establishing a focused research strategy based upon fundamental issues of the Andes region main interests; (iii) creating the scientific framework to help decision-making processes for the sustainable development of a highly environmentally and biogeophysically threatened region; and (iv) connecting the Andean region with global and regional initiatives.

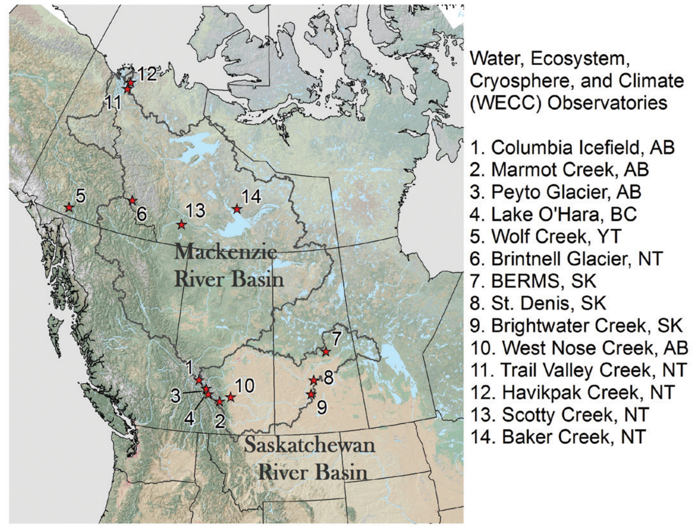
Participants of the ANDEX Workshop.

Changing Cold Regions Network (CCRN) Wraps Up at Final Meeting

Chris DeBeer, Howard Wheater, John Pomeroy and CCRN Colleagues
Centre for Hydrology and Global Institute for Water Security, University of Saskatchewan, Saskatoon, Canada

The Changing Cold Regions Network (CCRN) is a Regional Hydroclimate Project (RHP) of the GEWEX Hydroclimatology Panel (GHP), supported by a 5-year grant that terminated in March 2018. The overall objectives of CCRN were to understand, diagnose and predict interactions between the cryospheric, ecological, hydrological, and climatic components of the changing Earth system at multiple scales, with a geographic focus on Western Canada's rapidly changing cold interior. This cold region, including its two major river systems, the Saskatchewan and Mackenzie Basins, is experiencing rapid warming and significant environmental change, and CCRN has provided important insights into changing cold regions globally. Funded by the Natural Sciences and Engineering Research Council of Canada (NSERC) under its Climate Change and Atmospheric Research initiative, CCRN was the only active North American RHP during this period and one of only two fully working RHPs globally. The CCRN research team included a large and multi-disciplinary group of 45 co-investigators and collaborators from eight Canadian universities and four Canadian federal government agencies, as well as 18 international collaborators from Germany, France, USA, the United Kingdom and China. CCRN was strongly linked to collaborative efforts with the US National Center for Atmospheric Research and the National Aeronautics and Space Administration, including its Arctic–Boreal Vulnerability Experiment (ABoVE) and other missions, and had important links with other GEWEX projects, including the International Network for Alpine Research Catchment Hydrology (INARCH), the Cold/Shoulder Season Precipitation Near 0°C, and Including Water Management in Large Scale Models GHP cross-cutting projects.

A key aspect of CCRN is its network of 14 well-instrumented Water, Ecosystem, Cryosphere and Climate (WECC) observatories within the interior of western Canada, which provide opportunities to observe and understand processes and their interactions, as well as to develop and test numerical models and provide validation data for remote sensing products. These are representative of the permafrost regions of the Sub-Arctic, the Boreal Forest, the Western Cordillera, and the Prairies. The WECC observatories combine meteorological, hydrological, ecosystem and cryospheric observations with multi-scale coupled models from the surface to the atmosphere. All of these observatories have a history of research that predates the CCRN, and most have long-term legacy data sets, including hydrometeorological variables, remotely sensed data products [including Light detection and ranging (Lidar) topographic and vegetation structure mapping], and characterization of soils, geology, vegetation, permafrost, and glacial ice cover.



CCRN's 14 Water, Ecosystem, Cryosphere and Climate (WECC) observatories across the interior of Western Canada.

The CCRN program and its objectives were based on five interrelated Themes. **Theme A**, **Observed Earth System Change in Cold Regions–Inventory and Statistical Evaluation**, documented and evaluated observed change, including hydrological, ecological, cryospheric, and atmospheric components, in the cold regions of interior northwestern Canada over a range of scales. **Theme B**, **Improved Understanding and Diagnosis of Local-Scale Change**, has improved our understanding of local-scale change by developing new and integrative knowledge of Earth system processes; incorporating these into a suite of process-based integrative models and using them to better understand Earth system changes. **Theme C**, **Upscaling for Improved Atmospheric Modelling and River Basin-Scale Prediction,** has improved large-scale atmospheric and hydrological models for weather, climate, and river basin-scale modeling and prediction of the changing Earth system and its feedbacks. **Theme D**, **Analysis and Prediction of Regional and Large-Scale Variability and Change**, focused on the driving factors for the observed trends and variability in large-scale aspects of the Earth system, their representation in models, and the projections of regional-scale effects of Earth system change on climate, ecology, land, and water resources. **Theme E**, **Outreach and Engagement**, engaged a community of partners and users, including local stakeholder groups, provincial and federal policy/decision makers, national and international research organizations, and other relevant groups and disseminated the improved knowledge and tools within this extended community.

This year, two special issues in the journals *Hydrology and Earth System Sciences (HESS)* and *Earth System Science Data (ESSD)* are accepting submissions from CCRN and from related cold-region initiatives worldwide. The HESS issue (*https://www.hydrol-earth-syst-sci.net/special_issue919.html*) is entitled "Understanding and Predicting Earth System and Hydrological Change in Cold Regions," and will compile and synthesize recent science advances contributing to the over-

Participants of the 5th CCRN meeting in Saskatoon, Saskatchewan, Canada.

all aims and objectives of CCRN. The ESSD issue (*https://www.earth-syst-sci-data.net/special_issue901.html*) is entitled "Water, Ecosystem, Cryosphere and Climate Data from the Interior of Western Canada and Other Cold Regions," and will compile the CCRN data sets and make them available as a legacy for the network. Both issues will remain open for submissions until 1 September 2018.

CCRN Finale

The 5th and final CCRN annual general meeting was held 5–6 March 2018 in Saskatoon, Canada as a closing event for the program and to review its progress and scientific advancements, consider outstanding issues and further directions to be pursued, and plan outreach products and papers to be produced from the work. The meeting was attended by over 85 research scientists, students, and post-doctoral fellows from CCRN, along with several members of our International Advisory Panel (IAP) and other international scientists arriving early for the Howard Wheater Symposium on 7–8 March (*https://www.usask.ca/water/howardwheater-symposium/index.php*). The first day of the meeting consisted of individual research presentations by CCRN investigators and collaborators to synthesize their activities and achievements over the 5-year program. The second day involved presentations and discussions on international linkages, overviews and syntheses of each of the five CCRN Themes, a student poster session and competition, final Board of Directors meeting, and closing remarks from the IAP, Board, and Principal Investigator. The meeting ended with an evening public showing of a recently produced documentary film on CCRN and its work, along with a moderated panel discussion and question period. The film is available for viewing on our homepage at: *www.ccrnetwork.ca*.

CCRN Theme presentations and discussions at the Finale highlighted key achievements and outcomes and also helped identify future priorities for follow-on work.

Theme A. Inventory of Observed Change has involved a wide variety of local to regional to large river basin scale assessments of past Earth system change, extensive ecological work documenting of forest–climate–hydrological interactions and post-fire ecological change, and examination of recent extreme events (floods, droughts, wildfires) and the regional to hemispheric climate context surrounding these events. Insights and expert understanding from both observations of change and from process knowledge have been used to develop conceptual models of change for the different ecoregions and biomes in the CCRN study region, in order to aid with quantitative analysis and diagnosis of change in subsequent Themes. Research summaries and plain language information products have been developed from this work and are important for conveying the message to a wide audience.

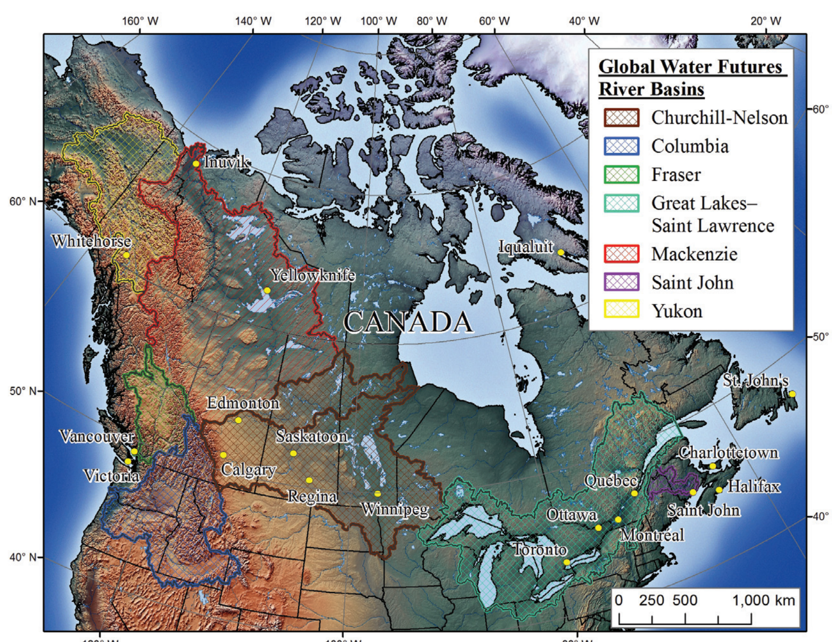
Theme B. Local-Scale Understanding and Diagnosis of Change has included a range of activities: (1) targeted process studies using the WECC observatories and in some cases revitalizing them to gain new process-level understanding, and the execution of a coordinated observation year (2014–2015); (2) development of improved local-scale models based on these insights, primarily involving the Cold Regions Hydrological Model (CRHM) platform, with numerous improvements and new process algorithms developed; and (3) diagnosis of local past change involving historical simulations at many WECC sites to examine sensitivities and unscramble the various factors affecting change and system functioning. Going forward there is a need to link detailed site-specific analyses with more regional level assessments (Theme A). At this point as initial results are coming in from climate model downscaling and bias correction work in Theme D, there are opportunities to feed this into the fine-scale modeling work for further insight on process-level responses and examination of future change at multiple scales. This is important work to pursue in the coming months. Key challenges remain in representing landscape changes such as permafrost thaw and the connectivity of hydrological pathways, linked with ecological processes, and in taking the fine-scale process representation and applying this in a simplified way in large scale hydrological models.

Theme C. Improved Large-Scale Modeling involving algorithm development has focused on both algorithm development for weather and large-scale hydrological models, and large basin-scale application and testing of weather, climate and large-scale hydrological models, including verification and assimilation of ground-based observations and remotely sensed data. In particular, Theme C has involved close collaboration with partners at Environment and Climate Change Canada (ECCC) and focused on the development and application of the Canadian LAnd Surface Scheme (CLASS), Modélisation Environmentale Communautaire (MEC)–Surface and Hydrology (MESH), and Canadian Terrestrial Ecosystem (CTEM) models. Many important developments have led to new and improved algorithms in CLASS. CCRN has set up MESH for the Saskatchewan and Mackenzie River systems and made major advancements in the MESH modeling system and its capability, including representation of prairie wetlands, water management (staged reservoir release and irrigation demand and abstraction), permafrost deep soil layer discretization, and new plant functional type representation for shrub tundra. Some challenges remain, particularly involving initialization of transient and non-stationary conditions for permafrost development, and improved representation of Earth system dynamics and change; for instance incorporating vegetation processes, disturbance and fire.

Theme D. Analysis and Prediction of Large-Scale Change has used the models developed in Theme C along with other data and climate reanalysis products to examine the changing regional climate and land surface systems and their influence on the hydrology of the Saskatchewan and Mackenzie River systems. Work has progressed on multiple fronts and has included examination of synoptic scale atmospheric controls on recent extreme events, analyses of changes in precipitation (amount, phase, extremes) and moisture indices, generation of 4-km resolution Weather Research and Forecasting (WRF) model outputs for historical (2001–2015), as well as future pseudo-global warming simulations (RCP8.5; 2086–2100), use of WRF and other climate model outputs to examine land–atmosphere interactions and feedbacks, development of expert-informed scenarios of future landscape change to apply in MESH under future climate, and preliminary model runs at multiple scales and complexity to examine future Earth system and hydrological change in the region. Going forward, there is tremendous momentum from the intensive modeling efforts as the program nears completion, and it will be important not to lose this over the coming months. In the near term it will be important to examine the predicted change and assess its consistency with other observations, process understanding, results and insights from fine-scale model applications, and there will be a need to ensure that physical processes are consistent at the large scale. In the longer term, there is a need to extend the WRF simulations for continuous, long-term pseudo-global warming runs, and perhaps nested runs in areas where finer detail is required, and to ensure consistency with synoptic-scale climate patterns and teleconnections.

Theme E. Outreach and Engagement have focused on connecting CCRN research and findings with a range of audiences, and in building linkages with various partners and stakeholders. This has included a broad range of activities, such as workshops, public events, field courses, community interaction, media engagement, development of research summaries, briefings and plain language information products, and the production of a documentary film on CCRN. There is a continued need to develop products to communicate CCRN results to the public (a list of potential brochures and other products was presented at the meeting), and in particular there is a need to tell the story of how CCRN has provided a service to Canada in terms of improving operational modeling and forecasting capability.

Observations and Data Management have been an integral component of CCRN activities, and the data sets from the network of WECC observatories and other field sites—as well



Canadian and transboundary river basins of initial focus within the Global Water Futures Program.

as from various atmospheric analyses and model runs—will form an important legacy for the network. CCRN has a central repository for its data and has been actively populating it with WECC and other datasets; many historical records can be found here (most of the observatories have contributed over 85% of their historical data) and near-real time data can be accessed from dozens of sites in the Saskatchewan and Mackenzie River Basins. Procedures have been established for registering data sets in a permanent archive and assigning digital object identifiers (DOIs) as required for submission of data papers to the journal ESSD. Going forward there is a profound role for outreach regarding data. CCRN will continue to prepare and present data sets in the special issue of ESSD, which will remain open until September 2018.

Future Directions

CCRN has reached the end of its 5-year term and formally concluded on 31 March 2018. A final detailed report on the progress and accomplishments made can be found on the CCRN website at *http://ccrnetwork.ca/outputs/reports*. Going forward, many of the research activities and directions will be continued within the recently funded Global Water Futures (GWF; *http://www.globalwaterfutures.ca*) Project, which is a 7-year (2016–2023), $143 million, University of Saskatchewan-led research initiative that has an overall mission to improve disaster warning, predict water futures, and inform adaptation to change and risk management. GWF is the largest investment of its kind in university-led freshwater research and aims to provide global leadership in water science for cold regions and to address the strategic needs of the Canadian economy in adapting to change and managing the risks of uncertain water futures and extreme events.

The linkage to the GHP will take place through the new GWF program, which is applying for status as an expanded RHP from CCRN. Its geographic focus includes not only the Mackenzie and Saskatchewan River Basins, but also a number of other major watersheds across all of Canada, and focuses on distinctive cold regions and transboundary aspects that are of unique interest. The scientific focus will expand to include water quality, social science, health, and water governance. Science questions will be structured around, for example: (1) How will extreme atmospheric events be translated by the hydrological system into hydrological extremes? (2) How will hydrological storage in lakes, managed reservoirs, glaciers, permafrost, groundwater and wetlands interact with a changing climate and shifting terrestrial ecosystems to create new hydrological regimes? and (3) How can humans better manage, mitigate and adapt to this change and conserve ecosystems through water and land management, prediction, and governance?

CCRN and Global Water Futures activities and science highlights will be presented to the GEWEX community at the upcoming 8th GEWEX Science Conference on Extremes and Water on the Edge in Canmore, Alberta, Canada on 6–11 May 2018.

Meeting/Workshop Reports

Future of the GEWEX Water Vapor Assessment: Summary of the 7th G-VAP Workshop

Leicester, UK
25–26 October 2017

Marc Schröder and 7th G-VAP Workshop Participants
Satellite-Based Climate Monitoring, Deutscher Wetterdienst, Offenbach, Germany

The purpose of the GEWEX Water Vapor Assessment (G-VAP) is to quantify the state of the art in water vapor products being constructed for climate applications, and thus support the selection process of suitable water vapor products by the GEWEX Data and Assessments Panel (GDAP) for its production of globally consistent water and energy cycle products. G-VAP workshops were held annually to discuss recent findings, to refine plans and implement new activities, as well as to draft and consolidate assessment reports.

The 7th G-VAP Workshop was hosted by the National Centre for Earth Observation at the University of Leicester. With the publication of the WCRP report on the assessment's first phase (Schröder et al., 2017), G-VAP has entered into its second phase, beginning with this workshop. Approximately 20 participants attended from research institutes, universities and small and medium-sized enterprises, including the City University of New York (CUNY), Freie Universität Berlin, Laboratoire de Météorologie Dynamique (LMD)/Université Pierre et Marie Curie, Maynooth University, Max Planck Institute for Chemistry, Rutherford Appleton Laboratory, the Space Sciences and Engineering (SSE), the University Corporation for Atmospheric Research (UCAR), the University of Cologne, the University of Leicester, and the Laboratoire Atmosphères, Milieux Observations Spatiales (LATMOS)/Versailles Saint-Quentin-en-Yvelines University). Participants from weather services included Spain's meteorological agency, AEMET, the Danish Meteorological Institute, the German Meteorological Service (DWD), and the U.S. National Oceanic and Atmospheric Administration. In addition, representatives from the ground-based and in situ measurement communities (Maynooth University) and space agencies (the German Aerospace Center (DLR) and the European Space Agency) attended the workshop. During the meeting, updates were given on water vapor data records and results from the analysis and characterization of water vapor products. The status and outputs from G-VAP were presented and discussions were held on the scope, objectives, procedures and major scientific activities for future analyses. Presentations and the complete report of the workshop are available at: *www.gewex-vap.org*.

The workshop began with introductory presentations on G-VAP, followed by presentations on Gap Analysis for the Integrated Atmospheric Essential Climate Variable (ECV) Climate Monitoring (GAIA-CLIM) Virtual Observatory, calibration and validation activities at the University of Leicester, and quality analysis of microwave sounder observations, data records and related validation results. A series of talks were given related to the analysis and characterization of water vapor products. The remainder of the workshop concentrated on potential future directions for G-VAP and included presentations on the contributions from the GAIA CLIM project, the Group for High Resolution Sea Surface Temperature (GHRSST) and the Global Positioning System Radio Occultation (GPS RO) group. Future directions for G-VAP were discussed and agreed upon, and are summarized in more detail in the minutes and will form the basis for an updated assessment plan. Following is a short summary of the related discussions and consensus results.

- G-VAP will continue with unchanged scope, objectives, procedures, variables, reporting, and governance under the umbrella of GDAP.
- Core activities will be continued to provide a sustained service to the community.
- New science activities have been discussed and defined. Science teams will work on these topics with the overall goal to publish peer-reviewed papers.
- The establishment of a project office would be beneficial to the ongoing and future efforts of G-VAP (e.g., following the GHRSST example).

Continued activities include the intercomparison of water vapor profile data records at certain pressure levels using probability density function (PDF) analyses, the assessment of consistency between reference observations, both on the basis of instantaneous data, as well as the intercomparison of humidity products and trend estimates and homogeneity analysis using gridded products. It was agreed to define new science activities with the goal to publish results in peer-reviewed literature prior to the drafting of the WCRP report and in time for potential consideration by the authors of the Intergovernmental Panel on Climate Change (IPCC). Consequently, the papers will need to be submitted in January 2020 and published mid-October 2020. New activities planned for G-VAP include:

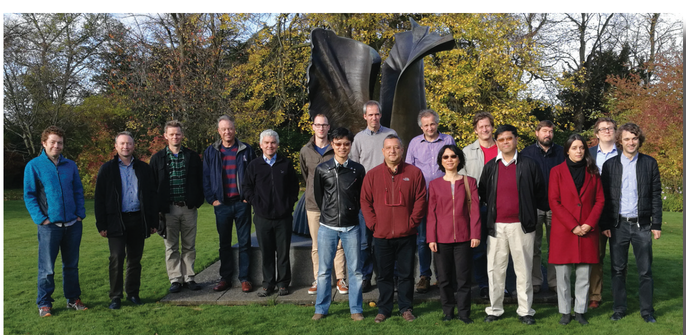
- Discuss and carry out joint Process Evaluation Studies (PROES) on Upper Tropospheric Clouds and Convection (UTCC) and G-VAP analysis of upper tropospheric humidity for deep convection and anvil clouds.
- Analyze free tropospheric humidity (FTH) variability in subsiding regions with a focus on the higher moments of the PDF.
- Analyze quality of profile data records over stratus regions using GPS RO (and potentially others) as a reference.
- Assess and characterize the differences between observations in all sky, cloudy sky and clear sky observations.

To a large extent the above analyses will be carried out at regions and periods characterized by consistent atmospheric conditions (subsidence regions, stratus regions and tropical convection). The last two activities follow G-VAP recommendations. Activities will be organized and executed in small teams and the teams will hold teleconferences (or meetings when feasible) organized by the activity leader. The science activities will primarily be defined at G-VAP workshops in consultation with GDAP. However, activities can also be introduced at any time via email to the co-chairs.

The workshop series will continue with the same organization. The frequency of meetings will be reduced and biannual teleconferences will be organized by the co-chairs. The status, outlook and dependencies across activities, and new ideas will be discussed during the teleconferences. The basis for the teleconferences will be activity summaries provided to the co-chairs by activity leaders. Participants will include the co-chairs and all activity leaders and co-chairs. Activity leaders may invite additional participants; however, for practical reasons the number of participants will be limited.

Lei Shi announced that she is stepping down as co-chair of G-VAP and her support was gratefully acknowledged. She will continue to participate in G-VAP and carry out intercomparisons and analysis using upper tropospheric humidity/FTH data. Hélène Brogniez and Shu-peng Ho volunteered and were accepted as the new G-VAP co-chairs.

G-VAP is a community effort and can only continue to be successful if the community is active, takes responsibility and carries out dedicated analysis. The community is encouraged to take responsibility and inform co-chairs on their willingness to commit to additional activities. The next workshop will take place at AEMET in Madrid, Spain in May 2019.



Participants at the 7th G-VAP Workshop in Leicester, UK.

Reference

Schröder, M., et al., 2017. GEWEX Water Vapor Assessment (G-VAP). WCRP Report 16/2017. World Climate Research Programme, Geneva, Switzerland, 216 pp.

3rd INARCH Workshop

Zugspitze, Germany
8–9 February 2018

John Pomeroy[1], Chris DeBeer[1], Matthias Bernhardt[2] and INARCH colleagues

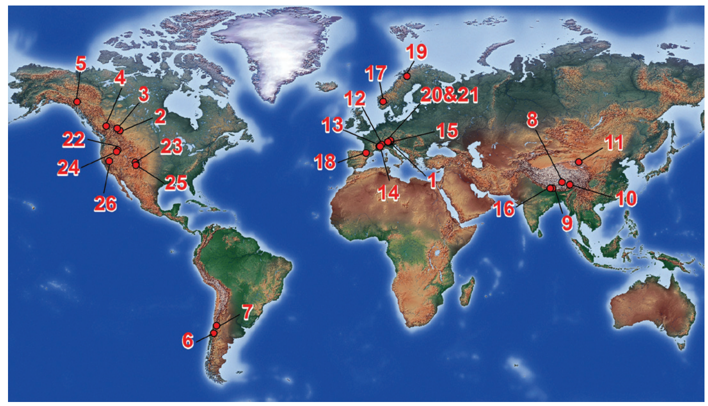
[1]Centre for Hydrology and Global Institute for Water Security, University of Saskatchewan, Saskatoon, Canada; [2]Institute of Water Management, Hydrology and Hydraulic Engineering, University of Natural Resources and Life Sciences, Vienna, Austria

The International Network for Alpine Research Catchment Hydrology (INARCH) is a crosscutting 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 addresses five core questions: (1) How do varying mountain measurement standards affect scientific findings worldwide? (2) What effect 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? and (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 26 well-instrumented mountain research basins maintained by its members and these are equipped to provide hydrometeorological, cryospheric and hydrological observations at multiple scales. Observations are embedded near the headwaters of larger river basins that supply water for vast downstream populations. The adjacent figure shows a map of INARCH mountain research basins. Sagehen Creek in the Sierra Nevada Mountains, California is the newest.

INARCH has important linkages to the GHP crosscutting project on Cold/Shoulder Season Precipitation Near 0°C and to the recently completed Changing Cold Regions Network RHP (CCRN; see article on page 11). CCRN is being expanded through the Global Water Futures (GWF) Program, which is the largest university-led freshwater research program in the world. INARCH provides a key mechanism for the GWF strategy to engage with the international mountain scientific community and policy makers. It contributes snow measurement information to the World Meteorological Organization (WMO), addresses the United Nations Educational, Scientific and Cultural Organization's (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 built direct links with the Third Pole Environment (TPE) Initiative, which is focused on central Asia and the Tibetan Plateau. INARCH supports ANDEX, the new Initiating RHP focused on the Andes

INARCH: International Network for Alpine Research Catchment Hydrology
Austria: 1.Open Air Laboratory (OpAL)
Canada: Canadian Rockies Hydrological Observatory; 2.Marmot Creek Research Basin;3.Peyto Glacier; 4.Quesnel River Research Basin;5.Wolf Creek Research Basin
Chile: 6.Upper Diguillín River Basin 7.Upper Maipo River Basin;
China: 8.Nam Co Monitoring and Research Station for Multisphere Interactions;9.Qomolangma Atmospheric and Environmental Observation and Research Station; 10.Southeast Tibet Observation and Research Station for the Alpine Environment; 11.Upper Heihe River Basin
France: 12. Arve Catchement; 13.Col de Porte Experimental Site; 14.Col du Lac Blanc Experimental Site
Germany:15.Zugspitze Basin and Schneefernerhaus Research Station
Nepal: 16. Langtang Catchment
Norway:17.Finse Alpine Research Centre
Spain:18.Izas Research Basin
Sweden:19.Tarfala Research Catchment
Switzerland: 20.Dischma Research Catchment; 21. Weissfluhjoch Snow Study Site;
USA: 22.Dry Creek Experimental Watershed; 23.Grand Mesa Study Site; 24. Reynolds Creek Experimental Watershed; 25. Senator Beck Basin Study Area; 26. Sagehen Creek, Sierra Nevada.



Current INARCH mountain research basins.

Mountains, and the role of mountains as water suppliers for the GEWEX Bread Baskets of the World initiative. INARCH links to the International Association of Hydrological Sciences International Commission for Snow and Ice Hydrology (IAHS-ICSIH) and contributes outreach information to the Mountain Research Initiative led from Bern, Switzerland.

Over the past year, INARCH has participated in several workshops and conferences. John Pomeroy presented an overview of INARCH at the UNESCO-IHP Knowledge Forum on "Water Security and Climate Change: Innovative solutions for sustainable water resources management," which was held in October 2017 in Paris, France. Chris DeBeer represented INARCH at the GHP-TPE Joint Meeting held on 17–20 October 2017 in Kathmandu, Nepal. INARCH members contributed to and led several mountain hydrometeorology sessions at the American Geophysical Union, European Geophysical Union and Canadian Geophysica Union meetings.

An INARCH Special Issue in the journal *Earth System Science Data (ESSD)* is open for submissions until 30 September 2018 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).

Several papers will be cross-listed in a CCRN-led special issue of *ESSD* on the topic "water, ecosystem, cryosphere, and climate data from the interior of Western Canada and other cold regions."

The 3rd INARCH Workshop was held at the Schneefernerhaus Environmental Research Station near the summit of Zugspitze, the highest peak in Germany, and provided an excellent opportunity for scientists to explore and discuss specific INARCH scientific topics and priorities. The meeting venue provided breathtaking and inspiring scenery, while also offering a comfortable space to gather as a group. Thirty scientists from the US, Canada, Chile, France, UK, Switzerland, Austria, Germany, Spain, and Norway attended the workshop. Local organizers included Matthias Bernhardt and Karsten Schulz (University of Natural Resources and Life Sciences, Vienna, Austria), and others in the organizing committee included Georg Kaser (University of Innsbruck, Austria), John Pomeroy and Chris DeBeer (University of Saskatchewan, Saskatoon, Canada).

The workshop addressed four themes: (1) snow hydrology, (2) glacier hydrology, (3) alpine measurements including remote sensing and (4) climate models and downscaling for mountains. Each theme was addressed by a keynote speaker and followed by a moderated discussion, along with topical poster sessions with a fast oral introduction to each poster. Keynote speakers included, respectively, Tobias Jonas (WSL Institute for Snow and Avalanche Research SLF, Davos, Switzerland), Georg Kaser (University of Innsbruck, Austria), Tom Painter (NASA Jet Propulsion Laboratory, Pasadena, US), and Roy Rasmussen (National Center for Atmospheric Research, Boulder, Boulder, US). Discussions on these topics, workshop statements, and future directions are summarized below. A detailed report written by Robert Sandford (Institute for Water, Environment and Health, United Nations University, Hamilton, Canada) is available on the INARCH website (*http://www.usask.ca/inarch/*) and describes all of the presentations and the progression of events.

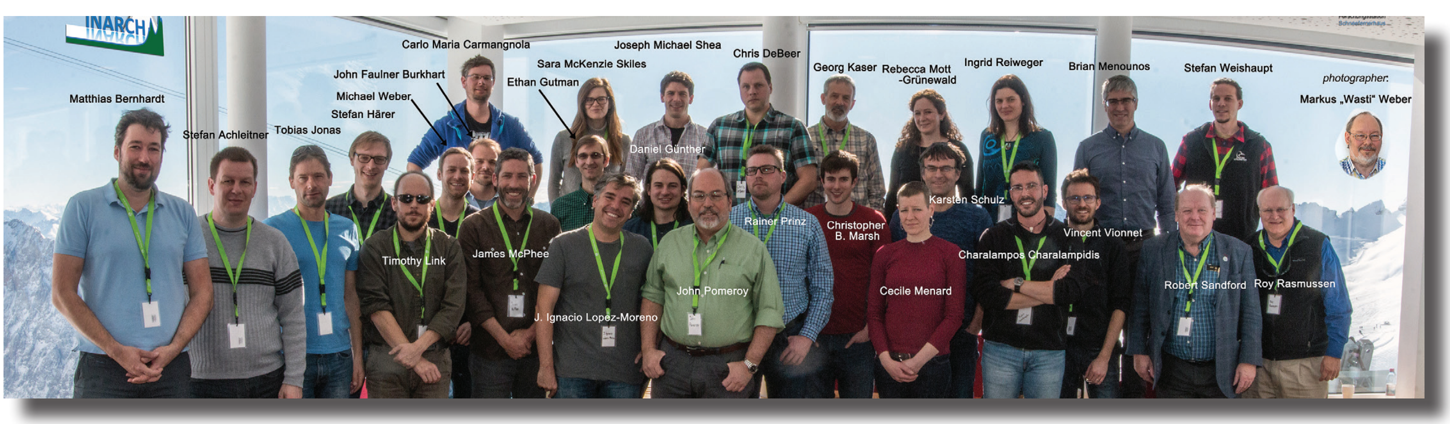
Snow and Glacier Hydrology Discussion

The discussion focused on issues of model input data, model resolution and parameterization, particularly involving the trade-offs between model complexity, computing resources, and the need for different applications; spatial variability and covariance of processes, variables, and fluxes, (e.g., melt energy and snow water equivalent) over multiple scales, and appropriate process representation with proper physics; availability and open access of data and model code; the influences of basin geometry, process sensitivities and responses, and feedbacks; and the need to link this community more closely with the atmospheric modeling community. Specific outcomes from the discussion included:

- Procedures are needed to generate model input data at appropriate scales for the model application—this involves links between atmospheric and surface models.
- There is continued need for detailed validation of individual processes at the process scale.
- Mechanisms are needed to inform large-scale and operational models from small-scale and process advances—advection, vegetation interactions, snow redistribution, human impacts, albedo dynamics, and 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.
- INARCH supports physical realism, not necessarily complexity, in models.
- Temperature index methods are not considered as scientifically appropriate, physically realistic approaches to snow and ice hydrology prediction, although there may be niche/legacy applications.

Key points and statements were:

- More climate sensitivity and vulnerability studies are needed in INARCH that focus on models driven by perturbed or downscaled climate using INARCH basins and data.



Participants at the 3rd INARCH Workshop (photo by Markus Weber).

- INARCH will continue to encourage scientifically appropriate, physically realistic approaches to snow and ice hydrology.

Observations Including Remote Sensing Discussion

This involved topics on data quality and fitness, linking surface observations, remote sensing, and modeling initiatives, the value of LiDAR ground surface and snowpack measurements, even if only obtained once, and different remote sensing platforms and sensors and their various applications. Some of the conclusions were:

- 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—digital surface models from airplanes, drones and satellites.
- Snow water equivalent still cannot be remotely sensed in mountains at scales relevant to the hydrology and hydrometeorology interests of INARCH.
- There is value in extending LiDAR or structure from motion estimates of topography and snowpack surface elevations with and without peak snowpacks for INARCH and other basins.
- There is a need to co-locate remote sensing initiatives and INARCH hydrometeorology basins for joint verification, upscaling, parameter identification, modeling and assimilation advances.
- Data quality should be identified and documented before it is used in atmospheric or surface models. Metadata is of high value in interpreting observations.

A resolution was adopted and some key points were:

- INARCH research basin observational data sets will be proposed to the WMO Global Cryosphere Watch (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 data sets and metadata in the *ESSD* special issue.
- INARCH basins will contribute to future coupled surface and remote sensing observational studies including multispectral missions.

Climate Models and Downscaling Discussion

Issues relating to policy climate model runs, the evolution of climate and atmospheric modeling capability and resolution, and the approaches and needs for various applications in different geographic regions were discussed. Key points included:

- Cases where coarse-scale atmospheric models miss events or fail to generate any precipitation signify a fundamental problem for how to handle such situations for bias correction and downscaling purposes. Regarding this, Roy Rasmussen coined the phrase "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.
- There is a possibility of mountain policy runs—multiple realizations of long-term, high-resolution climate models—with the opportunity to use high resolution weather models nested in climate models. This topic needs exploration and testing.
- Downscaling wind flow over complex terrain can and should employ physically based approaches.

The INARCH statement on this is: Dynamical downscaling is needed to create INARCH mountain policy runs for future climate at scales appropriate for snow and glacier hydrology models.

Future Directions

The deadline for submissions to the INARCH *ESSD* Special Issue is 30 September 2018. The mountain downscaling toolbox portal will soon be completed and posted to the INARCH website at: *http://www.usask.ca/inarch/*. Various important linkages across GEWEX are being pursued, including an LSS-H model comparison and development project that is ongoing and linked to GEWEX-Global Land/Atmosphere System Studies (GLASS) Panel and the GWF RHP, as well as other proposed RHPs. A multiscale climate change vulnerability analysis of cold alpine snow, ice and hydrological systems will be pursued by a collaboration between the University of Saskatchewan and the Spanish National Research Council using the Cold Regions Hydrological Model at INARCH basins. INARCH will also contribute a pre-assessment synthesis article and chapter on high mountains for the Sixth Assessment Report (AR6) report of the Intergovernmental Panel on Climate Change (IPCC). Future INARCH meetings include a convection-permitting atmospheric modeling workshop in Boulder, Colorado, USA on 4-6 September 2018 and a tentative next annual INARCH workshop in Santiago, Chile ahead of the joint GHP-ANDEX meeting in October 2018.

The workshop concluded with a formal statement highlight ing the importance of the observatories, the encouragement of process validation to inform large-scale and operational models, the implementation of hybrid downscaling approaches for mountain regions, and the use of these models to explore future integrated Earth system change in these regions.

Understanding and Modeling Atmospheric Processes: The 2nd Pan-GASS Meeting

Lorne, Victoria, Australia
26 February–2 March 2018

Xubin Zeng[1] and Daniel Klocke[2]

[1]Department of Hydrology and Atmospheric Sciences, University of Arizona, Tucson, Arizona, USA; [2]Hans Ertel Center for Weather Research, Deutscher Wetterdienst (DWD), Offenbach, Germany

Atmospheric processes are important for weather, climate, and water prediction, as well as climate change projection. The 2nd Pan-GASS meeting was held to review the progress in understanding and modeling atmospheric processes and to develop ideas for future projects of the GEWEX Global Atmospheric System Studies (GASS) Panel. The meeting was sponsored by the Australian Research Council's Centre of Excellence for Climate System Science and about 160 participants from around 20 countries, including individuals from government agencies, academia, private sector, and international organizations, attended. For more information about the meeting, see: *http://singh.sci.monash.edu/Pan-GASS/index.shtml.*

The five-day conference included oral presentations, posters, plenary discussions and parallel discussion sessions. The oral presentation sessions covered these topics: shallow and deep convection; clouds, radiation and circulation feedback; new observational efforts; surface drag and momentum feedbacks; next generation modeling; physics-dynamics coupling; polar prediction; microphysics and aerosol interactions; methods for gaining model insight and land-atmosphere interactions.

The parallel sessions discussed seven white papers on the following topics: constraining drag processes, modeling the precipitation diurnal cycle, fog modeling intercomparison, dynamics-physics coupling, joint modeling activity over the Caribbean, land temperature and snowpack impacts on subseasonal to seasonal prediction, and grey-zone modeling.

Looking forward, GASS is proactively pursuing new projects in four theme areas: model physics, high-resolution modeling, dynamics-physics coupling, and prediction. The white papers discussed in the parallel sessions are being considered as six GASS projects. Some of these will be jointly sponsored by GASS and other international programs. The following lists the topic for each proposed GASS project and one of the science questions to be addressed.

Surface drag and momentum feedbacks. Can high-resolution simulations and Large-Eddy Simulations (LES) really be used as a proxy for the truth, and at which resolutions are we fully resolving particular processes?

Modeling the precipitation diurnal cycle. Which subdiurnal processes are most essential for the simulation of the diurnal cycle and subdiurnal extreme events, and how can these be improved in weather and climate models?

Fog modeling intercomparison. What are the key processes governing the development of radiation fog (e.g., aerosol, cloud microphysics, radiation, turbulence, dew deposition)?

Grey-zone modeling (with grid sizes from 100 m to 10 km). What controls the convective mass flux, convective mixing, cloud depth and cloud fraction of shallow cumulus clouds?

Physics-dynamics coupling. How do different models perform when run with different timesteps, and how do changes in behavior relate to climate sensitivities or sensitivities in model tuning?

Land temperature and snowpack impacts on subseasonal to seasonal (S2S) prediction. What is the impact of the initialization of large-scale land surface and subsurface temperature and snow pack, including aerosols in snow and in climate models on the S2S prediction over different regions?

Implementation plans are being prepared for each of these topics to become GASS projects whenever they are ready.

Participants at the 2nd Pan-GASS Conference

2018 GEWEX Open Science Conference: *Extremes and Water on the Edge*

Coast Canmore Hotel, Canmore, Alberta, Canada

Pre-Conference Events and Side Meetings

THURSDAY–SATURDAY, 3–5 MAY 2018

Joint Young Earth System Scientists (YESS) and Young Hydrologic Society (YHS) Early Career Researcher (ECR) Workshop: (By Invitation)
Orchid and Cougar-Grizzly Rooms

Details are available at: *https://www.gewexevents.org/events/2018conference/ecr/*

SATURDAY, 5 May

09:00-12:00 **PLUMBER-2 Planning Meeting** (By invitation) *Wolverine Room*

18:30-21:00 **Community Event with GEWEX Scientists**
Canmore Collegiate High School Theatre and Lobby
Talks by Kevin Trenberth (NCAR), Martyn Clark (NCAR) and John Pomeroy (USASK), followed by a panel discussion and refreshments

SUNDAY, 6 MAY

0630-1730 **Columbia Icefield Tour** (Meet in lobby)

0900-1700 **CLIVAR/GEWEX Monsoon Panel Meeting** (By invitation)
Wapiti Room

1700-1030 **Conference Registration**
Lobby

1900 **Reception**
Wildrose Ballroom

2018 GEWEX Open Science Conference

Preliminary Program

For details on poster sessions and program updates,
see: https://www.gewexevents.org/events/2018conference

MONDAY, 7 May

07:30-09:30	Registration
08:30-10:05	**Opening Plenary**
08:30	Opening and Introduction – Peter van Oevelen (IGPO) and John Pomeroy (USASK)
	Welcome
08:35	– Honorable Stephen Lucas, Deputy Minister of Environment and Climate Change Canada
08:45	– Honorable Shannon Phillips, Minister of Environment and Parks, Government of Alberta
08:55	– John Borrowman, Mayer of Canmore
	Invited Talks
09:05	– The Changing Cold Regions Network—Integrating Disciplines Across Regions to Deliver New GEWEX Science Howard Wheater (USASK)
09:25	Global Water Futures Program and its Science Contributions to GEWEX – John Pomeroy (USASK)
09:45	Extremes and water on the edge: Including the human footprint – Sonia Seneviratne (ETHZ)
10:05	**Lightning Poster Talks (followed by coffee break)**
11:00-12:30	**Morning Parallel Sessions**
	Session 1. Open Session on Water and Extremes Research
	Session 23A. Land-Atmosphere Interactions and Climate Predictability, Including S2S Prediciton *(Continued on Tuesday)*
	Session 9. Energy and Water Budget Closure and Advances in Assessment Techniques
12:30-14:45	**Poster Session 1 (see conference website for schedule)**
12:30-14:45	**Lunch (provided in the Concourse)**
14:45-16:45	**Afternoon Parallel Sessions (followed by coffee break)**
	Session 25. High-Resolution Modeling and Resolved/Permitted Convection
	Session 16. Heat Waves and Heat Extremes in the Past, Present, and Future Climate
	Session 14. The Mountain Water Cycle
17:15-18:15	**Plenary-Extreme Weather in a Changing Climate**
17:15	Water and Extremes from Space – Jin Huang (NOAA/CPO)
17:35	A value chain approach to Extreme Earth – Paolo Ruti (WMO/WWRD)
17:55	Attributing human induced changes in extreme weather – Michael Wehner (LBNL)
18:15	Adjourn

Breakfast and lunch are provided to conference attendees as part of the registration from 7–11 May.
Breakfast is served each day at 07:00

TUESDAY, 8 May

08:30-10:00 Plenary on Extremes

08:30 The WCRP Grand Challenge on Weather and Climate Extremes – Lisa Alexander (UNSW)
09:00 How much information is required to well-constrain local estimates of future precipitation extremes? – Francis Zwiers (Pacific Climate Impacts Consortium)
09:30 Exploiting the climate archives for meaningful events – Bart van den Hurk (KNMI)

10:00 Lightning Poster Talks (followed by coffee break)

11:00-12:30 Morning Parallel Sessions

Session 19. Detection and Attribution of Climate Extremes
Session 23B. Land-Atmosphere Interactions and Climate Predictability, Including S2S Prediction *(Continued from Monday)*
Session 7. Cold Regions Earth System Changes, Including Precipitation Occurring Near 0°C

12:30-14:45 Poster Session 2 *(see conference website for schedule)* **and Lunch provided in the Concourse**

14:45-16:45 CLIVAR/GEWEX Monsoon Panel Meeting (by invitation) Wapiti Room

14:45-16:45 Afternoon Parallel Sessions

Session 18. Addressing the Challenge of Compound Events and Session 26. Documenting Extremes
Session 17. Storms and High Impact Weather
Session 10. Global Energy and Water Cycles, Clouds and Radiation

17:15-18:15 Plenary – Water and Extremes from Space

17:15 Studying Extremes with Satellite Observations: Before, During and After – Jared Entin (NASA)
17:35 ESA Earth Observing Program and Opportunities for GEWEX – Diego Fernandez (ESA)
17:55 JAXA Earth Observing Program and Opportunities for GEWEX – Riko Oki (JAXA)
18:15 Adjourn

WEDNESDAY, 9 May

08:30-10:05 Plenary on Water

08:30 Climate Change and Mountain Hydrology: Results from the Global Energy and Water Exchanges Project – Roy Rasmussen (NCAR)
09:00 Integrating human water management into land surface models – Jan Polcher (LMD)
09:30 Novel approaches for benchmarking – Martyn Clark (NCAR)

10:00 Lightning Poster Talks

11:00-12:30 Morning Parallel Sessions

Session 5. Irrigation Hydrology and **Session 11**. Water Cycle Over the Breadbaskets
Session 21. Climate Extremes, Ecosystems and Society: Impacts, Feedbacks and Emergency Risks
Session 15A. Land-Atmosphere Interactions and Water Cycle over the Third Pole Region *(Continued on Thursday)*

12:30-14:45 Poster Session 3 *(see conference website for schedule)* **and Lunch provided in Concourse**

14:45-16:45 Afternoon Parallel Sessions (followed by coffee break)

Session 20. Droughts in Present and Future Climate
Session 4. Sub-daily Rainfall Extremes and **Session 6.** Changes in Rainfall Intensity and Distribution
Session 2. Regional Hydroclimate Projects

17:15-18:15 Plenary – Land and Water Use in a Changing Climate

17:15 The NEXUS of Land, Food, Energy and Water: Water Management in Global Models – Richard Harding (CEH)
17:35 Land and water management in Earth System Models: Opportunities and challenges – David Lawrence (UCAR)
17:55 Adjourn

19:30 Conference Dinner (Keynote: Alan Betts)

THURSDAY, 10 May

08:30-10:05 Plenary on GEWEX Panels

08:30 GEWEX Hydroclimatology Panel (GHP) – Jason Evans (UNSW)/Joan Cuxart (UIB)
08:50 GEWEX Data and Analysis Panel (GDAP) – Rémy Roca (OMP/LEGOS)/Tristan L'Ecuyer (UW-Madison)
09:10 Global Land/Atmosphere System Study (GLASS) – Gab Abramowitz (UNSW)/Michael Ek (NCAR)
09:30 Global Atmospheric System Studies (GASS) – Xubin Zeng (U. Arizona)/Daniel Klocke (DWD)
09:50 Discussion

10:00 Lightning Poster Talks (followed by coffee break)

11:00-12:30 Morning Parallel Sessions

Session 24. Benchmarking and Metrics
Session 3. Evapotranspiration Determination and **Session 22**. Soils in Water and Climate Models
Session 15B. Land-Atmosphere Interactions and Water Cycle over the Third Pole Region *(Continued from Wednesday)*

12:30-14:45 Poster Session 4 *(see conference website for schedule)* **and Lunch provided in the Concourse**

14:45-16:45 Compound Events Side Meeting (by invitation) *Wapiti Room*

14:45-16:45 Afternoon Parallel Sessions (followed by coffee break)

Session 8. Modeling for Extremes
Session 12. Satellite Observations for Extremes, Water Cycle Processes and Land-Atmosphere Interactions
Session13. The Human–Climate-Water Nexus, Climate Change and Water Security

17:15-18:15 Plenary on Land Based Predictability

17:15 Title TBA – Andrew Pitman (TBC)
17:35 On the relevance of diurnal cycle model improvements to represent climate extremes – Gianpaolo Balsamo (ECMWF)
17:55 Confronting forecast models, reanalyses and land surface models with global remote sensing estimates of land-atmosphere coupling – Paul Dirmeyer (GMU)
18:15 Adjourn

Friday, 11 May

08:30-10:00 Plenary on Early Career Researchers

08:30 Why tracking the Earth's energy imbalance is an imperative – Kevin Trenberth (NCAR)
09:00 Results from Early Career Researcher (ECR) Workshop and ECR Competition Prizes – YESS/YHS

10:15-11:15 New Activities in GEWEX

10:15 A comparison of functional descriptions for estimating hydraulic and thermal properties in land-surface models: implications for the energy and water balance – Anne Verhoef (U. Reading)

10:30 ANDEX, A Hydroclimate Research Program for the Andes and a Prospective GEWEX Regional Hydroclimate Project (RHP) – Germán Poveda (UNAL)

11:15-12:45 Closing Plenary

11:15 Interactions between the water and carbon cycles – Eleanor Blyth (CEH)

11:45 Future strategic directions for WCRP – Guy Brasseur (WCRP)

12:15 The ever increasing importance of international research collaboration in climate sciences – Peter van Oevelen (IGPO)

12:30 GEWEX progress, challenges and opportunities – Graeme Stephens (NASA-JPL)

12:45 Conference Adjourns

12:45-14:30 Lunch provided in Concourse

14:30-17:30 Side Events

Knowledge Action Network on Extremes
Water for Food Baskets and Regional Hydroclimate Projects for the Americas

2018 GEWEX Open Science Conference

Venue Map for
Coast Canmore Hotel and Conference Centre