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

SoilWat: Improving Soil Representation in Land Models

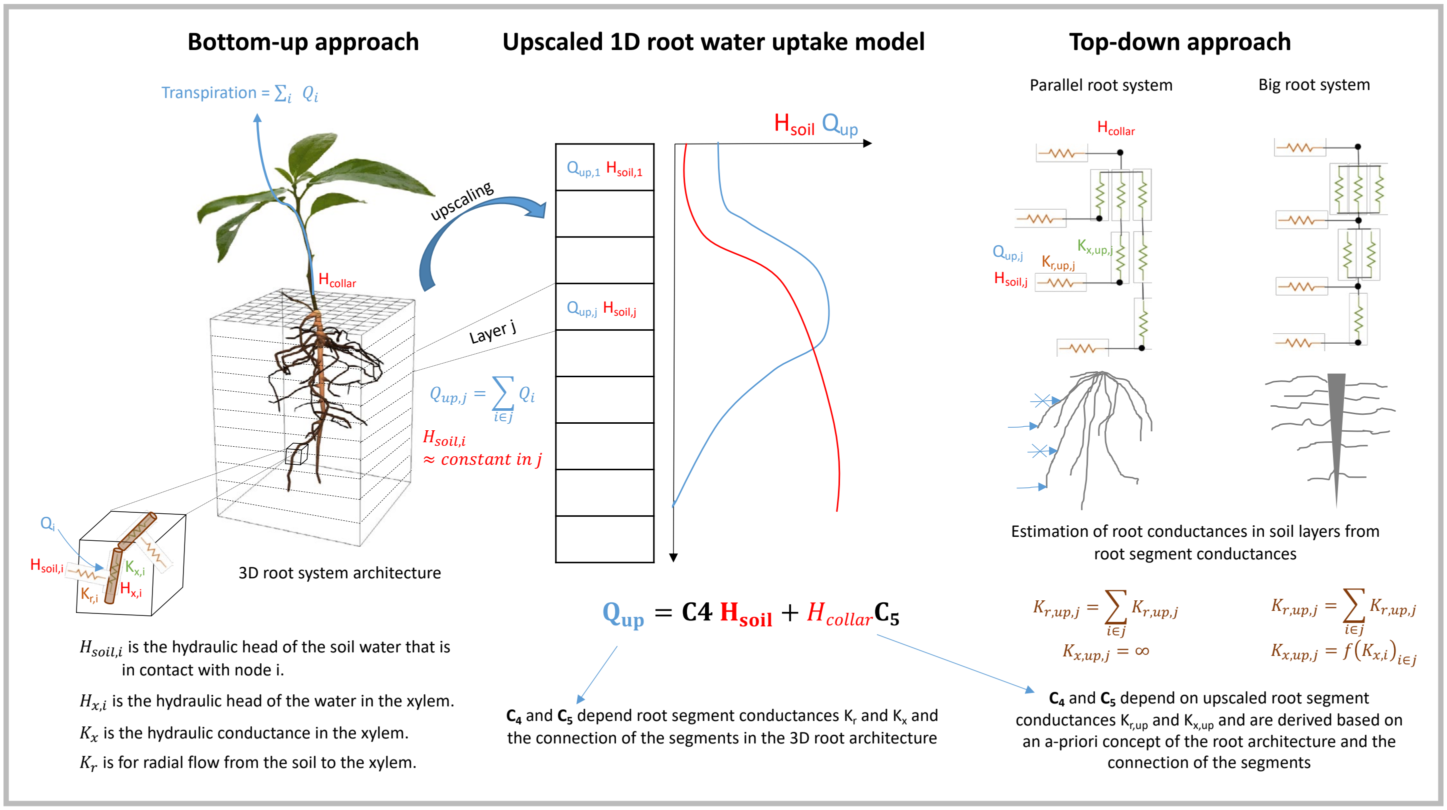

Figure 3 compares a bottom-up approach versus top-down approaches for a parallel and a big root system model to derive and parameterize an upscaled one-dimensional root water uptake model. (Adapted from https://doi.org/10.5194/hess-2021-14.) See Zeng et al. on page 4.

Inside This Edition

Commentary: Irrigation, an Anthropogenic Perturbation to the Continental Water Cycle GEWEX Should Address

Jan Polcher
GEWEX Scientific Steering Group (SSG) Co-Chair

Irrigation is arguably the largest water usage by mankind and certainly the most important consumptive abstraction from the natural water cycle. If GEWEX aims to understand the changes occurring in the continental branch of the water cycle, we need to tackle this process. Irrigation is an intervention in the water cycle which is not purely geophysical, as it also involves socio-economical choices such as water rights, cultural and historical considerations, the cost of water, and engineering issues linked to water management and transport. But all these processes are framed by the geophysical constraints of water demands by the atmosphere and water availability. These two mechanisms are squarely within the core competencies of GEWEX. As both are expected to change in a warmer climate, we have a responsibility to advance our knowledge in order to contribute to the discussions on adaptation of water usage to climate change occurring in many regions of the world. For our colleagues within WCRP, we need to evaluate the impact of irrigation on continental fresh water discharge and place it in an Earth system perspective.

A number of activities are already underway within the GEWEX community that are relevant to the topic of irrigation. For instance, we can cite the Land surface Interactions with the Atmosphere over the Iberian Semi-arid Environment (LIAISE) field campaign, which will be carried out in July 2021 within the Hydrological Cycle in the Mediterranean Experiment (HyMeX) Regional Hydroclimate Project. It aims to create a better understanding of how irrigation modifies regional evaporation and the structure of the atmospheric boundary layer. The evaporation cross-cut spearheaded by the GEWEX Hydroclimatology Panel (GHP) will improve our understanding of one of the main drivers behind the irrigation of crops. The European Space Agency (ESA) has funded a project to try and quantify water use for irrigation through the inversion of remote sensing observations.

A greater challenge will be acquiring the ability to simulate and predict water uptake by irrigation and its impact on the continental water cycle. A number of land surface models already include some sort of representation of irrigation, but often with strong assumptions. The first step in that modeling chain is to predict the water stress of crops, as it is the driving force behind the need to irrigate. But the amount of water applied will depend on regulations, the cost of water, and finally the farmers' choices. Once that irrigation demand is predicted, it needs to be determined where in the water cycle it will be extracted and how it will be applied in order to simulate its impact on climatic processes. All this obviously while respecting the water conservation principles central to our land surface models. As can be seen, modeling all these aspects will be challenging and will require expertise well beyond GEWEX. Nevertheless, we must start that process and interact with the other disciplines developing knowledge on irrigation. In the coming decade, our Earth system models will need to represent this important human intervention and enable us to predict the actual water cycle and its sensitivity to climate fluctuations.

GEWEX needs to identify a strategy to ensure progress in our knowledge of the role of irrigation in the continental water cycle. The observational capabilities that can contribute to advancing our understanding need to be identified and nurtured. We need to support a trans-disciplinary effort to monitor "Essential Water Variables" parallel to the one for essential climate variables. Development of land surface models needs to be encouraged so that various approaches can be compared and their qualities well-understood. Only once the GEWEX community recognizes what it can contribute to the discussion can a fruitful collaboration with agronomers, hydro-economists, and the other specialists be had. This trans-disciplinary conversation will allow us to better understand how climate change will affect water scarcity and move beyond the prediction of natural water resources we are performing today.

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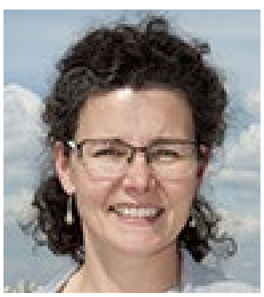
New SSG Co-Chair

Dr. Xubin Zeng, most recently Co-Chair of the GEWEX Global Atmospheric System Study (GASS) Panel, is the new Co-Chair of the GEWEX Scientific Steering Group (SSG), joining Co-Chair Jan Polcher. Dr. Zeng replaces Graeme Stephens, who served as SSG Co-Chair from 2014 to 2021. Dr. Zeng is the Agnese N. Haury Chair in Environment, Professor of Atmospheric Sciences, and Director of the Climate Dynamics and Hydrometeorology Center at the University of Arizona. He is also an affiliated professor of the Applied Mathematics, Global Change, and Remote Sensing and Spatial Analysis Interdisciplinary Programs. Through 202 peer-reviewed papers, Dr. Zeng's research has focused on land-atmosphere-ocean interface processes in the Earth system, weather and climate modeling, hydrometeorology, remote sensing, nonlinear dynamics, and big data analytics.

He is a fellow of the American Meteorological Society (AMS), American Association for the Advancement of Science (AAAS), and University of Arizona Academic Leadership Institute. He just accepted the AMS 2021 Charles Franklin Brooks Award for Outstanding Service to Society, and received the Special Creativity Award from the National Science Foundation. He received his Ph.D. from Colorado State University in 1992 and was given its Atmospheric Science Outstanding Alumni Award.



New GASS Co-Chair

Sandrine Bony joins the GEWEX Atmospheric System Studies (GASS) Panel as its new Co-Chair. Currently, Dr. Bony is a director of research at the Laboratory of Dynamical Meteorology (LMD) in Paris. After her Ph.D. from Sorbonne University, she worked at the Massachusetts Institute of Technology and joined the French National Center for Scientific Research (CNRS). Sandrine was a lead author for the 4th Assessment Report of the Intergovernmental Panel on Climate Change, and served as an editor for the *Journal of Climate* and the *Bulletin of the American Meteorological Society*. She has been active in WCRP as a co-chair of the Cloud Feedback Model Intercomparison Project (CFMIP), as a co-chair of the Working Group on Coupled Models (WGCM), and as a co-lead coordinator of the WCRP Grand Challenge on Clouds, Circulation, and Climate Sensitivity. Recently, she co-led the international Elucidating the Role of Cloud-Circulation Couplings in Climate (EUREC4A) field study over the western tropical Atlantic. Through the combined use of observations and models, she has developed extensive expertise in cloud processes and their role in climate, including in cloud feedbacks and in convective organization. By joining the GASS Panel as a Co-Chair, she wishes to promote observational and modeling studies of atmospheric processes that can both contribute to improved models and to address challenging science questions that are at the core of climate research.

YESS Engagement in the International Agenda and a Glimpse of Our Latest Activities

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

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As part of the objectives elaborated in the Strategic Action Plan, the Young Earth System Scientists (YESS) community has been very active in fostering new collaborations and opportunities for Early Career Researchers (ECRs) at international panels and meetings. Several YESS members (Pablo Borges de Amorim, Feba Francis, Leandro Diaz, and Gaby Langendijk) were selected to represent YESS in the World Climate Research Programme (WCRP)'s new Lighthouse Activities. In addition, our YESS members Faten Attig Bahar and Jorge Saturno were invited to represent YESS at the 25th German Committee Future Earth (DKN) meeting held in February 2021. YESS will also host a virtual side event during the next DKN Summit (*https://www.dkn-future-earth.org/events/087592/index.php.en*), to be held in July of 2021.

The YESS Online Events Working Group (WG), in collaboration with the Pan African University Institute of Water and Energy Sciences (PAUWES) and the contribution of the United Nations University and Future Earth Nexus Knowledge-Action-Network, is planning the third edition of the YESS-PAUWES webinars. The focus will be on sustainable development in Africa post-COVID. The first edition of the Global Atmosphere Watch (GAW) Training and Education Centre (GAWTEC) webinars series, a joint activity between the YESS community and World Meteorological Organization (WMO)'s GAW program, took place between December 2020 and January 2021, and focused on greenhouse gasses and atmospheric composition measurements. All the webinars can be accessed here: *https://www.yess-community.org/gawtec-webinar-series/*.

Finally, a new initiative, coordinated by the YESS Science WG, is the Science Interview series. The aim is to provide insights into ongoing Earth System science research projects and the current or potential opportunities for ECR engagement. The first article addresses the role of another core WCRP program, Stratosphere-troposphere Processes And their Role in Climate (SPARC), in fostering the new generation of Earth-System scientists. All the information on this initiative can be found at *https://www.yess-community.org/yess-science-interviews/*.

We invite international scientific community members to nominate any project you are aware of that offers opportunities for ECRs to be considered for our series. For this, please get in touch with us at *interviews@yess-community.org*.

H3S Welcomes New Members and Introduces New Initiatives in 2021

Julia Guimond
National Science Foundation (NSF) Postdoctoral Fellow, Dalhousie University

On January 28th, the American Geophysical Union (AGU) Hydrology Section Student Subcommittee (H3S) welcomed 15 new members to the committee, ranging in career stage from undergraduate student to postdoctoral researcher. Since the first meeting, H3S members and subcommittees have been busy brainstorming new initiatives, resources, and opportunities for students and early career researchers. On Friday, March 26th, H3S hosted the first virtual networking event of the year. This event was in the form of a speed networking social with approximately 30 one-minute blocks for early career researchers to meet and share interests. Similar events will be held virtually every month this spring with the hope of strengthening the early career community and building students' and early career researchers' networks. Events with similar goals are also in the planning stage, to be held this summer as well as at the 2021 AGU Fall Meeting.

One year ago, H3S launched its website (*agu-h3s.org*) to provide resources and highlight the research of early career scientists. This spring, H3S members are working hard to expand the website, including absorbing the *WaterPOC* database, created by students from the University of Waterloo. This database is a tool to support efforts of diversity, equity, and inclusion in the field of water research, including:

- Increasing the visibility of these researchers to their peers (both minoritized and not) up and down the career ladder
- Increasing recognition of the excellence of research conducted by these individuals
- Facilitating nominations and recruitment of these individuals for awards, leadership positions, and paid positions

This database also highlights the intersections of identities within water researchers, including race, gender, and career stage. There are currently 180+ entries in the database and it continues to grow. The *WaterPOC* database will soon be accessible through the H3S website for long-term access and maintenance.

Stay tuned for more event announcements in the coming months! Interested in learning more about H3S activities? Follow us on Twitter (*@AGU_H3S*) or Instagram (*agu_hydrology*).

GEWEX-ISMC SoilWat Project: Taking Stock and Looking Ahead

Yijian Zeng[1], Anne Verhoef[2], Dani Or[3,4], Matthias Cuntz[5,6], Lukas Gudmundsson[7], Lutz Weihermueller[8], Stefan Kollet[8], Jan Vanderborght[8], and Harry Vereecken[8]

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The Soil and Water (SoilWat) initiative is a joint activity between the Global Energy and Water Exchanges (GEWEX) project and the International Soil Modelling Consortium (ISMC). SoilWat aims to bring together two research communities to improve the representation of soil and subsurface processes in climate models. The soil modeling community (represented by ISMC) and the climate modeling community (represented by GEWEX) are working together to identify the most pressing challenges and topics related to this effort, in terms of understanding the role of soil properties and parameters, soil physical processes (e.g., infiltration, surface evaporation, water and heat flow), root hydraulics, groundwater dynamics, and their interactions with the vegetation and biogeochemical cycles, deploying a combination of Earth observations (in situ and remote sensing), modeling, and data assimilation.

Soil Properties and Pedotransfer Functions

There is a longstanding tradition in soil science of developing and applying pedotransfer functions (PTFs) for the calculation of hydraulic properties (Clapp and Hornberger, 1978; Cosby et al., 1984; Pachepsky and Rawls, 2004; Vereecken et al., 2010; Van Looy et al., 2017; Dai et al., 2019a). These functions use basic soil properties that are widely available, such as texture, organic matter, and bulk density, to estimate hydraulic, solute transport, thermal, and biogeochemical parameters (Van Looy et al., 2017). The soil hydraulic properties (water retention characteristic and the hydraulic conductivity curve) (Brooks et al., 1964; van Genuchten, 1980; Montzka et al., 2017; Gupta et al., 2020; Gupta et al., 2021) are pivotal in describing the flow and storage of water in soil and its availability for vegetation via root water uptake (Verhoef and Egea, 2014).

Besides applications in soil science, ecology, engineering, and hydrology, soil hydraulic functions and their PTFs are used extensively to derive hydraulic parameters for land surface models (LSMs). LSMs are embedded in global climate and numer-

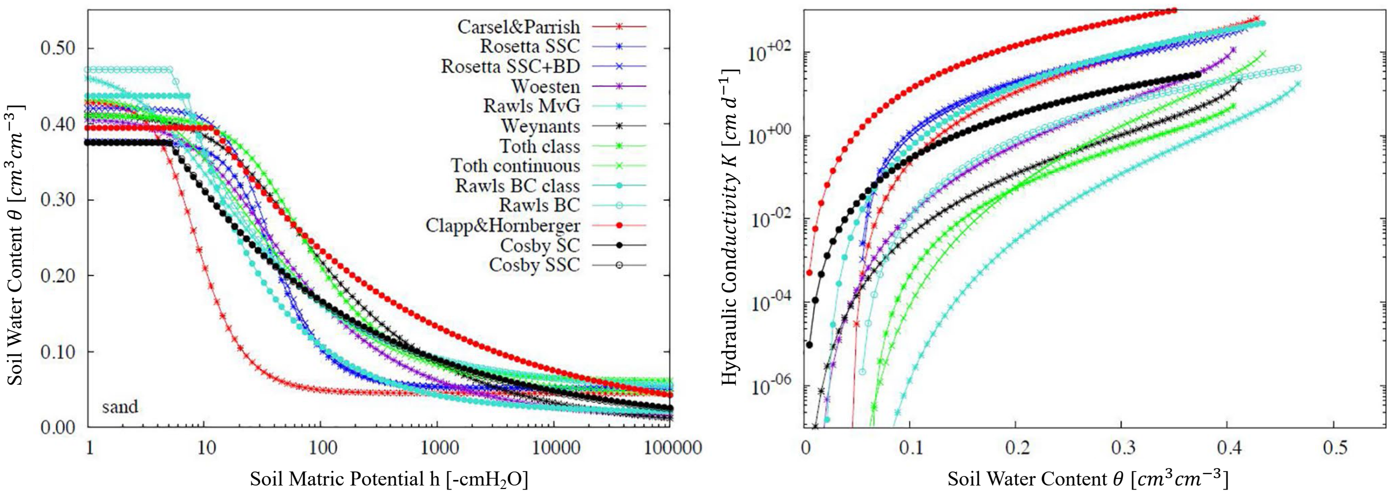

***Figure 1**. Soil water retention curve (left) and hydraulic conductivity curves (right) for the United States Department of Agriculture (USDA) sand class for 13 PTFs (colored curves).*

ical weather prediction (NWP) models to enable regional to global coverage and calculation of soil- and land surface-related processes, pertaining to the water, energy, and carbon balances. Consequently, uncertainty in basic soil properties propagates into the derived soil parameters and can affect fluxes and state variables simulated by LSMs (Weihermüller et al., 2021; Dai et al., 2019b). For example, the evaluation of European Centre for Medium-Range Weather Forecasts (ECMWF) soil moisture and temperature analyses against in situ data collected on the Tibetan Plateau (TP) revealed that the persistent systematic model bias is mainly caused by nonrepresentative values of saturated hydraulic conductivity used in the model and simplifications of certain soil physical processes (e.g., freeze-thaw) (Su et al., 2013; Yu et al., 2018). A further investigation into the five existing soil texture databases over the TP demonstrated a wide uncertainty range across different climate regions of the TP (i.e., arid, semi-arid, and subhumid) (Zhao et al., 2018). The results of these kinds of studies show that the choice of soil information and soil databases matters for LSMs (Dai et al., 2019a; Montzka et al., 2017; Fatichi et al., 2020).

Information on basic soil properties such as soil texture and porosity is also used to derive the parameters required in the equations used to calculate thermal soil properties (thermal conductivity and heat capacity) in LSMs (Dai et al., 2019a; Johansen, 1977; Lu et al., 2007; He et al., 2020; Ghanbarian and Daigle, 2016; Dai et al., 2019c). Hence, the term PTF can also be used in this thermal context. Furthermore, other than considering thermal property equations and their PTFs, SoilWat ultimately aims to develop a unified underlying theory to yield both thermal and hydraulic parameters in a physically-consistent way (Lu and Dong, 2015). This will help facilitate the harmonization of soil hydro-thermal properties and their PTFs as used in LSMs, to avoid artifacts potentially originating from the choice of soil property maps and PTFs (Weihermüller et al., 2021), and confusion with uncertainties stemming from different model structures and physics.

For this purpose, SoilWat is conducting a systematic assessment of the quality of resolved soil maps used in climate modeling, and the effect of different soil maps on the prediction of land surface fluxes and state variables. With this endeavor, we seek to improve the quality and resolution of soil maps used in LSMs. Current ongoing efforts include a "Soil Parameter Model Intercomparison Project" (SP-MIP, see Fig. 2); this involves eight LSMs [i.e., the Community Land Model (CLM), the Interaction Sol-Biosphère-Atmosphère (ISBA) model, the Joint UK Land Environment Simulator (JULES), the Jena Scheme for Biosphere Atmosphere Coupling in Hamburg (JSBACH) model, the Organising Carbon and Hydrology In Dynamic Ecosystems (ORCHIDEE) model, the Minimal Advanced Treatments of Surface Interaction and Run Off (MATSIRO) model, MATSIRO with Groundwater (MATSIRO-GW), and the Noah- Multiparameterization (Noah-MP) model] and the ISMC working groups of "Soil Thermal Properties" and "Pedotransfer functions and land surface parameterization" (*https://soil-modeling.org/science-panels/working-groups/pedotransfer-functions*). Analysis of the SP-MIP data is currently ongoing.

The recent paper by Weihermüller et al. (2021) explored the effect of using different PTFs (Clapp and Hornberger, 1978; Cosby et al., 1984; Pachepsky and Rawls, 2004) (see Fig. 1) on key components of the water balance for an area in Germany (using a 30 year set of meteorological driving data). It employed the widely used and tested HYDRUS model (Šimůnek et al., 2016) to avoid confounding effects of choice of PTF and model structure. The effects on the evapotranspiration were considerable, and they varied depending on the choice of soil type, land cover (bare, grass, or crop), and whether groundwater was present. Follow-on studies are currently being conducted to test the effects with other independent soil physical models, as well as the effects on the thermal regime.

Soil Infiltration Processes

Infiltration is a key soil process that partitions precipitation into surface runoff and water that enters the soil profile. As part of the SoilWat initiative, Vereecken et al. (2019) reviewed the basic principles and current approaches to describe infil-

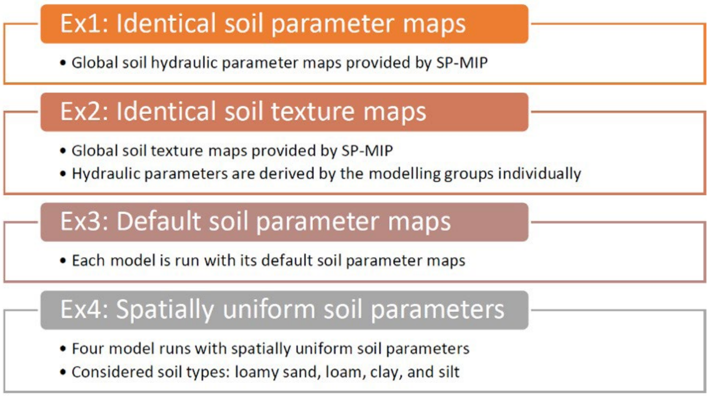

***Figure 2**. Summary of the SP-MIP effort. Comparison between experiments 1 and 2 will show the model diversity caused by the PTFs. Comparison between experiments 2 and 3 will show the model diversity that comes from different soil maps and aggregation schemes. Experiment 4 serves: (i) to quantify the effect of spatial variability of soil parameters on model diversity, (ii) to assess the sensitivity of each model to soil hydraulic parameters, and (iii) to investigate to which degree the spatial variability of key water and energy balance outputs is controlled by soil properties.*

tration in LSMs, its numerical implementation, and its sensitivity to model parameters. They found a large variation in infiltration approaches adopted by LSMs, also in relation to upscaling from the local to the grid-scale, in addition to the large variety of approaches used to estimate soil hydraulic properties as mentioned above. They identified several processes not yet considered in LSMs that influence infiltration into soils such as soil structure (Fatichi et al., 2020), water repellency, crusting, freeze-thaw processes, hysteresis, flow instability, and swelling and shrinking. At present, we lack information on how, e.g., vegetation and land use may impact soil structure and thus soil hydraulic properties and the process of infiltration, although efforts by Gupta et al. (2020, 2021) have tried to take this into account.

Soil Surface Evaporation

Soil evaporation is an important component of the hydrological cycle that affects plant available water and the surface energy balance. Knowledge of surface evaporation (defined as evaporation from soil pores and canopy interception, but not transpiration) is important for separation of evapotranspiration to its components (transpiration and evaporation) to better link the water and carbon cycles and for various aspects of water resource management (e.g., irrigation scheduling). The dynamics of soil evaporation and internal drainage following rainfall are sensitive to soil properties; in other words, soil type (as defined by its textural composition) affects the rates by which soil water percolates to deeper layers, and the surface resistance to evaporation. It also affects a characteristic depth below which water cannot be easily extracted by capillarity and related physical processes (of course, plant roots can access and extract soil water down to several meters). These common but often overlooked soil effects on soil evaporation have been formulated in a conceptual model by Or and Lehmann (2019) termed the *Surface Evaporation Capacitor* (SEC), and the model has been applied globally to improve climatic surface evaporation predictions (highlighting shortcomings of some of the common approaches presently used to deduce this important land surface flux). The SEC implements a simple and easy-to-use formulation of evaporation surface resistance (Lehmann et al., 2018) that has been tested using *FLUXNET* data and decadal lysimeter records from arid regions (Lehmann et al., 2019). More recently, the SEC model has been extended to include the competing effects of drainage in an analytical framework (Lehmann and Or, under review). This line of research not only fits into the SoilWat theme of linking soil and climate processes, but it also offers readily useable improvements for global models as has been shown recently (Or and Lehmann, 2019; Decker et al., 2017; Mu et al., 2021).

Soil Water and Heat Flow

Most of the current operational LSMs describe water flow via Richards' equation and heat flow via Fourier's law, and the soil water and heat flow are "softly" coupled via soil heat capacity and thermal conductivity, both of which are dependent on soil water content. Although such model treatments of soil physics can broadly capture the soil water-heat dynamics over humid and subhumid regions, their performance over arid and semi-arid lands (ASALs) (that make up >40% of the globe) are always compromised. Such model deficiency over ASALs is mainly caused by the missing mechanism of vapor transfer, which is key for actively and dynamically coupling soil water and heat flow, since it carries simultaneously mass and energy (Garcia Gonzalez et al., 2012; Zeng et al., 2011a; Zeng et al., 2011b; Shahraeeni and Or, 2010; Shahraeeni and Or, 2012; Shokri et al., 2009).

A study with water vapor transfer incorporated into the JULES model found that the water vapor flux contributes significantly to the water and heat transfer in the upper soil layers over three semi-arid and temperate arid sites (Garcia Gonzalez et al., 2012). The inclusion of vapor transfer has a direct and positive impact on the diurnal evolution of evaporation, soil moisture content, and surface temperature, which will contribute to the improved understanding and prediction of land-air interactions. Furthermore, the consideration of soil vapor flow can further our wider process understanding, including land-atmosphere feedbacks at larger scales. For instance, we might be better able to grasp why afternoon rain is more likely over drier soils (Taylor et al., 2012), or why the semi-arid ecosystem plays a dominant role in the trend and variability of the land CO_2 sink (Ahlström et al., 2015).

Afternoon rain falls preferentially over dry soils, particularly over semi-arid regions, where surface fluxes are sensitive to soil moisture and convective events are frequent (Taylor et al., 2012). Semi-arid ecosystems were found to account for 39% of interannual variability of global Net Biome Production (NBP), which is mainly driven by the local compensatory effects of soil water availability on NBP (Ahlström et al., 2015; Jung et al., 2017). To facilitate understanding the role of soil physical processes within the above context, SoilWat is conducting an in-depth survey on how key soil physical processes (water and heat flow) are represented in Earth System and Land Surface Models.

Soil-Root Hydraulics

Since the root system is the plant organ that is responsible for the acquisition of water and nutrients, its hydraulic properties play a key role in the functioning of the vegetation and in the water, carbon, and nutrient cycles of terrestrial ecosystems. Root hydraulics have been represented in LSMs in different ways: assuming a vertical "big root" (Amenu and Kumar, 2008; Tang et al., 2015) or assuming a network of parallel roots that take up water near the root tips and that are connected at the root collar (Sulis et al., 2019; Kennedy et al., 2019). These hydraulic root models are parameterized in a "top-down" approach by first postulating a simplified root hydraulic structure and then defining its parameters from root distributions and root segment hydraulic properties. Another approach is to start with a 3-D root hydraulic architecture model and solve the corresponding flow equations. This system of equations was scaled up to a 1-D model and general properties of the root system that describe total root water uptake and water uptake distributions as a function of the soil water potential distribution can be derived (Vanderborght et al., 2021).

It was found (Vanderborght et al., 2021) that the upscaled equations can be approximated by a form that is equivalent to the parallel root model. This implies that parameters of the parallel root model can be derived in a bottom-up approach from 3-D root hydraulic architectures, whereas this was not possible for the big-root model, which contains twice the number of parameters as the parallel root model (see Fig. 3, on cover). A parallel root model that was parameterized in a bottom-up approach predicted the root water uptake profiles better than parallel root or big root models that were parameterized in a top-down approach. These results show that simple 1-D root hydraulic models used in LSMs can represent uptake by complex 3-D root hydraulic architectures. Root density profiles could be used to parameterize root architecture models that are subsequently used to parameterize the upscaled root water uptake model. The 3-D root hydraulic architecture is currently being coupled with a soil-root transfer model that describes the water flow from the bulk soil to the root surface and represents non-linearities of soil water flow equations. First results show that upscaling the linear equations of the 3-D root hydraulic architecture, and then coupling the upscaled equations to the non-linear soil equations, results in good predictions of the root water uptake profiles compared to predictions by the full 3-D model coupled with the non-linear soil equations. The upscaling reduces the number of non-linear equations that need to be solved so drastically that this approach may be feasible for use in operational LSMs.

Soil-Groundwater Interactions

The groundwater system is an essential component of the global hydrological cycle, and is directly connected with the soil profile via the deep drainage at the bottom of the soil profile (groundwater recharge), and root water uptake and capillary rise from the groundwater for relatively shallow groundwater levels. Hence, groundwater can moderate soil water content, and therefore the root water uptake and related transpiration and evaporation processes. It also controls root distribution patterns, together with local climate conditions (i.e., precipitation-infiltration depth) (Fan et al., 2007).

The first generation LSMs did not include simulation of groundwater and simply applied a free drainage boundary condition to the bottom of a fixed soil column. More recently, however, groundwater simulation has been included in a number of LSMs (Yeh and Eltahir, 2005a, 2005b; Maxwell and Miller, 2005), and tested at a range of scales from single basins to the globe, with approaches ranging from lumped to distributed models. Note that lateral groundwater flow is not generally included in the majority of global hydrological models and LSMs, with some exceptions, e.g., Felfelani et al. (2021). Including water table dynamics has been shown to improve river discharge simulations (Yeh and Eltahir, 2005b; Koirala et al., 2014) and including capillary flux from groundwater increases evapotranspiration, with the global mean simulated to rise by up to 16% (Koirala et al., 2014; Niu et al., 2007; Yeh and Famiglietti, 2009; Anyah et al., 2008). Key SoilWat members, together with members of the wider GEWEX hydrological community, are currently in the process of resubmitting a paper on "Global groundwater modeling and monitoring: Opportunities and challenges" (Condon et al., under review) that looks at the complexities of implementing realistic groundwater modeling on the continental to global scale.

Summary and Outlook

There are a number of publications addressing relevant issues linked to SoilWat aims. Ongoing studies include the importance and influence of soil hydraulic and thermal properties, pedotransfer functions accounting for soil structure, soil-plant interactions (via root hydraulics), soil evaporation, coupled soil water and heat flow, as well as soil-groundwater interactions on land surface processes.

Outstanding issues are:

- Critically, how to systematically evaluate added value of improved soil process representation in LSMs (see Bonetti et al., 2021 for some of the challenges of showing improvement)
- How to best consider relevant soil-process-based evaluation metrics in Model Intercomparison Project (MIP) activities, e.g., via incorporation of suitable soil-related indices in the International Land Model Benchmarking Project (ILAMB, *https://www.ilamb.org/*) or *https://modelevaluation.org*
- Soil root hydraulics, and plant hydraulics, depend on the vegetation structure (leaf area index, canopy height, rooting depth, root density). Since roots are hidden, information about root distributions is scarce. Root systems adapt to the soil and environmental conditions. This plasticity has been addressed in LSMs by considering "optimal" distributions. However, in managed systems and when environmental changes occur faster than the

process that optimizes these distributions, optimality cannot be assumed. Describing how vegetation will respond to changing environmental conditions (either by management or due to climate change) will therefore be critical to predict land-surface processes.

- How to better represent preferential (aka bypass) flows in LSMs (Gharari et al., 2019), for example, as caused by macropore flows (Rahman and Rosolem, 2017), fingered flows, and funnel flows (Pales et al., 2018; Demand et al., 2019). This would also require concerted efforts in collaboration with the soil biological and related modeling communities.
- In ASALs, soil water and heat transfer are strongly coupled, and the soil vapor flow dominates (i.e., carrying both mass and energy). Nevertheless, the soil vapor flow is largely ignored in LSMs, and the water flow is only weakly coupled with heat transfer through the heat capacity and thermal conductivity functions (i.e., via soil water content). On the other hand, land surface fluxes and convective events are very sensitive to soil moisture over dry lands, and so is the interannual variability of NBP. Therefore, it is essential to revisit the importance of representing soil vapor flow in LSMs for understanding land-air interactions over ASALs. Related to this issue is the topic of vapor adsorption and how to represent this in LSMs for ASALs (Saaltink et al., 2020; Verhoef et al., 2006). Saaltink et al. show that, on a yearly basis, inward vapor flux (adsorption) into soil can be around a third of the outward vapor flux (evaporation). Detailed soil physical models can reproduce these diurnal evolutions of soil vapor flow, but only if the driest part of the soil water retention curve is represented properly, which brings us back to the importance of choice of hydraulic and thermal properties, and their PTFs.

SoilWat will organize workshops and seminars to facilitate discussions on the above issues, and report back to the community on the outcomes.

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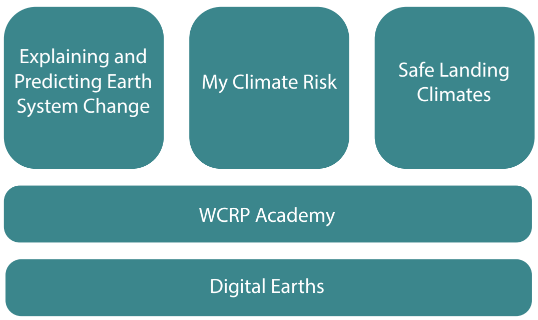
WCRP's New Lighthouse Activities

Jan Polcher[1] and the International GEWEX Project Office

[1]Laboratoire de Météorologie Dynamique (LMD), Centre National de la Recherche Scientifique (CNRS)/Institut Pierre Simon Laplace (IPSL)



A diagram of the new WCRP Lighthouse Activities and their provisional names, adapted from the Report of the 41st Session of the Joint Scientific Committee (WCRP, 2020)

The World Climate Research Programme (WCRP) is charting a fresh course, and its new Lighthouse Activities (LHAs) are beacons to guide programming in renewed areas of focus. There are five LHAs, each with a distinct emphasis and set of deliverables. The three main LHAs are Explaining and Predicting Earth System Change, My Climate Risk, and Safe Landing Climates. The two supporting LHAs are Digital Earths and WCRP Academy. GEWEX Panels and groups, with their expertise in process-level understanding from regional to global scales, are well-positioned to contribute to these LHAs.

Explaining and Predicting Earth System Change

This LHA tackles the design and potential delivery of a system for the quantitative observation, explanation, early warning, and prediction of Earth system change, on regional and global levels and multi-annual to decadal timescales. It will consist of a research program that will devise, improve, and evaluate individual components of the system and the of the system itself, and it will advance fundamental understanding of Earth system change on global and local scales. The expected result of this LHA is an integrated capability planned with input from WCRP, with Earth Year and Earth Observation decade components. All four of GEWEX's Panels, the Global Atmospheric System Studies (GASS) Panel, the GEWEX Data and Analysis Panel (GDAP), the GEWEX Hydroclimatology Panel (GHP), and the Global Land/Atmosphere System Study (GLASS) Panel, contribute to process-level understanding and prediction of the climate and can offer support to this LHA.

My Climate Risk

The My Climate Risk LHA will develop a new framework for assessing and explaining regional climate risk, delivering meaningful climate information at the local scale. It will involve several case studies in the form of labs, which will be dynamic, exploratory, transdisciplinary environments rather than physical infrastructure, intended to provide a forum for bringing together relevant stakeholders and partners. Examples include evaluation of different national or regional climate risk assessments and region-specific risk assessments. This LHA aims to develop a new practice to synthesize climate information and will lead to the production of consolidated regional climate information, global capacity exchange, and guides on best practice. Within GEWEX, the Regional Hydroclimate Projects (RHPs) stand as examples of regional climate research as they strive to improve understanding and prediction of local water and energy cycles.

Safe Landing Climates

This LHA will explore the routes to climate-safe "landing spaces" for human and natural systems on multi-decadal to centennial timescales, connecting climate, Earth system, and socioeconomic sciences. It will study pathways for achieving key sustainable development goals. This requires a worldwide research activity that will plan, encourage, and coordinate relevant activities globally; communicate and disseminate key findings; and facilitate user-oriented climate-safe landing tools. We expect several outcomes from this initiative, including new climate and Earth system models that will investigate how climate change and its ramifications might impact society and natural systems. GEWEX's focus on extreme and compound events can help in terms of Earth system feedbacks in safe landing spaces.

Digital Earths

The undertaking of this LHA involves the development of a digital and dynamic representation of the Earth system, blending models and observations to enable study of the past, present, and potential futures of the Earth system. This will be a joint activity, with external institutions providing the digital infrastructure and WCRP implementing selected versions for topics where significant progress is required. The result will be generic software-hardware solutions that allow simulation models and data assimilation to perform several orders of magnitude more efficiently. It will facilitate the extraction of Earth-system sector specific information from vast amounts of environmental data and allow exciting new ways of accessing and using climate data and information. GEWEX is poised to help with the regional focus of the Digital Earths LHA.

WCRP Academy

This concept is more fluid than the other LHAs, with an overall goal but no fixed approach yet established. The aim is to create one or more targeted capacity exchange climate programs, working with one or more of the other lighthouses and climate education providers. The program has the potential for online or in-person opportunities and either global or regional foci. Capacity development is key, and this LHA intends to provide knowledge and information to all regions worldwide to tackle the issues and opportunities that climate change brings.

The names and details of the LHAs may change as concepts are refined, and there has already been a good deal of evolution. Online meetings and consultations are taking place to shape the Lighthouse Activities, and the LHA leads are defining strategies to move forward. Knowing where and when GEWEX groups can contribute to each LHA will help their progress, and many GEWEX community members are active participants in the development process.

Meeting/Workshop Reports

The Second Determining Evapotranspiration Workshop

Virtual Meeting
10–12 February 2021

Oscar Hartogensis[1] and Joan Cuxart[2]

[1]Wageningen University, Wageningen, the Netherlands;
[2]University of the Balearic Islands, Palma de Mallorca, Spain

1. Introduction: Aims and Antecedents

Within the framework of GEWEX activities, the need for a deeper understanding of evapotranspiration (ET) has been identified. This objective is to be pursued through the analysis of the basic mechanisms to a synthesis resulting in parameterizations that can be used in applications such as numerical models or remote sensing estimations.

After an initial side meeting at the 2018 GEWEX Open Science Conference, organizers began assembling the interested community to determine the state-of-the-art in the field and to define courses of action. The first activity was a reflection paper published in *GEWEX News* in early 2019, structured on four main items related to ET: i) definition and understanding, ii) in situ measuring, iii) parameterization, and iv) estimations by remote sensing and at the catchment scale. A first workshop was held in Sydney in October 2019, where participants reflected on ET along five views of the ET process: open water, landscape-scale, interception, transpiration, and soil evaporation.

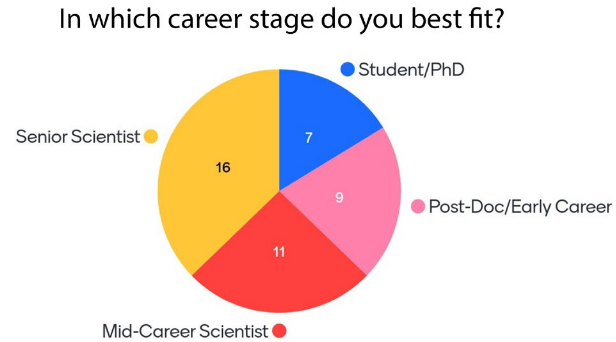
The second workshop was initially planned for August 2020 in the Netherlands, but the COVID-19 pandemic finally caused it to take place online in February 2021, organized by the Meteorology and Air Quality Group of the Wageningen University (WUR).

The workshop was dedicated to Jim Shuttleworth, a reference researcher in the domain, who passed away shortly before the workshop. A talk remembering his life and work was given by the workshop attendee Rafael Rosolem, Jim's last Ph.D. student.

2. The Participants and the Organization

Arranging the online-only workshop presented a number of challenges for the organizing committee, such as ensuring the attendance of scientists from a wide range of time zones, coping with shorter attention spans in online meetings, and fostering lively interactions. With this in mind, the following format was put together as an alternative to a "regular" format, with 10 minute talks followed by 5 minute question sessions for each participant:

1. three-hour sessions (14–17 CET) during three consecutive days,
2. presentations on the state-of-the-art in ET on the first day and future developments on the second day, and
3. an organized discussion on the third day.



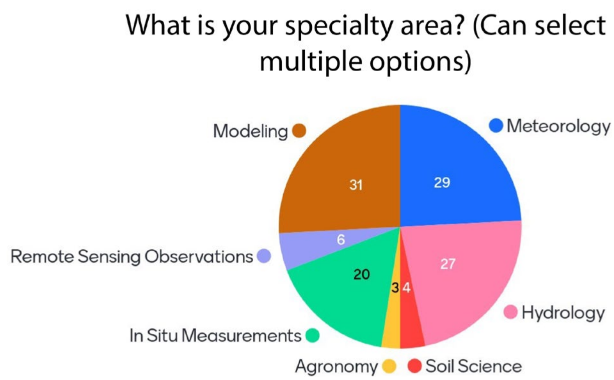


***Figure 1**. Characterizations of the GEWEX-ET workshop audience*

Participants were asked to send, in advance, three to five slides with their recent research highlights and an outlook on the major challenges ahead. Three early career scientists from Wageningen University organized this material into presentations on the state-of-the-art (first day) and future developments (second day), leaving plenty of time for open conversation afterwards in the plenary session or break-out groups. The third day's discussion was guided by an online questionnaire (*www.mentimeter.com*) with questions distilled from the first two days with the objective of seeing the different opinions and the research trends for the coming years.

Overall, the participants were enthusiastic about the format, and the Mentimeter poll provided a quantitative opinion of the audience on a number of outstanding issues. We started the questionnaire with some basic queries that characterized the audience (Figure 1). It is clear that there was a good balance between youth and experience, and enough interdisciplinarity and diversity of investigation methods.

3. The State-of-the-Art

WUR early career scientists Mary Rose Mangan, Femke Jansen, and Xabi Pedruzo Bagazgoitia summarized the contributions of the participants submitted with some anticipation on the first day. They did this broadly, according the various pathways of ET (vegetation, soil, open water, interception, atmosphere, and landscape-integrated ET), combining the materials of the participants using this main concept. Other dimensions of looking at the process, i.e., methodology (ground measurements, remote sensing, and computational models), study type (process understanding or

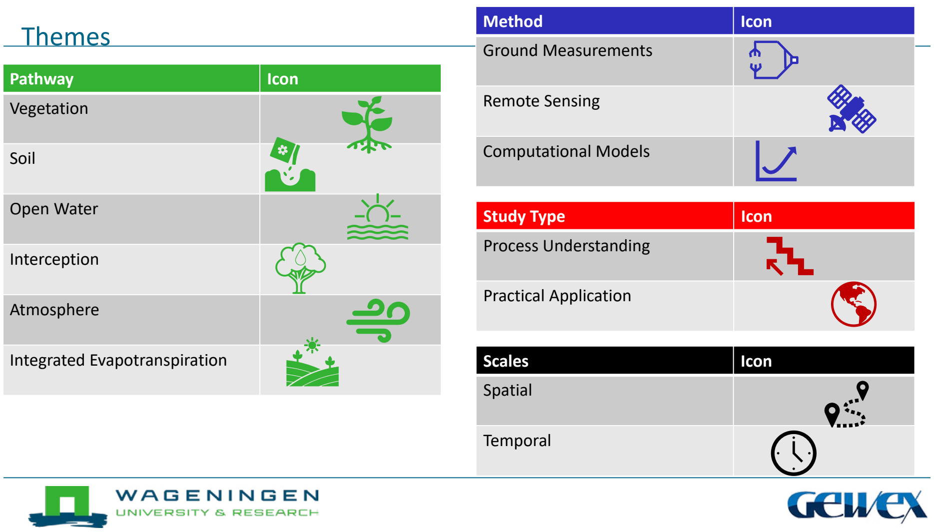


Figure 2. Dimensions along which the overview presentation by early career scientists was organized

practical application) and scales (spatial and temporal) were added as icons to each slide (Figure 2). In this way, a highly homogenized, organized, and comprehensive overview was assembled. These slides are available upon request from the authors.

It is beyond the scope of this report to provide a written overview of this material, which is an overview in itself. We will point out some of the main storylines here.

Vegetation was the opening subject, which was split into discussions on processes at the root and leaf scales and the land-atmosphere interactions at the canopy scale. Measurement strategies, radiation, and nighttime processes were mentioned. The field-scale implies dealing with terrain heterogeneity, both in observing and modeling approaches. Here the Penman-Monteith approach and Monin-Obukhov similarity relationships were discussed and the exploration of alternatives recommended. Larger spatial scales require the use of multiple sources of information, including numerical models and remote sensing information. Participants also identified the need for better monitoring and parameterization (representation) of irrigation and the link between ET and CO_2 uptake to improve ET estimates. Partitioning between evaporation and transpiration is deemed necessary for parameterizations, and using isotopes to investigate this is considered very promising.

Open water evaporation on land was discussed in terms of lake models and the need for specific observations to test and improve them. In addition, the representation of flooded areas has also proved difficult. The main challenges with soil evaporation are the large heterogeneity in soil moisture, the thermal contrasts resulting from it, and the circulations those thermal contrasts can generate. Again, the impact of irrigation was considered. A discussion on the interaction between soil moisture and atmospheric water vapor deficit followed, and the coupling of both factors was deemed important. Other points addressed are the reliability of the direct measurements of evapotranspiration (eddy-covariance and lysimeters) and the estimation of the horizontal transport of water vapor in the surface energy and water budgets. The determination of ET at large scales relies mostly on reanalysis products, remote sensing estimations, and good validation data (e.g., by scintillometers).

4. Discussion and the Way Forward

The surface energy budget is considered to be an outstanding issue since many approaches rely on assuming its closure, while it is well known that a 20% imbalance is quite usual. Even if recent studies indicate that local advections may partly explain the missing contributions, the issue is far from conclusive, as methodologies are still under development. Furthermore, good experimental estimates of ET are needed, and there is a call for better control of the factors leading to errors. It is also worth mentioning that some experimental estimates rely on similarity expressions that often do not work too well outside standard ranges. These issues impact the validation of remote sensing developments, pointing to a need for an integrative approach considering all methodologies simultaneously (model values, in situ data, remote sensing estimates) and exploring ways to make them converge.

Expanding the applicability of the most widely-used approaches (Penman-Monteith and similarity theory) is considered vital. Participants discussed opposing views of the use of machine learning techniques, considering possible good results and the lack of understanding of those results. The maintenance and growth–if possible–of current networks such as FLUXNET or the Integrated Carbon Observation System (ICOS) is considered a cornerstone of future activities, since validation at multiple sites is a necessary step for any new development.

Henk De Bruin indicated in his keynote speech that the standard United Nations Food and Agriculture Organization (FAO) equation based on Penman-Monteith needs to be revised. He also stressed that for well-watered surfaces, ET depends in the first degree on incident solar radiation, and air temperature and atmospheric water vapor deficit are a consequence, and not a driver of, the overall atmospheric boundary layer evolution.

The discussion on the third day using the Mentimeter tool was based on statements from the general discussions of the first two days. A sample of the questions is given in Figure 3. An important consideration is the surface energy balance (SEB) closure, which affects the validation of flux parameterizations, implying that land surface coupling may be a way to partially overcome this limitation. Other ideas concern the improvement of the closure through better observational methods or measurement of missing contributions, and the open question on what ET contributes to the total SEB imbalance.

Despite the fact that we are aware that heterogeneity at the surface is a major issue, the community indicated that 1D-models are still a good tool to test new developments. Concerning

separation of evaporation and transpiration, isotopes and lysimeters (on bare and vegetated surfaces) are considered to be the most promising methods so far, but other options are on the table, such as sap flow and chamber measurements. Distributed measurements and high-resolution modeling are seen as the most suitable approaches to estimate the role of advection.

Concerning the determination of ET at the global scale, four issues are considered almost equally important: i) good representation of land use and land cover, ii) taking irrigation into account, iii) a better understanding of the impact of increased CO_2 in the stomatal function, and iv) the response of the system to extreme events.

As for the immediate practical challenges ahead, a difficult but rewarding task involves improving the ET ground-truth network to be able to monitor global ET and quantify the impact of global change on ET. Some ideas for approaching this task are to refine the partitioning of ET, to study heterogenous landscapes, and to modify our conceptual vision of the ET process. Machine learning poses another challenge, as it is regarded as something that will happen with an unknown impact.

The community, when asked if any subjects were underrepresented or ignored during the discussion, cited interception, sublimation, dew, phenology, plant hydraulics, stomatal conductance, and human water use. Participants considered the Land surface Interactions with the Atmosphere over the Iberian Semi-arid Environment (LIAISE) campaign,

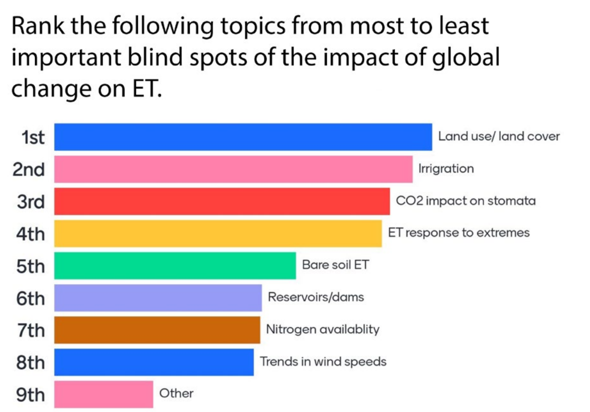


***Figure 3**. Some example questions from the Mentimeter questionnaire that guided the discussion on day 3 of the workshop*

which takes place during summer 2021, a good opportunity to test some of the elements discussed.

The meeting ended with congratulations to the organizers for a well-conducted online workshop making use of innovative ways of discussion, with one participant saying that it "was the most interesting online event of the past year for me; and we have all been to too many." The community will determine how to organize itself as a GEWEX Hydrolimatology Panel (GHP) Cross Cutting Project in terms of working groups and will follow up on workshop discussions and decide when it will be useful to meet again. The first order of business following the workshop is the LIAISE campaign, as many of the participants will contribute to it.

2020 GLASS Panel Meeting

Virtual Meeting
23–25 November 2020

Michael Ek[1], Kirsten Findell[2], and Anne Verhoef[3]

[1]Outgoing GLASS Panel Co-Chair, [2]GLASS Panel Co-Chair, [3]Incoming GLASS Panel Co-Chair

The GEWEX Global Land-Atmosphere System Study (GLASS) Panel met virtually for three partial days at the end of November 2020 to share progress in the 15 months since our last meeting. Despite the difficult circumstances of 2020, there was much to share. Discussion during the meeting was primed by a set of pre-recorded screen-casts shared by the project leads 1–2 weeks in advance of the meeting. Our core projects stem from process-based inquiries, to benchmarking activities, to global model intercomparisons, and now includes the GEWEX/GLASS Land-Atmosphere Feedback Observatories (GLAFO) initiative. The goal of the GLAFO initiative is to establish a network of long-term observing stations focused on the land-atmosphere system from groundwater, through the surface and vegetation, to the top of the boundary layer. In addition to the project updates summarized below, we welcomed new members Volker Wolfmeyer and Yijian Zeng, heard from guests describing projects relevant to GLASS, and marked the end of Mike Ek's tenure as GLASS Co-Chair. Anne Verhoef now joins Kirsten Findell as Co-Chair. We look forward to continued progress in the year ahead, and hope for an in-person meeting in later 2021 where we can properly thank Mike for a job well done and thank Anne for taking on the next four years!

Core Project Updates: Process-Oriented Projects

GLAFO (and New GLASS Panel Member Volker Wulfmeyer)

New GLASS Panel member Volker Wulfmeyer shared some background on his journey from physics student to designer of new observational instrumentation to multi-faceted meteorologist tackling a new frontier of boundary layer observational capabilities. These strands of expertise contribute to the GEWEX Land Atmosphere Feedback Observatories (GLAFOs, Wulfmeyer et al., 2020). GLAFOs will observe the relevant processes and variables with respect to mass, energy, water vapor, and momentum transport with unprecedented spatial and temporal resolutions, from bedrock to the lower troposphere. Volker presented how the GLAFOs will be designed in order to characterize all relevant interactions and feedback loops between the subsurface, vegetation, and the atmosphere. The measurements will be realized through the synergistic use of in situ instruments and ground-based scanning active remote sensing systems. This approach was pioneered during the Land-Atmosphere Feedback Experiment performed at the Atmospheric Radiation Measurement program's Southern Great Plains (ARM SGP) site in August 2017 (Wulfmeyer et al., 2018). By observing profiles of the mean, gradient, and turbulent fluctuations (if applicable) of all relevant variables, unprecedented data sets will be provided for the study of land-atmosphere (L-A) feedbacks. Such data include surface and entrainment fluxes, advection, and the evolution of key variables in the other compartments of the critical zone (such as ground water levels, soil moisture, and vegetation temperatures), from the diurnal cycle, via seasonal/annual to ideally climatological time scales. Due to the high resolution and accuracy of the observations, the measurements can also be used for operational data assimilation in numerical weather prediction (NWP) models as well as for tests and developments of parameterizations. It is envisioned that the GLAFOs will be set up and operated in all climate zones with different levels of complexity.

LoCo

The local land-atmosphere coupling (LoCo) project update was presented by Joe Santanello. LoCo consists of 20 international scientists across academic and government institutions. LoCo has continued to focus on three near-term objectives to enhance our ability to understand, quantify, and improve land-atmosphere coupling and prediction: (1) promote the importance and development of improved observations of the L-A system, namely in the planetary boundary layer (PBL), as well as improved utilization of soil moisture and surface fluxes measurements in models; (2) pursue adoption of LoCo metrics by operational NWP and climate centers; and (3) expand the scope and reach of LoCo in terms of processes and scales beyond that of warm season thermodynamics and beyond that of 1-D column assumptions. The GLAFO observational measurement system and the Land surface Interactions with the Atmosphere over the Iberian Semi-arid Environment (LIAISE) field campaign both plan extensive PBL measurements, and a number of initiatives are underway in response to the National Aeronautics and Space Administration (NASA)'s Decadal Survey prioritization of PBL measurements and spaceborne mission concepts. In addition, the National Oceanic and Atmospheric Administration (NOAA)'s Climate Process Team project (Coupling of Land and Atmospheric Subgrid Parameterizations, CLASP), led by five GLASS members, is working towards applying current and developing new LoCo L-A coupling metrics for Global Climate Model (GCM) development, as well as incorporating LoCo metrics into the International Land Model Benchmarking (ILAMB) package. To advance L-A science, the LoCo Working Group (WG) continues to convene annual American Geophysical Union (AGU) and American Meteorological Society (AMS) meeting sessions (which have become some of the largest in the hydrology sessions and conferences). The WG also influences and responds to agency solicitations that now reflect the priorities of LoCo and supports outreach to the scientific, modeling, and observational communities.

SoilWat

Anne Verhoef gave an update on SoilWat, describing a number of ongoing activities focused on providing reliable soil hydraulic and thermal properties for land models, and exercises describing the impact of these properties on the land fluxes. This also included recommendations to harmonize pedotransfer functions (PTFs) used in land models and related model intercomparison projects (MIPs) to avoid artifacts originating from the choice of PTFs rather than from different model structures. A number of corresponding publications are near submission or have just been submitted. An ongoing activity includes conducting a global soil hydraulic parameter MIP that could leverage ILAMB (described below). A recently-started activity is the compilation of a data set of globally-distributed soil thermal properties, ideally combined with hydraulic properties, where the data set would serve to support development and verification of models simulating thermal properties. Near-future work includes testing both single and combined influences of hydraulic and thermal properties in models. Finally, establishing a global soil temperature database for land model verification is planned, which would also fit nicely with ILAMB work by providing independent verification data. Yijian Zeng has now taken over from Anne as the SoilWat lead and rapporteur; his expertise spans detailed mechanistic land surface modeling, remote sensing, and in situ observations (see below for more information). Finally, note that the SoilWat activity cuts across the GLASS and International Soil Modelling Consortium (ISMC, *https://soil-modeling.org*) communities.

Core Project Updates: Benchmarking Projects

PLUMBER2, modelevaluation.org, and Urban-PLUMBER

Gab Abramowitz described the Protocol for the Analysis of Land Surface models (PALS) Land Surface Model Benchmarking Evaluation Project, Phase 2 (PLUMBER2) that is well underway, with contributions across land surface, carbon cycle, hydrological, and empirical model approaches contributing to a broad focus on land surface flux predictability. Data from 170 flux tower sites have been through a lengthy quality control process and some groups are already producing final simulation suites, although many have still yet to engage, with submission timelines extended into 2021. Ten of approximately thirty groups have begun submitting simulations via modelevaluation.org (*http://modelevaluation.org/*) to date. The modelevaluation.org web application has faced a range of logistical challenges this year, with the ramp up of PLUMBER2 and Urban-PLUMBER providing the first heavy-use cases. While these challenges are being resolved and have not greatly affected the progress of these experiments, broader engagement beyond a single institution to develop a shared, community-based model benchmarking resource would likely improve its longer-term security. To this end, the Centre of Excellence for Climate Extremes (CLEX) at the University of New South Wales (UNSW, Australia) and the MetOffice (UK) are intending to develop a modelevaluation.org-based automated testing system for model development that is model agnostic, incorporating details from process-based site diagnostics to global ILAMB-based analyses. In regards to Urban-PLUMBER, the initial feedback for Phase 1 (a single urban site) has been provided to the 26 participants, and results are being finalized and written up. The project webpage publishes submitted metadata and plots all requested variables, where observed energy fluxes will be compared with benchmarks. Data for Phase 2 (~25 urban sites) is being quality-controlled and standardized, and will be provided to participants starting in February and finishing in mid-2021.

ILAMB

Dave Lawrence provided an update on ILAMB, which is a model data intercomparison and integration project designed to improve the performance of land models and, in parallel, improve the design of new measurement campaigns to reduce uncertainties associated with key land surface processes. The ILAMB package has been run on the Coupled Model Intercomparison Project Phase 5 (CMIP5) and Phase 6 (CMIP6) historical simulations. Across the majority of models that participated in both CMIP5 and CMIP6, we are seeing general improvements from CMIP5 to CMIP6 across carbon, water, energy, and surface climate metrics, indicating improved model performance. ILAMB is also being utilized in the assessment of land-only versus coupled model simulations to help understand the role of climate biases in coupled models on key land carbon and water flux and state variables. Finally, ILAMB continues to expand, with over 30 variables being assessed against more than 80 global, regional, and site-level data sets and incorporating new metrics and methods to account for observational uncertainty.

Core Project Updates: Model Intercomparison Projects

LUMIP

Dave Lawrence also provided an update on modeling human land-use activities that have resulted in large changes to the Earth's surface, with resulting implications for climate. The Land Use Model Intercomparison Project (LUMIP) aims to further advance understanding of the impacts of land-use and land-cover change (LULCC) on climate through coordinated model experiments. A series of manuscripts have been published or are in preparation, including key papers on the new LULCC data set and on the multi-model response to idealized deforestation (see list of publications and projects at *https://www.cesm.ucar.edu/projects/CMIP6/LUMIP/*). Significant lack of agreement in terms of biogeophysical and biogeochemical impacts of LULCC on land surface fluxes and variables, as well as L-A feedbacks, persists across models.

GSWP3 and LS3MIP

Hyungjun Kim shared the current status of the Land Surface, Snow, and Soil Moisture Model Intercomparison Project (LS3MIP) of CMIP6. In LS3MIP, 13 modeling groups have submitted the tier one experiment results from the land-only configuration [i.e., land-hist, which shares the protocol with the Global Soil Wetness Project Phase 3 long-term retrospective experiment (GSWP3 EXP1)], and six of them submitted the results of the tier one coupled experiments (i.e, amip-lfmip-pdLC and amip-lfmip-rmLC). Three synthesis papers are being developed describing the first analysis results: (1) overview and benchmarks (led by Hyungjun Kim), (2) land water and carbon balances (led by Ryan S. Padrón, Swiss Federal Institute of Technology), and (3) simulation of cold processes (led by Lawrence Mudryk, University of Toronto) based on the land-hist experiment. Up-to-date data holding status of LS3MIP can be checked at *https://pcmdi.llnl.gov/CMIP6/ArchiveStatistics/esgf_data_holdings/LS3MIP/index.html*.

Updates from Liaisons and Other Initiatives

GASS

John Edwards summarized progress on projects organized by the GEWEX Global Atmospheric System Studies (GASS) Panel. The results of the intercomparison of large-eddy models participating in the GEWEX Atmospheric Boundary Layer Study Phase 4 (GABLS4) project on the boundary layer over the Antarctic Plateau have now been published (Couvreux et al., 2020). The models were able to simulate the very stable boundary layer, provided high resolution was used. Several new projects were launched following the second Pan-GASS Meeting in 2018. Recently-published results from the COnstraining ORographic Drag Effects (COORDE) intercomparison of orographic drag schemes (van Niekerk et al., 2020) demonstrate the large variation in parameterized drag between models and show that it is frequently underestimated over land. The Elucidating the Role of Clouds-Circulation Coupling in Climate (EUREC4A) field campaign was concluded successfully in February 2020 and an intercomparison of simulations of shallow convection based on these data will shortly be initiated. Good progress has been made in analyzing results from the intercomparisons of fog modeling and (sub-)diurnal precipitation.

GHP

Craig Ferguson gave a short presentation on the activities of the GEWEX Hydroclimatology Panel (GHP) before handing over the baton of GLASS-GHP liaison to Josh Roundy. There were three activities identified with particular relevance to GLASS. The first is the proposed Regional Hydroclimate Project (RHP) called the Third Pole Environment, led by Yaoming Ma. It has a large focus on measurements of land-atmosphere interactions across the Tibetan Plateau (with hopes to expand across Eurasia) and could be linked to the GLAFO project. The second is the Quantifying Evapotranspiration (ET) crosscut, led by Joan Cuxart, which aims to improve process-based ET estimates. The second workshop relating to this cross-cut topic took place remotely between 10–12 February 2021. Finally, the emerging U.S. North American proposed RHP, led by Timothy Schneider, aims to bring together multiple U.S. agencies on a focused hydroclimatological study over the U.S. This US-RHP is formulating an umbrella strategy of U.S. continental-scale modeling paired with intensive field studies and observational transects to better understand, represent, and predict coupled water and energy processes at the Earth's surface. Additional information can be found in a pair of recent *GEWEX Quarterly* articles (Schneider and van Oevelen, 2020; Scott and Schneider, 2020). For all of these projects, links between GLASS and GHP will continue to be developed and strengthened over the next year.

LIAISE

Aaron Boone provided an update on the international LIAISE project, where the overall objective of this new activity is to improve our understanding of the impact of surface heterogeneity (notably that induced by anthropization) on the water cycle in terms of land-atmosphere-hydrology interactions in a water resource-limited bread-basket region. However, the understanding of the impact of anthropization and its representation in models have been inhibited due to a lack of consistent and extensive observations. The project depends on an international intensive field campaign which consists of in situ and remotely-sensed measurements of (1) land surface physiographic parameters, biophysical and land state variables, and turbulent and radiative fluxes; and (2) atmospheric state and turbulence measurements within the atmospheric boundary layer. The campaign will extend over a Long Observation Period (LOP: April–September) and will consist of continuous monitoring of the surface and the lowest 50 m of the atmosphere, and two Special Observation Periods (SOPs). The SOPs will also include both in situ and remotely-sensed atmospheric measurements: five days in May or June with the objective of monitoring a typical dry-down event, and a 15-day SOP in late July with a focus on measurements over the entire study domain. This allows the inclusion of different representative land cover types over two strongly contrasting zones, one with extensive irrigation, the other over a bare-soil dry natural grass and rain-fed agricultural surface. LIAISE was delayed by the COVID-19 pandemic, but the research teams are tentatively moving forward for a campaign in summer 2021, where there is a planned expansion of some surface, atmospheric, and remotely-sensed measurements.

S2S

Paul Dirmeyer highlighted the International Subseasonal-to-Seasonal (S2S) Prediction Project, which involves mostly operational forecast modeling centers, with one of the S2S sub-projects focusing on the role of the land surface as a source of predictability beyond weather time scales. Operational model output is being evaluated for model skill and the potential role of soil moisture as a skill source for droughts and heat wave forecasts. Land surface temperature anomalies over elevated terrain is the focus of the ongoing Impact of Initialized Land Temperature and Snowpack on Sub-seasonal to Seasonal Prediction (LS4P) project of GASS, which is shifting focus from the Tibetan Plateau to the U.S. Rocky Mountains and high plateaus of western North America. In the near future, in addition to the proposed Vegetation-Global Land-Atmosphere Coupling Experiment (Veg-GLACE) modeling experiment (described below), another relevant effort regarding S2S forecasting and the role of the land surface as a source of predictability is the

NOAA-community effort to develop and implement the next generation Unified Forecast System (UFS) of models, where medium to extended range and S2S are an emphasis for the UFS.

Veg-GLACE

During discussion time, we learned from Souhail Boussetta and Gianpaolo Balsamo about Veg-GLACE, a new multi-model experiment that has been proposed to examine S2S predictability coming from improved vegetation modeling and based on the experience from a previous GLACE2 experiment (Koster et al., 2011) and the Snow-Global Land-Atmosphere Coupling Experiment (SNOWGLACE, Orsolini et al., 2013). The concept is developed within a new European Horizon project called the CONsistent representation of temporal variations of boundary Forcings in reanalysES and Seasonal forecasts (CONFESS, *https://confess-h2020.eu/*), and will allow us to investigate the impact of a satellite-based vegetation data set, where a set of experiments based on a multi-model [initially Météo-France, the European community Earth-System Model (EC-Earth), and the European Centre for Medium-Range Weather Forecasts (ECMWF)] will be run to evaluate the impact of realistic vegetation variability on subseasonal to seasonal forecast skill. The experimental protocol of Veg-GLACE will be tested within the CONFESS project and consolidated in 2022 to be proposed to WCRP/World Weather Research Programme (WWRP) and Working Group on Subseasonal to Interdecadal Prediction (WGSIP) modeling groups. The GLASS Panel Meeting welcomed the initiative and different modeling groups have already expressed an interest in contributing.

New GLASS Panel Member Yijian Zeng

New GLASS panel member Yijian Zeng presented his research on "Soil-Water-Plant-Energy Interaction in Cold Regions–Tibetan Plateau as the Research Testbed", with the goal of understanding soil-water-plant-energy interaction in cold regions. This uses an integrated modeling framework coupling a physically-based soil freeze-thaw model with groundwater and biogeochemical models. This allows study of the uncertainty in soil physical properties that cause uncertainties in soil hydro-thermal properties that then propagate further into the estimate of land surface states and fluxes. A comprehensive forward observation simulator is therefore suggested (i.e., a physically-based coupled-process model combined with a radiative transfer model) to assimilate remotely-sensed Earth observations [e.g., from the Soil Moisture and Ocean Salinity (SMOS) and Soil Moisture Active Passive (SMAP) missions] for a physically-consistent estimate of soil properties and surface states and fluxes. This then addresses the role of the land-surface in understanding water, energy, and carbon cycles at both local and global scales. Such an approach will in particular contribute to the GEWEX-ISMC SoilWat Initiative described above.

GDAP

GEWEX Data and Analysis Panel (GDAP) Co-Chair Rémy Roca (with input from fellow GDAP Co-Chair Tristan L'Ecuyer) provided an update on his Panel's activities. He noted that the precipitation data set from the centennial reanalysis elaborated under GSWP3 has now been added to the Frequent Rainfall Observations on GridS (FROGS) database (*http://frogs.ipsl.fr*), where users can easily download many precipitation products, including those from various reanalysis products. They expect that this new addition will be included in the future assessment run by GDAP as a way to provide some feedback to GLASS on these unique data sets. Further discussion will be facilitated in the coming year by the newly-appointed GLASS-GDAP liaison, Yunyan Zhang. There are also plans that began at the GEWEX SSG meeting in January 2020 regarding a possible land-atmosphere energy and water cycle closure and consistency assessment that could link local-scale surface processes to global-scale data sets, specifically the GEWEX Integrated Product. This was to have been discussed further at a workshop later in Spain, but was postponed due to the pandemic; we hope to address this in the near future as a GEWEX cross-Panel activity.

CORDEX Urban Project

Aude Lemonsu gave an update on the Urban Coordinated Regional Downscaling Experiment (CORDEX Urban) project, which began at the last International Conference on Regional Climate (ICRC)-CORDEX conference when a group proposed a Flagship Pilot Study project dedicated to urban areas and related issues. The proposal for "URBan environments and Regional Climate Change" (2021–2025) is coordinated by Tomas Halenka (Charles University) and Gaby Langendijk (The Climate Service Center Germany, GERICS) and involves more than 20 partners. The main objective is to understand the effect of urban areas on regional climate and the impact of regional climate change on cities with the help of coordinated experiments with urbanized regional climate models (RCMs). One important scientific question is to identify what urban processes need to be included in RCM simulations to account for urban effects and feedbacks on higher resolution and convection-permitting scales. In a related effort, Aude is coordinating a 4-year French research project with the urban region of Paris as a case study that will contribute to the preparation of the 2024 Olympic Games, and includes a large experimental component dedicated to the study of surface and atmosphere interaction processes and the impacts of urban areas on the dynamics of boundary layers and other meteorological phenomena. At the same time, a World Meteorological Organization (WMO)-approved research demonstration project has started, and includes several meteorological centers and research groups at the international level with the objective to advance high-resolution modeling of urban areas, and the predictability of certain meteorological phenomena (storms, heat waves) in cities.

iLEAPS

Eleanor Blyth and Xianhong Meng briefed the GLASS Panel on the Integrated Land Ecosystem-Atmosphere Processes

Study (iLEAPS). The focus of iLEAPS is on the biosphere as a mediator of Earth system processes, with study of the land and atmosphere together as a system involving physical, chemical, and biological processes. Land-atmosphere systems include important feedbacks between atmospheric chemistry and plants that have an impact on society and on the Earth system, where iLEAPS scientists also address key societal challenges related to health, biodiversity, climate, food and fuel security, and promote scientific excellence through developing international science initiatives that are multi-disciplinary. A Land Modelling Summit, co-sponsored by GEWEX, iLEAPS, and the Analysis, Integration and Modeling of the Earth System (AIMES) project, will be held 12–16 September 2022 in Oxford, UK, and the 6th Open Science Conference sponsored by iLEAPS is planned for February 2022 in Auckland, New Zealand. A Special Collection in the *Journal of Advances in Modeling Earth Systems* on "Next Generation Land Surface Modeling" will tie iLEAPS, GEWEX (GLASS), and AIMES together, with issues linking water and energy, carbon and the anthropogenic impact. Xianhong Meng is the new iLEAPS-GLASS liaison.

WGNE and WMAC

Mike Ek provided a general briefing on the WMO Working Group on Numerical Experimentation (WGNE) and the WCRP Modelling Advisory Council (WMAC), where WGNE and WMAC are interested in improving global NWP and climate models, and on coordinating high-level aspects of modeling across WCRP, respectively. The GLASS presence in these groups focuses on improving land modeling and land-atmosphere interaction in models. The new WCRP structure calls for designing a new "model-data home" that brings together WMAC and the WCRP Data Advisory Council.

WCRP Lighthouse Activities

Peter van Oevelen reported on the WCRP Lighthouse Activities (LHAs, https://www.wcrp-climate.org/wcrp-ip-la) that have been initiated to highlight major experiments and high-visibility projects as part of the new WCRP, where such activities truly integrate the capabilities (scientific, technical, infrastructure) across WCRP and with partners. Hyungjun Kim is serving on the Safe Landing Climates LHA (https://www.wcrp-climate.org/images/documents/WCRP_Implementation_Plan/Safe%20Landing%20Climates.pdf), and Kirsten Findell (as co-chair) and Mike Ek are serving on the Explaining and Predicting Earth System Change LHA (https://www.wcrp-climate.org/images/documents/WCRP_Implementation_Plan/Explaining%20and%20Predicting%20Earth%20System%20Change.pdf), where they see their role as leveraging GLASS and GEWEX activities on process-level understanding and modeling.

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