GEWEX QUARTERLY

WCRP World Climate Research Programme

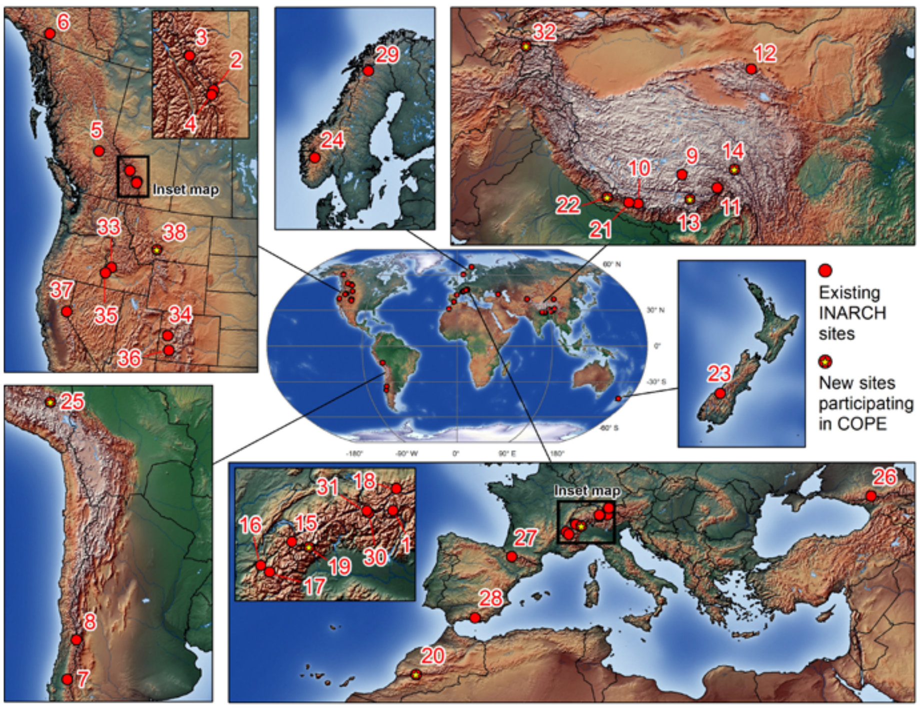
United Nations Educational, Scientific and Cultural Organization | Intergovernmental Oceanographic Commission

World Meteorological Organization | International Science Council

Vol. 33, No. 1 | Quarter 1 2023

GEWEX is a Core Project of the World Climate Research Programme on Global Energy and Water Exchanges

Updates from the International Network for Alpine Research Catchment Hydrology



Austria: 1. Rofental Open Air Laboratory (OpAL)

Canada: Canadian Rockies Hydrological Observatory: 2. Marmot Creek Research Basin; 3. Peyto Glacier; 4. Fortress Mountain; 5. Quesnel River Research Basin; 6. Wolf Creek Research Basin

Chile: 7. Upper Diguillín River Basin; 8. Upper Maipo River Basin

China: 9. Nam Co Monitoring and Research Station for Multisphere Interactions; 10. Qomolangma Atmospheric and Environmental Observation and Research Station; 11. Southeast Tibet Observation and Research Station for the Alpine Environment; 12. Upper Heihe River Basin; 13. Yala Shampo Cryosphere Hydro-Ecological Station; 14. Changdu Ecological Monitoring Station

France: 15. Arve Catchment; 16. Col de Porte Experimental Site; 17. Col du Lac Blanc Experimental Site

Germany: 18. Zugspitze Basin and Schneefernerhaus Research Station

Italy: 19. Torgnon Ecosystem Station

Morrocco: 20. Rheraya Catchment

Nepal: 21. Langtang Catchment; 22. Hidden Valley

New Zealand: 23. Brewster Glacier

Norway: 24. Finse Alpine Research Centre

Peru: 25. Salcca-Sibinacocha Catchment

Russia: 26. Djankuat Research Basin

Spain: 27. Izas Research Basin; 28. Guadalfeo Monitoring Network

Sweden: 29. Tarfala Research Catchment

Switzerland: 30. Dischma Research Catchment; 31. Weissfluhjoch Snow Study Site

Tajikistan: 32. Kyzylsu Glacier

USA: 33. Dry Creek Experimental Watershed; 34. Grand Mesa Study Site; 35. Reynolds Creek Experimental Watershed; 36. Senator Beck Basin Study Area; 37. Sagehen Creek, Sierra Nevada; 38. Bridger Range

This map of INARCH's instrumented research basins and experimental sites as of 2023 illustrates the network at the center of the cross-cutting activity. These basins and sites serve as testbeds for detailed process studies on mountain hydrology and meteorology, improving our understanding of alpine cold regions hydrology. For more, see Pomeroy et al., page 10.

Inside This Edition

Commentary: Lessons Learned from the First 30 Years of GEWEX

Xubin Zeng[1], Jan Polcher[1], Graeme Stephens[2], and Peter van Oevelen[3]
[1]Co-Chair, GEWEX Scientific Steering Group (SSG); [2]Former Co-Chair, GEWEX SSG; [3]Director, International GEWEX Project Office

During the review process of the article on the first 30 years of GEWEX and the path forward (Stephens et al., 2023), one reviewer encouraged us to reflect on the lessons learned. As that article is already quite long (but hopefully still enjoyable to read), we replied that we will address this issue after the publication of that paper. Keeping that promise, here we provide our non-comprehensive reflection on this topic.

Balance. GEWEX has benefited substantially from its balanced programs in three broad areas: coordinated field experiments; global data development, assessment, and analysis; and process understanding and model improvement. This has become the GEWEX culture that is fundamental for the long-term success of GEWEX.

Anchors. Ever since its inception, GEWEX has made the strategic decision to closely connect with space agencies and global weather, hydrological, and climate modeling centers. Space agencies provide the comprehensive global satellite data and the support for satellite data analysis, while GEWEX activities assess measurement gaps and the values of specific measurements for the planning of future satellite missions [e.g., by the National Aeronautics and Space Administration (NASA), the European Space Agency (ESA), and the Japan Aerospace Exploration Agency (JAXA)]. Modeling centers provide critical modeling and forecasting questions for process studies, while GEWEX progress is used to advance models and prediction systems (e.g., at the European Centre for Medium-Range Weather Forecasts (ECMWF) and the National Centers for Environmental Prediction (NCEP)].

Support. The continuous support from NASA of the International GEWEX Project Office has been foundational to the long-term success and organizational efficiency of GEWEX. This helps facilitate the GEWEX connection to space agencies and enables the hiring of long-term GEWEX Executive Directors. In fact, there have been only three Directors (plus one for one year only) in the 30+ years of GEWEX so far. These long-term Directors provide continuity in the GEWEX management and also work closely with GEWEX Scientific Steering Group Chairs or Co-chairs to assist the community in new project developments. Furthermore, they provide the institutional memory to many GEWEX participants.

Structure. GEWEX maintains a simple, yet flexible, structure, with 3–4 panels and organizing projects under panels. Panels can and have been restructured in different phases of GEWEX. The challenge is how to handle panel cross-cutting projects. The standard approach would be to treat these projects separately. In practice, it is realized that: a) any GEWEX project could collaborate with different panels and hence essentially becomes a cross-cutting project; b) some panels have cross-cutting activities as a category within a panel; and c) treating cross-cutting projects outside of panels makes the cross-panel interactions more complicated. Therefore, more recently, GEWEX encourages these projects to join one or more panels (for engagement and reporting) while continuing cross-cutting activities and drawing upon the expertise and wider membership in the respective panels.

Expectation. Leadership matters, particularly at the levels of GEWEX Co-chairs, directors, and panel co-chairs. Their vision, leadership style, and personality strongly affect the progress of GEWEX. Even with good intentions, some frictions are normal and expected, leading to the natural cycle of ups and downs of projects and even overall panel activities. However, the first four points help maintain the overall progress of GEWEX.

Focus. Another cornerstone for the long-term success of GEWEX is its focus on the coupled processes of global and regional energy and water cycles. For instance, this has allowed GEWEX to survive pushes to focus on one component of these cycles only (e.g., land). GEWEX champions the advance of understanding physical processes that are the foundation for other activities (e.g., impacts, adaptation, mitigation), while at the same time connecting to users, applications, and affected communities through coordinated field campaigns and regional hydrometeorological activities.

References

Stephens, G., and coauthors, 2023. The first 30 years of GEWEX. *Bull. Amer. Meteor. Soc.*, 104 (1), E126-E157, https://doi.org/10.1175/BAMS-D-22-0061.1.

Table of Contents

New GEWEX SSG and Panel Members

Prof. Susanne Crewell of the University of Cologne and the Center for Earth System Observation and Computational Analysis (CESOC) is a new GEWEX Scientific Steering Group (SSG) member specializing in microwave remote sensing that focuses on water vapor, clouds, precipitation, and evaporation. She aims to exploit synergy with other observing systems, and has initiated a range of projects optimizing efficiency and exploring the use of remote sensing for weather forecast and climate modeling.

Prof. Crewell shares the GEWEX interest to further integrate observations and models at high resolution (km-scale and below) and pursues these with her research group, Atmospheric Water Cycle and Remote Sensing (AWARES). AWARES works on different aspects of the water cycle with particular emphasis on Arctic amplification, water transports into deserts, tropical clouds, and satellite innovations. She has experience in the coordination collaborative research projects and is very active in the training of the next generation of scientists.

Dr. Linda Mearns, Senior Scientist and Section Head of the Regional Integrated Sciences Section the National Center for Atmospheric Research (NCAR), is a new member of the GEWEX Scientific Steering Group (SSG). Her expertise lies in climate change scenario formation, quantifying uncertainties, and climate change impacts on agro-ecosystems. She has worked extensively with regional climate models. As an author in the Intergovernmental Panel on Climate Change (IPCC) 1995, 2001, 2007, 2013/14, and 2021/22 Assessments, she focused on contributions involving climate variability, impacts of climate change on agriculture, regional projections of climate change, climate scenarios, and uncertainty in future projections of climate change. Dr. Mearns recognizes that credibility of climate model results determined through process level scientific understanding is fundamental for determining appropriate value and use of model results in various contexts.

Dr. Anna Stewart Ibarra joins the SSG as the Science Director of the InterAmerican Institute for Global Change Research (IAI). She has worked with networks of researchers and public sector experts (climate and health sectors, primarily) to investigate and co-develop climate services for infectious diseases such as dengue fever. Her areas of expertise are transdisciplinary science, global environmental change, science policy, climate and health, developing and leading international research teams, climate services, and social vulnerability. Dr. Stewart Ibarra specializes in the research-policy nexus of climate, environment, and health (CEH). She is designing and implementing regional (Americas) capacity-building and funding opportunities for researchers and policy practitioners, contributing to creating a community of practice on global environmental change and transdisciplinary research in the Americas. In her current role at the IAI, she works with national government focal points and scientists to ensure that research is co-created and translated to support decision-making.

An active GEWEX community member, Dr. Michael Bosilovich of the National Aeronautics and Space Administration (NASA) Global Modeling and Assimilation Office now joins the GEWEX Hydroclimatology Panel (GHP) after an extended term on the SSG. Some of his areas of research include water and energy cycles; applied uses of reanalyses regarding global and regional hydrology and climate variations and extreme weather; the planetary boundary layer; land-atmosphere interactions; Earth system models and the remotely-sensed observations needed to improve them; and quantification of all branches of the Earth's hydrologic cycles. His more recent interest in regional budgets, utilizing advances in reanalyses such as the ensemble spread, drew him to participate in GHP. He is also beginning to contribute to the development of the US Regional Hydroclimate Project (US RHP) strategy and science. His depth of expertise along with his knowledge of GEWEX's structure and vision will be an asset to the Panel.

Xuelong Chen is a professor in the field of land-atmosphere interaction at the Institute of Tibetan Plateau Research, Chinese Academy of Sciences (CAS). He joins the GEWEX Data and Analysis Panel (GDAP) with an interest in micro-meteorology, mountain meteorology, remote sensing, and boundary layer metrology. He is an associate editor of *Meteorological Applications* and journal referee for *Remote Sensing of Environment, Journal of Geophysical Research–Atmospheres*, and *Hydrology and Earth System Sciences (HESS)*, among others. He is principal investigator of the CAS-Royal Netherlands Academy of Arts and Sciences (CAS-KNAW) Joint Ph.D. Training Programme and the National Natural Science Foundation of China (NSFC) project on applying a remote sensing model to retrieve gap-filled evapotranspiration over the Tibetan Plateau.

He enjoyed the comradery of GEWEX activities during his Ph.D. studies, and looks forward to being even more involved in GEWEX as a specialist in land surface measurements in GDAP.

YESS Engagement in Early 2023 and Beyond

Faten Attig-Bahar[1], Gerbrand Koren[2], Valentina Rabanal[3], and the YESS Executive Committee

[1]University of Carthage, Tunisia Polytechnic School, Al Marsa, Tunis, Tunisia; [2]Copernicus Institute of Sustainable Development, Utrecht University, Utrecht, the Netherlands; [3]Servicio Meteorológico Nacional (SMN Argentina), Buenos Aires, Argentina

The Young Earth System Scientists (YESS) community is becoming larger and stronger in the international and regional science community and has achieved several milestones over the last few years. This year, YESS is very happy to celebrate its five-year partnership anniversary with the Pan African University Institute of Water and Energy Sciences (PAUWES). This fruitful collaboration began in 2017 when both the institute and YESS engaged in delivering activities and webinars to serve early career researchers (ECRs) and scholars in Africa.

Previously, three webinar series included about 12 expert talks, panel discussions, and capacity development activities for African scholars. A fourth edition is scheduled between January and June 2023 (*https://www.yess-community.org/sustainable-development-in-africa/*).

Moreover, the YESS community has been actively involved in organizing the Future Earth and Belmont Sustainability Research & Innovation (SRI) Congress, which is one of the world's largest transdisciplinary gatherings for the global sustainability community. Our ExeCom member Faten Attig Bahar is serving on the Outreach and Engagement Committee of the third edition of the SRI Congress 2023 (*https://sricongress.org/*), which will be hosted by the National Secretariat of Science, Technology, and Innovation of the Republic of Panama (SENACYT) and the Inter-American Institute for Global Change Research (IAI) in June 2023, and co-chairing the Program Committee and executive team of the SRI 2023 Africa Satellite (*https://sricongress.org/sri2023-africa-satellite-event/*) to be held between 20–22 June 2023 in South Africa.

Additionally, the World Climate Research Programme (WCRP) is organizing its Open Science Conference (OSC) from 23–27 October 2023, which will take place in Kigali, Rwanda, and YESS will also be represented during this event. YESS members will participate in a side event about the inequalities for climate scientists from the Global North and Global South (*https://wcrp-osc2023.org/program/program-side-events?view=article&id=75:side-event-th03&catid=18:side-events*). Furthermore, YESS is involved in the organization of the program for Early and Mid Career Researchers (EMCR, *https://wcrp-osc2023.org/emcr*), which will enhance EMCR participation in the conference through involvement in the program and side activities. We look forward to connecting with the scientific community to make progress in these fields.

In with the New but Not out with the Old at AGU H3S

Danyka Byrnes[1] and Paige Becker[2]

[1]Ph.D. Candidate, University of Waterloo, Waterloo, ON, Canada; [2]Ph.D. Candidate, University of Oregon, Eugene, OR, USA

American Geophysical Union Hydrology Section Student Subcommittee (AGU-H3S) is excited to welcome new early-career hydrological scientists to our group! This year, have members from 27 institutions internationally. New ideas and events are brewing, but we still have a ton of old resources you can check out.

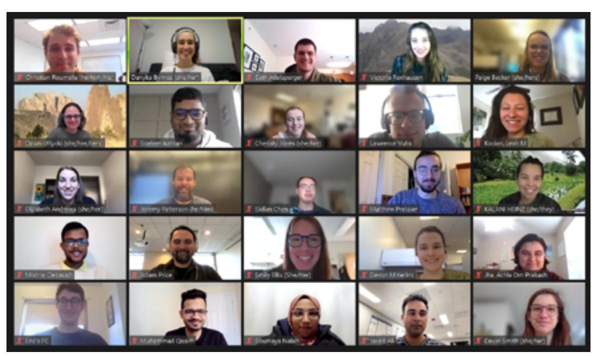
We are currently preparing our seminar series; new justice, equity, diversity, and inclusion resources; 2023 AGU Fall Meeting events; and, last but not least, a fresh new look for our website.

Follow all our events catering to students and early career professionals by following us on Twitter (*twitter.com/AGU_H3S*), Facebook (*tinyurl.com/h3s-faceb*), and LinkedIn (*tinyurl.com/h3s-linkedin*). You can also sign up for our quarterly newsletter (*agu-h3s.org/contact-us/*). In the meantime, be sure to check out our existing resources.

Highlighted research, from plenaries to panels, frequently needs more diversity in the author list. We want to help change that. We are now hosting the WaterPOC database to facilitate finding water experts of color. If you want to grow your network to find seminar speakers, panelists, and papers for class reading, consider checking out the database at *agu-h3s.org/waterpoc-database*.

We have compiled a database of mentorship, networking, and scholarship resources for early career scientists and the broader community. To access or contribute to the database, visit *agu-h3s.org/ajedi-resource-database*.

If you missed our 2022 Navigating Academic and Non-academic Waters seminars, you can find them all online at *tinyurl.com/2022H3SSeminars*. You can also find the rest of our past seminars on the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI)'s YouTube channel, *tinyurl.com/H3SSeminars*.



AGU-H3S Members. Not pictured: Emma Butzler, Sara Windoloski, Delaney Peterson, Shruti Upadhyaya, Chung-Yi Lin, Somita Chaudhari, Vasala Saicharan, Xinxin Sui, Jim Paulo Bautista, Nicole Lane

Groundwater Modeling in GEWEX: Closing the Terrestrial Water Cycle from the Regional to the Global Scale

Stefan Kollet[1], Laura Condon[2], and Peter van Oevelen[3]

[1]Agrosphere (IBG-3), Research Centre Juelich, Jülich, and Bonn University, Bonn, Germany; [2]University of Arizona, Tucson, AZ, USA; [3]George Mason University, Fairfax, VA, USA

Socioeconomic Significance

Groundwater (GW) is an important, and at the same time, distinct component of the global water cycle (for relevant literature related to this article, the reader is referred to Condon et al., 2021). While sustaining life and economies on Earth, GW is generally invisible and often ignored by the public, acting in the underground of the Earth, and only outcropping in relatively few places as surface water. As a result, on the one hand, GW is an unknown component of the terrestrial water cycle to many. On the other hand, because of its tremendous hydro-ecologic and socio-economic importance, GW has been valued and exploited by humans in many regions of the world throughout history. While GW is everywhere on the continents, it is the pronounced local to regional relevance and simultaneous invisibility that distinguishes GW from other components of the global water cycle.

Connection to the Global Water and Energy Cycle and GEWEX

Groundwater encompasses 99% of the liquid freshwater store of the continents. GW lives in the shallow and deep subsurface in aquifers, and is connected to the land surface and surface water along river corridors and in lake and wetland areas as base flow. The latter constitute the discharge areas, where most water finds its way back to the ocean and the atmosphere via the processes of continental runoff and evapotranspiration, respectively. Additional GW base flow occurs along the continental shelf. These processes are not only important for continental water drainage, but also for flushing the continents of (natural) solutes that would otherwise contaminate the terrestrial system. The amount of base flow and its geochemical composition is highly variable in space and time, reflecting various converging subsurface flow paths of GW governed by local and regional aquifer heterogeneity and GW recharge.

It is important to note that GW dynamics encompass two distinct time scales related to pressure propagation and porous media flow. The former acts on a much shorter time scale than the latter, and is governed by the ratio of (compressible) storage and transmissivity for the space scale under consideration. In contrast, time scales of porous media flow are much larger, resulting in GW residence times that are characterized by an extremely wide distribution with heavy tailing towards very long residence times on the order of hundreds to more than thousands of years.

While GW is often seen as a separate compartment of the terrestrial water cycle, it constitutes a continuum with surface water as aforementioned, and the variably saturated soil zone and land surface. The hydraulic connection depends strongly on the local topographic, climatic, heterogeneous subsurface, and land surface conditions. In the downward direction, the connection may lead to GW recharge if precipitation exceeds evapotranspiration, and in the upward direction, to capillary rise regionally sustaining evapotranspiration, surface water, and entire ecosystems. Both the upward and downward connections with the land surface in addition to baseflow constitute the link of GW with the atmosphere and the global hydrologic cycle. While mainly invisible, the link is ubiquitous and life sustaining, keeping the continents in a delicate hydrologic balance by closing the water cycle from the continent to the ocean.

Groundwater Mechanisms under Global Change

The mechanism and connections linking GW to the global water cycle are highly variable in space and time due to natural variability of land surface and atmospheric processes from the weather to the climate time scales. In addition, human interventions related to, e.g., land and water use play an ever-increasing role in GW processes and linkages to the global water cycle under climate change conditions. In the connection of GW with the global water cycle, changes in the main fluxes such as GW recharge and base flow will determine the new emerging water balance of the continents. How this new emerging water balance manifests itself spatially and temporally is not clear at all or highly uncertain. It will be strongly influenced by the aforementioned local to regional human interventions and large scale processes of the water and energy balance, including the global atmospheric circulation and precipitation.

Another challenge often overlooked is that we have only very little continuous knowledge in space and time of the past and current state of global GW; thus, the baseline for evaluating change is essentially unknown. There are many reasons, but the main drivers are the lack of collated long-term GW data sets and globally-consistent GW modeling and data assimilation approaches. However, the lack of information over large areas on the current state of the groundwater system and how it got there is problematic in two ways. First, global change and GW sustainability issues are essentially not detectable; and second, in forward simulations, initial conditions, which have a strong impact over large time scales due to slow GW dynamics, are highly uncertain and may lead to large prediction errors.

State-of-the-Art in Groundwater Modeling

GW monitoring and modeling has been performed routinely from the test site to the regional scale, including some GW models of continental scale aquifers. By combining large supercomputing resources with efficient software, global GW modeling is now possible in principle when ignoring the data challenge. Continental to global hydrologic modeling including GW parameterizations has been originating more from the land surface modeling community. Many of the models applied today stem from, or are part of, global climate models, constituting the lower boundary conditions for the atmospheric simulations (Yang et al., 2011). Other global hydrologic models were developed from mass balance considerations to simulate global to regional water budgets, including land surface processes and human interventions and water management. Quite recently, these types of models were coupled to, e.g., single or two layer GW flow models applying Darcy's equation in 2D. At the continental scale, 3D variably-saturated groundwater and surface water flow models have been applied that incorporate land surface parameterization treating the groundwater-soil-vegetation system as a continuum.

However, what makes the difference between a conceptual and sophisticated GW flow model is perhaps often not the numerical approach to simulating flow, but the hydrogeologic or hydrofacies model constituting a complex 3D image of geologic subsurface heterogeneities and correlated structures across scales. At the global scale, this is difficult if not impossible to come by, and prohibits GW modeling at the global scale in the eye of a hydrogeologist. This is especially true if, e.g., conjunctive water use and GW-surface water interactions and also water quality become important.

Numerical implementation and computational efficiency are also large challenges to global modeling. Currently, only very few GW models would be able to simulate GW flow in a continuum approach at high spatial resolution over large scales, even if the required detailed hydrogeologic information were available, because of the lack of efficient parallel code implementation. This computational challenge grows exponentially in the case of data assimilation, calibration, and uncertainty quantification, where a large number of model runs is required.

Areas of Improvement

Areas of improvement are easily identified, yet improvements are difficult to achieve. Certainly, relatively large amounts of observations, such as groundwater level measurements, are available regionally. However, in many places in the world, the data is missing or owned and stored by different legal entities, leading to a fragmentation of information. This also holds for hydrogeologic information. Thus, in order to consolidate the required information, incentives must be generated to convince data owners to provide the information to a central or federated data center (e.g., the proposed GEWEX Hydroclimatology Panel (GHP) Data Center), where it can be used to construct and improve global scale GW models. Much can be learned from extremely successful activities such as the international Soil Moisture Network and the Global Runoff Data Centre, both with strong GEWEX involvement. With the exception of the Gravity Recovery and Climate Experiment (GRACE) and GRACE-Follow On, remote sensing plays a relatively small role in GW modeling, which may change in future. Newer technologies such as quantum gravimetry may be able to connect in situ measurements with satellite information. High-performance computing solutions must be created in terms of hardware and GW software to perform a large number of simulations over large areas at high spatial resolution. Cyberinfrastructure solutions are clearly needed, but will only be successful if they happen in conjunction with community engagement. Global data standards and simulation protocols are needed to facilitate continued model development and comparison. Simulations and services also need to be established, including, e.g., GW availability quantification and prediction under global change conditions up to the climate time scale. Here, a key GHP aspect is the connection of the local/regional scale with the continental/global scale, and the propagation of knowledge between different regions. Because GW is part of the hydrologic continuum from the bedrock to the top-of-atmosphere, GW should become an integral part of GEWEX and the global Earth system modeling community and activities [e.g., the World Climate Research Programme (WCRP) Digital Earths Lighthouse Activity].

Place in GEWEX (Regional Study, Cross-Cutting Project, Global Data Center)

GW has been mentioned in many existing and completed GEWEX activities [e.g., in the GEWEX Global Land Atmosphere System Study (GLASS) Soil and Water initiative], yet not included in a formalized way. Thus, a call for a dedicated GEWEX GW activity is urgently needed in times of increasing pressures on water resources. Locally and regionally, GW is well understood and managed in many countries at the interannual time scale. However, in the case of continental scale aquifers and decadal to climate time scales under global change conditions, the role of groundwater in the hydrologic cycle as a buffer and connector of (hillslope/mountain) recharge and discharge zones is still difficult to characterize and quantify. This connection also determines interactions of GW with the land surface and atmosphere, and vice versa. Important aspects are the two-way interactions of large-scale hydrologic forcings with GW that are undergoing major trends. These are the changing regimes related to precipitation, temperature and evapotranspiration, continental snow-ice cover, hydraulic base level change due to sea level rise, and human water use. Thus, global change greatly influences the new emerging water balance down to the local scale and, thus, strongly impacts all water sectors.

This highlights the need for research leaps to understand the role of GW in the global water cycle based on regional to global GW modeling and observations and their relevance for GEWEX. In one way forward, local to regional and global expert hydrogeologists need to join forces to define the agenda of a concerted GEWEX GW activity contributing to understanding and problem solving across scales. Knowledge, problem solving strategies, and communication generated by a GEWEX activity will contribute significantly to a better understanding of the continents' new emerging water balance and, thus, increased resilience of societies. Therefore, we are advocating for a GEWEX workshop bringing regional to global GW experts together, in order to define and implement the next steps of a GEWEX-guided GW activity. If you would like to be involved or want to know more about this activity, feel free to contact: Stefan Kollet (*s.kollet@fz-juelich.de*), Laura Condon (*lecondon@arizona.edu*), or the IGPO (*gewex@gewex.org*).

References

Condon, L.E., et al., 2021. Global Groundwater Modeling and Monitoring: Opportunities and Challenges. *Water Resour Res*, 57(12).

Hot Spots of the Remote Effect of Tibetan Plateau Spring Temperature in Global S2S Prediction–GEWEX/LS4P Phase I Highlights and Phase II Initiation

Yongkang Xue[1], Aaron Boone[2], Tandong Yao[3], Ismaila Diallo[4], William K.M. Lau[5], Hara Nayak[1], and the LS4P team
[1]University of California, Los Angeles (UCLA), CA, USA; [2]Centre National de Recherches Météorologiques, Université de Toulouse, Météo-France; CNRS, Toulouse, France; [3]Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Beijing, China; [4]Pennsylvania State University, University Park, PA, USA; [5] Earth System Science Interdisciplinary Center (ESSIC), University of Maryland, College Park, MD, USA

In 2018, the Global Energy and Water Exchanges (GEWEX) program launched an initiative, the "Impact of Initialized Land Temperature and Snowpack on Sub-seasonal to Seasonal Prediction" (LS4P, *https://ls4p.geog.ucla.edu*; Xue et al., 2021), as a community effort to test the impact of initializing land temperatures in high mountain regions in multiple Earth System Models (ESMs) on subseasonal to seasonal (S2S) prediction. The World Weather Research Program (WWRP) and World Climate Research Programme (WCRP) S2S project has listed the study of land initialization and configuration as one of its major activities (Merryfield et al., 2020). Climate scientists, especially climate modelers, from more than 40 institutions worldwide, many of which are major climate research and prediction centers, participated in this project.

The development and objectives of LS4P and evidence of land memory and persistence of land temperature anomalies in high mountains have been presented in Xue et al. (2021), which also introduced the LS4P phase I (LS4P-I) experimental protocol. LS4P-I focuses on the remote effect of the land surface temperature (LST) and subsurface temperature (SUBT) in the Tibetan Plateau (TP). The year 2003, when extreme summer drought/flood occurred to the south/north of the Yangtze River, respectively, after a very cold spring in the TP, is the focal case. The causes of the severe drought to the south of the Yangtze River in 2003 have never been identified. As such, LS4P is different from and complements other international projects that focus on operational S2S prediction (Kirtman et al., 2014; Pegion et al., 2019). Eighteen ESM groups have completed the LS4P-I experiment. The highlight of the LS4P-I results from sixteen ESMs[1] has been presented in the *Bulletin of American Meteorological Society* (Xue et al., 2022) to elucidate the new development in the S2S prediction.

LS4P-I has examined the LS4P models' bias in simulating the TP surface temperature. The analyses of LS4P-I resulting from the control simulation reveal that every ESM has a large bias in producing the observed TP May 2003 2-meter temperature (T-2m) cold anomaly, -1.4°C. Furthermore, the LS4P-I ESMs also produce large biases for June precipitation, not only over East Asia but over many parts of the world. To reproduce the observed TP May T-2m cold anomaly, initialization of the LST/SUBT was conducted to generate the observed T-2m anomaly in the model simulation. The LS4P hypothesis is that if the May land temperature anomaly in the TP contributes to the June precipitation anomaly, then by reducing May land temperature bias in the TP through initialization to produce the adequate temperature anomaly in the TP, the ESMs should produce better prediction of the June precipitation anomaly. LS4P-I has developed an innovative new land state initialization approach based on the observed surface T-2m anomaly and the model's bias over the TP (Xue et al., 2021). After using this initialization set up, the LS4P-I ESMs' ensemble mean has partially produced the observed TP May T-2m anomaly, which is -0.82°C.

The initial goal of LS4P was merely to test whether the preliminary results from one model (Xue et al., 2018), i.e., the spring TP LST/SUBT effect on the summer precipitation of the lowland plains of the Yangtze River Basin, could be confirmed by a multi-model ensemble. However, the statistical analyses and regression testing based on observational data reveal that the lag relationship between the May T2m anomaly over TP and the June precipitation anomaly not only exists over East Asia, but also over many parts of the world (Xue et al., 2022). Taking advantage of multiple state-of-the-art ESMs contributions, the LS4P-I participants promptly decided to evaluate the results beyond East Asia and compare the LS4P results with observations at global scale.

The observed and simulated June 2003 precipitation anomalies are compared in Fig. 1. In Fig. 1a, it is shown that in addition to the observed anomalies over East Asia, there were many other regions associated with large precipitation anomalies[2]. The most noticeable are the anomalies over North and Central America and the Eurasian continent. Meanwhile in parts of northern South America, West and East Africa, Australia, and many other areas, the precipitation anomalies are apparent. The precipitation anomaly produced by the LS4P-I ensemble mean after the May cold TP anomaly is displayed in Fig. 1b, which covers many regions in the world. We define the areas with a significant June precipitation impact due to the TP May cold temperature, which is also consistent with the observations (Fig. 1a), as hot spots.

Based on this definition, eight hot spot regions are identified with a significant precipitation difference (statistical significance at $p < 0.10$) (Fig. 1b). For those hot spot regions, the results of the ensemble mean suggest that observed lag relations represent cause and effect. To make quantitative assessments on the impact and uncertainty of the TP effect, we have made statistics for each hot spot region over the box area as shown in Fig. 1b. In addition to the expected difference in the southern Yangtze River Basin, the regions of the South Great Plains and Central America show the largest impacts. For these hot spots, very few models produce anomalies that are different in sign compared to the observations (inserted bar graphs in Fig. 1b). For some hot spot regions, such as the Sahel and East Africa, model uncertainties are relatively large. It should be pointed out that in the southern Yangtze River Basin, South Great Plains, and a few other regions, the TP LST/SUBT effect produces 25-50% of the observed anomaly.

[1]Two model results were completed after the paper had been submitted

[2]The observed anomaly uses the climatology (the mean of 1981–2010) as a reference

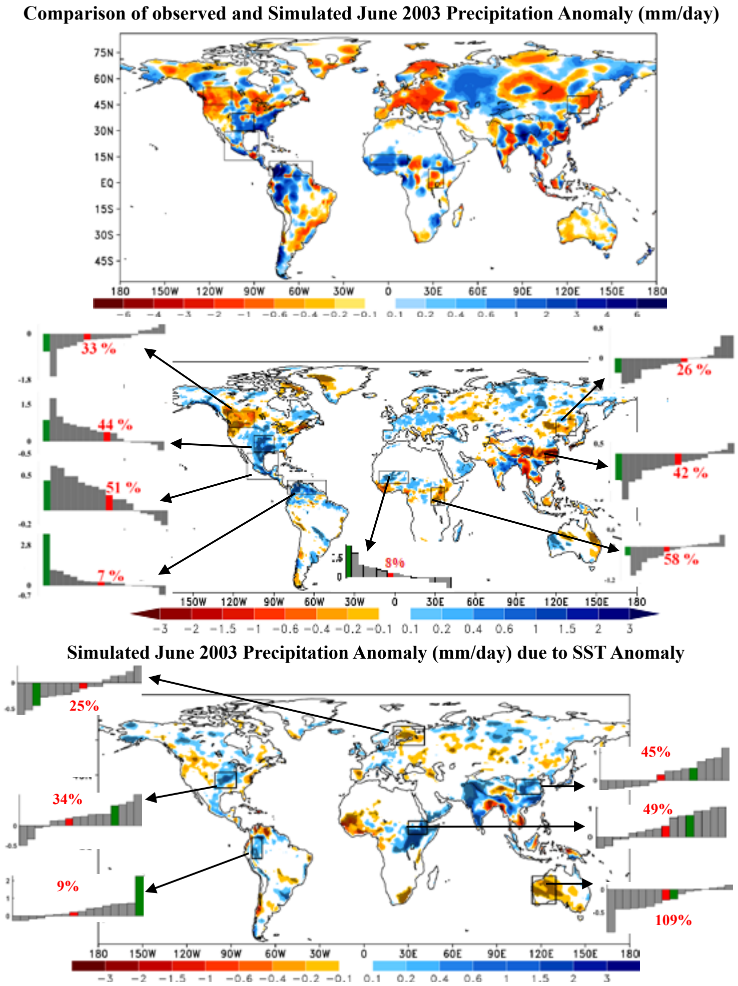


Figure 1*. Comparison of Observed and Simulated June 2003 Precipitation Anomaly (mm/day). (A) Observed June 2003 anomaly. (B) Model-simulated precipitation anomalies due to the cold TP anomaly. Figure is from Xue et al. (2022,* BAMS*). (C) Model-simulated precipitation anomalies due to the global SST anomaly. Figure is from Xue et al. (2023,* Climate Dynamics)

Notes: (1) Boxes indicate the hot spots regions; (2) Gray bars denote different models and are arranged in a descending order for each region; green bar is observation and red bar is ensemble mean in each hot spot; (3) Simulated percentages of observed anomalies from the ensemble mean are shown in red color above or below the red bars.

LS4P-I has also conducted another experiment, in which the observed May and June 2003 sea surface temperature (SST) in previous experiments is replaced by the climatological SST to test the SST effect, which will be reported in a forthcoming paper in a special issue "Sub-seasonal to Seasonal (S2S) predictability and Land-induced Forcing" in Climate Dynamics, which is expected to be published in 2023. With the same definition for hot spots, the SST experiment has identified six regions where the SST has significant effect. They are the U.S. Great Plains, West Amazon Basin, Horn of Africa, northern Yangtze River Basin, Western Australia, and Northern Europe (Fig. 1c). Among them, the first three regions partially overlap with the TP LST hot spots, indicating both LST/SUBT and SST factors produce the same sign of forcing. In the northern Yangtze River Basin, central America, northwestern North America, and northeastern Asia, both factors produce the same sign of anomalies, but only one factor produces statistically significant results. In western Australia, Northern Europe, and the Sahel, the SST and LST/SUBT produce the opposite signs of anomalies, indicating their effects compensate each other there. Nevertheless, our study reveals for the first time that high mountain land temperature could be a first order source of S2S precipitation predictability, and its effect is probably as large as ocean surface temperature over global "hot spot" regions identified here.

The LS4P-I results also suggest a strong linkage between the TP spring LST/SUBT and summer precipitation over North America (Xue et al., 2022). To explore the relationship between North America and the TP, the Tibetan Plateau Index (TPI) and the Rocky Mountain Index (RMI) are defined as the averaged T2m observed anomaly over the region bounded by 29°N~37°N and 86°E~98°E, and 32°N~45°N and 110°W~125°W, respectively. The May TPI and May RMI from 1981 to 2015 have a correlation of -0.44 with $p < 0.01$. Furthermore, the existence of a wave train from the TP through the Bering Strait to the western part of North America, referred to as the Tibetan Plateau-Rocky Mountain Circumglobal (TRC) wave train, has also been identified based on the May TPI. The heating change over the high mountain TP region efficiently modifies the phase, strength, as well as the shape of the wave train, which may intrinsically exist in the midlatitude atmosphere along with the westerly jet, affecting the atmospheric circulation in its downstream region, such as the west coast of North America. Five hot spot regions are located along the TRC wave train or its extension.

With the completion of LS4P-I, we launched LS4P-II in 2023 to make further investigations to explore more outstanding S2S prediction issues that are associated with the high mountain LST/SUBT. A hybrid kickoff workshop was held on Sunday, December 11, during the 2022 American Geophysical Union (AGU) Meeting, and 57 participants attended the workshop either in person or remotely (Image I). Although the workshop occurred in the middle of the night to early morning in some time zones, some in those regions still attended the entire workshop. During the event, representatives from the GEWEX Scientific Steering Group, the WCRP/WWRP S2S Project, the GEWEX Global Land-Atmosphere System Studies (GLASS) Panel, the US-Regional Hydroclimate Project (US-RHP), and other organizations presented the latest developments in relevant fields. LS4P Phase I achievements were reported, including two LS4P-I group papers (Xue et al., 2021, 2022) and more than 10 papers from the individual LS4P group, most of which are in the Climate Dynamics LS4P special issue. The protocol for LS4P Phase II has also been discussed. LS4P Phase II will focus on the Rocky Mountain LST/SUBT effect and the interaction between TPI and RMI. The LS4P approach intends to explore a new and potentially far-reaching perspective to stimulate the community's interest in more follow-on explorations. With this new approach, many challenging issues have been discussed and identified and listed in the LS4P-II protocol:

1. Despite the improved initialization, the LS4P-I ensemble mean is still unable to produce fully the observed TP T-2m anomaly. It is imperative to further improve the initialization

procedure/methodology of LST/SUBT (Xue et al., 2021) and convert the methodology for use in operational applications.

2. In some regions, such as in the Eurasian continent and India, the statistical analysis revealed lag correlation between precipitation there and TPI (Xue et al., 2022), but models fail to produce such a relationship. The cause(s) of such discrepancies need to be explored.

3. In some regions, the TP LST/SUBT anomaly of the LS4P-I ensemble mean produces significant June precipitation anomalies (Fig. 1b), such as in western Australia and western Europe, but with the opposite sign compared to the observations. It is unclear whether this is a model deficiency, or if some other processes involved, such as SST interactions, are more dominant than the TP LST effect.

4. The causes of the LST/SUBT anomaly. The possible roles of snow, aerosols in snow, winter Arctic circulation, soil memory, and other factors in producing LST/SUBT anomaly in the high mountain regions need further investigation as was done in Zhang et al. (2019) and Liu et al. (2020).

5. So far, we have only focused on the TP and Rocky Mountains as the S2S predictability source regions. Recent studies have suggested that there are probably more regions such as the Central Asian highlands and West Asian highlands where LST/SUBT may produce remote effects (Z. Yang et al., 2019; J. Yang et al., 2021), which deserves more investigation. In particular, the LST/SUBT effect of the Southern Hemisphere mountains merits more attention for a possible LS4P-III.

For LS4P Phase II, we have selected the year 1998, which was a year with severe flooding in the Yangtze River (Diallo et al., 2022) and severe drought in Texas and Oklahoma (Hong and Kalnay, 2002). In addition, the year 1998 was a strong El Niño year. A strong SST effect is expected and will be compared with the mountain LSTs. The fully coupled model with land-ocean-atmosphere interaction is encouraged to be compared with specified SST. We have conducted pilot experiments with one ESM for this case (Diallo et al., 2022; Nayak et al., 2022), and the preliminary results are encouraging. We expect the LS4P experiment will further advance our understanding of the LS4P hypothesis, and some issues listed above will be tackled. Thus far, the focus of LS4P research is mainly on later spring to early summer (or at monsoon onset stage). We notice 2022's severe anomalies (droughts and floods) occurred in middle and late summer (or at late monsoon stage), and the preliminary analysis revealed that the year 2022's situation may be similar to 1998. The LS4P-II experimental design will take this into account. More detailed information for the LS4P-II workshop including files and recording for some presentations, as well as LS4P-II protocol can be found on the LS4P website (*https://ls4p.geog.ucla.edu/*).

Image 1. *Participants of the LS4P-II hybrid kickoff workshop*

References

Diallo, I., Y. Xue, Q. Chen, X. Ren, and W. Guo, 2022. Effects of Spring Tibetan Plateau Land Temperature Anomalies on Early Summer Floods/Droughts over the monsoon regions of South East Asia. In the special issue "Sub-seasonal to Seasonal (S2S) predictability and Land-induced Forcing". *Clim. Dyn.*, doi: 10.1007/s00382-021-06053-8.

Hong, S.-Y., and E. Kalnay, 2002. The 1998 Oklahoma–Texas drought: mechanistic experiments with NCEP global and regional models. *J. Clim.*, 15, 945–63.

Kirtman, B., et al., 2014. The North American Multimodel Ensemble: Phase-1 seasonal-to-interannual prediction; phase-2 toward developing intraseasonal prediction. *Bull Am Meteorol Soc*, 95, 585–601, *https://doi.org/10.1175/BAMS-D-12-00050.1*.

Liu, Y., Y. Xue, Q. Li, D. Lettenmaier, and P. Zhao, 2020. Investigation of the variability of near-surface temperature anomaly and its causes over the Tibetan Plateau. *J. Geophys. Res. Atmos.*, 125, e2020JD032800, *https://doi.org/10.1029/2020JD032800*.

Merryfield, W.J., et al., 2020. Current and Emerging Developments in Subseasonal to Decadal Prediction. *Bull Am Meteorol Soc*, 101(6), E869-E896, *https://doi.org/10.1175/BAMS-D-19-0037.1*.

Nayak, H.P., Y. Xue, and I. Diallo, 2022. High Mountain late spring land surface and subsurface temperature influence on 1998 summer precipitation prediction, A22F-1743, *2022 American Geophysical Union Fall Meeting*, Chicago, USA, 12–16 December 2022.

Pegion, K., et al., 2019. The Subseasonal Experiment (SubX): A multimodel subseasonal prediction experiment. *Bull Am Meteorol Soc*, 100, 2043–2060, *https://doi.org/10.1175/BAMS-D-18-0270.1*.

Xue, Y., I. Diallo, W. Li, J.D. Neelin, P.C. Chu, R. Vasic, W. Guo, Q. Li, D. A. Robinson, Y. Zhu, C. Fu, and C.M. Oaida, 2018. Spring land surface and subsurface temperature anomalies and subsequent downstream late spring-summer droughts/floods in North America and East Asia. *J. Geophys. Res. Atmos.*, 105, 5001–5019, *https://doi.org/10.1029/2017JD028246*.

Xue, Y., T. Yao, A.A. Boone, I. Diallo, Y. Liu, X. Zeng, W. Lau, et al., 2021. Impact of Initialized Land Surface Temperature and Snowpack on Subseasonal to Seasonal Prediction Project, Phase I (LS4P-I): Organization and Experimental design. *Geosci Model Dev*, 14, 1–30.

Xue Y., I. Diallo, A.A. Boone, T. Yao, Y. Zhang, X. Zeng, J.D. Neelin, W. K.-M. Lau, et al., 2022. Spring Land Temperature in Tibetan Plateau and Global-Scale Summer Precipitation – Initialization and Improved Prediction. *Bull Am Meteorol Soc*, 103, 12, doi: *https://doi.org/10.1175/BAMS-D-21-0270.1, E2756–E2767*.

Xue, Y., I. Diallo, A.A. Boone, Y. Zhang, X. Zeng, W.K.M. Lau, et al., 2023. Remote effects of Tibetan Plateau spring land temperature on global subseasonal to seasonal precipitation prediction and comparison with effects of sea surface temperature–The GEWEX/LS4P Phase I experiment. *Clim. Dyn*. In review.

Yang, J., H. Chen, Y. Song, S. Zhu, B. Zhou, and J. Zhang, 2021. Atmospheric Circumglobal Teleconnection Triggered by Spring Land Thermal Anomalies over West Asia and Its Possible Impacts on Early Summer Climate over Northern China. *J. Clim.*, 34, 5999–6021, *https://doi.org/10.1175/JCLI-D-20-0911.1*.

Yang, Z., J. Zhang, and L. Wu, 2019. Spring soil temperature as a predictor of summer heatwaves over northwestern China. *Atmospheric Sci. Lett.*, 20, e887, *https://doi.org/10.1002/asl.887*.

Zhang, Y., T. Zou, and Y. Xue, 2019. An Arctic-Tibetan connection on subseasonal to seasonal time scale. *Geophys. Res. Lett.*, 46, 2790–2799, doi: 10.1029/2018GL081476.

Update on the Activities and Workshops of the International Network for Alpine Research Catchment Hydrology (INARCH) and Its Second Phase as a GEWEX Cross-Cutting Project, 2021–2026

John Pomeroy[1], Ignacio López Moreno[2], James McPhee[3], and Chris DeBeer[1]

[1]Centre for Hydrology and Global Institute for Water Security, University of Saskatchewan, Canada; [2]Institute for Pyrenean Ecology, Spanish National Research Council, Zaragoza, Spain; [3]Department of Civil Engineering, Faculty of Physical and Mathematical Sciences, Universidad de Chile, Santiago, Chile

Overview of INARCH

The International Network for Alpine Research Catchment Hydrology, INARCH (*https://inarch.usask.ca*), is a cross-cutting project of the GEWEX Hydroclimatology Panel (GHP) to better understand alpine cold regions hydrological processes, improve their prediction, diagnose their sensitivities to global change, and find consistent measurement strategies. At its core is a network of highly instrumented mountain observatories and experimental research sites, which are testbeds for detailed process studies on mountain hydrology and meteorology, developing and evaluating numerical simulation models, validating remotely sensed data, and observing, understanding, and predicting environmental change. INARCH began in late 2014 with 14 instrumented catchments; there are now 38 research catchments and sites in 18 countries and six continents, with more continuing to join the network (Fig. 1, see cover). By the end of 2022 the network has grown to 57 formal researcher participants from government and academia; however, there have been nearly one hundred other researchers, graduate students, and post-doctoral fellows involved in field research activities, modelling, remote sensing, and participating in our workshops. The network is open to scientists involved in field-based mountain hydrometeorological research or snow, glaciers and water modelling and remote sensing research in mountain headwaters.

INARCH provides an active mechanism for coordinating, sharing, and enhancing cold regions mountain hydrological science. It directly addresses many of the GEWEX science questions and provides a tool for collaboration with other GEWEX Panels and World Climate Research Programme (WCRP) activities. It further contributes to many other high-level international organizations, including the World Meteorological Organization (WMO), the United Nations Educational, Scientific, and Cultural Organization (UNESCO) Intergovernmental Hydrological Programme (IHP), the UN Water Decade, Future Earth, and the United Nations Framework Convention on Climate Change (UNFCCC). INARCH helped organize and co-hosted the WMO High Mountain Summit in 2019 in Geneva, Switzerland (*https://highmountainsummit.wmo.int/en*). This led to a Call for Action entitled "Avoiding the Impending Crisis in Mountain Weather, Climate, Snow, Ice and Water: Pathways to a Sustainable Global Future." Participants agreed on the need for an Integrated High Mountain Observation and Prediction Initiative to improve observations, forecasts, and data exchange in mountain ranges and headwaters around the world. At the 2019 Future Earth meeting in Bengaluru, India, INARCH, through its Future Earth–Water Futures working group, hosted a session and discussions on Global Mountain Water Security and contributed to discussions for a Mountain Water Solutions Laboratory for the Indian Himalaya. More recently at the 27th UNFCC Conference of the Parties (COP) in November 2022 in Egypt, a non-binding resolution on Implementation of the Global Climate Observing System was adopted that specifically addresses filling gaps in observations in mountain and polar regions and of the cryosphere, and follows from the case INARCH has made at several COPs and other forums, including the WMO High Mountain Summit. At the UN General Assembly, INARCH informed the development of the International Year of Glaciers' Preservation-2025, which was adopted by the UN General Assembly in December 2022. The International Year of Glaciers' Preservation will raise awareness of the loss of snow and ice resources and associated risks, give impetus at the global level to act, mobilize financial resources, and improve international cooperation and data sharing. UNESCO-IHP has approved a UNESCO Chair in Mountain Water Sustainability amongst several INARCH members for 2023–2027 that will provide a long-term focal point of research and outreach on mountain waters and how to reach the UN sustainable development goals for high mountain catchments under the stress of development and climate change.

Phase I Advances

A first phase of the network (2015–2020) was completed, and during this time INARCH grew and made significant advances. These include establishment of a suite of well-instrumented research catchments, high-resolution forcing meteorological datasets, and advanced snowdrift-permitting and glacier-resolving hydrological models. These have been used to improve our scientific understanding and evaluate observed changes, data, and models around the world. The models continue to be used to estimate the sensitivity of the high mountain cryosphere and hydrology to climate change. Data sets from around the world were compiled and made available in the journal *Earth System Science Data* in a special issue, "Hydrometeorological data from mountain and alpine research catchments" (*https://essd.copernicus.org/articles/special_issue871.html*). More data sets continue to be added to this special issue.

The global COVID-19 pandemic resulted in a hiatus of network activities, but individual research groups mostly carried on with their work and field-based activities, persevering and developing innovative ways to continue. INARCH held an online workshop in October 2021 to review the status and activities at INARCH's mountain research catchments, advances in modelling, and the use of modelling and observations to find solutions to mountain water sustainability under climate change. Discussions helped refine specific science questions to address as we move into a time when integrated observations, predictions, and services have been adopted for mountains by

WMO and the UNFCCC and as our models can better reflect and engage with the research basins to provide answers for regional river basins. During this workshop INARCH developed a collective vision and plans for a second phase of the network (2021–2026), building on achievements during the first phase.

Phase II Science Plans and a Common Observation Period Experiment (COPE)

For Phase II of INARCH, the objectives are to better:

- Measure and understand high mountain atmospheric, hydrological, cryospheric, biological and human-water interaction processes,
- Improve their prediction as coupled systems,
- Diagnose their sensitivities to climate change and propose how they may be managed to promote water sustainability under global change.

The following Science Questions have been proposed to help focus our activities:

1. How different are the observation and measurement approaches amongst INARCH basins and do we expect distinctive differences in our understanding of basin response and hydrological predictability because of the sampling schemes, and data quality and quantity?
2. How do the predictability, uncertainty, and sensitivity of energy and water exchanges vary with changing atmospheric thermodynamics, ecosystem structure, and water management in various high mountain regions of the Earth?
3. What improvements to high mountain energy and water exchange predictability are possible through improved physics in, coupling of, and downscaling of models in complex terrain, and improved and expanded approaches to data collection and assimilation?
4. To what extent do existing model routines have global validity, are transferable, and meaningful in different mountain environments for providing service to society?
5. Can mountain systems be predicted and managed to find solutions to help achieve water sustainability in river basins under climate change?

We aim to eventually contribute to answering: How have mountain atmospheric-cryospheric-hydrological-ecosystem-human systems co-evolved to their current states and how will they respond to climate change over the next century?

As a starting point for Phase II we have begun to provide common and archived observations for basin diagnosis and modelling through a Common Observation Period Experiment (COPE). The focus is on obtaining high-quality measurements to the extent possible, defining this as starting in 2022 to coincide with the start of the snow season in the southern hemisphere, and carrying on until 2024. During this COPE we will ensure all sensors are working, enhance observations at our mountain research basins, fly supplementary drone acquisitions, run high resolution models, and work together for comparison of processes, data sharing, and model testing in challenging environments. By getting these instruments into place and the campaign underway, this would be a start for longer-term observations of higher quality that can be comparable. Tremendous value can accrue from activities such as this and the approach has been used in the past with various GEWEX initiatives. We plan to take a variety of different models and apply them in different basins to see how they work, make sure we have the proper forcing information, try different forcing and apply it at different scales, see what corrections are needed for those forcings, calculate snow and ice dynamics and hydrological dynamics at the surface, and look at these diagnostically with available measurements from ice and snow changes, to soil moisture, streamflow, and turbulent fluxes, as available. This has not been done globally in alpine regions and could be potentially very powerful.

INARCH Workshop, Baños de Panticosa, Spain, October 18–20, 2022

INARCH held its first in-person workshop since before the start of the COVID-19 pandemic, meeting in the Spanish Pyrenees in October. The workshop brought together about 30 scientists from around the world to discuss some of the latest advancements in alpine hydrology, including observations and measurement techniques, prediction, comparability and validity of models, data management, and the ongoing COPE across the network of research basins. All participants presented research updates and new activities, and the presentations can be viewed on the INARCH website.

Summary of Observatories and Measurement Techniques

- Advances in using isotopes to supplement hydrometeorological observations and diagnostic modelling, including model calibration and structural design decisions from isotopic data
- Advances in satellite observations of snow depth, but limited to non-steep and non-forested sites. Density is still a challenge.
- Advances in field techniques to include basin-scale gravimetry, unmanned aerial vehicle LiDAR & IR, tower and terrestrial LiDAR
- Expansion of INARCH instrumented basins to all inhabited continents and new mountain ranges (Pamirs, High Atlas)
- Advances in reanalysis data in the Andes, North America (historical)
- INARCH basins are starting or ready for the COPE observing period

Summary of Predictions, Comparisons, Validity

- Advances in deployment of ecohydrological models to explore co-evolution of snow and vegetation and models addressing vegetation change (shrubification, forest change), revised interception, greening, drought, and management
- Improvements in atmospheric model forcing of precipitation phase and wind fields, high resolution nested models for dynamical downscaling (greater extent)

Participants of the Sixth INARCH Workshop, Baños de Panticosa, Spain, October 20, 2022

- Downscaling of atmospheric models to complex terrain snow models at snow-drift permitting scales (<100 m) applied at continental scales–intercomparison and evaluation against satellite and surface observations are needed to assess model outputs. Standardized comparisons to areal metrics need to be developed
- Improvements in data assimilation techniques for prediction
- Examination of parameter uncertainty, transferability, and machine learning techniques in hydro-cryosphere modelling. Noted that calibration from streamflow of physically based parameters in hydro-cryospheric modelling should focus on routing and subsurface rather than observable surface parameters (equifinality, self-deception)
- Comparisons of impacts of climate change on cryosphere and hydrology in different glaciated and snow dominated basins show different sensitivities to climate change.
- Identification of the distinctive research needs for marginal snowpacks–e.g., ground heat flux and thermal interactions between snowpacks and warm soils

COPE and Data Management

- COPE represents a unique opportunity to implement, focus, and accelerate model comparison and validation, observation comparison, and collaboration to compare process operation and model improvements on INARCH testbed basins.
- GWFNet data catalogue (*https://gwfnet.net/cope*) can help INARCH researchers find each other, papers, models, instrumented sites, data records, and model outcomes.
- Need for INARCH researchers to provide information to the data manager, Stephen O'Hearn, for cataloguing
- Keeping long-term research basins going remains a continual challenge.
- Specific COPE research projects need to be developed–same model for elasticity to change applied at different basins, observed response to extremes and climate differences, comparative eco-hydrology, new model testing?
- Plan for several papers from COPE analyses/comparisons and an overarching COPE data paper

INARCH Statement 2022

We have:

- begun Phase II, started COPE;
- expanded investigators, observations, basins, mountain ranges, and models;
- implemented a data cataloguing system, snowdrift-resolving models continentally;
- explored new measurement techniques, data assimilation, parameter uncertainty, and machine learning;
- started linking to ecosystems and downstream water resources; and
- informed a proposed UN Year of Glacier Preservation and contributed to WMO, UNESCO, WCRP, Future Earth, and the UN Water Decade.

We need to:

- develop detailed science investigations in COPE and ensure that it is used by other groups (WMO, intercomparison projects);
- apply atmospheric/hydrological/other models to INARCH basins for the COPE period; and
- co-develop plans to and share experiences on increasing mountain community/regional science and decision-making capacity.

Next Steps and Future Workshops

INARCH has begun the COPE initiative, which will have tremendous scientific value and contributes directly to GEWEX, WMO, UNESCO, Future Earth, UNFCC, and other global programs. This is expected to produce a valuable set of observations, model simulations and intercomparisons, new process understanding and insights, and better prediction of the changing mountain water cycle in headwater regions around the world. The team is energetic, enthusiastic, and fully engaged. INARCH welcomes new participants who wish to contribute to its goals and objectives, and to participate in the COPE initiative.

At this time INARCH is developing plans to hold the next workshop some time during October, 2023 in Idaho, USA. This would include a field trip and tour of some local experimental snow research sites and exciting presentations and discussions amongst the group over a couple of days. We are looking forward to the opportunity to meet together again in-person. INARCH will also plan for one or a series of online meetings to review and coordinate COPE activities in the coming months. Feel free to contact us or check our website for updates.

Did We Demistify the Fog?

Ian Boutle
Met Office, Exeter, UK

At the 2nd Pan-GASS meeting in Lorne, Australia, a new project began, endeavoring to build on the extensive Global Atmospheric System Studies (GASS) community experience of single-column model (SCM) and large-eddy simulation (LES) intercomparisons. The Demistify project turned this experience to the ever-challenging topic of radiation fog, something no operational center will claim is top of their "easy to forecast" list. Radiation fog is dominated by the subtle interplay of numerous processes, most of which are parameterized in numerical weather prediction (NWP) models. Weak dynamical forcing is a prerequisite for radiative, land-surface, microphysical, and turbulent processes to drive the formation, development, and dissipation of a fog layer which can pose numerous dangers to human activity, particularly in the transport sector.

Boutle et al. (2022) published the results of this project, which brought together 20 fog experts, representing 10 SCMs and five LES models. Drawing together fog experts from different modeling centers to form a community working on the fog problem was one successful aim of the project.

Fig. 1 presents a summary of the scientific results of the project. Whilst at first glance the LES results (Fig. 1a) may appear relatively good, the degree of consistency was not at the level seen in previous GASS projects covering other cloud regimes or stable boundary layers. Even for the case shown in Fig. 1a, the LWP of the highest LES model is double that of the lowest by midnight, and when the background aerosol concentration was changed, the differences became much more pronounced. Cloud microphysics and surface flux representation were seen as the key drivers of uncertainty between the LES models, supporting our conclusion that the LES models themselves could not be used as an adequate baseline against which to compare the NWP models.

The SCM results (Fig. 1b) were of highly variable quality, although the general trend was to overdevelop the fog. It was typically both optically and physically too thick, developed too quickly, and persisted for too long. However, two key differences stood out, enabling us to provide the following advice to NWP centers:

1. Inclusion of cloud-droplet sedimentation is key to accurate representation of fog—without this process, the fog water cannot be adequately depleted, resulting in the overdevelopment of fog.
2. Adequate near-surface vertical resolution is essential—a lowest level below 10 m and at least six levels below 150 m was a necessary (but not sufficient) condition for a good simulation.

Further differences, similar to the LES models, were dominated by differences in parameterizations, particularly those of microphysics and the surface fluxes. Finally, results from both LES and SCM experiments demonstrated that whilst aerosol representation was crucially important for fog development, the uncertainty arising from this was of similar magnitude to that of more fundamental aspects of the microphysical parameterization (e.g., representation of the cloud drop size distribution). This reinforces the idea that in fog, everything is important.

The Demistify project will now draw to a close. Whilst the fog problem has by no means been solved, the project achieved its stated aims, and further work will continue in future projects, e.g., the SOuth west FOGs 3D experiment (SOFOG3D, Burnet et al., 2020). Microphysics and land-surface interaction would appear the key places to focus future effort, but undoubtedly as improvements to those parameterizations are delivered, errors in others will begin to dominate. In summary, we made things slightly less hazy, but there is certainly more to do to fully clarify our knowledge.

References

Boutle, I., W. Angevine, J.-W. Bao, T. Bergot, R. Bhattacharya, A. Bott, L. Ducongé, R. Forbes, T. Goecke, E. Grell, A. Hill, A.L. Igel, I. Kudzotsa, C. Lac, B. Maronga, S. Romakkaniemi, J. Schmidli, J. Schwenkel, G.-J. Steeneveld, and B. Vié, 2022. Demistify: a large-eddy simulation (LES) and single-column model (SCM) intercomparison of radiation fog. *Atmos. Chem. Phys*., 22, 319–333. 10.5194/acp-22-319-2022.

Burnet, F., C. Lac, P. Martinet, N. Fourríe, M. Haeffelin, J. Delanoë, J. Price, S. Barrau, G. Canut, G. Cayez, A. Dabas, C. Denjean, J.-C. Dupont, R. Honnert, J.-F. Mahfouf, T. Montmerle, G. Roberts, Y. Seity, and B. Vié, 2020. The SOuth west FOGs 3D experiment for processes study (SOFOG3D) project. In *EGU General Assembly Conference Abstracts*, page 17836. 10.5194/egusphere-egu2020-17836.

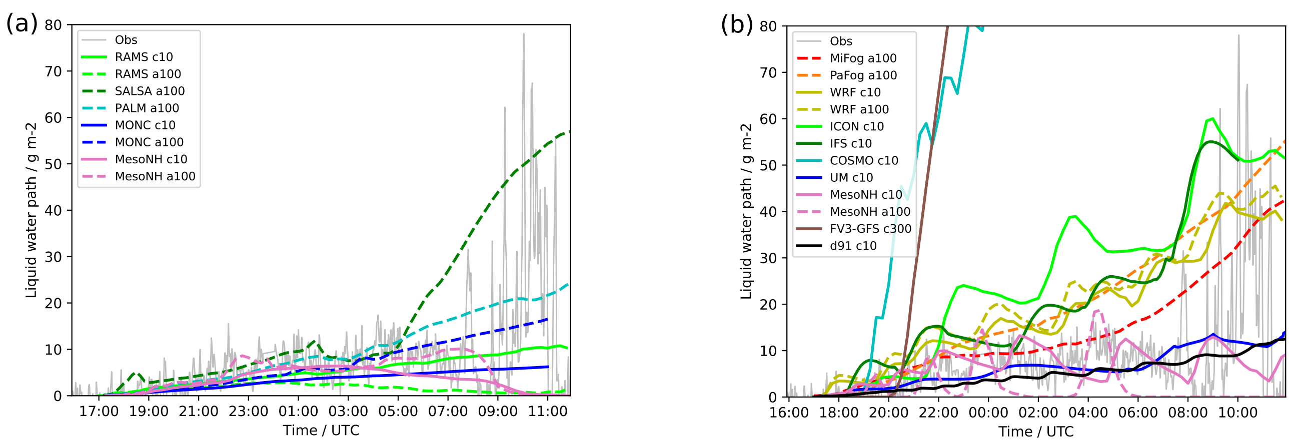


Figure 1. *Liquid water path (LWP) observed and modeled by (a) the LES models, and (b) the SCM models. From Boutle et al. (2022), unaltered and shared under the Creative Commons Attribution 4.0 Licence (https://creativecommons.org/licenses/by/4.0/).*

Meeting/Workshop Reports

6th PannEx Workshop: Regional Environmental Challenges in the Pannonian Basin

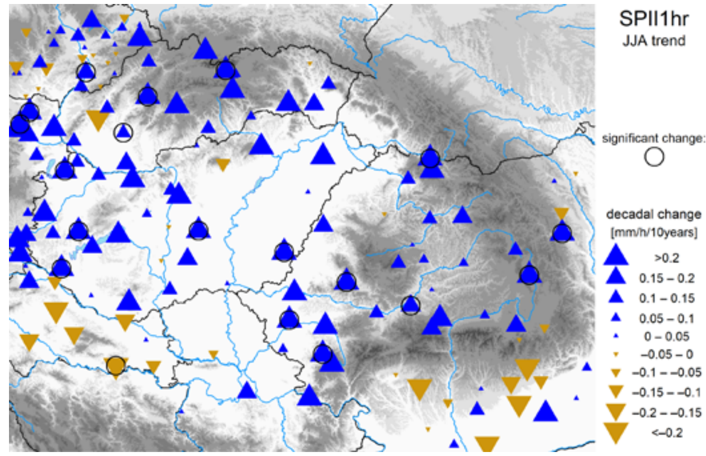
Cluj-Napoca, Romania
20–22 June 2022

Monika Lakatos[1] and Csaba Horváth[2]
[1]Hungarian Meteorological Service (OMSZ), Budapest, Hungary; [2]Babes-Bolyai University, Cluj-Napoca, Romania

The Pannonian Basin Experiment (PannEx) is a Regional Hydroclimate Network that aims to achieve a better understanding of the Earth system components and their interactions in the Pannonian Basin (*https://pannex.org/*). The international efforts involve the global research community in an integrated approach towards identifying and increasing adaptation capacity in the face of climate change in the Pannonian Basin. After the two-year shift due to the COVID-19 pandemic, the 6th workshop was announced amongst the members of the PannEx community for experienced and young researchers, experts, and decision makers involved in climate change adaptation.

The 6th PannEx Workshop was held in Cluj-Napoca, Romania, known as the city in the heart of Transylvania, due not only to its geographical position, but also its varied, multicultural environment and reputation as an esteemed university city. The event was hosted by the oldest university in Romania, Babeș-Bolyai University (BBU), and took place in the Faculty of Geography facilities. The event was a side meeting of the workshop "Climate Service for a Sustainable Agriculture", organized within the framework of the research project AGROCLIMRO (*https://agroclim.ro/*). The main partners of the AGROCLIMRO research project were two universities (BBU and University of Agricultural Sciences and Veterinary Medicine, UASVM) and Indeco Soft, a software developer firm. The main aim of the project was to develop a platform identifying suitable areas for maize and winter wheat crops based on agro-climatological and soil conditions in Romania. The scientific results, combined with the available data in the multifunctional platform created in AGROCLIMRO for displaying the spatial distribution of data, represents an extremely useful agro-climatic service for the field of agriculture and food security. The service is available free of charge on the project website. It is, moreover, the first agro-climatic service available at the national level and has among the best spatial resolution in Europe.

The first session was dedicated to the AGROCLIMRO project, which was attended by local stakeholders. The other sessions of the meeting focused on recent activities in PannEx. The number of abstracts submitted to the scientific organizing committee was 22. The detailed program and the abstract book are available at the meeting website: *https://pannex.org/6th-pannex-meeting/*. Almost 40 participants attended the AGROCLIMRO project meeting and PannEx Workshop altogether, hailing from Romania, Hungary, Serbia, Croatia, the Czech Republic, and Austria.



Decadal change of the mean 1-h precipitation intensity in summer in the PannEx region (Source: Lakatos et al., 2021)

The presentations covered a wide range of topics:

- Urban climate studies for Prague (Czech Republic) and Budapest (Hungary) pointed out the increasing frequency of heat waves and warm nights and the irregularities of the precipitation regime. A country-scale assessment of the heat hazard risk in urban areas in Romania was also introduced. In addition, a study compared three clothing resistance parameterization methods in the human thermal bioclimate models.
- One study showed the expected future natural vegetation of Hungary under climate change scenarios; another discussed a machine learning-based crop yield forecasting system for the Pannonian Basin and examined its skill, with special focus on drought years.
- Talks related to the surface-energy budget presented the evaluation of the surface layer stability functions for momentum, heat, and water vapor in a semi-arid location. The Pannonian Atmospheric Boundary Layer Study analyzed the evolution of the air and soil temperature profiles near the surface during a clear summer night in Szeged, located near the south border of Hungary.
- Detected and projected trends of extreme precipitation indices over the Pannonian plains were analyzed. The research compares the Pannonian Basin to other plains regions of Europe. A methodology to develop a representative database (spatially and temporally) for studying the climate of the Carpathian Basin was introduced.
- A micrometeorological measurement program for analyzing foggy situations in Budapest and near Lake Balaton was presented. The measurement campaigns and data-

Participants of the PannEx IPC Meeting during the 6th PannEx WS

processing procedures implemented in Hungary fit the framework of the European Cooperation in Science and Technology (COST) Action CA20108 - FAIR NEtwork of micrometeorological measurements (FAIRNESS), which is a great achievement of our network, as it was initiated in collaboration with PannEx. The main goals of the action are "to improve standardization and integration between micrometeorological measurements established for special purposes, create a transboundary network of researchers and stakeholders, and establish a knowledge sharing platform".

- A preliminary analysis illustrated the impact of rainfall erosivity on irrigated and non-irrigated arable land in Romania. A result of the joint work in PannEx, maps and graphs of the detected changes of sub-daily precipitation for the region were shown. PannEx contributes to the INTElligent use of climate models for adaptatioN to non-Stationary hydrological Extremes (INTENSE) project global hydro-climatic indices database with this work.

The PannEx International Planning Committee (IPC) met during the workshop. The primary focus of the IPC meeting was to consider the next steps to strengthen and organize the work of the PannEx Task Teams and to discuss the development of a new iteration of the Science and Implementation Plan. Mónika Lakatos stepped down as chair and Rita Pongrácz [Eötvös Loránd University (ELU), Meteorological Department, Budapest, Hungary] took over this role. The IPC agreed to specify new, more focused directions and to attract more young Ph.D. students to the community. Plans were discussed for the next PannEx Workshop, which is to be held in June 2023 at ELU in Budapest, Hungary.

References

Lakatos, M., O. Szentes, K. Cindrić Kalin, I. Nimac, K. Kozjek, S. Cheval, A. Dumitrescu, A. Irașoc, P. Stepanek, A. Farda, P. Kajaba, K. Mikulová, D. Mihic, P. Petrovic, B. Chimani, D. Pritchard, 2021. Analysis of Sub-Daily Precipitation for the PannEx Region. *Atmosphere* 2021, 12, 838. https://doi.org/10.3390/atmos12070838.

YESS, GEWEX, and YHS Workshop: Reflecting on African Early Career Researchers' Role in Earth Observations and Geospatial Science in the Service of Sustainable Development Goals

Faten Attig-Bahar[1], Bethel Ugochukwu Ukazu[2], Peter Waswa[3], Patrick Nii Lante Lamptey[4], and Modathir Zaroug[5]

[1]The University of Carthage, Tunisia Polytechnic School, Tunisia; [2]Technical University of Darmstadt, Germany; [3]Institute for Water Research, Rhodes University, South Africa; [4]Ghana Space Science and Technology Institute, Ghana Atomic Energy Commission, Ghana; [5]Nile Basin Initiative Secretariat, Uganda

The Young Earth System Scientists (YESS) community, GEWEX, and the Young Hydrological Society (YHS) were pleased to host the one-day workshop on "*the role of Early Career Researchers (ECRs) in contributing to Earth Observations and Geospatial Science*" (https://www.yess-community.org/activities/workshops/yess-gewex-and-yhs-workshop/) as a side event of the International Conference on "Earth Observations and Geospatial Science in the service of Sustainable Development Goals". The conference was organized by the African Association of Remote Sensing of the Environment (AARSE) and the Institut d'Enseignement Supérieur de Ruhengeri (Ines-Ruhengeri) between October 24th and October 28th, 2022, in Kigali, Rwanda.

This workshop brought together a community of early career researchers (ECRs) from the African continent, and enabled discussions and reflections on the importance of open science and Earth observation in and for Africa. Moreover, the workshop was a great opportunity to promote the participation of the climate research-interested community in the World Climate Research Programme (WCRP) Open Science Conference (OSC) to be held in Kigali, Rwanda next October 2023.

The workshop was held in two sessions: a morning session featured three impulsive talks provided by senior scientists, namely Prof. Peter J. van Oevelen from GEWEX, Prof. Zoltan Vekerdy from the Earth Observation for Africa network (EO-4Africa), and Prof. Diana Chavarro-Rincon from Twente University. The morning session was followed by a round table discussion in the afternoon. The presentations and the Q&A sessions highlighted the importance of open access to science and open data to all scientists and emphasized the need for more African representation in Earth observation-related projects, particularly those provided by GEWEX.

Moreover, strategies to empower the science community through more capacity development activities such as the EO-4Africa online training and the Massive Open Online Courses (MOOCs) on Earth observation were discussed, and ideas on fostering collaboration between scientific communities and building on more North-South and South-South partnerships in the field of Earth observation and data handling were shared and debated.

Participants of "the role of Early Career Researchers (ECRs) in contributing to Earth Observations and Geospatial Science" workshop in Kigali, Rwanda

Additionally, the round table discussion explored the challenges that early career scientists are facing in climate-related research in Africa and discussed the role that the ECRs networks, such as the YESS community and YHS, could play in bridging the gaps in this regard. Thus, the discussion highlighted the following concerns and opportunities:

- **Data access and availability**: Climatic data presents a significant part of research work in the field of Earth and climate science. Data collection, quality control, data formats, data storage, and analysis are regular activities carried out by researchers. Africa has long struggled to maintain adequate accessible data. African weather stations are sparsely distributed and government investment in weather monitoring is still low and very limited to cover the science needs. Although Earth observation products derived from merging satellite and in situ data have improved significantly over recent decades, they still display large uncertainties over Africa and are limited in terms of temporal and spatial coverage. Usually, the data sets required by ECRs to further their work are not accessible and commercial in nature. Moreover, meteorological data provided by government departments are not always accessible to local universities due to restrictive sharing policies, which results in more frustration and often delays in their careers. This further forces some to abandon their research topic completely, especially within novel areas of research.

- **Technology and technique handling**: Data collection, data storage, and analysis could represent one of the major contributions of scientists in the field of Earth and climate sciences. The growing quantum of data generated daily has required special skills in computing as well as computing power to access, and led to the need for big data technologies such as Artificial Intelligence (AI) and Machine Learning (ML). There currently needs to be more computing skills and platforms for accessing and analyzing these data sets. There has been some progress towards creating and accessing high-performance computing platforms for Earth systems and Earth observation data analysis. These platforms include Google Earth Engine (https://earthengine.google.com/), Digital Earth Africa, and WEkEO (https://www.wekeo.eu/). However, these require some level of programming proficiency to work with.

- **Some Opportunities**: African Earth system and climate research are crucially needed to confront the disastrous effects of climate change and can serve as platforms for national and regional developments. Earth observation is one of their most important components. To encourage global scientific progress, data sets should be shared as freely as possible. Efforts to increase networks of weather observation stations must be encouraged further to improve data quality. Collaboration with national and international entities is also necessary to feed the local data into global data systems. Moreover, collaborative exchanges of scientists between countries and promoting networks to link scientists such as YESS and YHS would help build research capacity in Africa. Both networks could support activities such as summer schools and webinar series on the topic of Earth observation as well as surveys to identify cross-cutting themes, and organize those online events across the African continent.

Finally, there has been a lot of progress in data access and computing, but more effort is needed to encourage, empower, and promote ECRs, especially in Africa. Moreover, local- and regional-level collaboration is needed to ensure impactful research that meets the needs of local and marginalized communities across the continent.

GEWEX/WCRP Calendar

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

27–29 March 2023—1st Land surface Interactions with the Atmosphere over the Iberian Semi-arid Environment (LIAISE) Conference and Determining Evapotranspiration CrossCut Workshop—Lleida, Spain

27–29 March 2023—International Core-to-Core Project on Global Storm Resolving Analysis (ICCP-GSRA) Workshop 2023 and 2nd EarthCARE Modeling Workshop—Shizuoka, Japan

27–31 March 2023—International Baltic Earth Winter School for Young Scientists on "Earth System Science for the Baltic Sea Region"—Warnemünde, Germany

11–13 April 2023—Integrated Product Workshop—Toledo, Spain

16–21 April 2023—5th Committee on Space Research (COSPAR) symposium—Singapore

17–21 April 2023—Cloud Tracking Workshop—Oxford, United Kingdom

1–4 May 2023—35th GEWEX SSG (SSG-35) Meeting (*by invitation only*)—Santiago, Chile

3–5 May 2023—2023 ANDEX Meeting (*by invitation only*)—Santiago, Chile

8–12 May 2023—44th Session of the World Climate Research Programme Joint Scientific Committee— Brussels, Belgium

15–17 May 2023—2023 Global Water Futures (GWF) Annual Science Meeting—Saskatoon, Saskatchewan

15–18 May 2023—Earth Energy Imbalance Assessment Workshop—Frascati (Rome), Italy

3–7 July 2023—2023 GEWEX Hydroclimatology Panel (GHP) Meeting—Maynooth, Ireland

3–7 July 2023—Berlin Summit to Advance Climate Science and Service—Berlin, Germany

3–7 July 2023—World Weather Research Programme (WWRP)/ World Climate Research Programme (WCRP) Subseasonal to Seasonal (2SS) Summit 2023—Reading, United Kingdom

6–7 July 2023—Tropospheric Lapse Rate: Observations and Modeling of Past, Present and Future Variations—Paris, France

9–13 July 2023—Joint Cloud Feedback Model Intercomparison Project (CFMIP)-Global Atmospheric System Studies (GASS) 2023 Meeting—Paris, France

30 July–4 August 2023—20th Asia Ocean Geosciences Society (AOGS) Annual Meeting—Singapore

29–31 August 2023—7th Convection-Permitting Modeling Workshop—Bergen, Norway

WCRP OSC 2023
WORLD CLIMATE RESEARCH PROGRAMME
OPEN SCIENCE CONFERENCE
23 - 27 OCT. 2023 | RWANDA

The World Climate Research Programme invites you to attend the WCRP Open Science Conference, focusing on "advancing climate science for a sustainable future." 40 science sessions and over 40 poster clusters will bring together a broad range of topics under three conference themes: Advances in Climate Research, Human Interactions with Climate, and Co-produced Climate Services and Solutions. Visit https://wcrp-osc2023.org/ for more information.

Save the Date!

9th GEWEX Open Science Conference

July 7–12 2024 | Sapporo, Japan

Watch for more details at www.gewexevents.org

GEWEX QUARTERLY

Published by the International GEWEX Project Office

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

International GEWEX Project Office
c/o George Mason University
111 Research Hall, Mail Stop 6C5
4400 University Drive
Fairfax, VA 22030 USA

E-mail: gewex@gewex.org
Website: *http://www.gewex.org*