GEWEX NEWS

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New Snow Water Equivalent Dataset over the US Will Aid Climatological Snow Studies

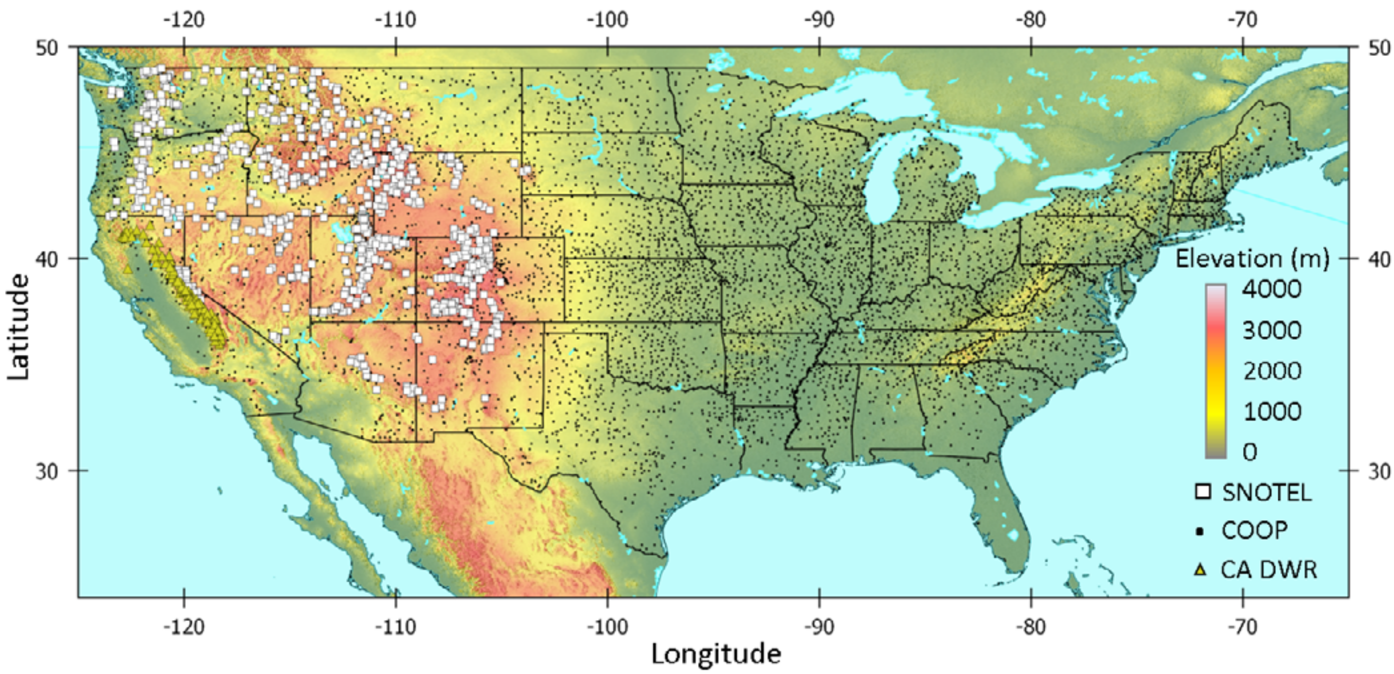

Figure 1 shows snow stations used in the creation of the new University of Arizona (UA) snow water equivalent (SWE) dataset. The stations belong to three networks: the National Resource Conservation Service Snow Telemetry (SNOTEL) network, the National Weather Service Cooperative Observer (COOP) network, and a network of snow stations operated by the California Department of Water Resources (CA DWR).

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Human Influence on the Water Cycle: A New Frontier for GEWEX

Jan Polcher
Co-Chair, GEWEX Scientific Steering Group

We owe it to society to answer the question of which part of the changes in the global water cycle can be explained by climate change and which are attributable to human water management. Modifications in water resources, a component of the continental branch of the water cycle, can either be the consequence of a warmer world or caused by water and land management practiced to increase agricultural productivity or satisfy industrial and domestic needs. I believe that separating both drivers will be an exciting challenge for the GEWEX community and I would like to present here how we could tackle this in the coming years.

Detecting and attributing the observed changes in the various components of the water cycle will be much more challenging than it has been for temperature. First of all, changes in the water cycle can have two distinct causes that need to be separated, as their evolution in the future will be different and the ability of our societies to mitigate or adapt to them are quite dissimilar. Secondly, the unintentional (climate warming driven) and intentional changes to the water cycle will interact over the continents.

At first order, we can assume that over oceans and in the free atmosphere, the past changes in the water cycle are dominated by the warming climate and our ability to attribute them will be conditioned by our ability to predict the natural and unperturbed system. Over continents and in the lower atmosphere, the observed modifications in the water cycle will have been caused by a combination of warming and anthropic modifications of water and land use. The relative weight of both changes will vary strongly from one region to another. In order to disentangle both effects and be able to predict the future water resources, we will need better observations and predictive capabilities for both processes.

There is ample evidence that in a warmer climate, many rainfall characteristics will be modified. This ranges from the amplitude and phase of the annual cycle to the intensity of rainfall events. Evaporation will also be affected as the demand from the atmosphere is likely to become more intense. Our community has established that modifying land cover or increasing evaporation through irrigation will affect the lower atmosphere and in some cases even rainfall events. At the moment, these climate warming and water and land use sensitivities have been studied independently.

In the real world there is an interaction between both. In a dry year, farmers will apply more irrigation if possible. If the situation repeats itself, the crop could be abandoned in favor of a more resilient agricultural product. Should the snow amounts in the mountain decrease, more of the runoff will be stored in reservoirs in order to maintain evaporation during the entire growing season. If warming increases the water demand of plants, the farmers will request that more resources be used for irrigation. This interplay between the evolving atmospheric water cycle and societal water usage has driven past changes and will shape the situation under climate change. The GEWEX community needs to better understand these interactions to be able to attribute the causes of past change and predict future water resources.

To make progress in this direction, we will require more observations of the interactions between climate and water usage over regions where these can be assumed to be dominant. These are obviously the food baskets of the world, where water management for agriculture is essential. We should envisage dedicated field campaigns, such as the European community is currently planning with the new Land Surface Interactions with the Atmosphere over the Iberian Semi-Arid Environment (LIAISE) project (See Boone et al., page 8 of *GEWEX News*, Quarter 1 2019). Other regions such as the western United States would also be excellent candidates to observe and further our understanding of these processes. A global observing strategy will also be required. The planned Surface Water Ocean Topography (SWOT) mission will give us access to lake and reservoir levels. First estimates of irrigation amounts derived from space observations of surface soil moisture also offer excellent prospects.

Land surface models (LSMs) will provide an important contribution to solving this problem, but first representations of the interactions between human processes and land/atmosphere fluxes will need to be included. This will be a major development as it requires us to introduce non-physical processes, but it will lead to more consistency within the models. For instance, most LSMs today consider land use changes for a correct representation of the carbon cycle, but neglect the anthropic water supply, which is often needed. It is an open question if the approaches to modeling water management developed by hydrologists will be applicable when coupled to climate models and whether or not they are usable for future climate scenarios. Perhaps the approach proposed by the community of hydo-economists, which is based on the balance between supply and demand while minimizing costs, will be more suitable in our case. I believe all options need to be tested and it opens exciting perspectives for model developments.

Understanding the various processes which drive the water cycle in the three components of the Earth system is the raison d'être of GEWEX. Adding those processes which govern the relation between the climatic water potential and its usage by society will be a captivating challenge and an original contribution to WCRP. It will produce knowledge and understanding that will be of value to a much wider community and will require that we collaborate with other communities dealing with water resources. It is a true multidisciplinary problem.

A New Initiative to Seamlessly Integrate Climate Change Education with the Core Curriculum

Shipra Jain, Gaby Langendijk, Anita Nagarajan, Marisol Osman and Valentina Rabanal
On Behalf of the YESS Community

Shipra Jain and Kinley Choden during the TROP ICSU workshops in India (left) and Bhutan (right), respectively.

The Young Earth System Scientists (YESS) community has recently partnered with the Trans-disciplinary Research Oriented Pedagogy for Improving Climate Studies and Understanding program (TROP ICSU, *https://tropicsu.org*) for the review and dissemination of teaching materials that are being developed under this project. TROP ICSU, a global project funded by the International Science Council (*https://council.science*), aims to integrate climate change into the core educational curriculum across various disciplines. The main objective is to provide instructional resources for educators in schools and colleges (high school to undergraduate level) to impart better knowledge of the science of climate change. The pedagogical resources being produced will also help any educators associated with core climate change research communities, like GEWEX, to seamlessly merge climate change knowledge into the classroom, which will play an instrumental role in sensitizing the students towards the implications of a warming world.

The Early Career Researchers (ECRs) from the YESS community study multidisciplinary areas including science, mathematics, geophysics, economics, governance and more that are directly or indirectly related to the subject of meteorology and climate change. Feedback from ECRs on the educational resources will lead to enhancing their quality, scientific correctness and appropriateness. The teaching tools and lesson plans that are being curated and developed are freely available.

Under this partnership, the YESS reviewers will also receive an acknowledgement certificate from TROP ICSU as recognition for their time and efforts. This collaboration will not only help TROP ICSU in the scientific validation of its tools, but will also help the ECRs to raise their scientific profile. YESS Executive Committee member Dr. Shipra Jain attended the TROP ICSU pilot workshop in New Delhi, India in October 2018 and recently, YESS South East Asian member Kinley Choden joined one of its regional workshops in Thimphu, Bhutan. There are several other workshops coming up in Pretoria, Cairo, Beijing, Melbourne and Adelaide.

If you are an ECR and interested in reviewing some of TROP ICSU's tools, get in touch with the YESS community (*https://www.yess-community.org*, contact@yess-community.org).

Summer Plans for H3S

Caitlyn Hall
AGU H3S Chair

The American Geophysical Union's (AGU) Hydrology Section Student Subcommittee (H3S) will be highlighting the research of early career scientists and students this summer on Twitter (@AGU_H3S) and Instagram (@AGU_H3S). If you want to highlight your work or know someone who would be interested, we will be posting these using #hydrosummer. We also invite researchers to do a week-long Instagram and Twitter takeover. If you would like to take part in this, please email H3S.AGU@gmail.com or Caitlyn Hall at caitlyn.hall@asu.edu.

H3S will also be carrying out its annual Haiku Your Research event on Twitter (@AGU_H3S) from May to September! Tag your entry with #HaikuYourResearch. The most re-tweeted haikus will win prizes that will be distributed at the 2019 AGU Fall Meeting in San Francisco.

Article Submissions to *GEWEX NEWS*

Do you have an idea for a *GEWEX News* article on scientific research results or other information related to GEWEX activities? E-mail us at *gewex@gewex.org* with your suggestion. Contributions of 1-2 pages (800-1600 words) are sought, and we require at least one figure or image. The graphic should be sent as a separate, high-resolution file, and not be embedded in your document.

New GEWEX Scientific Steering Group Members

We welcome three new GEWEX SSG members.

Gabi Hegerl is professor of climate system science at the University of Edinburgh, UK. Her scientific work focuses on identifying the drivers and mechanisms of observed climate change, including attributing causes to changes in global temperature and rainfall patterns, and attributing changes in the intensity and frequency of extreme events. She is also interested in using observed changes to constrain predictions of future climate change and climate system parameters, such as climate sensitivity. Gabi is also co-lead of the World Climate Research Programme's Grand Challenge on Extreme Events, and has contributed extensively to the Intergovernmental Panel on Climate Change (IPCC) assessments.

Christian Jakob is the Professor for Climate Modeling at Monash University. His career has focused on advancing our understanding of the role of the tropics in the Earth's energy and water cycles. He develops new approaches for the representation of tropical convective systems in weather and climate models. Before joining academia, he held positions at the European Centre for Medium-Range Weather Forecasts and the Australian Bureau of Meteorology. He is a past co-chair of the World Climate Research Programme's Modeling Advisory Council and was a lead author on the IPCC's 5th Assessment report chapter on climate model evaluation. He has a long-standing connection to GEWEX, having served as the Chair of the GEWEX Cloud System Study and the GEWEX Modeling and Prediction Panel in the past.

Professor Dr. Zhongbo (Bob) Su is holder of the Chair of Spatial Hydrology and Water Resources Management and Chairman of Department of Water Resources in the Faculty of Geo-Information and Earth Observation (ITC) of the University of Twente, The Netherlands. His scientific interests include remote sensing and numerical modeling of land surface processes and interactions with the atmosphere, Earth observation of water cycle and applications in climate, ecosystem and water resources studies and monitoring food security and water-related disasters.

A 35 Year Dataset for Climatological Snow Studies over the Conterminous US

Patrick Broxton[1], Xubin Zeng[2] and Nicholas Dawson[3]
[1]School of Natural Resources and the Environment, University of Arizona, Tucson, Arizona; [2]Department of Hydrology and Atmospheric Sciences, University of Arizona, Tucson, Arizona; [3]Idaho Power Company, Boise, Idaho

Snow is one of the most important land surface variables for regulating land-atmosphere interactions, and it represents important hydrologic storage that serves as a water supply for billions of people and countless ecosystems across the world. Despite recent advancements in the observation and modeling of snowpack, there is still great uncertainty about the amount of snow in many areas. Satellite remote sensing of snow water equivalent (SWE) is limited by coarse resolutions as well as issues that affect the quality of the measurements. Point observations of snow offer high quality measurements, but due to the extreme spatial heterogeneity of SWE, can be poor indicators of the amount of snow in the surrounding landscape. This uncertainty in snow data contributes substantially to snow modeling uncertainties, which are especially high in mountains and forests, where water supply depends critically on snowpack.

To better quantify the amount and distribution of SWE across the conterminous United States (CONUS), we have recently developed an observation-based snow dataset to address the challenge of linking point measurements to gridded data. The dataset, called the University of Arizona (UA) SWE product over CONUS (Broxton et al., 2016a,b), is based on the interpolation of snow data from thousands of snow stations across CONUS (Figure 1, on cover), and gives daily values of SWE and snow depth at ~4 km resolution across CONUS since 1981. Our interpolation technique, by which we interpolate station SWE data normalized using a background SWE field generated with Parameter Elevation Regression on Independent Slopes Model (PRISM) climate data, is robust and consistent. It not only produces much smaller differences than other interpolation methods using SWE itself (Broxton et al., 2016a), but it also gives similar results regardless of whether a small or large number of stations are used for the interpolation (Broxton et al., 2016a,b). In addition, it includes a novel snow density parameterization (Dawson et al., 2017) to convert between SWE and snow depth.

The resulting dataset is consistent with the best-available operational snow estimates for CONUS (Broxton et al., 2016b), yet produces high quality SWE and snow depth estimates going back to the early 1980s. Furthermore, despite incorporating no satellite data in its development, it does a good job reproducing satellite-measured snow cover extent data over CONUS (Dawson et al., 2018). Also, it has been shown to perform better than the operational snow monitoring data against airborne LiDAR-based snow depth retrievals (currently the best available technology to make distributed measurements of snow depth in mountain forests) over a river basin in California, which has had multiple years of repeated LiDAR observations (Dawson et al., 2018). The good comparison between the UA SWE data and LiDAR-based snow depth data and satellite snow-cover data demonstrates that it is an effective product to bridge the scale gap between LiDAR (<100m grid spacing) and remotely-sensed (>25km grid spacing) snow data.

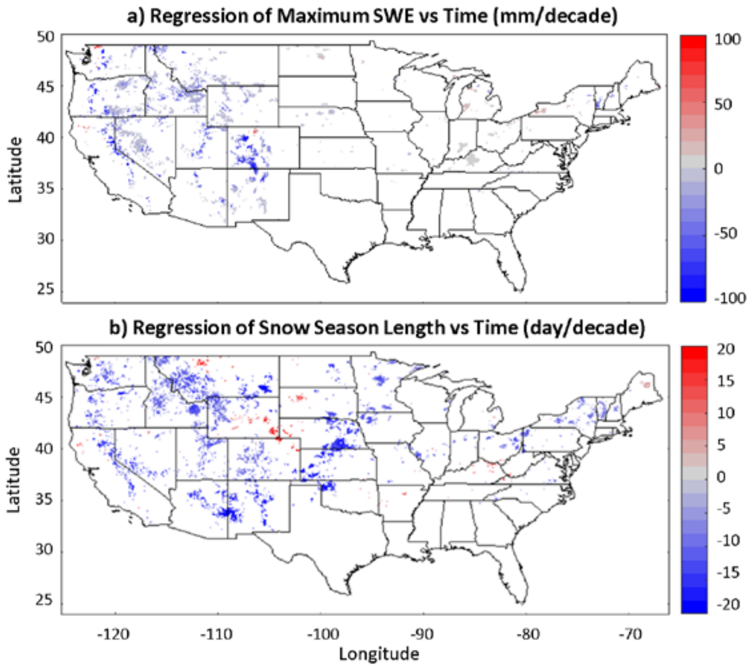

Figure 2. Linear Trends of a) Maximum SWE and b) Snow Season Length from 1982–2016. Insignificant trends based on student t-test (p > 0.05) are shaded white as are pixels with average maximum SWE < 10 mm and pixels with snow season length < 30 days.

This dataset has enabled us to gain a new perspective on the ability of models and satellite snow data products to represent SWE. We have evaluated a variety of satellite-based products, reanalysis products and global land data assimilation systems over CONUS (Broxton et al., 2016b, 2017; Dawson et al., 2016, 2017, 2018) and found that they can deviate substantially from the UA SWE product. The most common problem is that they tend to underestimate SWE in snowier regions (e.g., the mountains of the western US) for a variety of reasons, such as incorrect partitioning between rainfall and snowfall or snow ablation that proceeds too quickly (Broxton et al., 2016b). This uncertainty with how snow is represented in models poses a particular challenge for weather and climate forecasting systems as the snowpack can affect other forecast model quantities. For example, we found that biases in a variety of quantities in seasonal forecast model simulations in the Climate Forecast System (CFS) occurred simply because SWE was initialized at too low a level (Broxton et al., 2018).

The UA SWE product's long temporal record (beginning in 1981) also allows, for the first time, the detection of SWE changes since the early 1980s across CONUS. In general, annual maximum SWE did not show a significant trend from 1982–2016 over most of the areas. However, both maximum SWE and snow season length decreased significantly during this period for some areas, particularly over the western US (Zeng et al., 2018; Figure 2). Over the eastern US, trends in SWE were much smaller and can largely be explained by changes in temperature, whereas in the western US, SWE changes are linked to changes in both temperature and precipitation. Overall, annual maximum SWE decreased significantly by 41% on average for 13% of snowy pixels over the western US, and the snow season was shortened significantly by 34 days on average for 9% of snowy pixels over CONUS. This decline was primarily due to later arrival of the snow season in the eastern US and earlier ending of the snow season in the western US.

This dataset is now available for download from the National Snow and Ice Data Center (NSIDC) to help investigators study scientific problems related to seasonal snowpack (*https://nsidc.org/data/nsidc-0719*; doi: 10.5067/0GGPB220EX6A). It will be updated annually based on the availability of finalized input datasets (which have a lag time of ~6 months). These data will be useful for assessing the ability of Earth system models to reproduce historical snowpack variability and trends. The fact that it provides daily SWE and snow depth data for more than 35 years means that it can be used to provide a more comprehensive and quantitative measure of the performance of global SWE products over a longer period and over a larger area than was possible in the past. In addition, these snow data can be used as input to various hydrological models (e.g., seasonal streamflow projections for water supply modeling). We would like to thank staff at NSIDC for assisting the transition of our data to NSIDC for open access and thank the National Aeronautics and Space Administration (NASA) Modeling, Analysis, and Prediction (MAP) and Soil Moisture Active Passive (SMAP) Programs for the support.

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Meeting/Workshop Reports

Water in the Anthropocene: Predicting How We Interact with Our Modified Environment

Canberra, Australia
31 January–1 February 2019

Seth Westra[1] and Albert van Dijk[2]
[1]University of Adelaide, Adelaide, Australia; [2]Australia National University, Canberra, Australia

In predicting the trajectory of future climate, water and ecosystems, we can no longer ignore the many ways in which human feedbacks modify our natural systems.

The 5th National OzEWEX Workshop explored how well we understand stores and fluxes of water and energy at the landscape scale subject human influences including greenhouse gas emissions, landscape, soil and vegetation modification, water extraction and river regulation. The topic was approached not only from a biophysical perspective, but also social, economic, ecological, engineering and policy standpoints.

The workshop was held at the Australian National University in Canberra on 31 January and 1 February 2019, and was divided into three themes. It coincided with the culmination of the 3rd Australian Climate and Water Summer Institute, where 18 early career researchers worked in teams on a variety of projects over a period of six weeks.

Theme 1: Dynamics of Human-Environmental Interactions

The workshop first reviewed how the environment is modified by human actions, and how human behaviors in turn respond to changes in the environment. The presentations were kicked off by Stuart Bunn, the Director of the Australian Rivers Institute, who described both the research and planning implications of the Anthropocene on how we manage our water. Stuart emphasized how important it is for science to focus on solutions and discussed the imperative for society to better balance water needs for humans and nature, address water pollution, restore connectivity and provide a balanced voice in the public discourse on water.

Colin Mues from the Murray Darling Basin Authority reflected on Australia's rich history of policy development in the nation's largest and most contested watershed, and the need to continue the work into the future. Two key messages involved ensuring adaptive management to allow for continual learning and developing an improved understanding of how climate change may influence environmental resilience, water quality, agricultural productivity and various other water management issues in the Basin. Jamie Pittock from the Australian National University also framed his presentation through a review of the history of water reform in Australia, and called for greater transparency in water-related decisions, stressed the need to recover additional water to achieve measurable improvements to environmental outcomes, and advised that we must prepare for the prospect of a future with less water.

One feature of the Murray-Darling Basin is the presence of water markets, in which ownership of water has been separated from ownership of land, meaning that farmers and other parties can buy and sell water as part of a sophisticated water trading regime. Sarah Wheeler of the Centre for Global Food and Resources at the University of Adelaide spoke about behavioral responses of farmers to water markets, and Tom Rooney, Chief Executive of water trading company WaterFind, delved into the complex world of water market dynamics. Tom highlighted that his company alone has facilitated the transfer of 3000 GL of water across 22,000 transactions, representing a value of about $1 billion and more than a quarter of mean annual water use across Australia. The dynamics of the markets in terms of changes to water pricing and the function of derivative markets in water trading provided a fascinating insight into how these sorts of markets will become increasingly relevant for understanding Basin-wide water stores and fluxes.

The changing evolution of landscapes in response to climate was raised by Holger Maier of the University of Adelaide, who presented on scenario-based approaches for capturing landscape dynamics, pointing out that land use is critical in linking human and natural systems and that this requires understanding the spatial and temporal dynamics of land use change. By providing land-use dynamics platforms, this then can be coupled to other models to understand feedbacks and explore plausible future scenarios. The Unified Natural Hazard Risk Reduction Exploratory Decision Support System (UNHaRMED) was given as an example of how this framework can be applied for understanding adaptive responses to natural hazard risk.

The effects of human actions on the environment take many forms. Michael Liddell from James Cook University spoke about relative climate and human impacts on humid tropics ecosystems. Shaun Levick from the Commonwealth Scientific and Industrial Research Organization (CSIRO) presented on a similar topic in the context of savannah ecosystems, including the importance of climate and water in driving fire regimes, the carbon cycle and ecology. Both highlighted significant human impacts that included a broad range of drivers, and suggested that the link between climate and humans often was subtle, with complex feedbacks and non-linear dynamics.

Craig Simmons of the National Centre for Groundwater Research and Training and Flinders University gave an inspiring presentation that focused on groundwater challenges and opportunities. He called attention to the importance of a national water strategy that linked a broad set of disciplines to focus on significant problems. Understanding the interface between water research and other parts of the system was highlighted as critical, with the food-energy-water nexus being a key challenge for the 21st century. Neil McIntyre from the University of Queensland then spoke about the water-energy-climate nexus from a mining perspective, noting that even though mining consumes relatively little water when considered from a national or global perspective, water consumption is highly significant in the semi-arid and arid regions where mining frequently occurs. In mine operations, there is also often a significant tradeoff between energy and water, with greater levels of water efficiency requiring higher levels of energy and vice versa.

Theme 2: Implications of Climate Change–The Long View

The Millennium Drought, which occurred in the first decade of the millennium, was one of the worst droughts to occur in Australia since European settlement. Francis Chiew from CSIRO reflected on what might happen if the drought was to reoccur, given the significant changes that have occurred in the Basin even over the last decade. Since climate projections generally point at a decline in water availability in the Murray-Darling Basin, he raised the question of how to manage the balance between consumptive water and environmental water under the scenario of ever-decreasing total water availability.

Fiona Johnson from the University of New South Wales then talked about climate change, water and—critically—of considering people in dealing with water challenges, emphasizing the need for knowledge in history, culture, politics, economics and inter-disciplinary communication to supplement more technical skills. Lastly, Yongqiang Zhang from CSIRO spoke about the role of urbanization in changing surface energy and water balances, and considering various measures to improve urban resilience through improving surface and groundwater connectivity.

Theme 3: Data, Modeling and Information Services

Robert Argent, General Manager of Water at the Bureau of Meteorology, spoke about how Australian water information services are changing water management. Argent underscored the data value chain and moving along the spectrum from data to information to insight, with the latter enabling additional focus on key societal questions such as "how," "why" and "so what?" The outcomes of these services include more timely and evidence-based decisions, greater trust and more support for investment prioritization.

Tony Jakeman of the Integrated Catchment Assessment and Management Centre at the Australian National University described the role of human decision-making in hydrologic predictions and assessment. Key messages were the importance of accommodating uncertainty from the outset, the role of models (not just prediction, but also building knowledge, trust and capacity) and the obligation to embrace subjectivity and think cleverly about quantitative and qualitative uncertainty methods. Many of these sentiments were echoed by Geoff Podger from the private company Water Bubly, who spoke about human feedbacks in river management modeling, including the significant need to manage trade-offs in terms of issues, priorities and stakeholders. Models can be used to provide robust and defensible evidence to support negotiations.

Claire Krause from Geoscience Australia demonstrated the role of remote sensing for trusted and transparent water management, with emerging technologies capable of estimating the water content in relatively small farm dams. Mark Thyer from the University of Adelaide spoke about seasonal streamflow forecasting for water management, with a strong emphasis on accurately representing modeling uncertainty. A key message of the presentation was the role of passionate humans and partnerships in ensuring that scientific research is translated into national-scale impact. Staying on the theme of remote sensing, Ashish Sharma from the University of New South Wales presented research on measuring river discharge through satellite-based passive microwave remote sensing and spoke about the potential to improve our ability to detect flood signals in ungauged basins.

Chantal Donnelly, Unit Head of Water Resources Modelling at the Australian Bureau of Meteorology, discussed ways of incorporating human activities into large-scale water models such as the Australian Water Resources Assessment (AWRA) modeling system. After reviewing how human decisions such as irrigation and reservoir operations are included in global and continental scale modeling, she finished with a roadmap of improvements to the AWRA system to the year 2021 and beyond. On a similar theme, Annette Hirsch of the Australian National University spoke about including water management in climate models, emphasizing the opportunities afforded by higher-resolution remote sensing and modeling. She concluded that embedding hydrological models into climate models can lead to significant improvements in representing land-atmosphere interactions. Lastly, Marcus Thatcher from CSIRO spoke about the potential of high-resolution climate model simulations using the Cubic Conformal Atmospheric Model to understand local scale convective rainfall effects in regions with complex topography or experiencing urban-scale land-use change.

Australian Climate and Water Summer Institute Presentations

A highlight of the workshop was the project presentations from the Australian Climate and Water Summer Institute research fellows. Project topics included understanding links between fuel moisture, soil moisture and vegetation type; an intercomparison of machine learning methods for estimating continental carbon and water fluxes; quantifying wetland volume change in the Murray-Darling Basin using remote sensed data; characterizing hydrological uncertainty using rainfall ensembles; understanding post-bushfire streamflow response dynamics; and the links between blue-green algae and water temperature.

Participants of the Australian Climate and Water Summer Institute

UCP2019: Understanding Clouds and Precipitation

Berlin, Germany
25 February–1 March 2019

Daniel Klocke[1], Wiebke Schubotz[2], Allison Wing[3], Bjorn Stevens[2], Ulrich Löhnert[4] and Andreas Macke[5]

[1]Hans Ertel Centre for Weather Research, Deutscher Wetterdienst, Germany; [2]Max Planck Institute for Meteorology, Hamburg, Germany; [3]Florida State University, Tallahassee, Florida, USA; [4]University of Cologne, Cologne, Germany; [5]Leibniz Institute for Tropospheric Research, Leipzig, Germany

The international scientific community working at the forefront of advancing the understanding of clouds and precipitation through observing, modeling and theory gathered in Berlin during the last week of February 2019. The Understanding Clouds and Precipitation (UCP) Conference was the second of its kind, following the 2016 meeting in the same location. The conference was organized as part of the WCRP Grand Science Challenge on Clouds, Circulation and Climate Sensitivity and the German National Project High-Resolution Clouds and Precipitation for Climate Prediction [HD(CP)^2] to discuss recent progress and coordinate future activities. The event also marked the end of HD(CP)^2, which was funded by the German Ministry of Education and Research over the last eight years. The meeting was attended by 220 participants from 16 countries, with about half of the participants from Germany, linking the national and international community of atmospheric researchers.

Clouds, through their influence on radiative transfer, help determine Earth's energy budget and its susceptibility to perturbations. In addition, convection and its associated precipitation influence the dynamics of circulation systems, especially in the tropics. Increasingly, cloud radiative effects are recognized as an additional mechanism for organizing circulation systems. The meeting brought together a rich diversity of approaches to address gaps in our understanding of clouds, ranging from laboratory studies, storm resolving and large-eddy resolving simulations, large-scale modeling studies, simple conceptual models, as well as new observational networks and observational programs that are integrating community efforts. The conference grouped research into five themes, summarizing the approaches for improving understanding of clouds and precipitation:

- Looking toward global storm-resolving climate simulations
- Insights on clouds and precipitation from recent and planned field studies
- Technical advances for simulating, computing and observing clouds and precipitation
- Coupling of aerosols, clouds and precipitation to circulation systems or the environment
- Progress in understanding and representing unresolved processes in storm-resolving simulations

The oral presentations were grouped in thematic sessions on separate days. Each session started with a keynote presentation to introduce and drive the themes. Masaki Satoh (University of Tokyo) and Christoph Schär (Eidgenössische Technische Hochschule Zürich) discussed global storm-resolving simulations, Christopher Bretherton (University of Washington) and Susanne Crewell (University of Cologne) introduced new insights from observational campaigns, Peter Düben (European Centre for Medium-Range Weather Forecasts, ECMWF) and Mike Pritchard (University of California, Irvine) started the session on technical advances for understanding clouds and precipitation, Cathy Hohenegger (Max Planck Institute for Meteorology) and Aiko Voigt (Karlsruhe Institute of Technology) set the scene for presentations on circulation and cloud interactions and Irina Sandu (ECMWF) introduced the topic of unresolved processes still relevant for storm-resolving models.

With the first theme, the conference offered a look into the future of climate modeling. Several presentations demonstrated that global storm resolving modeling–with employed grid spacings of 4km or less–is emerging as a practical tool that can be applied to important questions related to clouds and precipitation and their role in the climate system. Results from the first global storm-resolving model intercomparison project (Dynamics of the Atmospheric general circulation Modeled On Non-hydrostatic Domains, DYAMOND) were presented by several conference participants. Nine models simulated for the first time the same period of 40 days and 40 nights. The hope is that some of the uncertainties in the sensitivity of Earth's climate, where convective clouds play a dominating and stubbornly frustrating role for climate scientists, could be reduced. The initial results show that this hope has some merit and that this new class of models might lead the community to scientific breakthroughs when runs can be performed on centennial time scales in the future. Instead of using global models and subsequently reducing their horizontal resolution, another approach was presented in which realistic large-eddy simulations are performed over limited but increasingly larger domains. This route was, for example, followed by the above mentioned HD(CP)^2 project, which produced many results presented by conference attendees. High-resolution modeling also facilitates the link to the real world, where observations often represent the smaller scale dynamics that models are now beginning to resolve.

In the context of the second topic, planned and recent field studies were presented. One anticipated experiment discussed in several conference contributions is the Elucidating the Role of Cloud-Circulation Coupling in Climate project (EUREC4A). This field study is an international effort, born out of a French-German initiative to support the World Climate Research Programme's Grand Science Challenge on Clouds, Circulation and Climate Sensitivity. The experiment will focus on shallow cumulus clouds and their environment in early 2020 east of Barbados. Several aircraft and ships will help to identify the drivers of variations in shallow cloud amounts, the factors controlling the various degrees of spatial organization and the implications for Earth's radiation balance with the response of shallow cumulus clouds to warming. Another observational backbone to climate questions and the role of clouds in particular are the longer term national initiatives to continuously monitor the climate system. A new initiative in this context was the Ruisdael Observatory in The Netherlands. This observatory will cover The Netherlands at a spatial resolution of a hundred meters and will be merged in real time with atmospheric models. The goal is to form a virtual laboratory to study multi-scale processes in atmospheric physics and chemistry and ultimately improve weather and climate models.

The topic on technical advances for understanding the role of clouds and precipitation emphasized machine learning as an emerging method in the field. Several talks demonstrated that many aspects of the science could be addressed with machine learning approaches. Presentations demonstrated the potential to learn parameterizations by training deep neural networks, showcased the use of artificial intelligence to probe the inputs and outputs of existing parameterizations and highlighted how computationally expensive parts of the model could be replaced by faster algorithms. Others showed how organizational structures of shallow convection can be identified in satellite data sets spanning many years after creating training data sets by having scientists classify cloud organizational structures into cloud patterns resembling fish, gravel, sugar and flowers in a subset of satellite images. It became clear from the presentations that the atmospheric sciences community is still figuring out how best to use data-driven machine learning, but promising and exciting new approaches to cloud-related questions are emerging.

A major topic in the theme of the coupling of clouds, aerosols and precipitation with their environment was mechanisms of organization of convection and clouds and the role they play in climate. This topic has established itself very much as a central focus of research in recent years and has led to the organization of an intercomparison project of models configured in the idealized radiative-convective equilibrium (RCEMIP) setup. The goal is to determine the role of convective self-aggregation in climate and climate change, assess mechanisms for changes in convective clouds with warming and to determine the robustness of the radiative-convective equilibrium state across the multi-model ensemble. The ensemble is unique in its incorporation of large-eddy resolving models, storm-resolving models, global storm-resolving models, general-circulation models and single column models.

Participants of the 2019 Understanding Clouds and Precipitation Conference

The fifth topic focused on approaches to improving the parameterization of unresolved processes. Even global large-eddy resolving models with horizontal grid spacing of about 100m, which might be possible at large scales in the future, would still have to include sub-grid representations of processes like cloud microphysics, radiation and turbulent mixing. Laboratory studies with cloud chambers showed how experience from controlled experiments of the formation of cloud droplets on cloud nuclei could be used to improve microphysics parameterization. Another approach to improve cloud physics is benchmark simulations with Lagrangian bin microphysics simulations. Several talks presented complex bin schemes, which now can be applied to a wider set of cases with the increasing availability of computing power.

The overall conference keynote presentation was given by Sandrine Bony (French National Center for Scientific Research, CNRS), tying the topics together in the context of achievements during the WCRP Grand Challenge on Clouds and Circulation over the last couple of years and the initiatives, such as EUREC4A, that have arisen from it. The Grand Challenge was articulated around four questions related to the role of cloud feedbacks and convective organization in climate, the factors that control the tropical rain belts and the extra-tropical storm tracks. The great achievement of the Grand Challenge on Clouds and Circulation is that clouds and convection are viewed and interpreted in the context of their environment and not in isolation, which is manifest in the conference program and presentations.

The conference was organized to allow as much room as possible for interaction among the participants. Most attendees stayed at the conference venue where all meals were provided, maximizing the chances for interaction. Posters were sorted randomly, rather than by topic, and each poster was displayed for two days, so that it was easier for presenters to visit posters of the same topic during the week. Cloud-themed candy was distributed in celebration of the start of the carnival season in the same week and scientific dialogue was deepened during a 9km walk in the spring sun around a nearby lake. Talk on topics apart from the thematic focus was also fostered by round table discussions after dinner. A common round table setup was around 10 participants interacting for about 30-60 minutes on topics proposed before the conference by participants. After the round table leader very briefly introduced the topic, the table was open for questions and conversation. The format enabled discussion on issues of shared concern and gave space to generate ideas for action. The setting was very much appreciated by the attendees; for example, the topics "*Publishing*" and "*The future of HPC for the weather and climate*" sparked the most interest. A list of all topics can be found at the conference website given in the next paragraph.

In an opening note to the conference participants, a representative of the German Federal Ministry of Research and Education (BMBF) welcomed everyone and emphasized that the ministry will continue to actively help advancing the frontiers of climate modeling. The meeting was financially supported by the HD(CP)^2 project, which is funded by the German Federal Ministry of Education and Research within the framework of the program "Research for Sustainable Development (FONA)" under the grant number 01LK150; the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation), project number 417881912; the German Federal Ministry of Research and Education; and the Max Planck Society. Further detailed conference information and a list of presentations and posters is available on the conference website (*https://indico.mpimet.mpg.de/e/UCP2019*).

CMIP6 Model Analysis Workshop

Barcelona, Spain
25–28 March 2019

Pablo Ortega[1] and Markus Donat[1], on behalf of the local and scientific organizing committees

[1]Barcelona Supercomputing Center, Barcelona, Spain

A workshop to update and discuss the developments and progress of simulations and analysis within Phase 6 of the Coupled Model Intercomparison Project (CMIP6) was held in Barcelona from 25–28 March 2019. The workshop was hosted by the Barcelona Supercomputing Center (BSC), and was jointly organized by the World Climate Research Program (WCRP) Working Group on Coupled Modelling (WGCM) CMIP Panel and the European Commission Horizon 2020 projects PRIMAVERA (PRocess-based climate sIMulation: AdVances in high-resolution modelling and European climate Risk Assessment), which held its annual general assembly at the same time, and EUCP (European Climate Prediction system).

Participants of the CMIP6 Model Analysis Workshop

The workshop gathered 249 participants (including the PRIMAVERA attendees in a joint session) from 26 different countries around the world, with a large number of early career scientists (67). Representatives from at least 20 CMIP6-Endorsed Model Intercomparison Projects (MIPs) and 25 modeling groups were present. This sizeable and heterogeneous international turnout stimulated the organization of several parallel scientific meetings during the week, from which we highlight the 22nd session of the WGCM CMIP Panel, an EUCP-organized workshop on "Scientific knowledge gaps related to decadal climate prediction," and a "Carbon Cycle Predictability Meeting" to foster collaboration of different modeling groups in C4MIP activities.

Following the successful format of the WCRP CMIP5 model analysis workshop held in 2012, the meeting was organized into seven half-day poster sessions, each beginning with a round of two-minute oral communications during which all poster presenters had the opportunity to summarize the topic and main conclusions of their posters. In addition, a selected number of plenary talks distributed throughout the week covered different topics of broad interest, from the status of CMIP6 modeling activities and infrastructure to the latest developments from high resolution modeling to a final overview of emerging properties of the CMIP6 ensemble and future plans for CMIP7.

Scientifically, the workshop was structured around three major cross-cutting questions:

1. How does the Earth system respond to forcing?
2. What are the origins and consequences of systematic model biases?
3. How can we assess future climate change given climate variability, predictability and uncertainty in scenarios?

These were addressed among the different sessions, which were devoted to a large variety of scientific interests, from CMIP6-Endorsed MIP and CMIP6 model overviews and infrastructure, to forcing and feedbacks, uncertainty, biases and constraints, high resolution, variability and extremes, future projections and regional impacts. Special emphasis was also given to studies performing multi-model evaluations (preferably with CMIP6 models), implementing new inter-comparison methods, connecting model developments to increased realism in Earth system models or exploring climate change impacts. The workshop format, making poster presentations the central part of scientific discussion, which then led into the common coffee and lunch breaks, allowed for lively exchanges on scientific progress in the different topics covered by the event.

Further workshop information and relevant materials (including the abstract and the slides of the plenary talks and two-minute presentations) can be found at the website: *https://cmip6workshop19.sciencesconf.org/*. Also, highlights of the first CMIP6 results presented at the workshop and the future perspectives for CMIP6 and CMIP7 have been published in a recent WCRP news item: *https://www.wcrp-climate.org/news/wcrp-news/1478-cmip6-first-results*.

The 5th Satellite Soil Moisture Validation and Application Workshop

Fairfax, Virginia, USA
24–25 October 2018

John J. Qu[1], Wolfgang Wagner[2], Michael H. Cosh[3] and Ray Motha[1]
[1]George Mason University, Fairfax, VA, USA; [2]Vienna University of Technology, Vienna, Austria; [3]US Department of Agriculture, Beltsville, MD, USA

The Global Environment and Natural Resources Institute (GENRI) at George Mason University (GMU) hosted the 5th Satellite Soil Moisture Validation and Application Workshop on 24–25 October 2018. This meeting facilitated discussion of recent methodological advances in the development, validation and application of global, regional and local integrated soil moisture data products, and helped to develop comprehensive recommendations on the opportunities and challenges in operational applications for satellite-based soil moisture products. An emphasis of this workshop was to utilize spatially-rich satellite soil moisture data together with point source in situ ground-truth measurements to implement standardized, calibrated and validated integrated soil moisture databases for applications in monitoring, modeling and prediction.

Background: The 5th Satellite Soil Moisture Validation and Application Workshop brought together over 100 participants from government, universities and the private sector in the United States, Canada, Mexico, a number of European countries and Australia. Previous workshops analyzed calibration and verification procedures for integrating satellite and in-situ soil moisture observations that provide standardized and more systematic soil moisture data sets for a wide variety of user communities. The workshop first reviewed specific studies of soil moisture calibration and validation as well as retrieval and downscaling techniques, bringing the audience up to date on the latest progress in soil moisture performance. These developments in technology were followed by sessions focusing on a variety of applications of soil moisture data, including: weather and climate modeling, carbon and ecology, hydrology and water resources and agriculture and food security. Summaries of some of the important topics discussed in these application-oriented sessions were provided in the closing plenary session and during one of the panel discussions.

Topics of discussion: Soil is the medium for plant growth and the substrate for all biogeochemical and biogeophysical processes. Its unique natural organization forms the foundation of any food–water–energy nexus system, and it also serves as a very large reservoir for water and carbon with strong influences on local, regional and global climate. Soil forms a habitat for diverse micro, meso and macrofauna and flora and is the fundamental basis of ecosystems. With this background, the workshop sessions included: 1) Satellite Product Validation, 2) Spatial and Temporal Analysis of Soil Moisture, 3) Weather and Climate Modeling, 4) Carbon and Ecology, 5) Hydrology and Water Resources, and 6) Agriculture and Food Security. More detailed information can be obtained from the SMW2018 workshop website (*http://genri.gmu.edu/smw2018*).

5th Satellite Soil Moisture Validation and Application Workshop participants

Outcome: The nexus of food, energy and water has prompted sustainability concerns as interactions between these interdependent human needs are degrading the natural resources required for a secure future world. Soil is responsible for 99% of the world's food production. Soil erosion and soil management are major factors affecting soil degradation and declines in productivity. The importance of soil in the food, energy and water nexus is clearly apparent. This necessitates the creation of an integrated soil moisture database, which would serve as a significant step toward a more holistic approach to sustainable monitoring and development.

Some of the most salient recommendations resulting from the workshop panel discussions follow.

1. Satellite technology must be integrated with in situ observations for improved monitoring, modeling and information dissemination related to food, energy and water security (FEWS).
2. Further development of international soil moisture guidelines and standards is essential to support integrated soil moisture database development, validation and applications.
3. Capacity needs to be expanded for applications of soil moisture data in natural hazards monitoring that includes flood and extreme weather events as well as droughts and their management.
4. To meet stakeholders' needs, collaboration must be further enhanced between soil moisture experts in satellite system analysis, in situ data analysis and modeling techniques to improve best practices for standards and guidelines, data sharing and integration and building a systematic global database for operational applications.
5. Research efforts to explore the importance of integrated soil moisture data in carbon cycles and in high latitude regions shall be intensified.

Workshop sponsors: The organizers would like to thank the workshop sponsors, which include: 1) World Meteorological Organization (WMO); 2) Food and Agriculture Organization (FAO); 3) Group on Earth Observations (GEO); 4) National Aeronautics and Space Administration (NASA); 5) National Oceanic and Atmospheric Administration (NOAA); 6) United States Department of Agriculture (USDA); 7) United States Geological Survey (USGS); 8) European Space Agency (ESA); 9) George Mason University (GMU); 10) Vienna University of Technology (TU Wien); 11) Global Energy and Water Exchanges (GEWEX) project; 12) Stevens Water Monitoring Systems; and 13) US Army Corps of Engineers.

GEWEX/WCRP Calendar

For the complete Calendar, see http://www.gewex.org/events/

6–10 May 2019—Fortieth Session of the World Climate Research Programme (WCRP) Joint Scientific Committee (JSC)—Geneva, Switzerland

13–17 May 2019—2019 Living Planet Symposium—Milan, Italy

15–17 May 2019—Annual Science Meeting of the Global Water Futures Program—Saskatoon, Canada

20–24 May 2019—Twelfth Hydrological Cycle in Mediterranean Experiment (HyMeX) Workshop—Split, Croatia

27–31 May 2019—International Young Scientists School and Conference on Computational Information Technologies for Environmental Sciences (CITES-2019)—Moscow, Russia

29–31 May 2019—Twenty First Working Group on Subseasonal to Interdecadal Prediction (WGSIP)—Moscow, Russia

29–31 May 2019—Workshop on Correlated Extremes—New York, New York, USA

3–5 June 2019—Fifth PannEx Workshop: Building PannEx Task Teams to Address Environmental Needs in the Pannonian Basin—Novi Sad, Serbia

3–6 June 2019—Computational Information Technologies for Environmental Sciences (CITES-2019)—Moscow, Russia

10–14 June 2019—Tutorial and Workshop: Future Physics for Global Atmospheric Models—Boulder, Colorado, USA

13–14 June 2019—Eighth GEWEX Water Vapor Assessment (G-VAP) Workshop—Madrid, Spain

19–21 June 2019—Second Dynamics of the Atmospheric general circulation Modeled On Non-hydrostatic Domains (DYAMOND)–Centre of Excellence in Simulation of Weather and Climate in Europe (ESiWACE) Hackathon— Mainz, Germany

19–21 June 2019—Twelfth International Precipitation Conference (IPC12) and the Soroosh Sorooshian Hydrometeorology Symposium—Irvine, California, USA

7–9 July 2019—International GEWEX/GASS/LS4P and TPEMIP Regional Modeling and Aerosol in Snow Workshop—Nanjing, China

8–18 July 2019—Twenty Seventh International Union of Geodesy and Geophysics (IUGG) General Assembly—Montréal, Canada

8–18 July 2019—GlacierMIP Meeting at the Twenty Seventh IUGG General Assembly—Montréal, Canada

15–17 July 2019—Third International Surface Working Group (ISWG)—Montréal, Canada

15–19 July 2019—Paracon International Workshop on Convection Parameterization and GASS Project Side Meeting—Exeter, UK

28 July–2 August 2019—Asia Oceania Geosciences Society (AOGS) Sixteenth Annual Meeting—Singapore

28 July–2 August 2019—Fifteenth Atmospheric Chemistry Colloquium for Emerging Senior Scientists (ACCESS) and Gordon Research Conference in Atmospheric Chemistry (GRC)—Upton, New York, USA

19–24 August 2019—Advanced School and Workshop on American Monsoons—São Paulo, Brazil

21–23 August 2019—High Resolution Climate Modeling: Perspectives and Challenges—Zurich, Switzerland

21–23 August 2019—Third GEWEX Workshop on Convection-Permitting Climate Modeling—Zurich, Switzerland

26 August–2 September 2019—Fifth International Baltic Earth Summer School on Climate of the Baltic Sea Region—Trosa, Sweden

4–7 September 2019—Sixteenth International Conference on Environmental Science and Technology (CEST2019)—Rhodes, Greece

8–12 September 2019—International Mountain Conference—Innsbruck, Austria

9–11 September 2019—Committee on Earth Observation Satellites (CEOS), World Meteorological Organization (WMO)-Global Space-based Inter-Calibration Sytem (GSICS) Workshop on an SI-Traceable Space-based Climate Observing System—London, UK

9–13 September 2019—European Meteorological Society (EMS) Annual Meeting 2019—Copenhagen, Denmark

9–13 September 2019—Soil Moisture Validation and Application over Highlands Workshop—Fairbanks, Alaska, USA

17–19 September 2019—Fifth Conference on Modelling Hydrology, Climate and Land Surface Processes—Lillehammer, Norway

23–25 September 2019—Second International Conference on Our Climate–Our Future: Regional Perspectives on a Global Challenge—Berlin, Germany

24–27 September 2019—Future Earth Water Future Conference: Towards a Sustainable Water Future—Bengaluru, India

30 September–4 October 2019—Cloud Feedback Model Intercomparison Project (CFMIP) 2019 Meeting on Clouds, Precipitation, Circulation, and Climate Sensitivity—Mykonos, Greece

7–9 October 2019—African Climate Risks Conference—Addis Ababa, Ethiopia

7–9 October 2019—GEWEX Hydroclimatology Panel (GHP) Crosscuting Project (CC) Workshop: Determining Evapotranspiration—Sydney, Australia

10–11 October 2019—2019 GEWEX Hydroclimatology Panel (GHP) Meeting—Sydney, Australia

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Peter J. van Oevelen, Director
Shannon F. Macken, Editor

International GEWEX Project Office
c/o USRA
425 3rd Street SW, Suite 605
Washington, DC 20024 USA

Tel: 1-202-527-1827
E-mail: gewex@gewex.org
Website: *http://www.gewex.org*