GEWEX QUARTERLY

WCRP World Climate Research Programme

Vol. 32, No. 2 | Quarter 2 2022

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

New Version 3 of Monthly and Daily Global Precipitation Climatology Project Data

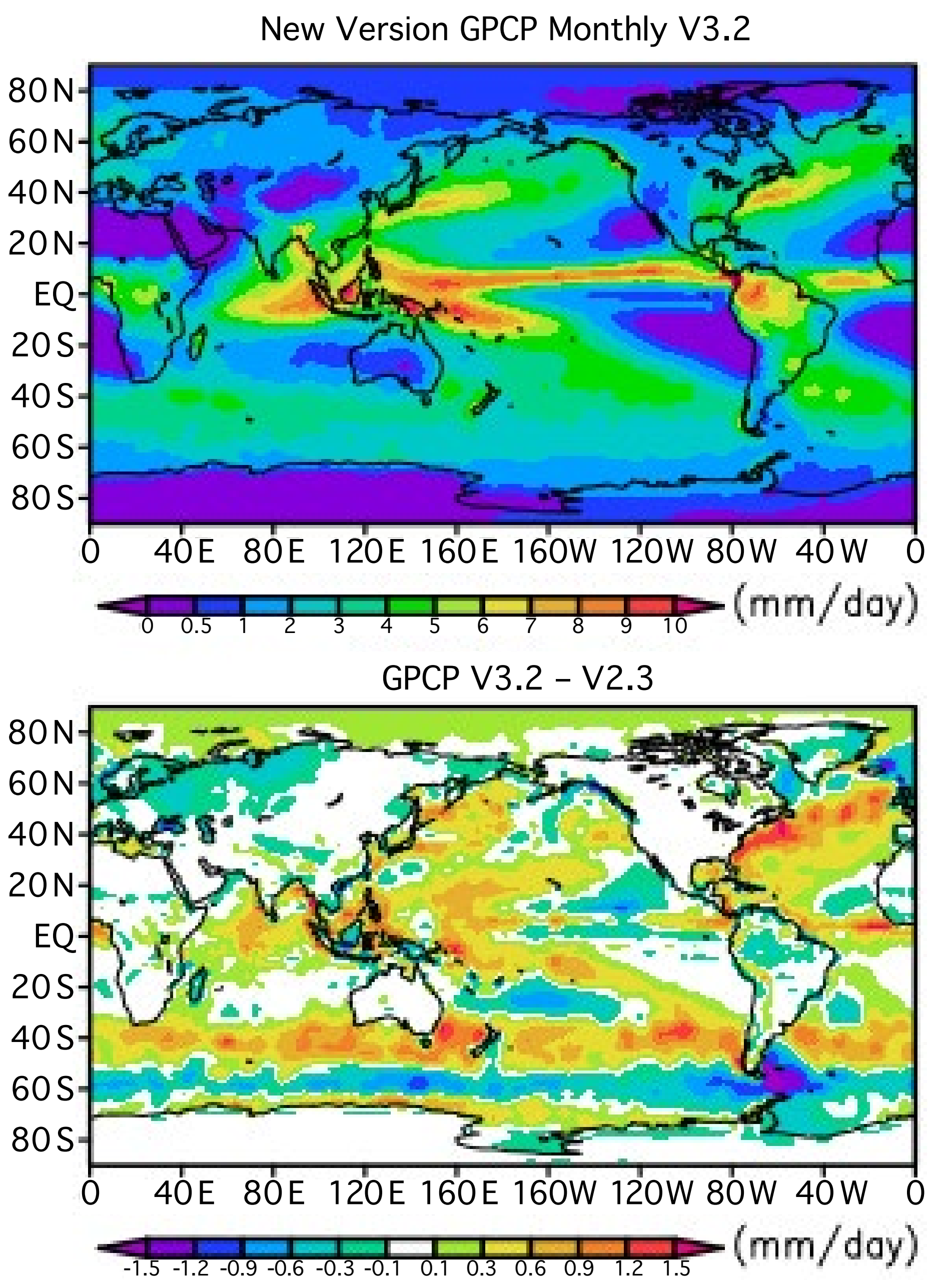


Figure 1. The new Version 3 precipitation climatology map for 1983–2020 from the Monthly product (top panel) and difference from Version 2 (bottom panel). See Adler et al., pg. 11.

Inside This Edition

Commentary and News

General

3rd Pan-GASS Meeting

12 July 2022 Registration Deadline

Register by 12 July 2022 to attend and present a poster at the 3rd Pan-GASS Meeting, Understanding and Modeling Atmospheric Processes (UMAP2022). Details are available at *https://www.gewexevents.org/meetings/3rd-pan-gass-meetingunderstanding-and-modeling-atmospheric-processes/registration/.*

Silicon Valley, Entrepreneurship, and Scientific Innovation

Xubin Zeng
GEWEX Scientific Steering Group (SSG) Co-Chair

Recently, my wife and I attended the in-person graduation ceremonies of our two children at Stanford University in June 2022, which were delayed due to COVID-19. Stanford has played a major role in the development of Silicon Valley as a leading hub and startup ecosystem for high-tech innovation, with the largest concentration of venture capital (VC) firms in the world. While visiting this area and interacting with people (including our two children) working in startups and high-tech companies, VC firms for startup funding at different stages, and intellectual property law firms, I was also thinking about the question: what can we learn from Silicon Valley and its entrepreneurship for our scientific innovation?

There has been increased competition for research support in our field. Knowing that there is usually no chance for proposal revision, most proposers don't want to include risky new ideas with high potential impacts that might be difficult to justify to some reviewers who may not have experiences in evaluating such ideas.

Recognizing this issue, various funding organizations are trying new ideas. For instance, the National Aeronautics and Space Administration encourages "high risk, high potential return" proposals by asking proposers to self-identify such proposals. If these proposals are not selected for funding during the normal review process, they will be reviewed again by program managers for a small additional chance of selection.

VC investment has evaluation metrics similar to those for science proposals (e.g., unique idea, experience of the team, business model or scientific method, growth potential or broader impacts, appropriate budget). The difference is that experienced VC partners or managers do the evaluations (usually through in-person pitching), while volunteers do the reviews of scientific proposals. One way to promote scientific innovation would be to hire more managers with the expertise to cover a broad range of topics who would conduct the reviews full time, just like VC partners or managers, or like full-time examiners of patents (remember the most famous patent examiner–Albert Einstein).

Another way would be to recruit experienced scientists with a fixed term (similar to the National Institutes of Health Scientific Review Group) for full-time proposal review (e.g., for 1–2 months in summer) with some compensation. The stability of this group of reviewers for particular areas would instill proposers' confidence in submitting "high risk, high potential return" proposals. Some compensation is necessary because of the substantial time commitment, as also recognized by the American Geophysical Union for its journal editors' service.

A related issue is the substantial growth in recent decades in peer-reviewed publications that document our science innovations. For instance, as one of the most impactful journals on climate science, the *Journal of Climate* has published eight times as many pages in 2021 (10,026) compared with three decades ago (1,216 pages in 1991). At the same time, although an adequate statistic does not exist, most of us probably agree that the corresponding increase in scientific innovation has been much less.

This is partly related to our scientific culture of emphasizing success. For instance, peer-reviewed papers rarely discuss the numerous failures before the final success. One consequence is that many scientists might repeat the same mistakes, leading to incremental science.

The entrepreneurship culture values the lessons learned from failures. Indeed, as an ancient Chinese proverb says, "Failure is the mother of success" (失败是成功之母). Therefore, the scientific community should create a new culture of celebrating failure to inspire innovation. One way is to include the discussion of failed ideas in peer-reviewed publications. To lead by example, GEWEX projects could include such discussions in relevant publications.

Table of Contents

Upcoming Student and Early Career Events

Dan Myers[1] and Deon Knights[2]

[1]Stroud Water Research Center, Avondale, PA, USA; [2]West Virginia University, Morgantown, WV, USA

The Hydrology Section Student Subcommittee for the American Geophysical Union (AGU-H3S) has an exciting lineup of activities this summer.

Professional Development Workshops: Starting in August will be a series of webinars for students and early career scientists on navigating academic and non-academic career paths. We will have two panel discussions: (1) succeeding as a postdoc (Thursday, August 11) and (2) non-academic jobs (Thursday, September 8). In the fall, we will have two webinars on best practices in grant writing (dates to be decided). These webinars will be free and virtual, in partnership with the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI). Check back at our events page (*https://agu-h3s.org/events/*) for more information.

International Scholars: Are you an international student or early career researcher studying or working in a country that you're not a permanent resident of? The H3S Accessibility, Justice, Equity, Diversity, and Inclusion (AJEDI) committee is hosting a social hour (August 2022) designed for international students and researchers (or anyone who is interested) to network with scientists at similar career stages who are dealing with the added pressure of working in a foreign country. This event will provide an informal support network for participants to talk about culture shock, homesickness, work and travel restrictions, making friends, and language barriers. Visit *https://agu-h3s.org/events/* for more information.

Social Media: Savvy on social media? Engage with other student and early career hydrologists on twitter (*https://twitter.com/AGU_H3S*) and LinkedIn (*https://tinyurl.com/h3s-linkedin*).

Blog: We regularly post highlights of stellar student and early career researchers, as well as professional development and diversity, equity, and inclusion resources at *https://agu-h3s.org/*.

WaterPOC: We are now hosting the WaterPOC database, a database of Black, Indigenous, and People of Color pursuing water-related research to increase the visibility of research to their peers. Check out the WaterPOC database at *https://agu-h3s.org/waterpoc-database/*.

What's H3S? The AGU-H3S is an inclusive, multicultural organization that serves student and early career hydrologists with professional development, conference activities, outreach, and social opportunities. Visit our website (*https://agu-h3s.org/*) to get involved! We would love to see you at our events.

Recent Activities from the Young Earth System Scientists (YESS) Community

Gerbrand Koren[1], Faten Attig Bahar[2], Carla Gulizia[3], and the YESS Executive Committee

[1]Copernicus Institute of Sustainable Development, Utrecht University, the Netherlands; [2]University of Carthage, Tunisia Polytechnic School, Al Marsa, Tunis, Tunisia; [3]Centro de Investigaciones del Mar y la Atmósfera (CIMA/CONICET-UBA), Buenos Aires, Argentina

The Young Earth System Scientists (YESS) community is proud to announce the release of the new "YESS video" with the support of the World Meteorological Organization's World Weather Research Programme (WWRP). This video clip represents the diverse activities performed by the network of enthusiastic early career researchers. These researchers work passionately in shaping the future of Earth system science and fostering the scientific profile of young scientists by supporting their active role in interdisciplinary and transdisciplinary science. To watch the video, please click here: *https://www.youtube.com/playlist?list=PL2LikZXIOUIaNcFHDoC5AGOO1YtRs9bOl*.

The YESS Council has recently elected the new generation of Executive Committee (ExeCom) members and Regional Representatives. The ExeCom oversees and guides YESS activities and is the contact point for communication both internally, with its members, and externally, with its partners. In addition, the Regional Representatives support the YESS community by sharing experience and information from their region and promoting the growth of YESS in their region. The election results can be accessed through the YESS website: *https://www.yess-community.org/2022/04/08/yess-elections-2022-results/*.

In the past year, the YESS community worked on an online activity for learning about the application of machine learning (ML) in the Earth system sciences (see also the YESS article in the previous *GEWEX Quarterly* edition for Quarter 1, 2022). The activity started off with two online seminars from ML experts, after which several groups of approximately eight researchers were created that applied ML methods to a specific problem. This culminated in a series of presentations in December 2021. During the European Geosciences Union (EGU) meeting in May, the YESS organizing committee looked back on this activity (*https://doi.org/10.5194/egusphere-egu22-3713*) and presented an overview of the lessons learned, from both the participants' and the organizing committee's perspectives.

My Climate Risk

Regina R. Rodrigues[1] and Theodore G. Shepherd[2], Co-Chairs of the WCRP My Climate Risk LHA

[1]Federal University of Santa Catarina, Brazil; [2]University of Reading, Reading, UK

The World Climate Research Programme (WCRP) Lighthouse Activities (LHA) are designed to be ambitious and transdisciplinary (integrating across WCRP and collaborating with partners) so that they can rapidly advance some of the new science, technologies, and institutional frameworks that are needed to more effectively manage climate risk and meet society's urgent need for robust and actionable climate information. Note that all LHAs address climate risk in various ways, although only ours has the word "risk" explicitly in its title.

The *My Climate Risk* (MCR) LHA aims to develop and mainstream a bottom-up approach to regional climate risk, which starts with the requirements of regional decision-makers (hence the "My"). This approach is in contrast to the more traditional top-down approach to the production of regional climate information, as exemplified in the Intergovernmental Panel on Climate Change (IPCC) assessment reports, and to a large extent, in WCRP. This is not to say that top-down approaches don't have their place, only that they need to be complemented by bottom-up approaches. The call for bottom-up approaches is not new, and it is recognized that parts of WCRP (notably GEWEX and the Coordinated Regional Climate Downscaling Experiment, CORDEX) have been developing related initiatives within their own contexts. However, the pace of climate change impacts is accelerating, and this sort of approach needs to be rapidly mainstreamed across all of WCRP science. That is where MCR comes in.

By developing a new framework for assessing and explaining regional climate risk using all the available sources of climate information (observations, reanalyses, model simulations, better understanding, etc.), climate information will be made meaningful at the local scale. Whilst any application of the framework will inevitably be specific and tailored to local concerns, the framework itself will be generic, hence flexible and applicable across a number of region types and intended to become much-needed support for the development of locally-based climate services. At the same time, MCR can identify needs to be addressed by the WCRP Core Projects and other LHAs. Both the *Explaining and Predicting Earth System Change* and *Safe Landing Climates* LHAs complement MCR's local perspective by taking more of a continental-to-global perspective, on near-term and long-term time horizons, respectively.

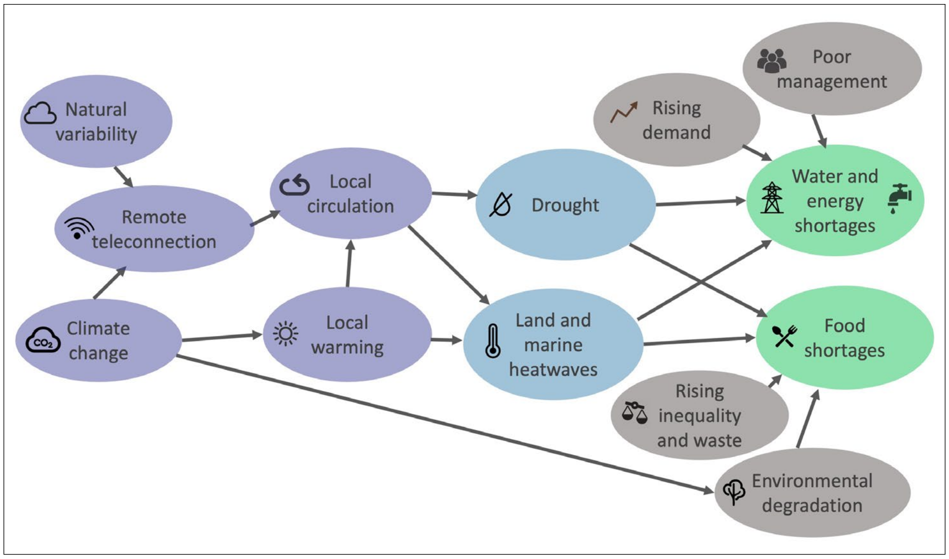
MCR will primarily use a case-study approach in the form of labs (communities of practice) that provide dynamic, exploratory, and transdisciplinary environments. These communities of practice could take a variety of forms depending on local needs and interests. A canonical activity would be to discuss current risk in a given situation, with proximate explanations, and then developing storylines of future climate-related risk based on those explanations. In this way, the past can be related to the future within a risk framing. An example of this way of thinking (which is highly relevant to GEWEX) is shown in Fig. 1, which represents the various factors affecting local climate risk in eastern South America as manifested during the 2013/2014 austral summer with the failure of the South American monsoon system (see Rodrigues and Shepherd, 2022, for further discussion).

To facilitate the desired bottom-up approach, *My Climate Risk* will be implemented in a non-hierarchical way through an informal ecosystem of regional hubs. This is in contrast to, and complementary with, the traditional WCRP structure of working groups and panels. Together, the regional hubs will support a "mycorrhizal network" of communities of practice, sharing knowledge and resources. Regional hubs need to be anchored in an existing locally-based institution with a commitment to the principles of MCR, to ensure long-term continuity and local engagement. Representatives of the hubs, together with a Scientific Steering Group (who are responsible for reporting to WCRP) and Ex-Officio Members (who are responsible for liaison with international partners, both within and outside WCRP), will constitute a (virtual) General Assembly (Fig. 2), providing connection points between the hubs and the relevant expertise that exists in the wider climate science community. Our first General Assembly was held from May 30 to June 2, 2022.

There are currently eight regional hubs that are in the process of spinning up:

- Australian Bureau of Meteorology (Melbourne, Australia)
- Ateneo de Manila University (Manila, Philippines)
- Himalayan University Consortium (Kathmandu, Nepal)
- National Scientific and Technical Research Council (Buenos Aires, Argentina)
- University of Cape Town (Cape Town, South Africa)
- Walker Institute, University of Reading (Reading, UK)
- University of Manitoba (Winnipeg, Canada)
- Climate Futures, Norwegian Research Centre (Bergen, Norway)

Importantly, the hubs are not expected to coordinate all MCR-relevant activity within their region. Rather, they are available as a potential contact point, and source of support, for those who need it. Perhaps the word "hub" is misleading, and they can be seen more as "outposts" of MCR. The network of hubs is expected to help WCRP to bridge climate information and society by grappling with the complexity of local situations while maintaining the methods of analysis simple enough



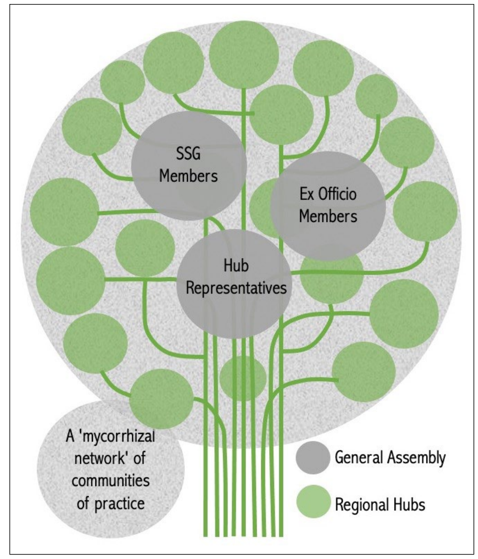


Figure 1 *(top left). Causal network for the austral summer of 2013/2014 in eastern South America, which affected the food-water-energy nexus. The purple shading indicates elements whose causality lies in the weather and climate domain, the blue shading indicates the hazards, the gray shading exposure and vulnerability, and the green shading the impacts. Causal networks allow one to navigate the cascade of uncertainty involved in such a complex risk landscape through the device of conditionality, which means specifying the state of some of the nodes in the network. By, thereby, seeking conditional rather than unconditional predictions, counter-factual outcomes and system sensitivities can be explored in a targeted way. From Rodrigues and Shepherd (2022)*

Figure 2 *(top right). The envisaged organizational structure of My Climate Risk.*

to be interpretable and open to interrogation. In addition, the use of more straightforward methodologies that build trust and transparency facilitates the co-production and co-ownership with the end-users of the climate information. The ultimate goal of MCR is to empower local communities to make sense of their own situation. More discussion of the MCR philosophy can be found in Rodrigues and Shepherd (2022).

Details of the planning documents that led to the development of MCR, past events, and information on how to get involved are available from the MCR web page: https://www.wcrp-climate.org/my-climate-risk. A subset of the initial Science Plan Development Team is continuing on the SSG, and a call for new SSG members has just closed. We anticipate strong connections to GEWEX through a variety of channels, where MCR's transdisciplinary approach can complement GEWEX's core climate science expertise and combine it with expertise from other WCRP core projects. Our view is that such synergies are most effectively developed at the community of practice level, in the context of specific problems.

References

Rodrigues, R.R., and T.G. Shepherd, 2022. Small is Beautiful: Climate-change science as if people mattered. *PNAS Nexus*, 1, pgac009. https://doi.org/10.1093/pnasnexus/pgac009.

First LIAISE Conference

LIAISE First Science Conference and GEWEX's Evapotranspiration Crosscutting Project Workshop

Location: Parc Científic i Tecnològic Agroalimentari de Lleida, Lleida, Spain

Date: Spring 2023

The main objective of the GEWEX-supported Land surface Interactions with the Atmosphere over the Iberian Semi-arid Environment (LIAISE) project is to improve the understanding of land-atmosphere-hydrology interactions in a semi-arid region characterized by strong surface heterogeneity owing to contrasts between the natural landscape and intensive agriculture. Understanding the impact of anthropization on the lower atmosphere and representing it in models have been inhibited due to a lack of consistent and extensive observations. In recent years, land surface and atmospheric observation capabilities have advanced while irrigated surfaces have been increasing, leading to a renewed need for dedicated field campaigns over contrasting (climate) regions, especially over so-called breadbasket areas where climate change is directly threatening our food production.

This conference invites contributions on topics that include:

- Modeling studies aimed at including anthropogenic processes (land surface, meteorological, or hydrological) within or including the LIAISE area addressing the main project objectives
- Studies using observational data from the LIAISE field campaign
- Applications using remote sensing data (from planes, drones, or satellites) to estimate irrigation requirements or evapotranspiration over the region

We encourage contributions from the GEWEX Determining Evapotranspiration (ET) Crosscutting Project. For more information on the conference, visit https://www.hymex.fr/liaise/conf_22.html.

How Can We Improve Estimates of Precipitation and Evaporation over Global River Basins?

Xubin Zeng[1], Jan Polcher[2], J.E. Jack Reeves Eyre[3], Peter J. van Oevelen[4], Tim Schneider[5], Tristan L'Ecuyer[6], and L. Ruby Leung[7]

[1]Department of Hydrology and Atmospheric Sciences, University of Arizona, Tucson, AZ, USA; [2]Laboratoire de Météorologie Dynamique, IPSL, CNRS, Ecole Polytechnique, Palaiseau, France; [3]Cooperative Institute for Climate, Ocean and Ecosystem Studies, University of Washington, Seattle, WA, USA; [4]International GEWEX Project Office, George Mason University, Fairfax, VA, USA; [5]Research Applications Laboratory, National Center for Atmospheric Research, Boulder, CO, USA; [6]Department of Atmospheric and Oceanic Sciences, University of Wisconsin-Madison, Madison, WI, USA; [7]Atmospheric Sciences and Global Change Division, Pacific Northwest National Laboratory, Richland, WA, USA

Introduction

Precipitation (P) and evaporation (E) over land have been extensively studied by atmospheric and climate scientists, hydrologists, and ecologists, and are also directly relevant to coastal oceanography. They are part of the global and regional water cycle (L'Ecuyer et al., 2015; Dorigo et al., 2021): P, water vapor divergence and change of column water vapor in the atmosphere, and land surface E, terrestrial water storage change (ΔS; related to snowpack, surface and ground water, and soil moisture change), and river and groundwater discharge (which is linked to ocean salinity near river mouths).

Because of their importance, many P and E products from satellite remote sensing, in situ measurements, and reanalysis have been developed. Some of these P and E products have also been adjusted to satisfy water balance constraints (Pan et al., 2012; Aires, 2014; Rodell et al., 2015). However, a definite answer to a simple, yet quantitative question like "how much does it rain and evaporate over the Amazon River basin?" remains elusive. Conventional approaches to addressing this kind of question include: a) the use of surface-based and airborne measurements to quantify the individual data product uncertainties over specific areas by that community (e.g., the uncertainty of P as a climate data record), and b) the use of multi-product ensemble means to represent the "best available" estimate along with the spread as a proxy for uncertainty of the quantity (e.g., E). However, such approaches don't necessarily reduce the large biases in the water cycle over the Amazon River basin (Reeves Eyre and Zeng, 2021). In this piece, we offer a multi-disciplinary, iterative approach to improving estimates of P and E in river basins across the globe through water balance estimation, and illustrate this approach using the Amazon as an example below.

The key differences of our proposed approach from prior studies are that, before water balance is forced, P and E products need to pass the evaluations in Steps 1 and 2, and P, E, ΔS, and streamflow products need to show good performance based on the metrics in Steps 5 and 6. Poor performances in Steps 5 and 6 would also be a strong motivation for planning regional hydroclimate experiments, e.g., as organized by GEWEX.

An Iterative Approach with Six Steps, Taking the Amazon as an Example

First, we need to determine what P data sets are reliable over the Amazon through the evaluation and improvement of the P retrieval algorithm from satellite remote sensing, validation against field experimental measurements, and validation against densely-distributed rain gauge measurements (e.g., Roca et al., 2021). In particular, the transferability of the validation results to areas with few or no rain gauges should be explicitly addressed.

Second, E products should be developed that are constrained by flux tower measurements, P data sets, and observed net radiation flux. These E products should also be constrained by soil moisture, state of the vegetation, and floodplain inundation. Furthermore, they should be constrained by the ecosystem measurement of gross primary production. These can be done through the collaboration of scientists in eddy-covariance measurements of energy, water, and carbon fluxes; measurements of precipitation, radiation flux, and soil moisture; land modeling; and data assimilation.

While it is difficult to constrain P and E separately, their difference (P – E) can be better constrained by water vapor convergence and temporal change of column water vapor in the atmosphere (e.g., from reanalysis). The computation of water vapor convergence depends on horizontal wind velocity, with generally smaller errors over midlatitudes than over the tropics due to the lack of radiosonde data and weak relation of temperature and pressure with wind fields over the tropics. This is also affected, to a certain degree, by the lack of water mass conservation in reanalysis.

Third, ΔS can be estimated from the Gravity Recovery and Climate Experiment (GRACE) satellite measurements of the time variations in Earth's gravity field. For the whole Amazon River basin, the ΔS differences among different estimates are relatively small (Reeves Eyre and Zeng, 2021). The differences would be larger over smaller river basins. The interpretation of GRACE estimates for ΔS is more challenging over regions where tectonic movements cannot be neglected. To separate the surface and groundwater contributions to ΔS, the measurement of surface water elevation over floodplains and wetland becomes important (Fassoni-Andrade et al., 2021).

Fourth, the monthly streamflow at the Amazon River mouth can be estimated based on the measurements at the Obidos station using a seasonally-variable adjustment factor (e.g., Reeves Eyre and Zeng, 2021) or by making new in situ or remote sensing measurements near the Amazon River mouth. The water level measurements from the new Surface

Water Ocean Topography (SWOT) mission (to be launched in 2022) will be very helpful. All gauging stations on the river network should be used, as they contain a wealth of information that has been underused by the climate community. In contrast to the river discharge measurement, the groundwater discharge cannot be directly measured, but may be constrained by the salinity measurements near the river mouth or estimated using data assimilation methods (Wang and Polcher, 2019).

Fifth, the residual (P – E – ΔS – streamflow) using the most reliable P, E, ΔS and streamflow data sets, identified in Steps 1–4, can be computed for the whole Amazon River basin and for the catchment (about 80% of the basin) associated with the Obidos streamflow measurements. While the residual will never reach zero due to uncertainties in the input data sets, the smaller the residual in magnitude, the better.

Sixth, satellite measurements of Atlantic Ocean surface salinity near the Amazon River mouth [e.g., from the Soil Moisture Active Passive (SMAP) and Soil Moisture and Ocean Salinity (SMOS) satellites] can be used to further constrain the above estimates by comparing the salinity correlation with estimated streamflow at the mouth from Step 4 versus with that computed from (P – E – ΔS). The higher the correlation, the better.

Finally, the first few combinations of data sets with small residuals in Step 5 and high correlations in Step 6 would be selected to represent reasonable estimates of P, E, ΔS, and streamflow in Steps 1–4. If no combinations are good enough (e.g., if the residual is greater in magnitude than the combined uncertainties in the input data sets), this would indicate that P, E, ΔS, and/or streamflow are unrealistic. If so, the above process needs to be iterated by disciplinary research (e.g., on P data uncertainties and model uncertainties) and interdisciplinary interactions (e.g., on the constraint of E products by net radiation flux, floodplain inundation, or vegetation states). With these relatively good combinations of data sets, various methods can then be used to force water balance, including data assimilation methods [e.g., variational method (Rodell et al., 2015) and constrained Kalman filter (Pan et al., 2012)], data integration methods (e.g., Aires, 2014), and physical models or physics-informed machine learning as constrained by these data sets.

A similar approach (without Step 6) should also be used for sub-basins, as the variable with the largest uncertainty changes from one sub-basin (e.g., near the Andes with steep topography) to another (over relatively flat surface with floodplain inundation) (Fassoni-Andrade et al., 2021). Furthermore, the water cycle budget over sub-basins can be balanced simultaneously by constraining the horizontal water exchanges between them (Pellet et al., 2021).

This iterative, multidisciplinary approach is also relevant to current and future national and international efforts in organizing interdisciplinary and integrated field campaigns and research projects. For example, for the regional hydroclimate project under discussion in the U.S., key suggestions would be: a) to select specific river basins as the focus region, rather than to select a region (e.g., with a continental divide) that covers part of several river basins; and b) to design field campaigns (along with satellite remote sensing, high-resolution modeling, and data assimilation) that will help close the water balance, following Steps 1–7 above.

Over mid- and high latitudes and high altitudes, additional complexity in the water cycle is the partitioning of P into liquid and solid forms, measurement of snowpack and glaciers on the ground, and partitioning of soil moisture into soil water and ice. The importance of global snow mass measurement has been recognized as one of the seven observables for the National Aeronautics and Space Administration (NASA) Explorer class satellite mission competition in 2022. The change of snowpack mass can also help constrain the estimate of snowfall.

Over many river basins, additional complexity in the balance of the water cycle is created by human activities. These activities include agricultural, industrial, and municipal use of water and its source (i.e., ground or surface water; local or remote) and operations of dams, reservoirs, canals, and agricultural drainage systems. They also include land cover and land use change (e.g., deforestation over the Amazon) with the data available from the venerable Landsat satellites from the 1970s to present.

The water cycle is fully coupled with the energy cycle, including the constraint of net radiation flux on E, as mentioned earlier. Indeed, simultaneously imposing energy and water cycle closure is central to the variational approach used in L'Ecuyer et al. (2015) and Rodell et al. (2015) and to their suggestion that both P and E are underestimated on the global mean, a result that cannot be obtained through enforcing water balance alone.

If we can close the water balance over various river basins, these terrestrial estimates of P, E, ΔS, and streamflow would be directly linked to the regional and global sea level rise (Stephens et al., 2020), further demonstrating that all elements of Earth system science are inter-related, and both disciplinary efforts and cross-disciplinary collaborations are needed to fully address and understand the Earth system. For futher inquiry, contact Xubin Zeng (*xubin@arizona.edu*).

Acknowledgements

We thank Rémy Roca, Graeme Stephens, and Duane Waliser for helpful discussions. Zeng is supported by NASA (80NSSC20K0660 and 80NSSC22K0285).

References

Aires, F., 2014. Combining datasets of satellite-retrieved products. Part I: Methodology and water budget closure. *J. Hydrometeorol.*, 15(4), 1677–1691. *https://doi.org/10.1175/JHM-D-13-0148.1*.

Dorigo, W., S. Dietrich, F. Aires, L. Brocca, et al., 2021. Closing the water cycle from observations across scales: Where do we stand? *Bull. Amer. Meteor. Soc.*, 102(10), E1897–E1935. *https://doi.org/10.1175/BAMS-D-19-0316.1*.

Fassoni-Andrade, A.C., et al., 2021. Amazon hydrology from space: scientific advances and future challenges. *Rev. Geophys.*, 59(4). https://doi.org/10.1029/2020RG000728.

L'Ecuyer, T.S., et al., 2015. The observed state of the energy budget in the early twenty-first century. *J. Clim.*, 28, 8319–8346. https://doi.org/10.1175/JCLI-D-14-00556.1.

Pan, M., A.K. Sahoo, T.J. Troy, R.K. Vinukollu, J. Sheffield, and E.F. Wood, 2012. Multisource Estimation of Long-Term Terrestrial Water Budget for Major Global River Basins. *J. Clim.*, 25, 3191–3206. https://doi.org/10.1175/JCLI-D-11-00300.1.

Pellet, V., F. Aires, D. Yamazaki, and F. Papa, 2021. Coherent Satellite Monitoring of the Water Cycle Over the Amazon. Part 1: Methodology and Initial Evaluation. *Water Resour. Res.*, 57 (5). https://doi.org/10.1029/2020WR028647.

Reeves Eyre, J.E.J., and X. Zeng, 2021. The Amazon Water Cycle: Perspectives from Water Budget Closure and Ocean Salinity. *J. Clim.*, 34, 1439–1451. https://doi.org/10.1175/JCLI-D-20-0309.1.

Roca, R., Z.S. Haddas, et al., 2021. *The Joint IPWG/GEWEX Precipitation Assessment WCRP Report* 2/2021, World Climate Research Programme (WCRP): Geneva, Switzerland, 125 pp. https://doi.org/10.13021/gewex.precip.

Rodell, M., et al., 2015. The observed state of the water cycle in the early 21st century. *J. Clim.*, 28, 8289–8318. https://doi.org/10.1175/JCLI-D-14-00555.1.

Stephens, G.L., J.M. Slingo, E. Rignot, J.T. Reager, M.Z. Hakuba, P.J. Durack, J. Worden, and R. Roca, 2020. Earth's water reservoirs in a changing climate. *Proc. Royal Soc. A*, 476: 20190458. http://dx.doi.org/10.1098/rspa.2019.0458.

Wang, F., and J. Polcher, 2019. Assessing the freshwater flux from the continents to the Mediterranean Sea. *Sci. Rep.*, 9. https://doi.org/10.1038/s41598-019-44293-1.

3rd Pan-GASS Meeting

Understanding and Modeling Atmospheric Processes (UMAP 2022)

In-Person Event
25–29 July 2022 | Hyatt Regency Monterey, CA, USA

The GEWEX Global Atmospheric System Studies Panel (GASS) will hold its 3rd Pan-GASS Meeting, Understanding and Modeling Atmospheric Processes (UMAP 2022), at the Hyatt Regency Hotel in Monterey, CA, USA, from 25–29 July 2022.

UMAP 2022 aims to bring together weather and climate scientists, including both observationalists and modelers, to discuss the key issues of atmospheric science. The program will include all aspects and methods of model development, from deterministic numerics to stochastic forcing, process modeling to parametrization, observational constraints to diagnostic techniques, and idealized modeling to operational forecasting and climate predictions. The purpose of the conference is to discuss progress in understanding atmospheric processes and representing them in models, to coordinate current initiatives and make plans for the future.

For detailed information and to register, please visit the UMAP 2022 website at https://bit.ly/3DOBgTe.

Global Precipitation Experiment (GPEX)

Jin Huang[1], Renu Joseph[2], Chungu Lu[3], David Considine[4], Sally McFarlane[2], Sandy Lucas[1], Jared Entin[4], Drew Story[5], and Mike Patterson[6]

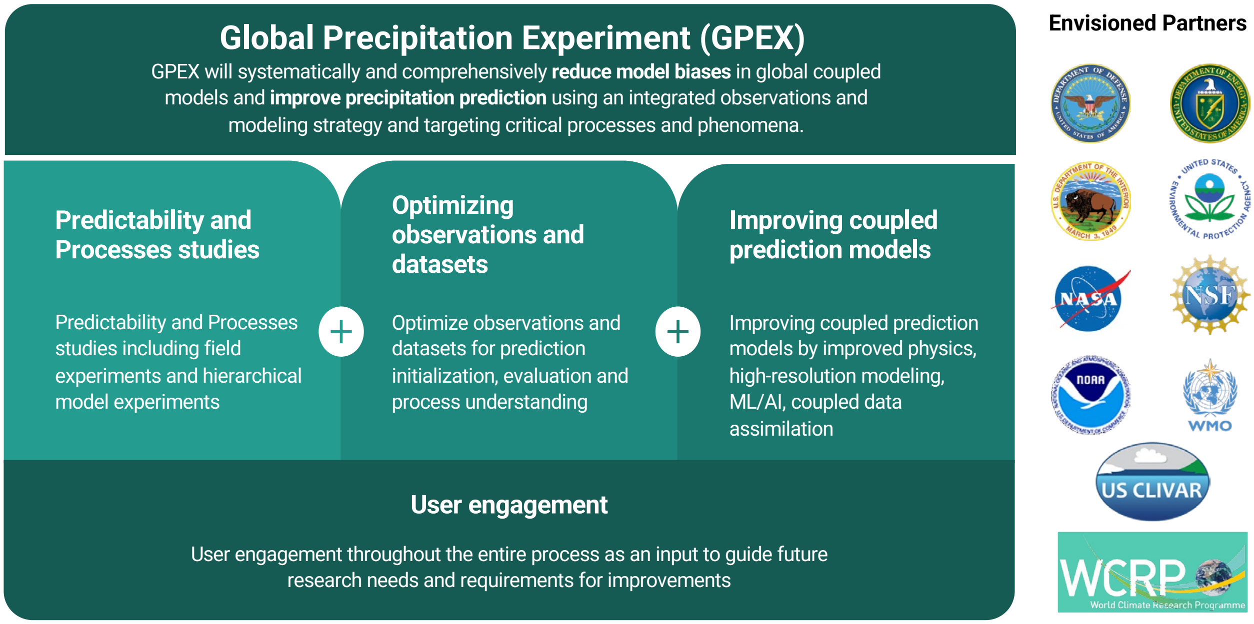
[1]NOAA Climate Program Office, Silver Spring, MD, USA; [2]DOE-SC Earth and Environmental Sciences Division, Germantown, MD, USA; [3]NSF Physical and Dynamic Meteorology Program, Alexandria, VA, USA; [4]NASA Earth Science Division, Washington, DC, USA; [5]US GEWEX Program Office, Washington, DC, USA; [6]US CLIVAR Project Office, Washington, DC, USA

The impacts from extreme precipitation (too much or too little precipitating water) are deadly, damaging, and increasing with a warming climate. When, where, and how much precipitation will occur, and in what form, are of critical importance to every person, business, and water resource manager. Users need this information and answers for the next few hours, months, seasons, and decades. Although temperature forecasts have generally improved greatly over the last few decades, precipitation forecasts beyond a few days have not. Climate models have huge uncertainties in regional precipitation projections as indicated by the recently issued Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) report. One fundamental reason for the lack of improvement in precipitation prediction and projections is that today's global coupled models do not accurately capture the physical processes critical to precipitation and continue to exhibit persistent systematic biases leading to errors in prediction and location, timing, and event intensity across timescales. The sources and limits of precipitation predictability are still not well understood.

The Global Precipitation Experiment (GPEX) is aimed at reducing model biases in global coupled models using an integrated observations and modeling strategy and targeting priority processes and phenomena that are key to enhancing precipitation predictability and improving precipitation predictions and projections. GPEX includes three major research components with user engagement throughout the entire process to guide future research needs and requirements for improvements:

1. Predictability and process studies to advance understanding of precipitation predictability sources and limits, and improve processes key to global and regional precipitation distributions and variability as well as the representations of these processes in coupled models. This will be achieved through process studies of intensive and innovative field campaigns and hierarchical model experiments.

2. Optimizing observations and data sets (including satellite, radar and in situ) for prediction initialization, evaluation, and process understanding. This includes enhancement of existing observation networks, applications of new observing technologies to fill in observation gaps in



GPEX is envisioned to be a multi-year project with national and international coordination and collaboration.

key regions, targeted observations focusing on specific high impact events, and integrated data sets for process understanding and process-level model diagnosis.

3. Improving global coupled model systems, including improved physics, high-resolution modeling, and novel approaches to represent processes critical to precipitation (e.g., applications of artificial intelligence and machine learning) in global coupled models, development of coupled data assimilation capability, and creative numerical configurations.

The magnitude of the systematic biases in global coupled models has remained essentially the same since the late 1990's. Similar systematic errors exist in both weather models and climate models and in all global models. Therefore, the GPEX goal of reducing model biases in global coupled models and improving precipitation predictions/projections will benefit all global models and will also require a coordinated global commitment. It is envisioned that GPEX will be a multi-year project with national and international participation and collaboration.

The concept of GPEX has been discussed within the agencies involved in the U.S. Climate Variability and Predictability (U.S. CLIVAR) and the United States Global Change Research Program (USGCRP)/ U.S. Global Energy and Water Exchanges (U.S. GEWEX) programs [e.g., the National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Energy (DOE), the National Science Foundation (NSF), and the National Aeronautics and Space Administration (NASA)] and with international CLIVAR and GEWEX. GPEX is supportive of U.S. agencies' priorities and can leverage agencies' capabilities; for example, NOAA's Precipitation Prediction Grand Challenge (PPGC) Initiative[1], DOE's research areas in the integrated water cycle, NSF foundational science, and NASA's space-based Earth system observations.

The envisioned GPEX research could contribute to and also benefit from the core programs in the World Climate Research Program (WCRP), especially CLIVAR and GEWEX, and cross WCRP activities, such as the Digital Earths Lighthouse Activity[2]. WCRP is enthusiastic about GPEX and has adopted GPEX as a major international WCRP activity, also in coordination with other international programs. WCRP is forming a GPEX Tiger Team to identify concrete steps in organizing and facilitating GPEX.

The next step for the GPEX planning process is to engage the broader research community toward planning potential GPEX research activities. The feedback from the community will inform GPEX planning and help coordinate ongoing and future field campaigns, modeling experiments, analyses of observations and data sets, and improvements to model biases and uncertainties in predictions and projection. The U.S. GEWEX Project Office and U.S. CLIVAR Project Office will coordinate the participation of the U.S. federal agencies and serve as a point of connection to the U.S. scientific community. For more information, please contact Jin Huang at *Jin.Huang@noaa.gov*.

[1]NOAA Weather, Water, and Climate Board, "Precipitation Prediction Grand Challenge Strategy", October 30, 2020, *https://cpo.noaa.gov/Portals/0/Docs/ESSM/Events/2020/PPGC%20Strategy_FINAL%202020-1030_ForWeb.pdf?ver=2021-10-07-142824-477*.

[2]"Digital Earths", WCRP, last modified 14 September 2021, *https://www.wcrp-climate.org/digital-earths*.

New Means to Measure Snow Depth from Space

Yongxiang Hu and Xiaomei Lu

NASA Langley Research Center, Hampton, Virginia, USA

Using a concept adapted from the mathematics and biology communities, a group of scientists from the National Aeronautics and Space Administration (NASA), University of Arizona, Stevens Institute of Technology, and Ball Aerospace developed a method to directly measure snow depth using lidar measurements from the Ice, Cloud, and land Elevation Satellite-2 (ICESat-2) (Hu et al., 2022).

Snow depth is an important measurement in understanding climate, weather, and Earth's water cycle, but there are limitations to current measurement methods, both from space and from airborne platforms. Airborne measurements can only cover limited areas. Historically, satellite measurements have been limited by low-resolution microwave sensors. More recently, scientists have used ICESat-2 to measure the top of the snow layer on sea ice and CryoSat-2's radar to "see" the top of the sea ice beneath the snow layer. However, geolocation differences of just a few meters in where these two satellites directly take measurements can introduce significant inaccuracies to inferences of snow depth.

Direct global measurements of snow depth over land and over sea ice would increase our understanding of the water cycle and snowfall. In combination with the ICESat-2 measurements of the height of snow cover and sea ice above the ocean, the new measurements also enable satellite estimates of sea ice thickness (see Fig. 1 as an example), since so much sea ice is covered by snow. Sea ice thickness measurement is critical, especially as climate change intensifies. Snow also plays an important role in regulating climate because it reflects the sun's energy back out into space and helps keep the planet cool.

Increased accuracy in snow depth measurements could boost confidence in estimates of sea ice thickness and water cycle predictions.

To determine how to use ICESat-2's laser to measure snow depth, we turned to a principle adapted from biologists and physicists who figured out the average length of the path an ant travels inside its colony before coming back out. What those scientists came up with is that the average time an ant walks around inside the colony before coming back is roughly four times the volume of the colony divided by its surface area.

Similar to an ant disappearing into a colony and walking around randomly, a photon of light from a lidar enters the snow and bounces around as it is scattered by the snow particles until it exits and is collected by the telescope on ICESat-2. All this happens very fast—at the speed of light.

Using the lidar radiative transfer model simulation and an equation almost identical to the one from the ant problem, we discovered we could measure the average distance a photon traveled inside the snow before it's eventually measured by the lidar. Specifically, we determined that the snow depth is half of that average distance laser light traveled inside the snow.

This innovation will advance the ability of scientists to better understand and interpret difficult-to-make measurements such as this from space. Launched in 2018, ICESat-2 fires 10,000 laser pulses a second and measures the elevation of sea ice, ice sheets, forests, and more in unprecedented detail. For more information on this new method to measure snow depth, please contact Yongxiang Hu at yongxiang.hu-1@nasa.gov.

References

Hu, Y., X. Lu, X. Zeng, S.A. Stamnes, T.A. Neuman, N.T. Kurtz, P. Zhai, M. Gao, W. Sun, K. Xu, Z. Liu, A.H. Omar, R.R. Baize, L.J. Rogers, B.O. Mitchell, K. Stamnes, Y. Huang, N. Chen, C. Weimer, J. Lee, and Z. Fair, 2022. Deriving Snow Depth From ICESat-2 Lidar Multiple Scattering Measurements. *Frontiers in Remote Sensing*, 3. https://www.frontiersin.org/article/10.3389/frsen.2022.855159.

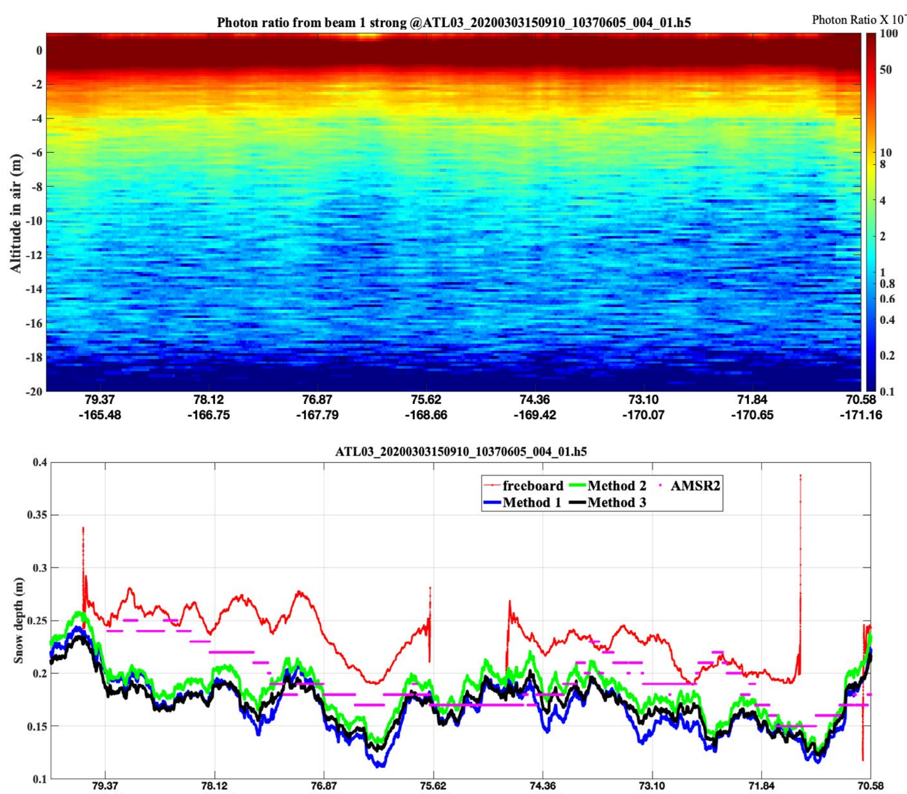


***Figure 1**. (A) ICESat-2 snow backscatter signal above first-year sea ice in the Arctic (north of the Chukchi Sea); (B) snow depth computed using three methods from Hu et al. (2022) (blue, green, and black), Advanced Microwave Scanning Radiometer 2 (AMSR2) microwave 25 km snow depth estimate (purple), and ICESat-2 freeboard (the total height of the snow cover and sea ice above the ocean) data (red).*

The New Version 3 of the Monthly and Daily Global Precipitation Climatology Project (GPCP) Products

Robert Adler[1], George Huffman[2], and Ali Behrangi[3]

[1]University of Maryland, College Park, MD, USA; [2]NASA Goddard Space Flight Center, Greenbelt, MD, USA; [3]University of Arizona, Tucson, AZ, USA

The new Version 3.2 Global Precipitation Climatology Project (GPCP) data sets for both monthly and daily global precipitation have been released. The GPCP analyses are observation-based precipitation analyses using satellite-based estimates over ocean and land and the Global Precipitation Climatology Centre (GPCC) gauge analysis over land, with care taken to preserve Climate Data Record characteristics.

Compared to Version 2, Version 3 has finer spatial resolution (now 0.5° latitude-longitude), new input products, the latest GPCC gauge analysis, and uses climatological information over oceans from the Tropical Rainfall Measuring Mission (TRMM), the Global Precipitation Measurement (GPM) mission, and CloudSat. The Monthly and Daily products cover the periods 1983–2020 and June 2000–December 2020, respectively. Version 3 development is being supported by the NASA Making Earth System data records for Use in Research (MEaSUREs) program.

The new data sets are being archived and distributed by the NASA Goddard Earth Science Data and Information Services Center (GES DISC) and data set links, documentation, and contact information for the Monthly and Daily products are provided in the respective landing pages:

- *https://disc.gsfc.nasa.gov/datasets/GPCPMON_3.2/summary?keywords=GPCPMON_3.2*
- *https://disc.gsfc.nasa.gov/datasets/GPCPDAY_3.2/summary?keywords=GPCPDAY_3.2*

The previous operational Version 2.3 Monthly (Adler et al., 2018) and 1.3 Daily (Huffman et al., 2001) data sets continue to be produced as Version 3.2 is introduced for evaluation and use by the community.

Fig. 1 (see cover) shows the new V3.2 climatology (1983–2020) map and the difference from the older V2.3, indicating the major changes over ocean where the TRMM, GPM, and CloudSat information has a major effect on the mean values. In V3, these three observations are employed for the first time in GPCP and through two products: (1) Tropical Composite Climatology (TCC) over the tropics (Adler et al., 2009) and (2) the Merged CloudSat, TRMM, and GPM (MCTG; Behrangi and Song, 2020) product over the extra-tropics and higher latitudes. Increases over oceans are seen in the center of the ITCZ over the Pacific Ocean with small decreases to the north and south, with the Atlantic ITCZ and most of the Indian Ocean also showing larger estimates. The middle latitude oceanic storm tracks have generally larger values, with small decreases noted in some drier, sub-tropical areas. The east-west bands near 40°S and 60°S in the difference map, respectively positive and negative, are related to a correction of an analysis artifact in V2. The CloudSat information was critical in determining that change. Over land the changes are small, related to the use of the latest GPCC Full global gauge analysis (Schneider et al., 2020) and small changes in the gauge under-catch adjustment over northern Eurasia that are applied to the raw gauge totals. This change in V3 can be seen in northern Eurasia, which now has slightly lower mean values, mainly in winter. This reduction in precipitation is consistent with the Gravity Recovery and Climate Experiment (GRACE) analysis (Behrangi et al., 2018).

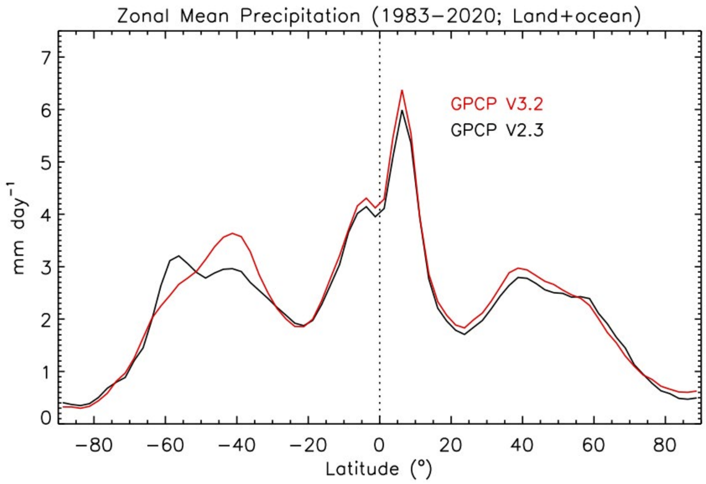


***Figure 2**. Climatological zonal mean values as a function of latitude (land + ocean) for 1983–2020*

The zonal mean profile (Fig. 2) covering both land and ocean summarizes the changes in mean precipitation, showing the increases in the estimates over both the tropics and middle latitudes, mainly over the oceans as seen from the map in Fig. 1. Also seen is the improvement in the Southern Hemisphere. The new estimate of mean climatological (1983–2020) global total precipitation is 2.81 mm/d (2.21 mm/d over land, 3.09 mm/d over ocean). These new estimates based on Version 3 are ~4.5% larger for the global total (about 6.5% over just ocean) than for Version 2.3.

The V3 Monthly product (1983–2020) shows seasonal and inter-annual variations in patterns and amounts, now at the finer, half-degree scale. At a global scale, the total precipitation is nearly constant through the period, with global variations clearly a function of El Niño-Southern Oscillation (ENSO) and volcanoes. Although the global total precipitation is about constant during the period, strong regional trends are obvious, as seen in Fig. 3. This trend pattern across the planet is nearly identical with the pattern derived from V2 (see Adler et al., 2017 for V2-based analysis of means and variations) and is related to a combination of inter-decadal signals [e.g., from the Pacific Decadal Oscillation (PDO)] and longer-term change (i.e., global warming).

GPCP Version 3.2 also includes a globally-complete Daily analysis at 0.5° latitude-longitude from 2000–2020 that is based primarily on the NASA Integrated Multi-satellitE Retrievals for the Global Precipitation Measurement (GPM)

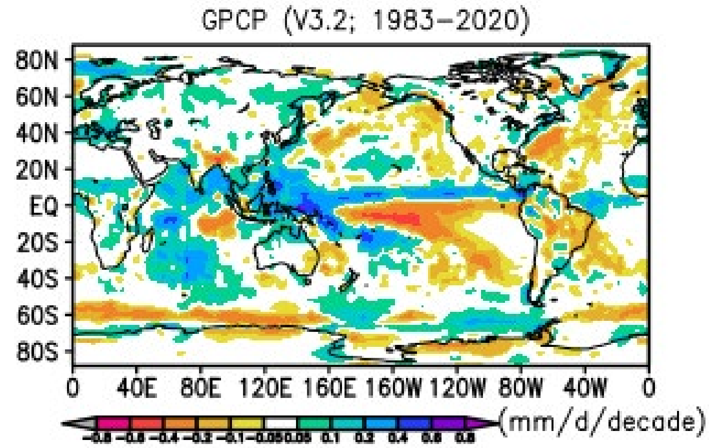


***Figure 3**. Regional trend map (1983–2020). Units are mm/d/decade*

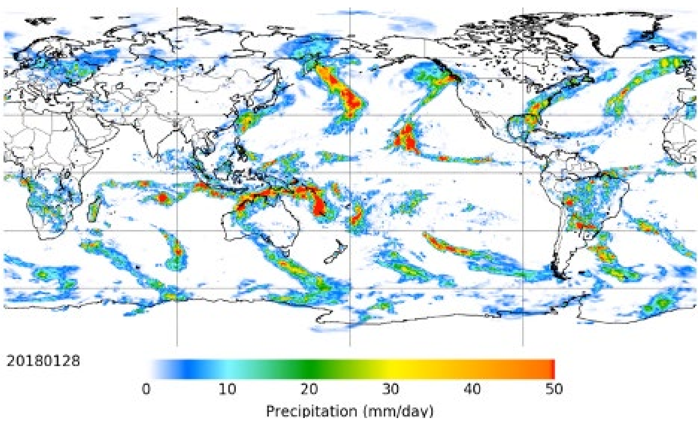


***Figure 4**. An example of GPCP V3.2 Daily (2000–2020) for January 28, 2018*

mission (IMERG; Huffman et al., 2020) Final product and other inputs (e.g., precipitation analysis from infrared sounders in high latitudes), with results adjusted to the Monthly product. Both the Monthly and Daily products also include a Probability of Liquid Phase (PLP) based on a specification using reanalysis surface information.

The GPCP group welcomes feedback from users of these new products while we continue to improve observation-based analysis of global precipitation.

References

**The full list of references can be found at* https://www.gewex.org/gewex-content/uploads/2022/06/Q22022_GPCP_References.pdf.

Adler, R.F., J.-J. Wang, G. Gu, and G.J. Huffman, 2009. A ten-year tropical rainfall climatology based on a composite of TRMM products. *J. Meteorol. Soc. Japan*, 87A, 281–293.

Adler, R., G. Gu, M. Sapiano, J. Wang, and G. Huffman 2017. Global Precipitation: Means, Variations and Trends During the Satellite Era (1979-2014). *Surv. Geophys.*, 38: 679–699, doi:10.1007/s10712-017-9416-4.

Adler, R., M. Sapiano, G. Huffman, J. Wang, G. Gu, D. Bolvin, L. Chiu, U. Schneider, A. Becker, E. Nelkin, P. Xie, R. Ferraro, and D. Shin, 2018. The Global Precipitation Climatology Project (GPCP) Monthly Analysis (New Version 2.3) and a Review of 2017 Global Precipitation. *Atmosphere*, 9(4), 138; doi:10.3390/atmos9040138.

Meeting/Workshop Reports

2021 GEWEX Hydroclimatology Panel (GHP) Meeting

Virtual Meeting
8–9 November 2021

Ali Nazemi and Francina Dominguez
GHP Co-Chairs

In response to the ongoing Covid-19 pandemic, the 2021 GHP Meeting was held fully online through Zoom. This was the second consecutive virtual annual GHP meeting, which provided an opportunity for Panel members and project leaders from across the globe to share and review the status of current and future GHP activities, including: (1) Regional Hydroclimate Projects (RHPs), (2) Cross-Cutting Projects (CCs), (3) Global Data Centers (GDCs) and (4) GHP Networks. While these projects are fully independent, together they provide an integrated understanding of environmental water and energy exchanges at regional scales, from observing and modeling of physical processes to assessing socio-economic impacts. Building on the experience obtained in 2020, the meeting was distributed over two days, each including two sessions divided by a short break. Similar to the 2020 GHP Meeting, each ongoing and envisioned project submitted its presentation(s) and report(s) in advance, so Panel members could review each activity prior to the meeting. As a result, each project could be effectively overviewed and discussed in 10- to 15-minute slots.

Day 1

The first day of the meeting was kicked off by reviewing the progress of ongoing networks, CCs, and RHPs. After a brief welcome by the co-chairs, the existing networks were reviewed. Networks aim at maintaining collaboration and capacity for activities relevant to GHP science objectives. PannEx, previously an initiating RHP, has now evolved into a thriving network. During 2021, the network published a special issue with 14 contributions on understanding of Earth system processes over the Pannonian Basin. The team was also awarded funding for a new project on micrometeorological measurements and analyses. The Panel is pleased with the progress made despite Covid-19 restrictions and suggested more interactions with other GHP projects, such as Third Pole Environment-Water Sustainability (TPE-WS). The Panel regretted to see the sunset of the Australian Energy and Water Exchanges research initiative (OzEWEX). The Panel suggested reaching out to other colleagues in the region to maintain this space for engaging the Australian community with GEWEX.

CCs are global efforts focused on knowledge syntheses around GEWEX Science Questions relevant to GHP. They encourage collaboration between GHP projects, other GEWEX Panels, and broader World Climate Research Programme (WCRP) activities. The Transport and Exchange Processes in the

Atmosphere over Mountains Experiment (TEAMx) CC aims at improving the current understanding of exchange processes in the atmosphere over mountains and how these processes are parameterized in climate models. TEAMx progressed well and organized a workshop with nearly 200 participants. While the activities of TEAMx are mainly concentrated in the Alps region, their focus is on processes and therefore have global relevance. The Panel noted the exceptional opportunity for knowledge sharing between TEAMx and other RHPs and CCs. The International Network for Alpine Catchment Hydrology (INARCH) is entering its second phase. INARCH submitted its draft activity proposal, which is due to be reviewed by the Panel. One key focus of INARCH's second phase will be on human-water interactions in mountainous regions and downstream areas. So far, the activity includes 29 operational research sites in 14 counties. The Panel is very satisfied with how the second phase of INARCH is developing and suggested more interactions with relevant CCs and RHPs.

Participants of the 2021 GHP Meeting

After a short break, ongoing RHPs were discussed. RHPs are generally large, multidisciplinary projects, developed for improved understanding of the physical processes that affect water and energy exchanges within a region. The two ongoing RHPs are mature projects that involve a large group of active researchers with strong ties to stakeholder groups, which create exceptional opportunities toward addressing the impacts of changing hydroclimatology on human activities and the environment. Global Water Futures (GWF) continues to be a flagship for a top-down RHP with clear contributions to the science, practice, and policy-making of water futures in Canada. The Panel is pleased to see how GWF is expanding to include Indigenous knowledge and views on water. In addition, GWF has become a truly global effort through collaboration with other RHPs and CCs. Unlike GWF, Baltic Earth operates as a bottom-up network of collaborating scientists. It reported major progress on dissemination of the project results through a comprehensive special issue on the past, current, and future of the Earth system in the Baltic region, along with producing fact sheets for stakeholders and policy makers. The Panel also discussed the second phase of the Hydrological cycle in the Mediterranean eXperiment (HyMeX). It is envisioned that a young generation of researchers will lead the new phase of HyMeX, which will serve more as an umbrella for understanding the regional response to climate change and the associated impacts on users and stakeholders. The new HyMeX team has submitted two proposals and been actively involved in the Land Surface Atmosphere Interactions over the Iberian Semi-Arid Environment (LIAISE) campaign.

The meeting continued with the introduction of two new Panel members. Rowan Fealy from Maynooth University of Ireland is actively involved with research on the use of Artificial Intelligence in observing and modeling land surface processes. Anna Sörensson from the University of Buenos Aires of Argentina is heavily involved with the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6), particularly in terms of linking global to regional climate change. The Panel welcomed the two new members and noted their potential contributions, particularly as a part of GHP contributions to the new WCRP Lighthouse Activities (LHAs) and the Regional Information for Society (RIfS) core project. Day 1 concluded with discussion on the two prospective CCs, namely Precipitation over Mountainous Terrain (MOUNTerrain) as well as the Flood CC. These efforts are particularly relevant to the My Climate Risk LHA and RIfS. MOUNTerrain has started recruiting team members through a special issue and plans for a kickoff workshop in the fall of 2022. The Flood CC will look at a wide spectrum of challenges around understanding flooding processes from observation to model development to socio-economic impact assessments. It published its first GEWEX Quarterly article and has started to build a community around the topic.

Day 2

The second day of the annual GHP meeting was dedicated to the review of prospective RHPs, current GDCs, and prospective joint CCs between GHP and the Global Land-Atmosphere System Studies (GLASS) Panel. The day kicked off with a review of the prospective RHPs. The Regional Hydrology Program for the Andes (ANDEX) demonstrated significant progress, including a white paper consisting of published manuscripts and its science plan, which is currently with the Panel for review. The Asian Precipitation Experiment (AsiaPEX) also had a fruitful year, running a conference session and publishing a review paper. The science plan of AsiaPEX is currently under preparation and will be submitted in 2022. TPE-WS also demonstrated significant progress, publishing high-quality papers and data sets as well as setting up new observational transect sites. The project plans to submit its science plan in 2022. The Panel was pleased to see the significant developments made around the United States-RHP

(US-RHP), given that it is still in its beginning stages. The US-RHP benefits from a dedicated leadership team, which is taking an inclusive and comprehensive approach to build this RHP from the bottom up. A strong affinity group with a wide range of sub-groups has been holding regular meetings and the leadership team has presented the project idea at major conferences. It has set a realistic timeline for applying to initiating RHP status in 2022. The Central Asia initiative, a collaboration between the SysTem for Analysis, Research and Training (START) and the National Aeronautics and Space Administration (NASA), is a prospective RHP also showing significant progress in building a regional community. It had its first workshop in 2021, and is planning for a hydrological modeling workshop in 2022.

GDCs collect and distribute hydrologically relevant data and are an integral part of GHP activities. The Global Precipitation Climatology Centre (GPCC) is well-connected to the other GHP and GEWEX activities. Steady and significant progress was reported related to precipitation data from both near real-time and non-real time data sources. The Global Runoff Data Centre (GRDC) focuses on acquisition, harmonization, and storage of global historical river discharge data, and has also demonstrated noteworthy progress as new data are continuously added into the system. Discussions occurred around the International Data Centre on Hydrology of Lakes and Reservoirs (HYDROLARE) and how this GDC can collaborate with similar initiatives outside GHP and GEWEX.

GHP also includes two prospective CCs, i.e., Determining Evapotranspiration (dET) as well as the Irrigation CC. These are joint initiatives between the GHP and GLASS Panels. dET focuses on advancing the understanding and determination of evapotranspiration across scales. It experienced a fruitful year as the second ET workshop was held online in February, which led to shaping the working groups. The activity has also benefited from the successful LIAISE campaign, which will result in comprehensive data support for informing ET studies. The dET leadership also had some discussions with AmeriFlux on potential avenues for collaboration. The Irrigation CC focuses on intercomparison of irrigation algorithms in current Earth system models and had its first workshop online in early November 2021. Discussions led by Josh Roundy, GLASS-GHP liaison, identified other potential joint activities between the GLASS and GHP Panels, most notably around the GEWEX Land-Atmosphere Feedback Observatory (GLAFO), a network of measurement sites sampling the atmospheric boundary layer and upper surface.

While the 2021 annual GHP meeting enjoyed focus and effectiveness in the discussions and remained quite targeted during both days, it became very clear that such online meetings cannot deliver the spirit of previous in-person GHP meetings–something that was greatly missed by the Panel and projects' leads. We are pleased to announce that next GHP meeting will be held in-person in late July 2022 during the Pan-GEWEX conference in Monterey. We very much look forward to this upcoming meeting.

High-Resolution Climate Modeling and Hazards: A Summary of the 5th Convection-Permitting Modeling Workshop

Izuru Takayabu[1], Andreas F. Prein[2], Hiroaki Kawase[1], Nobuhito Mori[3], and Roy Rasmussen[2]

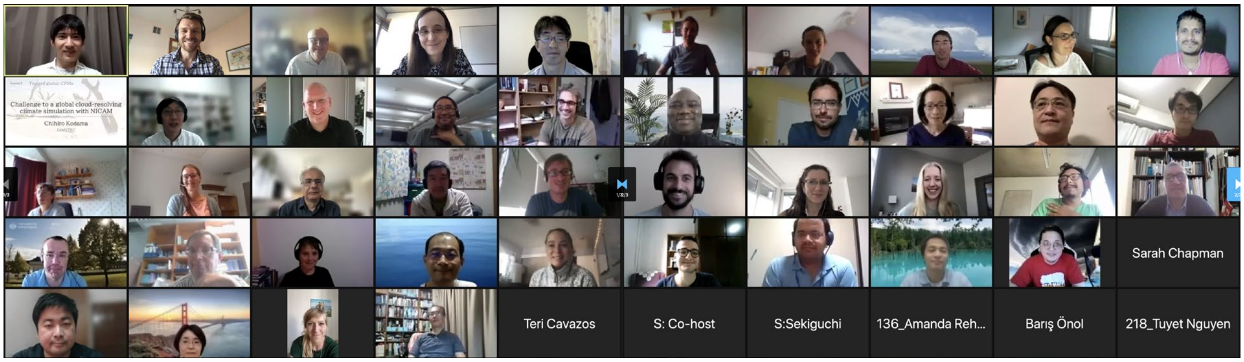
[1]Meteorological Research Institute (MRI), Japan Meteorological Agency, Tsukuba, Japan; [2]National Center for Atmospheric Research (NCAR), Boulder, CO, USA; [3]Disaster Prevention Research Institute, Kyoto University (DPRI), Kyoto, Japan

The fifth installment of the Convection-Permitting Modeling (CPM) Workshop series was held online between September 7–14, 2021. The workshop was organized by Japan Meteorological Business Support Center (JMBSC) Disaster Prevention Research Institute, Kyoto University (DPRI), Meteorological Research Institute (MRI), and the National Center for Atmospheric Research. A total of 139 participants from 28 countries took part in seven live sessions and online poster presentations. The fifth CPM workshop had the theme "High-Resolution Climate Modeling and Hazards", and the main focus of the workshop was on simulating mesoscale processes and extreme events with CPMs at local to global scales and the use of high-resolution climate models for hazard and impact assessments. Recent advancements were discussed in CPM simulations and wind, flood, and other hazard modeling; ensemble and high-resolution climate modeling activities; computational and data volume challenges; and how to facilitate interactions between interdisciplinary communities.

It is important to assess the impacts of climate change on extreme natural hazards such as strong winds, water-related hazards, and hazards from other aspects of the hydrological cycle due to their significant socio-economic costs. However, hazard assessments are difficult on regional scales because of the small-scale nature of hazards (less than 10–500 km), which currently cannot be resolved in General Circulation Models (GCMs). Although the general impact of climate change on natural hazards has been largely addressed and discussed, the latest assessments from the Intergovernmental Panel on Climate Change (IPCC) 6th Assessment Report (AR6) highlight that quantitative hazard assessments at regional to local scales are still limited.

In recent years, projections for assessing regional climate at high resolution using CPMs and their projections have become increasingly important to address this research gap. CPM-based simulations of extreme precipitation and heavy snowfall have made significant progress in reproducing extreme weather events on the regional or national scale. Coupled atmosphere-ocean-wave models are also being developed and are expected to be used to better understand coastal and other hazards. In addition, CPMs have facilitated great progress in improving projected future climate change impacts on extreme events such as river and storm surge impact assessments.

So far, most CPM simulations are performed on regional scales. There is an increasing interest in running global CPMs for climate change assessments. It is hoped that such models will provide novel insights into climate change impacts on



Some of the participants of the 5th CPM Workshop

mesoscale phenomena, such as tropical cyclones or mesoscale convective systems; deliver more useful local-scale climate change information; improve feedback mechanisms; and correct long-standing deficiencies in coarse-resolution GCMs. The global CPM modeling community has made significant progress in speeding up its modeling systems, which now allows its members to run deterministic transient climate simulations. However, future speedups by a factor of 10 or more are needed to run ensemble-based simulations. The community also made substantial advancements in coupled modeling, and several modeling systems are now able to run ocean-atmosphere coupled simulations. An alternative approach towards global CPM modeling is the expansion of regional modeling domains. The presented results on this topic were very encouraging and showed that improvements of regional models over North America are transferable to other continents such as South America, indicating that models can be configured to perform well in various climate regimes. Some remaining challenges for global CPM modeling include storing and sharing model output, analyzing the massive amount of model data, treating persisting model biases such as tropical precipitation biases, and spining up high-resolution ocean models. The World Climate Research Programme (WCRP) Digital Earths Lighthouse Activity (*https://www.wcrp-climate.org/digital-earths*) was presented as a framework for coordinating international activities to push the co-development of high-resolution Earth system modeling and the exploitation of billions of observations with digital technologies from the convergence of novel High-Performance Computing (HPC), big data, and Artificial Intelligence (AI) methodologies.

During a two-hour breakout group discussion, we considered how collaborations between the regional and global climate modeling community can be improved, how to best train the next generation of researchers, the future of coupling CPMs with other models (ocean, hazard, hydrology), future research avenues for CPM modeling, how to share and analyze the huge output from CPM simulations, and what key observations are missing to improve CPMs. Sharing the available computing resources and developing computational capabilities in resource-limited communities were identified as important needs to make climate research more equitable and to build knowledge in the global south. This is closely linked to the need to train students and early career scientists to efficiently work in an increasingly interdisciplinary research environment. Providing mentorship, additional educational resources, and building adequate curricula at universities were identified as ways to address these needs. Coupling CPMs with other models such as hydrology, chemistry, ocean, and biology is required to advance our understanding of climate change impacts on regional to global scales. Promising frontiers for research are at the intersection of these coupled systems and their associated feedback processes. The strong impact of feedback processes on the local atmosphere was discussed on the example of groundwater flows and marine heat waves.

We inevitably drive high-resolution regional climate models to downscale global climate model products, responding to the demand of local end users. Stakeholders or governments are now interested in local extreme weather information for disaster risk management, due to the increasing frequency and intensity of such events (as shown in Fig. SPM3 and Fig. SPM.6 of IPCC, 2021). To provide improved risk estimates for current and future extreme phenomena, we need to produce ensemble simulations, which is challenging due to their high computational cost. Storyline event attribution and multi- or single-model ensemble runs using regional climate models or CPMs [Coordinated Regional Climate Downscaling Experiment Flagship Pilot Studies (CORDEX-FPS) in Europe, UK Climate Projections 2018-Local (UKCP18-Local) in the UK, Database for Policy Decision-Making for Future Climate Changes (d4PDF) in Japan] were introduced to address this challenge. We believe that a more integrative framework, which leverages the benefits of multiple approaches to generate future climate information, such as CPM modeling, Coupled Model Intercomparison Project (CMIP)-style modeling, and statistical approaches, is needed to generate more robust information on future climate change, particularly at local and regional scales.

Progress in CPM modeling is strongly linked to advancements in high-performance computing (HPC) and storage technologies. For instance, the advance of CPM modeling during the recent decade at the National Center for Atmospheric Research (NCAR) was enabled by a 300-fold increase in peak computing power. This trend is expected to continue, but the technology of HPC systems is rapidly evolving and future HPCs can be expected to be more heterogeneous and will demand adaptations of the CPM code to run efficiently. The co-design of new HPC systems will gain in importance to ensure that user needs are met. Data storage and data sharing were identified as a bottleneck. New efforts such as the University Corporation for Atmospheric Research (UCAR)'s Geoscience Data Exchange (GDEX) program (*https://gdex.ucar.edu/repo/about.html*) were highlighted. The community expressed the urgent need for systems that allow data processing at the data storage location, which would minimize the duplication of data sets and data transfer. This issue is particularly important to allow participation of scientists from the global south in CPM research. Additionally, building capacity to run CPM simulations in these countries was highlighted as a pressing issue.

The key outcomes of the 5th CPM Workshop are:

- The CPM community identified the need to better connect to the global climate modeling and impact research community. The connection to the global modeling community is needed to combine strengths and weaknesses of our approaches to increase the robustness of future climate change projections while better collaborations with the impact community will allow us to create more actionable climate science to inform climate change adaptation and mitigation efforts.
- Coupling with other Earth system components, e.g., ocean, cryosphere, ecosphere, anthroposphere, was identified as a research frontier of CPM modeling. This was motivated by the novel findings presented that showed the strong atmospheric response of coupling CPMs to ocean and groundwater models.
- A key challenge of the CPM community is to sample uncertainties in future climate projections and to produce large-enough ensembles that allow us to assess climate change impacts on extreme events at local scales. Novel single and multi-model ensemble simulations were presented that allow us to address this challenge.
- Future advancements in CPM modeling will continue to be closely tied to advancements in computational science. There is an urgent need to enable CPM models to run on future exascale high-performance computer systems, which will leverage accelerator technologies such as graphic processing units. This will demand restructuring and rewriting CPM code.
- The increasing domain size, ensemble size, and simulation length of CPM simulations results in a major challenge in how to store, share, and analyze CPM model output. Storage technologies that facilitate processing model outputs before downloading them are needed particularly to include the scientific community in the global south.

More information on the 5th CPM Workshop can be found on the workshop website under *https://www.pco-prime.com/tougou2021_ws/index.html*. We are currently organizing the 6th CPM Workshop, which will be held as a hybrid event on September 7–9, 2022, in Buenos Aires, Argentina. Please visit *http://www.cima.fcen.uba.ar/cpcmw2022/* or subscribe to the CPM email list (*ral-cpcm@ucar.edu*) for more information.

References

Intergovernmental Panel on Climate Change (IPCC), 2021. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (V. Masson-Delmotte, P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou, eds.). Cambridge and New York, Cambridge University Press. In press.

GEWEX/WCRP Calendar

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

16–24 July 2022—COSPAR 2022: 44th Scientific Assembly—Athens, Greece
19–22 July 2022—2022 Cloud Feedback Model Intercomparison Project (CFMIP) Meeting—Seattle, Washington, USA
25–29 July 2022—3rd Pan-GASS Meeting: Understanding and Modeling Atmospheric Processes (UMAP 2022)—Monterey, California, USA
26 July 2022—34th Session of the GEWEX Scientific Steering Group, Part B (SSG-34B) (*by invitation only*)—Monterey, California, USA
27–30 July 2022—Pan-GEWEX Meeting (*by invitation only*)—Monterey, California, USA
31 July–5 August 2022—22nd World Congress of Soil Science—Glasgow, Scotland
7–9 September 2022—VI Convection-Permitting Climate Modeling Workshop—Buenos Aires, Argentina
10 September 2022—Convection-Permitting Climate Modeling School—Buenos Aires, Argentina
17–19 October 2022—2nd GCOS Climate Observation Conference—Darmstadt, Germany
Spring 2023—LIAISE First Science Conference and GEWEX Evapotranspiration Crosscutting Project Workshop—Lleida, Spain

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*