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

New Data Set Roots Satellite Observations to Surface Conditions for the Tibetan Plateau

Researchers at the Maqu site of the Tibetan soil moisture and soil temperature observation network (Tibet-Obs), where the European Space Agency has provided an L-band microwave observation system (ELBARA-III) for ground-based observations. See Su et al. on page 8.

Inside This Edition

Commentary: The New Era of GEWEX

Graeme Stephens
GEWEX Scientific Steering Group (SSG) Co-Chair

To declare that 2021 is a year of change would be an understatement. It is a year of change not only for the world, but also for the World Climate Research Programme (WCRP) and specifically for GEWEX. WCRP is moving forward with a restructuring that first recognizes the fundamental and foundational role of its core projects while trying to develop a way to integrate activities of mutual relevance across these projects. These integrative efforts are referred to as WCRP Light House Activities (LHA). While these LHAs are defined topically, what really goes inside them and how they integrate core efforts is still in a state a flux. Fundamental questions for the core projects and WCRP include how they are going to evolve, reflecting the climate challenges of the decade ahead, and how integrative efforts like the LHAs will embrace this evolution.

The five lighthouse activities (LHA) of the WCRP. The formation of these activities, what they represent, and which of the activities of the core projects contribute to them is currently under review. Each core project of the WCRP is repented in each LHA.

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GEWEX, too, is undergoing change. We are in the process of developing a science plan both reflective of the challenges of the coming decade and the aspirations of WCRP expressed in its new strategic plan (*https://www.wcrp-climate.org/wcrp-sp*). An executive summary of this new GEWEX plan will appear in an upcoming version of this newsletter.

Other changes are also on the near horizon. I have served GEWEX as SSG Co-Chair now since 2014 and will step down at our next SSG meeting in May. Professor Xubin Zeng of the University of Arizona, an insightful, energetic, and visionary leader, will join Jan Polcher as SSG Co-Chair. GEWEX couldn't be in better hands, especially with Peter providing GEWEX its great stability and Jan and Xubin steering it into new waters. GEWEX will continue to prosper.

As I reflect back on this time, I have always appreciated how GEWEX, and WCRP more broadly, is about the volunteer efforts of its members who do the real work. We owe a great debt of gratitude to our Panels, their chairs, and all the members who have contributed over the years. To me, this works only if our joint efforts address issues big enough to need international and linked activities, and important enough to continue to motivate us throughout our careers. The basic tenet of GEWEX, how water and energy link, embodies exactly this.

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New GLASS Co-Chair

Anne Verhoef received her Ph.D. in Meteorology from Wageningen University in 1995. She worked as an ecosystem modeler at the Institute of Hydrology (now the Centre for Ecology & Hydrology) in Wallingford, UK, between 1996–1999. She joined the Faculty of Science at the University of Reading, UK, in 1999, moving into the position of Professor of Soil Physics and Micrometeorology in 2013. Anne has extensive expertise in land surface modeling and experimental field campaigns, leading a number of related research projects on applied and theoretical environmental science. She currently co-leads the Hydrology science module for the Met Office Joint UK Land Environment Simulator (JULES) land surface model, and she is an executive board member of the International Soil Modeling Consortium. She became a GLASS Panel member in 2018, and along with Kirsten Findell, leads the GLASS Panel as the new Co-Chair. Anne replaces Mike Ek, who joins former GLASS Co-Chairs Gab Abramowitz, Aaron Boone, Joe Santanello, Martin Best, Jan Polcher, and Paul Dirmeyer in remaining involved in GLASS and GEWEX activities.

New GHP Co-Chair

Ali Nazemi is the new GEWEX Hydroclimatology Panel (GHP) Co-Chair, and will serve alongside Francina Dominguez to guide the Panel's activities. He replaces Joan Cuxart Rodamilans, who is now leading efforts to better understand evapotranspiration within the Panel. Ali is an Associate Professor at the Department of Building, Civil and Environmental Engineering at Concordia University, in Montreal, Quebec. As a hydrologist with a civil engineering background, his areas of expertise are in hydroclimatology, water security and climate change, and mathematical modeling of coupled human-water systems. He is an Associate Editor or Editorial Board Member of several journals, including *Scientific Reports* (*Nature*), *Scientific Data* (*Nature*), and the *Journal of Hydrologic Engineering* (American Society of Civil Engineers) among others. He has been a member of the GEWEX Hydroclimatology Panel since 2019. Apart from water and the environment surrounding it, he is also interested in good music, good thoughts, and good people.

The 3rd Pan-GASS Meeting Moved to 2022 Due to COVID-19

After careful consideration of the current COVID-19 situation, the GEWEX Atmospheric System Studies (GASS) Panel has decided to move the 3rd Pan-GASS Meeting, which was originally scheduled for October 2021, to the following year. The tentative dates for the rescheduled meeting are 17–21 October 2022, in Monterey, CA, USA.

The data analysis competition for Early Career Researchers (ECRs) to win a travel award will remain unchanged, but the deadline to submit required results is extended to 31 May 2022. This competition is sponsored by the U.S. Department of Energy Atmospheric Radiation Measurement (ARM, *https://www.arm.gov/*) program and the center of Excellence in Simulation of Weather and Climate in Europe (ESiWACE, *https://www.esiwace.eu/*) to encourage the use of ARM data and Dynamics of the Atmospheric general circulation Modeled On Non-hydrostatic Domains (DYAMOND) simulation output in atmospheric system studies. The postponement of the meeting provides more time for ECRs to do interesting science and contribute to GASS and the Pan-GASS Meeting. More details about the data analysis competition are provided in the announcement about these competitions in the Quarter 4 2020 *GEWEX Quarterly* at *https://www.gewex.org/gewex-content/uploads/2020/12/Q42020.pdf*.

In Memoriam: Peter Eagleson

The field of hydrology has lost a pioneer with the passing of Professor Peter S. Eagleson on 6 January 2021. Prof. Eagleson gave shape to the modern concept of hydrology, melding a branch of engineering with other disciplines to create a robust area of study in the geosciences. Much of the work carried out in the GEWEX community is informed by his ideas and approaches.

Prof. Eagleson began teaching in 1952 at the Massachusetts Institute of Technology (MIT) until his retirement, remaining in the position of Professor Emeritus there. His career is littered with distinctions: he served as president of the American Geophysical Union (AGU) from 1986–1988, and in 1991, he chaired the U.S. National Research Council Committee on Opportunities in Hydrologic Sciences. The many awards and accolades he received include the 1997 Stockholm Water Prize.

Three of his books are seminal publications in the discipline, starting with *Dynamic Hydrology* in 1970. The 1967 publication of six papers in *Water Resources Research* that Eagleson wrote with some of his students heralded a shift in the field. His insight and capacity for cultivating multidisciplinary perspectives will continue to influence the study of hydrology.

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"Professor Emeritus Peter Eagleson, pioneering hydrologist, dies at 92." Department of Civil and Environmental Engineering. *MIT News*, January 13, 2021. *https://news.mit.edu/2021/professor-emeritus-peter-eagleson-pioneering-hydrologist-dies-0113*.

AGU Staff. "In memoriam: AGU former president Peter Eagleson." From the Prow, January 19, 2021. *https://fromtheprow.agu.org/in-memoriam-agu-former-president-peter-eagleson/*.

In Memoriam: Franco Einaudi

Peter van Oevelen
Director, International GEWEX Project Office

It is with a sad and heavy heart we report the passing of Dr. Franco Einaudi on December 10, 2020. Born in Turin, Italy, on October 31, 1937, he graduated from the Politecnico di Torino in 1961 and a year later he came to the U.S. Franco became a member of the GEWEX Scientific Steering Group (SSG) in 2004, the same year I joined GEWEX as the European GEWEX Coordinator. At that time, he was the Director of Earth Sciences at the Goddard Space Flight Center and was familiar to many in the GEWEX community. Franco's scientific interests were broad, and the areas of expertise that made him an invaluable member of the SSG were a reflection of that: atmospheric dynamics, the stability theory of stratified flows, the generation and propagation of gravity waves, mesoscale and microscale processes, triggering of condensation and convection by gravity waves, and gravity wave-turbulence interactions, among others. I remember him as warm and kind, easy to approach and work with. We will miss Franco for all his scientific contributions and his support of GEWEX, but above all, he will be remembered for the kind person he was. We wish strength to his family and friends. A longer obituary can be found at *https://www.legacy.com/obituaries/baltimoresun/obituary.aspx?pid=197279343*.

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In Memoriam: Jim Shuttleworth

Hoshin Gupta[1], Thomas Maddock III[1], and Xubin Zeng[1]
[1]The University of Arizona

William James Shuttleworth, Emeritus Regents Professor of Hydrology and Atmospheric Sciences (HAS) at The University of Arizona (UA), affectionately called "Jim" by all those who knew him, passed away on Sunday, 20 December 2020. Jim was an incredibly warm, kind, and compassionate person, and will be deeply missed.

Jim was trained in high energy nuclear physics, but decided to use his experimental and quantitative background to pursue hydrology research at the Institute of Hydrology in the UK, and later became its Hydrological Processes Division Head. He was recruited by Soroosh Sorooshian to UA in 1993. With his deep interest in terrestrial hydrometeorology, he actively pushed for the creation of the degree program in hydrometeorology and spearheaded the formation of HAS at UA. He also served as the second director of the National Science Foundation Science and Technology Center for Sustainability of Semi-Arid Hydrology and Riparian Areas (SAHRA), from 2004 to 2008.

Jim's research focused on how climate change is affected by land surfaces, and he was particularly interested in the effects of global climate change caused by deforestation in the Amazon basin and desert formation in Africa. He received many international recognitions, and notably was awarded the International Hydrology Prize in 2006. Just before retiring, Jim published *Terrestrial Hydrometeorology*, widely considered to be the definitive textbook on the subject. Jim was also active in national and international program planning, including his important role in the GEWEX Continental International Project (GCIP).

We are reminded of the following advice given by Jim to young scientists in his acceptance of the International Hydrology Prize:

- First, in one's progress through life there are basically two ways to proceed: either to take safe, small steps or make risky leaps forward, recognizing that in the latter case one is bound to fail about half of the time. In my experience, the latter way ultimately leads to more rapid progress and is certainly more exciting! Do not be afraid of risks.
- Second, as a young scientist, respect the established peers in your field, and listen to what they say, but don't necessarily believe them! Always question.
- Finally, and perhaps most importantly, remember that it is very difficult to keep your own end of the boat afloat while trying to sink the person at the other end. Water is the life-blood of the earth system, and water is a commodity we necessarily all must share. In this respect, we are all in the same boat.

In Memory of Dr. Françoise Guichard-Kergoat, Senior Scientist at Centre National de Recherches Météorologiques (CNRM)

Jean-Luc Redelsperger[1], Fleur Couvreux[2], Dominique Bouniol[2], and Frederic Hourdin[3]

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In Agoufou, Mali, during AMMA

Françoise Guichard unexpectedly passed away on 5 December 2020 in the town of Concarneau, in her native region of Bretagne (French Brittany). This note outlines some of the scientific achievements that inspired so many of her colleagues around the world.

Françoise received her Ph.D. in Physics and Environmental Chemistry from the University of Toulouse in 1995. At that time, cloud-resolving modeling was emerging and she was a pioneer in the simulation of tropical convective cloud population. Her Ph.D. work contributed greatly to the interpretation of observations from the Tropical Ocean-Global Atmosphere Coupled Ocean Atmosphere Response Experiment (TOGA-COARE) campaign. She performed a detailed analysis of the processes involved in the life cycle of the cloud population, and developed thermodynamical budgets for different representative areas (See Fig. 1). This innovative analysis allowed her to evaluate and improve cloud parameterizations used in weather and climate numerical models, a strategy which became central in GEWEX Cloud Systems Studies (GCSS).

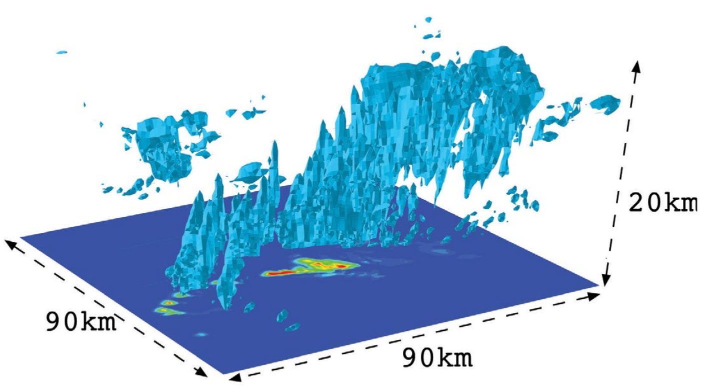
After her Ph.D., Françoise spent time at the European Centre for Medium-Range Weather Forecasts (ECMWF) (UK) and the National Center for Atmospheric Research (NCAR) (USA), where she continued her work on deep convection and its representation in large-scale models. During this period, she developed a pronounced taste for observations. She acquired skills not only in their interpretation, but also in their necessary corrections before numerical weather prediction (NWP) data assimilation or use in process studies. This willingness to use observations as a reference persisted throughout her career.

In 2001, she took up a permanent position as researcher scientist at the Centre national de la recherche scientifique (CNRS). She became deeply involved in the GEWEX community by participating in or leading several intercomparison GCSS exercises [TOGA-COARE, Atmospheric Radiation Measurement (ARM), and idealized cases] and collective European projects [European Cloud Resolving Modelling Project (EUCREM), European Cloud Systems project (EUROCS)]. At the same time, she broadened the spectrum of her research to include shallow convection, surface-atmosphere interactions, and planetary boundary layer processes, particularly through the supervision of students.

From 2004, with the beginning of the African Monsoon Multidisciplinary Analysis (AMMA) program, she focused her activities on West Africa, which quickly became a profound passion. She carried out multiple field campaigns, particularly in Mali at the Agoufou site (see photo). The analysis of the data collected over several years allowed her to revisit the annual cycle of the surface energy balance over the semi-arid Sahel. In this reference work (Fig. 2), she highlighted the subtle relationships linking radiative and thermodynamic parameters, including seasonal changes of their diurnal cycles. This work is a perfect illustration of Françoise's ability to build an understanding of climate physics and processes from observations.

Subsequently, AMMA allowed her to develop a network of international collaborators in very diverse fields relevant to GEWEX, ranging from the interactions between vegetation, soil, and atmosphere to the hydrological and energy cycles. With her work on observations covering vast fields of knowledge, she developed a deep understanding of physical processes involved in the West African Monsoon and evaluated their representation in models. As a recognized expert in the field, she joined the CLIVAR/GEWEX Monsoons Panel in 2014 and then co-chaired it from 2017 to 2020. She was also a member of the Regional Working Group on the African Monsoon.

Recently, Françoise continued her work on West Africa, focusing more specifically on extreme events. She was one of the first in the community to push studying the increase in temperature



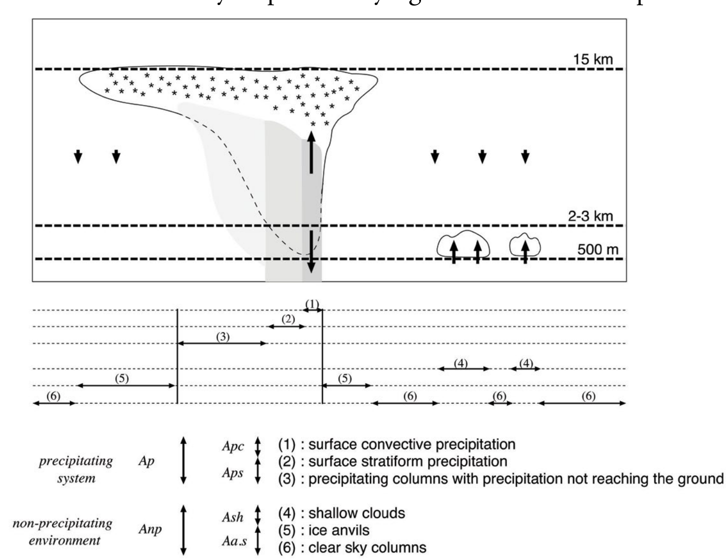


***Figure 1**. 3-D view of the cloud population simulated during Françoise's Ph.D. research and its simplified representation in view of its parametrization in general circulation models (GCMs) through defined areas: convective, precipitating, cloudy, updrafts, etc. (Guichard et al., 1997).*

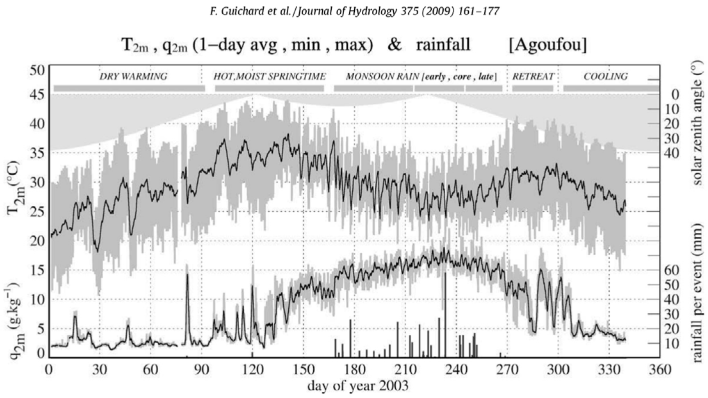


Figure 2. Time series of 2 m temperature T2m (upper curve) and specific humidity q2m (lower curve) in 2003 (the black lines correspond to a 24 h running mean and the dark grey shadings delineate 24 h minimum and maximum values), rainfall amounts per rainy event (bottom bars), and midday solar zenith angle (top light shading). Different time periods are roughly delimited by the top thick grey lines with their name specified above (Guichard et al., 2009).

extremes in this region, when the focus had generally been on precipitation changes. Her work has highlighted a significant increase in temperature over the Sahel during the spring months for the last 50 years (Fig. 3).

Her knowledge of convection and the Sahel semi-arid climate was a source of inspiration and expertise well beyond her immediate colleagues, and includes teams developing global climate models.

As colleagues, we remember her warm and welcoming smile and her engaging yet supportive nature, but above all, we remember her as a great human being, generous and open-minded. She was especially giving with students and young people, and was always cheerful and positive in scientific discussion. Her students, colleagues, and our field of research suffer a great loss without her guidance and contributions. She will remain for all those who had the chance to meet her as an example of honesty, scientific integrity, kindness, and open-mindedness. We offer our sincere condolences to her family, friends, and colleagues.

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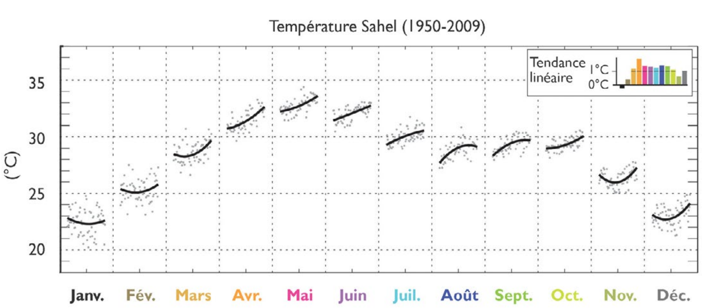

Figure 3. Warming observed in the Sahel between 1950 and 2009, depending on the month of the year with Climatic Research Unit (CRU) data (over the region defined by 10°W-10°E, 10°N-20°N). For each month, the temperature trend is represented by a black curve. The inset shows the linear trend (Guichard et al., 2017).

Influence of Midlatitude Soil Moisture Conditions on Upstream Subtropical Circulation

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Soil moisture (SM) conditions have both local and remote effects on precipitation, temperature, atmospheric wind patterns, and even the post-landfall intensity and precipitation of hurricanes (e.g., Betts et al., 1996; Emanuel et al., 2008). In general, increases in SM result in a higher probability of subsequent precipitation locally by increasing atmospheric water vapor in the boundary layer (through surface evapotranspiration) and decreasing stability (e.g., Vivoni et al., 2009; Findell et al., 2011). The relationship between SM content and subsequent rainfall is more complex in some regions and can vary as a function of the atmosphere circulation pattern (Welty et al., 2020). SM conditions also have remote effects on precipitation as air masses modified by the underlying soil are transported horizontally downstream, by over 1000 km in some cases, and influence atmospheric water vapor and stability (e.g., Benjamin and Carlson, 1986; Beljaars et al., 1996; Wei and Dirmeyer, 2019). SM conditions have similar local and downstream remote influences on near-surface temperature, which can enhance the severity of heat waves and droughts (e.g., Changnon et al., 1996; Schumacher et al., 2019).

SM conditions also have a significant impact on the atmospheric circulation pattern on seasonal timescales. Using a set of general circulation model experiments, Koster et al. (2016) show how a dry land surface within the central United States (and nearby regions) results in a perturbation ridge (positive streamfunction anomaly) over the dry soils in the central and western United States and a perturbation trough (negative streamfunction anomaly) downstream in the eastern United States near jet stream level at 250 hPa. Clearly, SM conditions can influence both temperature and precipitation extremes, and significantly perturb the continental-scale atmospheric flow pattern in midlatitudes on seasonal timescales.

While these previous studies show that SM impacts occur locally and primarily downstream, an interesting question is: **can SM affect upstream circulation?** Here we will present an example in which SM conditions influence the upstream subtropical atmospheric flow pattern that, in turn, affects the track of an approaching hurricane (Galarneau and Zeng, 2020; hereafter GZ20).

GZ20 use a suite of convection-allowing numerical simulations from the Advanced Weather Research and Forecasting model (WRF-ARW; Skamarock et al., 2008) to analyze the sensitivity of Hurricane Harvey's (2017) track, intensity, and rainfall to the underlying SM conditions. The control simulation (CTL) is initialized at 1200 UTC 23 August 2017 (2.5 days before Harvey made landfall near Rockport, Texas) and integrated through 0000 UTC 31 August 2017. In addition to CTL, two perturbation simulations are run in which the initial SM over all land regions on the inner model domain is modified to be fully saturated (SAT) or dry (DRY). Three additional perturbation simulations are run in which the initial SM is held constant throughout the simulation (CTLC, SATC, and DRYC). The results from these hypothetical SM conditions presented here are derived from the convection-allowing inner model domain.

The storm track of Hurricane Harvey is similar among the suite of simulations through 0600 UTC 24 August (18 h), but depart thereafter with the storm track from the DRY and DRYC simulations taking a more westward course compared to the other simulations (Fig. 1a). The more westward storm track is driven by a 850–700 hPa layer-mean northeasterly perturbation wind (relative to CTL) in the subtropics in south Texas and the Gulf of Mexico that developed after 1200 UTC 24 August (24 h) in DRY (and DRYC) as shown schematically in Fig. 1a. The northeasterly wind is associated with a perturbation anticyclone that developed in the dry simulations in the southern Great Plains, with the core of the anticyclone located in southeast Oklahoma. Warmer daytime near-surface temperatures, linked to a 100–150% increase in surface sensible heat fluxes over dry soils, contribute to a warming and deepening of the planetary boundary layer (PBL) beginning at 3–6 h into the simulation and peaking at 36 h (Figs. 1b–d). In response to the deeper and warmer PBL, positive geopotential height anomalies develop rapidly in the 800–500 hPa layer by 9 h into the simulation and peak at 36 h where its attendant perturbation atmospheric flow began to steer Harvey farther south by 0000 UTC 25 August (Fig. 1d). Conversely, the simulations with saturated soils do not develop significant temperature and height perturbations in the region (Fig. 1e).

The divergence of tracks between DRY and CTL at landfall leads to different nonlinear interactions between simulated Hurricane Harvey and the midlatitude synoptic weather pattern (Fig. 1a), resulting in different tracks, intensity, and rainfall after landfall (not shown).

The local and downstream effects of SM in prior studies as well as the upstream effect of SM in this study underscore the importance of accurately depicting SM conditions in numerical models used for short-to-medium-range weather prediction in addition to numerical models used for longer-term seasonal prediction.

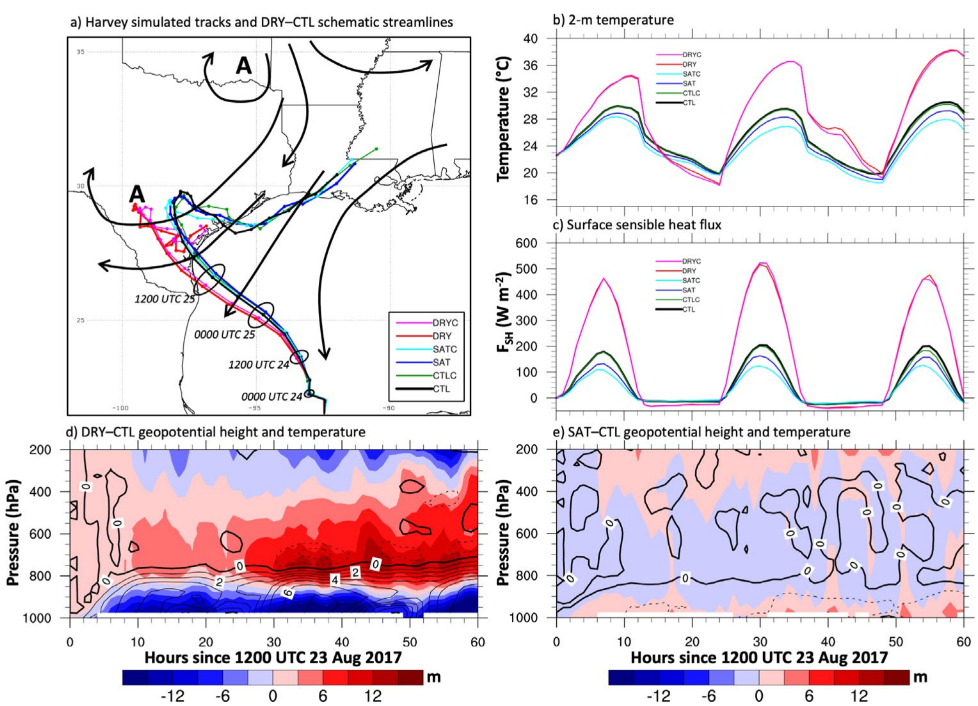

Figure 1. (a) Schematic streamlines (black arrows; based on Fig. 14d in GZ20) of the layer-mean perturbation wind (DRY–CTL) in the 850–700 hPa layer time-averaged for 0000–1200 UTC 25 August 2017 overlaid on the storm tracks for Hurricane Harvey in the CTL (black lines), CTLC (green), SAT (blue), SATC (cyan), DRY (red), and DRYC (magenta) simulations. Locations are marked along the storm tracks every 6 h using a filled circle. Locations of Harvey at key times are labeled by the unfilled black ovals. The center of the anticyclonic circulation perturbations are labeled "A". Time series of area-mean (b) 2-m temperature (°C) and (c) surface sensible heat flux (W m^{-2}) in a 120 km×120 km region centered on the anticyclone in southeast Oklahoma for each simulation (colored according to the key). Time-pressure diagrams of area-mean geopotential height (shaded according to the color bar in m) and temperature (black contours every 1 K; positive, solid; negative, dashed) perturbations relative to CTL for (d) DRY and (e) SAT for the same region as in (b) and (c).

Acknowledgements

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Magic and Mystery in Tibet: Rooting Satellite Observations on the Tibetan Plateau

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Background

The GEWEX Asian Monsoon Experiment on the Tibetan Plateau (GAME/Tibet, 1996–2000) and Coordinated Enhanced Observing Period (CEOP) Asia–Australia Monsoon Project (CAMP) on the Tibetan Plateau (CAMP/Tibet, 2001–2005) (Ma et al., 2003) were conducted to investigate the role of the Asian monsoon as a major part of the energy and water cycles in the global climate system. Both experiments sought to understand the feedback processes of the Tibetan Plateau in the monsoon system, particularly on radiation, clouds, and land surface hydrology associated with their intraseasonal, seasonal, and interannual variability. However, given the Tibetan Plateau's vastness, remoteness, and high altitude, any lengthy field campaign there would require substantial financial and human resources. Satellite observations provide essential alternatives in spatial coverage and temporal repetition to complement intensive field campaigns. Among the various satellite missions, the Soil Moisture and Ocean Salinity (SMOS) satellite (Kerr et al., 2010) of the European Space Agency (ESA) and the Soil Moisture Active Passive (SMAP) satellite (Entekhabi et al., 2010) of the National Aeronautics and Space Administration (NASA) are the two dedicated satellite missions for observation of soil moisture, providing global soil moisture products at nearly daily temporal resolution and coarse spatial resolution. Rooting these observations to the actual surface conditions would enhance our ability to effectively use these data and retrievals.

Because soil moisture is a source of water for evaporation and transpiration over land surfaces, it acts as a key element in the water, energy, and carbon cycles of the Earth system and has a large impact on the climate system through atmospheric feedbacks. Several international programs have been established in recent years to produce global soil moisture data, but despite the advances in the past decades, the current operational retrieval algorithms have relied on simple radiative transfer theory with lots of empirical assumptions in soil moisture retrievals using satellite microwave observations (de Rosnay et al., 2020; Kerr et al., 2012; O'Neill et al., 2020). The precise nature of surface roughness and vegetation in microwave scattering and emission and their representation in retrievals remain unresolved (Wigneron et al., 2017). As a result, large

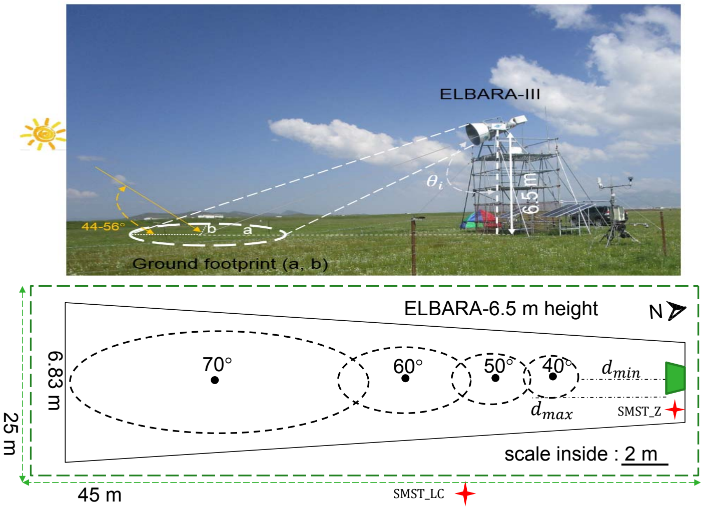

***Figure 1**. A schematic overview of the ELBARA-III tower setup (top panel) and the footprints (bottom panel). The footprints vary from 3.31 m² to 43.64 m² for incidence angles from 40° to 70°. The half-axes of the elliptic footprint are indicated as* a *and* b *for a given incidence angle θ_i (top panel) and the projected ground distances from the radiometer to the closest- and the farthest-side of the elliptic footprints at -3 dB sensitivity of the antenna are indicated as d_{min} and d_{max} (bottom panel). The locations of the installed in situ soil moisture and soil temperature sensors are indicated as SMST_Z and SMST_LC. The fence (25 m x 45 m) is not drawn to scale.*

uncertainties and inconsistencies among different operational soil moisture products exist and impede their applications for climate change studies. As a further complication, when a land surface undergoes freeze-thaw processes, the behavior of microwave observation abruptly changes in response to seasonal changes of soil water into soil ice and vice versa at different soil depths. For such cases, current satellite retrievals only provide limited freeze-thaw information.

To advance our knowledge of the precise scattering-emission mechanism of vegetated lands and to investigate in-depth freeze-thaw processes, the European Space Agency has provided an L-band microwave observation system (ELBARA-III) for ground-based observation at the Maqu site of the Tibetan soil moisture and soil temperature observation network (Tibet-Obs) (Su et al., 2011; Zeng et al., 2016; Zhao et al., 2018) for long-term observation of land surface processes. The multiyear in situ L-band brightness temperature data (Su et al., 2020), together with hydro-meteorological observations, have facilitated the development of an air-to-soil transition (ATS) model (Zhao et al., 2021a) for understanding the scattering-emission mechanism of grassland, which is widely distributed over the eastern Tibetan Plateau. Furthermore, the Community Microwave Emission Model (CMEM) (de Rosnay et al., 2009) has been extended to consider the abrupt changes of the land surface undergoing freeze-thaw processes (CMEM-FT) (Lv et al., 2020), based on this valuable data set.

Multiyear In Situ L-Band Microwave Radiometry of Land Surface Processes

We are happy to present the collected data set (https://www.nature.com/articles/s41597-020-00657-1) to the community,

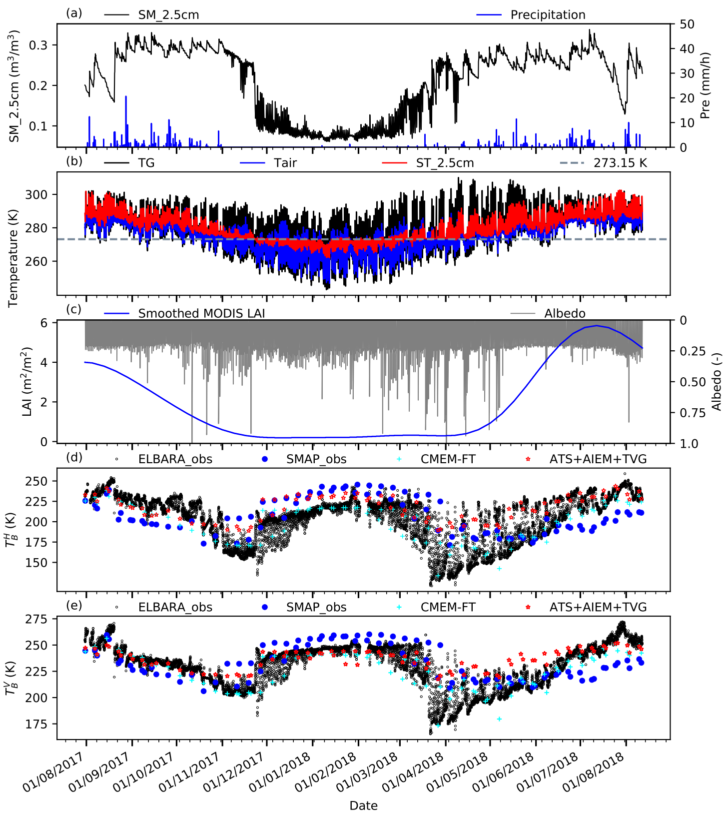

***Figure 2**. Seasonal variations of the Maqu ELBARA-III radiometry data set between 01/08/2017–01/08/2018. Plotted are soil moisture at 2.5 cm depth (SM_2.5cm), precipitation, ground surface temperature (TG), air temperature (Tair), soil temperature at 2.5 cm depth (ST_2.5cm), the nominal freezing point as a reference (273.15 K), leaf area index (LAI), albedo, and the brightness temperature intercomparison between ELBARA-III observations (ELBARA_obs), SMAP observations (SMAP_obs), CMEM-FT and ATS+AIEM+TVG simulations, in both horizontal and vertical polarization (T_B^H, T_B^V) at 40° incidence angle.*

which contains measurements of L-band brightness temperature, profile soil moisture and soil temperature, CO_2/H_2O fluxes, and meteorological data as well as auxiliary vegetation and soil texture information (Su et al., 2020).

Understanding the Scattering-Emission Mechanism of Vegetated Lands

Topsoil structures and inhomogeneous distribution of moisture in the soil volume will induce dielectric discontinuities from air to bulk soil, which in turn may induce volume scattering and affect the microwave surface emission (Mätzler, 2006; Schneeberger et al., 2004). The above data are exploited to understand the effect of surface roughness on coherent and incoherent emission processes, and result in an air-to-soil (ATS) model (Zhao et al., 2021a). The ATS model incorporates the dielectric roughness (i.e., resulting from fine-scale topsoil structures and the soil volume), characterized by soil moisture and geometric roughness effects. The ATS model is then coupled to the advanced integral equation model (AIEM) (Fung, 1994; Chen et al., 2003) for soil surface scattering with a discrete scattering-emission model for vegetation (TVG, known as the Tor Vergata model) (Ferrazzoli and Guerriero, 1996) (henceforth ATS-AIEM-TVG) for modeling the overall vegetation-soil scattering-emission. The integrated ATS-AIEM-TVG model can simulate well the seasonal and diurnal variations of brightness temperature, and help to interpret physically the involved physical processes and mechanisms. However, the integrated model is not yet able to capture the dynamic change of land surface and soil conditions undergoing rapid freeze-thaw processes, and this is where the model simulation of brightness temperature starts to deviate from ELBARA-III observations (see Fig. 2).

L-Band Microwave Emission of Frozen Soil during the Thawing Period

Currently, SMAP and SMOS missions provide global coverage of freeze-thaw (FT) states, characterizing surfaces as either freeze or thaw with binary flags. However, the transition between freeze and thaw is a continuous process in space and time, especially for L-band, whose penetration depth reaches tens of centimeters below the ground surface (Schwank et al., 2004; Zheng et al., 2019). In this case, the SMAP and SMOS brightness temperature is a mixed signal of FT states over the footprint and is generated from a soil column that might encompass the freezing/thawing front. To model such complex states, we extended CMEM in Fresnel mode with the freezing/thawing component by allowing for: 1) a varying fraction of open water surface, which may be modeled or estimated from surface temperature, and 2) implementing a freezing/thawing phase transition delay based on the difference in soil temperature at the surface and 2.5 cm depth. The augmented CMEM-FT is capable of capturing the brightness temperature dynamics, from a completely frozen to a thawed state (see Fig. 2).

Synthesis and Outlook

As demonstrated, this data set can be used to validate satellite brightness temperature observations and retrievals, and verify radiative transfer model assumptions (see Fig. 2). Furthermore, this valuable data set will help to validate land surface models and reanalysis outputs, as well as to quantify land-atmosphere exchanges of energy, water, and carbon, and to reduce discrepancies and uncertainties in current Earth System Model (ESM) parameterizations. To this purpose, we can combine the coupled ATS-AIEM-TVG, or CMEM-FT, with a physically-based soil process model, such as the Community Land Model Version 5 (CLM5, Lawrence et al., 2019) or the Simultaneous Transfer of Energy, Mass, and Momentum in Unsaturated Soil model (STEMMUS, *https://blog.utwente.nl/stemmus/*, Zeng et al., 2011; Yu et al., 2018; Yu et al., 2020), in a data assimilation framework to assimilate satellite observation data for various research purposes. For example, it could be used to retrieve not only soil properties (Zhao et al., 2021b), but also soil and land-surface fluxes and state variables (Mwangi et al., 2020). We hope this data set of multiyear, in situ L-band microwave radiometry of land surface processes on the Tibetan plateau, together with the long-term Tibet-Obs network, will help the community to resolve some of the myriad magic and mysteries of the Tibetan Plateau.

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Meeting/Workshop Reports

Summary of the 2020 GEWEX Data and Analysis (GDAP) Annual Meeting

Virtual Meeting
12–14 October 2020

Rémy Roca and Tristan L'Ecuyer
GDAP Co-Chairs

The 2020 GDAP Meeting occurred virtually from 12–14 October 2020. Unfortunately, because of the global pandemic, we had to cancel our scheduled meeting planned to take place in the heart of Paris at the University of Jussieu. Even though the GoToMeeting™ setup is not as appealing as the Tour Zamansky, we were still able to have fruitful exchanges on the status of the various projects and activities. The Panel members and activity leads were able to join most of the sessions.

We had two project update sessions on Monday the 12th. The first one was more favorable to the European Union and Japanese time zones and the second was more favorable to the United States and European Union time zones, although our Asian colleagues ended up participating as well. On Tuesday and Wednesday, two additional sessions were held in the United States and European Union time zones dedicated to discussing the Earth's Energy Imbalance assessment and the International Satellite Cloud Climatology Project–Next Generation (ISCCP-NG) project. Though favorable to U.S. participants, the timing was still a bit harsh for our California-based colleagues who joined the meeting at 6:30 AM.

On Monday, Hiro Masunaga gave an update about the Joint International Precipitation Working Group (IPWG)/GEWEX Precipitation Assessment. The project is in its final stage and the report is in press. Rémy Roca is in contact with the International GEWEX Project Office to elaborate on the preferred mode of publication of the report. Udo Schneider gave a status report about Global Precipitation Climatology Centre (GPCC) network activities. The most prominent takeaway from the presentation was the upcoming new release of a full daily 1982–2019 precipitation analysis using enhanced data streams and a new method of interpolation. The International Soil Moisture Network (ISMN) activities were summarized by Irene Himmelbauer, who presented on behalf of Wouter Dorigo. The link to the U.S. network has not been finalized because some data policy issues have emerged. The ISMN operations are planned to transition from the Vienna University of Technology (TU Wien) to the German Federal Institute of Hydrology (BFG), although the pandemic has delayed this move. A paper describing the network is in the process of being drafted and the authors have been gathered and will give an overview of the activity. The discussion highlighted the interest in sharing experiences between the various ground-based sites operating under the auspices of GDAP, as ISMN appears a bit isolated from the other networks. Finally, the session ended with an update on the Water Vapor Assessment by Marc Schröder. A coordinated special issue in the European Geosciences Union (EGU) journal is underway and accepting papers until December of 2021. The production of the assessment report has been delayed and is now projected for release in fall 2021. Similarly, the database update will be finished in 2021. Inquiry into the possibility of a third phase of the assessment has been discussed and the format needs to be identified (extension, new objectives) by the water vapor community.

The Monday afternoon (morning in the U.S.) session began with a presentation by Christian Lanconelli about the status of the Baseline Surface Radiation Network (BSRN) activities. A new co-chair of BSRN has been identified: Laura Riihimaki will help Christian with the various duties of the chair position. Participants raised the point that BSRN's positioning between the World Climate Research Programme (WCRP) and the Global Climate Observing System (GCOS) could be clearer. New activities include support from BSRN to establish standards for ocean-based radiation measurements. The discussion identified the need to initiate a satellite working group in BSRN to strengthen the links between space-based and ground-based radiation measurements. Chris Kummerow then provided an overview of the Integrated Product (IP) project. The missing longwave and shortwave surface radiation time series have been completed, offering the products in a now-complete 1988–2017 period. A data paper is being written and a special issue in *Frontiers* has been identified as a suitable outlet for this. The scientific analysis of the data has started, and Chris Kummerow reported that a dedicated water budget closure analysis over the tropical ocean shows non-stationary biases in the precipitation consistency over the West Pacific Ocean. Rémy Roca mentioned preliminary efforts to run the L'Ecuyer et al. (2015)[1] optimization framework on the IP products, revealing the need to boost the evaporation for better closure at the global scale. The future of the IP project was briefly mentioned, and there is no strong current motivation to extend the effort. As for the land-atmosphere initiative that was due to kick off in March 2020 in Toledo, the whole project has been shifted to next year and its progress waits on the resolution of the pandemic.

The Tuesday session was dedicated to the Earth's Energy Imbalance (EEI) Assessment. The first presentation by Benoit Meyssignac and Tim Boyer gave a status update of the Assessment. The effort has grown since last February and is now composed of six actions addressing various time scales, ranging from recent climate to the previous century, and various sources of EEI estimates, including in situ floats, satellites, and reanalysis. Preliminary results were also presented, highlighting the first comparison between the Clouds and the Earth's Radiant Energy System (CERES) EEI time series and the 0-2000m heat content estimates as well as sensitivities of the altimetry-based ocean heat content estimation to the computation of the Expansion Efficiency of Heat. The group plans to write an American Geophysical Union communication. A short exchange about the yet-to-start embedded top of atmosphere radiation assessment

[1]L'Ecuyer, T., et al., 2015. The Observed State of the Energy Budget in the Early Twenty-First Century. *J Clim.* 28, 21: 8319–8346. https://doi.org/10.1175/JCLI-D-14-00556.1.

then took place. The discussion further mentioned the addition of a dedicated chapter in the Precipitation Assessment about the consistency between global precipitation and global radiation that eventually links to the EEI. Jim Mather gave a short presentation about the Atmospheric Radiation Measurement (ARM) facility activities that triggered a discussion about planning a smaller, more focused workshop, prior to the delayed IP workshop, jointly held with the BSRN team. It would concentrate on strengthening the link between the existing facilities, the satellite activities in GDAP, and the scientific questions of GEWEX. Organizers are aiming to hold this ground-based, data-centric event as soon as sanitary conditions permit.

The Wednesday session focused on the ISCCP-NG initiative. It was also a year since the first ISCCP-NG workshop took place at the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) headquarters in Darmstadt, and we reviewed progress made since then. An overview was first provided by Andy Heidinger, which gave both the programmatic context and some updates on the working group dedicated to the L1G product. The link with the International Cloud Working Group (ICWG) is very strong and has enabled sustained discussions since the workshop. This L1G "georing" product is based on advanced geostationary platforms and would form the basis for the ISCCP-NG product suite developments. Andy reported significant progress in building a prototype or a demonstration product and created some excitement among participants by showing a movie of estimated outgoing longwave radiation (using 11- and 6.3-microns observations) at ~5km sub-hourly to hourly resolution. The governance, science-wise, was discussed and Graeme Stephens recalled the role of GEWEX as a steward of international data efforts. It is anticipated that the ISCCP-NG would report to GEWEX [GDAP or the Scientific Steering Group (SSG)]. The exchange further suggested that the project should begin to communicate with the broader cloud science community to advertise the activity and its anticipated outcomes. In particular, the next GEWEX SSG meeting might provide a good forum to present the progress in order to bridge out to the "Digital Twin" Earth modeling effort, for which such a data set is highly relevant. Andy also presented slides from Joerg Schultz that summarized the effort to inform the Coordination Group for Meteorological Satellites (CGMS) council about the activity. The project and its ambition were very well received and are now being inserted into the complex multi-agency program where EUMETSAT will keep a leading role. Finally, the science applications of a new ISCCP-NG data set were discussed. Brian Kahn synthetized the various types of anticipated outreach spanning from cloud processes to aerosols and lightning. Graeme Stephens emphasized the strong connection with the scientific objectives of the National Aeronautics and Space Administration (NASA)-led Aerosol and Cloud, Convection and Precipitation (ACCP) international cooperation effort. Graeme suggested that Andy give a seminar in the framework of the ACCP science seminar series. The discussion about the next steps for the project focused first on a hands-on virtual workshop to showcase what can be derived from the prototype L1G. This should happen in the spring of 2021 after the prototype is accessible. Later, a more conventional workshop is envisioned, but its realization depends on the trajectory of the pandemic.

2020 GEWEX Hydroclimatology Panel (GHP) Meeting

Virtual Meeting
26–27 November 2020

Ali Nazemi, Francina Dominguez (GHP Co-Chairs) and Joan Cuxart (Past GHP Co-Chair)

The 2020 GHP Meeting occurred during the COVID-19 pandemic and marked the first fully virtual GHP meeting. Held through the GoToMeeting™ online platform, the 2020 GHP meeting provided an opportunity for Panel members and project leaders from across the globe to share and review the status of current and future GHP projects. To accommodate diversity in time zones, the Co-Chairs decided to schedule 3-hour sessions each day to outline and discuss each project in short 10- to 15-minute time slots. To make this possible, each project submitted its presentation(s) and report(s) in advance, so Panel members could review each activity prior to the meeting. Although the spirit and socializing opportunities of previous in-person GHP meetings was missing, this iteration clearly showed that there are also benefits in virtual meetings. One lesson learned was that if the presentations are uploaded ahead of time, then the meeting itself will be dedicated only to targeted discussion, which makes it easier to maintain the focus and effectiveness of the discussion. We believe meetings with such a format can enrich the experience of the attendees and can potentially be a complement for some in-person events in post-pandemic situations.

GHP is comprised of four different types of activities: (1) Regional Hydroclimate Projects (RHPs), aiming at understanding and predicting hydroclimatology in a specific region; (2) Cross-cutting Projects (CCs), encouraging knowledge mobilization and global synthesis around a specific problem; (3) Global Data Centers, collecting and distributing hydrologically-relevant data; and (4) Networks, maintaining collaboration and building capacity for activities relevant to GEWEX science. During the GHP meeting, the group reviewed and discussed the progress of ongoing and prospective projects in these three categories.

Ongoing and Prospective Regional Hydroclimate Projects (RHPs) and Networks

RHPs are generally large, multidisciplinary projects, developed to improve our understanding of the physical processes that affect water and energy exchanges within a region. There are currently three ongoing RHPs, including Global Water Futures (GWF), Baltic Earth, and The Hydrological cycle in the Mediterranean eXperiment (HyMeX). These are mature RHPs with a large group of active researchers and established ties with local communities. GWF and Baltic Earth are progressing continuously and at a good pace. While HyMeX is now officially over, there is a strong willingness to continue this RHP. A new group of young researchers, who were present at the meeting, will take the lead on the next phase of HyMeX. The Land Surface Atmosphere Interactions over the Iberian Semi-Arid Environment campaign (LIAISE) may serve as an effective link between the old and the new HyMeX initiatives.

Participants of the 2020 GHP Meeting, courtesy of Vidya Samadi

We also took the opportunity to exchange ideas about lessons learned from the three successful RHPs and how these lessons can apply to prospective RHPs. There are currently six prospective RHPs, four of which are quite advanced and almost ready to launch. These RHPs include the Asian Precipitation Experiments (AsiaPEX), the Third Pole Environment-Water Sustainability (TPE-WS) project, the Regional Hydrology Program for the Andes (ANDEX), as well as the United States-RHP (US-RHP). We expect AsiaPEX, US-RHP, and ANDEX to submit their integrated science and implementation plans in 2021. PannEx, an initiating RHP to provide a better understanding of Earth system processes over the Pannonian Basin, has decided to become at this point a GHP Network. Networks provide a more flexible way to continue the interactions of an RHP. For PannEx, this will allow developing a more widely-involved community, delaying its application to become a full, active RHP to a later stage. We also expect another group to join our Networks this year, namely the Australian Energy and Water Exchanges research initiative (OzEWEX), which will operate as a "space" for researchers and users from various organizations to engage with topics relevant to the GEWEX science. There are also two preliminary RHPs, including an activity in Eastern Africa along with a developing joint global change SysTem for Analysis Research and Training (START)/National Aeronautics and Space Administration (NASA) initiative in Central Asia. These projects are at very early stages and are expected to flourish some years from now.

Ongoing and Prospective Crosscutting (CC) Activities

CCs are integral activities within the GHP structure, aimed at addressing GEWEX Science Questions, creating collaborations between RHPs, other GEWEX Panels and WCRP activities. The 2020 GHP meeting marked an end to the successful CC INTElligent use of climate models for adaptation to non-Stationary hydrological Extremes (INTENSE). It was also the end of the first phase of the International Network for Alpine Catchment Hydrology (INARCH), which will continue on. During its phase one activities, INARCH produced a number of open data sets and improved science for predictive modeling capability in mountainous regions. INTENSE focused on the collection and analysis of sub-daily extreme precipitation data and model outputs for improved understanding of how extremes of precipitation are responding to global warming. INTENSE will keep the legacy of a well-managed CC with a considerable amount of scientific publications and data products, some already added to the Global Precipitation Climatology Center (GPCC) repository.

There is currently one other ongoing CC in GHP, Transport and Exchange Processes in the Atmosphere over Mountains Experiment (TEAMx), aimed at improving the current understanding of exchange processes in the atmosphere over mountains and how these processes are parameterized in climate models. TEAMx activities are progressing very well. Despite the fact that the activities are mostly centered in the Alps region, the main focus of TEAMx is on processes and therefore has global relevance. Both TEAMx leaders and GHP members noted the tremendous opportunity for knowledge sharing between TEAMx and relevant ongoing and prospective RHPs (i.e., ANDEX, TPE-TS, GWF) as well as current CCs (e.g., INARCH). There were discussions around TEAMx tentatively forming a Process Evaluation Study (PROES) and collaborating with the GASS and GLASS Panels. GHP also includes a prospective CC, i.e., Determining Evapotranspiration (ET), focused on advancing the understanding and determination of evapotranspiration across scales. The 2nd ET workshop was held online in February 2021 with the goal of defining its governance structure, scope, and main objectives, and applying for CC status within GHP. Possibilities for considering this CC as a PROES within the broader GEWEX context, e.g., GLASS, were discussed.

Data Centers

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. The Global Runoff Data Centre (GRDC) focuses on acquisition, harmonization, and storage of global historical river discharge data. The center is progressing very well and new data are continuously added into the system. Although its pace is relatively measured, the International Data Centre on Hydrology of Lakes and Reservoirs (HYDROLARE) continues gathering information on the water level of lakes and reservoirs worldwide. The possibility for collaboration between HYDROLARE and similar initiatives outside GHP was discussed.

Other Business

Potential links between GHP and GLASS were examined, through linkage between some CCs and RHPs with the GEWEX Land-Atmosphere Feedback Observatory (GLAFO), a network of measurement sites sampling the atmospheric boundary layer and upper surface around the globe. Possible interactions between RHPs and CC with broader WCRP activities were also discussed through WCRP Light House Activities (LHAs), in particular "My Climate Risks", a new initiative for assessing and explaining regional climate risk. GHP co-chair Ali Nazemi is currently part of the science program in this LHA.

The 2020 GHP Meeting was concluded by welcoming new members and thanking those rotating off the GHP Panel. After seven years in the GHP Panel and four years of excellent leadership, Joan Cuxart stepped down as Co-Chair and Ali Nazemi was appointed as the new Co-Chair of GHP. Also, after six years of dedicated service to GHP, Craig Ferguson stepped down as GLASS-GHP liaison and was replaced by Josh Roundy.

Summary of the 4th International Convection-Permitting Modeling Workshop for Climate Research

Virtual Meeting
2–4 September 2020

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Introduction and Scope of the Workshop

The 4th International Convection-Permitting Modeling (CPM) workshop, originally planned as an in-person meeting for September 2020 in Kyoto, Japan, has been postponed until next year due to the COVID-19 pandemic. Because of the rapid development of the CPM field, we felt the need to host a virtual workshop this year to maintain community interactions and to provide a forum where scientific advances are presented and discussed.

The virtual workshop was held 2–4 September 2020 with the main focus on the simulation of mesoscale processes and extreme events with CPMs at global and local scales and the use of CPM data for hazard and impact assessments. Recent advancements in CPM research were highlighted and key challenges were discussed. The workshop had 324 participants from 23 countries and areas and featured four sessions with invited presentations. All presentations were pre-recorded and are available on the workshop website at *https://www.pco-prime.com/togo2020_ws/index.html*. Participants were able to watch the presentations and ask written questions before the live discussion sessions, which occurred on 2–4 September 2020. The questions were answered during the live discussion period. A recording of the discussion sessions can also be accessed through the above website. In the following, we provide a summary of each session and conclude by identifying future focus research areas.

Can CPM Improve Our Understanding of Precipitation and Its Future Change?

The first session highlighted the advantage of CPMs in gaining a better understanding of the atmospheric phenomena associated with precipitation and its future change. We addressed the reasons why CPMs improve the representation of the atmospheric phenomena associated with heavy precipitation [e.g., convective clouds, mesoscale convective systems (MCSs), topographical precipitation, snowfall, etc.] and focused on new insights regarding the future projection of precipitation that cannot be obtained by coarse-resolution climate models. An important question that this session addressed was the dependence of simulating local-scale precipitation on the structure and organization of convection and the role of local orography.

The difference in the horizontal scale needed to represent low-level convergence was examined in several talks. In some cases, such as for back-building mesoscale convective systems in Japan or single-cell convective storms, kilometer-scale grid spacing may be too coarse to capture the structure and organization of convection. Organized convective storms in the U.S., however, are typically well-simulated with kilometer-scale models. Another focus was the performance of CPMs in representing various types of precipitating clouds (single cell, back-building type convection, orographic, and other types) at various locations around the world. In addition, the importance of indices for evaluating the representation of simulated clouds was also pointed out.

Presentations on future climate simulations of precipitation focused on whether scaling rates between temperature and precipitation correlated with the changes in moisture predicted as a function of temperature by the Clausius-Clapeyron (CC) equation. In most cases, changes in the stratification of the troposphere impact the response of precipitation to the temperature.

Towards Global Convection-Permitting Climate Simulations

The second session focused on the development and application of global convection-permitting models. One of the goals of using global CPMs is to improve long-standing biases in global climate models by simulating key physical processes such as convection directly rather than parameterizing them. Global CPMs are currently in an experimental stage, but initial results such as an improved representation of gravity waves, convection, and boundary layer processes are promising (e.g., Neumann et al., 2019). However, major challenges remain in using global CPMs for climate change studies that can be summarized into two categories: 1) model hardware and software and 2) model performance.

The first category is mainly related to technical challenges. Most existing CPMs that can run globally will not be able to run efficiently on future high-performance computers due to fundamental changes in future computer architectures (e.g., Schär et al., 2020). Adapting to future architectures demands a rewriting of the model code, making it more flexible to run on a variety of platforms. To effectively run global climate CPMs, a speedup of 100 times is necessary, which would allow us to simulate a one-year timeframe in one physical day. The Swiss Federal Institute of Technology in Zürich (ETH Zürich) and the European Centre for Medium-Range Weather Forecasts (ECMWF) have plans to achieve this goal with a 3 km grid spacing model by 2024. An important additional challenge is the storage and sharing of model output.

The second major obstacle in using global CPMs is related to model performance. One key challenge is the simulation of low-level sub-tropical clouds over the ocean, due to their im-

A sub-set of the participants of the virtual 4th International Convection-Permitting Modeling Workshop for Climate Research

portance in the Earth's energy balance and simulated climate sensitivity. Simulations from the DYnamics of the Atmospheric general circulation Modeled On Non-hydrostatic Domains (DYAMOND, https://www.esiwace.eu/services/dyamond) project show a large variability in the representation of low-level clouds in global CPMs. The source of this variability is not fully understood, but model numerics, the representation of convection, and microphysical processes seem to be important. Additional challenges arise in ocean-atmosphere coupled global CPMs. Initial tests with such models show large drifts in the global mean states.

An alternative pathway to global CPMs is to test the performance of regional CPMs over various climate regimes to detect and improve model biases and to find physics suites that perform well in various climatic regimes. The importance of coupling with other Earth system components such as the ocean and land-surface has been exemplified by the strong sensitivity of the simulated summer climate in the central U.S. to the representation of groundwater (Barlage et al., 2018). Furthermore, even at kilometer scales, most convective motions are still under-resolved, resulting in systematic model biases such as an overestimation of hourly precipitation extremes. More sophisticated gray-zone convection parameterizations are promising in mitigating these deficiencies. Finally, the use of satellite observations and targeted model experiments that make use of field campaign data was discussed for evaluating global CPMs.

CPM Applications for Hazard Assessment under Climate Change

The third session focused on the roles of CPMs toward hazard assessment under climate change. For hazard assessment, high spatiotemporal resolution and quantitatively accurate predictions are required. The appropriate spatiotemporal scale depends on the type of disaster considered. It is hoped that CPMs improve not only the simulation and prediction of hazards, but also our understanding of processes associated with the hazard. Discussions during the session focused on the use and significance of CPM for better hazard risk assessment under both the present and future climate.

As for sediment-related disasters such as landslides, predictions of precipitation and its three-dimensional character related to the slope scale were shown to be important, especially the occurrence of landslides depending on peak rainfall intensity and rainfall pattern. Concerning flooding, accurate predictions across various catchment sizes are very important. Additionally, correctly simulating the trigger process of convective initiation is essential to represent the timing and location of localized events that might cause flash flooding and landslides in small river basins. High-resolution and high-quality observations were identified as crucial for a better understanding of processes and phenomena that cause extreme events and for supporting the development of parameterization schemes.

Since rainfall is expected to intensify at small spatial and temporal scales in future climates, the impact of precipitation on the initiation of landslides in small river catchments becomes increasingly important. This intensification causes the need for a new framework of early warning and evacuation systems. CPMs are playing a vital role in understanding future change for not only total rainfall, but also peak rainfall as well as maximum wind speeds, which are relevant for hazard and disaster assessments. Multi-model and large CPM ensembles in particular are expected to better map future uncertainties and increase our confidence in the magnitude of future changes. The 18th UK Climate Projections (UKCP18, https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/index), which contain an ensemble of current and future climate CPM simulations, were presented as a groundbreaking example of such a research effort.

CPM Research in Asia

Session 4 highlighted the important role of CPM in understanding and estimating future projections of representative meteorological phenomena and hazardous weather in Asia. We identified the Asian monsoon processes (Meiyu, Baiu, Shurin, and Changma in East Asia), typhoons in East Asia and Southeast Asia, and MCS in tropical regions as the most important meteorological phenomena concerning impacts. Mesoscale models such as the Weather Research and Forecasting (WRF) model, the Japan Meteorological Agency Nonhydrostatic Model (JMA-NHM), and the Cloud Resolving Storm Simulator (CReSS of Nagoya University) are playing a vital role in simulating these phenomena. One to two kilometer horizontal grid spacing was found to be sufficient in simulating typhoons, although sub-kilometer grid spacing was noted to be ideal. It was also pointed out that CPMs are vital for simulating orographic effects on rainfall.

Regarding future projections, non-hydrostatic regional climate model (NHRCM)-based simulations by the Meteorological Research Institute (MRI) are widely used in Japan and southeastern and tropical Asia. For hazards, rainfall information is needed with spatial resolutions of a few kilometers for hydrological run-off computation and a few hundred meters for sediment hazard. NHRCM and WRF are the most widely-used models in Asia for generating CPM climate change projections, and projects such as the Coordinated Regional Climate Downscaling Experiment (CORDEX, *https://cordex.org/*) and the Integrated Research Program for Advancing Climate Models (TOUGOU, *https://www.jamstec.go.jp/tougou/eng/program/index.html*) are playing vital roles. As in previous sessions, the impact of model grid spacing on simulating high-impact atmospheric phenomena and the need for high-quality and high-resolution rainfall observations for model validation and model output statistics were discussed. The observation system could be advanced by increasing the number of in situ rain gauges, installing polarimetric weather radar, and improving satellite-based rainfall products.

Meeting Outcomes and Future Research Needs

The virtual meeting posed challenges concerning the accommodation of major times zones and only allowed limited personal interactions compared to an in-person workshop. The format (e.g., prerecorded presentations and live discussions sessions) was very well received by the participants and allowed the involvement of scientists who were unable to join previous CPM workshops. The main outcomes and major future research needs identified during the workshop are the following:

- Multiple global convection-permitting modeling systems are currently being developed, and decadal-long CPM climate simulations will be available within the next five years.
- Closer collaboration between computer scientists and climate model developers is needed to efficiently run CPM models on future high-performance computers.
- CPMs can provide valuable information for climate impact modeling, and future CPM workshops will focus on better connecting CPM researchers to hazard modelers.
- We need an improved understanding of the necessary model grid spacing, model numerics, and complexity of model physics to reliably simulate high-impact weather in various climate regimes.
- High-resolution observational data sets are needed to evaluate and further develop CPMs. Those data sets include station, ground radar, and satellite observations.
- Important CPM development needs to include the simulations of oceanic clouds, the representation of convection in the turbulent grey zone, coupling to the ocean, and an improved representation of land-surface processes and their interaction with the atmosphere.
- Enhanced coordination between CPM modeling studies is needed to improve their comparability and to better understand uncertainties in CPM climate change projections. Such efforts show promising results over Europe and should be extended to other regions. The establishment of joint CPM experiments in Asian countries was a key discussion point.

We are in the process of planning the 5th International Convection-Permitting Modeling Workshop, which is planned for late summer 2021 at Kyoto University in Japan. Workshop announcements will be posted through the convection-permitting climate modeling e-mail list (ral-cpcm@ucar.edu) and by GEWEX.

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