Report on the GEWEX 2022 GLASS Panel Meeting

Monterey, California, USA
28–29 July 2022

Anne Verhoef[1] and Kirsten Findell[2], GLASS Panel Co-Chairs

[1]University of Reading, Reading, UK; [2]Geophysical Fluid Dynamics Laboratory, Princeton, NJ, USA

The GEWEX Global Land-Atmosphere System Studies (GLASS) Panel had a very successful Panel meeting during 28–29 July 2022, in Monterey, California, USA. Many of our Panel members were present in person, and most of the remaining ones joined online. Our meeting took place concurrently with the Pan-GASS and Pan-GEWEX Meetings, which meant that there also were opportunities to touch base with the chairs and some members of the other Panels (e.g., via dedicated "speed-dating" sessions). Below we give a summary report for the various GLASS projects (see Fig. 1 and *https://www.gewex.org/panels/global-landatmosphere-system-study-panel/glass-projects/*), followed by an outlook, based on our discussions in Monterey, including those with our rapporteurs from the GEWEX Scientific Steering Group: Bob Su and Gianpaolo Balsamo.

Volker Wulfmeyer provided an overview of the status and recent progress on the **GEWEX/GLASS Land-Atmosphere Feedback Observatories (GLAFO)**. The hierarchical design is fixed, but may be extended with new sensors (e.g., Solar-Induced Fluorescence, or SIF). Two observatories agreed to become a GLAFO: the Ruisdael Observatory in Cabauw, The Netherlands, and the Meteorological Observatory Lindenberg (MOL) of the German Meteorological Service. A new matrix of the required data sets to qualify as a GLAFO has been developed, which includes variables needed to compute key land-atmosphere (L-A) feedback metrics such as two-legged metrics, CTP-HIlow, and the Heated Condensation Framework. Volker demonstrated how GLAFO data can be used to study and improve turbulence parameterizations and presented initial L-A feedback results from the LAFO at the University of Hohenheim and from MOL. Finally, he presented results of machine learning applied to surface flux data with the aim to replace or improve Monin-Obukhov similarity theory.

The **Local Land-Atmosphere Coupling (LoCo) project** update presented by Craig Ferguson covered the four current focal areas of LoCo working group activities. This includes engaging operational numerical weather prediction (NWP) and climate centers to adopt more integrative, process-level metrics, influencing and leading observational advancements in boundary layer profiling, contributing to the design and application of field campaigns, and continuing to expand the scope of LoCo via collaborations and proposals while influencing agency priorities to fund core land-atmosphere related research. Strong opportunities exist for LoCo to contribute to the 3rd ARM Mobile Facility (DOE-AMF3), GLAFO, U.S. Regional Hydroclimate Project (U.S. RHP), and the National Aeronautics and Space Administration (NASA) Earth Venture Suborbital-4 (EVS-4) in the coming years. With regards to ESV-4: NASA will fund approximately five new, $30M, 5-year suborbital and ground campaigns (initial proposal due dates will be next spring). There is a good chance this opportunity could not only leverage, but also enhance and expand existing GLAFO and U.S. RHP plans. There are also strong LoCo connections with the GLASS-GEWEX Hydroclimatology Panel (GHP) cross-cut on irrigation modeling and with assessment and application of the Data and Analysis Panel (GDAP) integrated product.

Yijian Zeng provided an overview of the ongoing and emerging **Soils and Water (SoilWat)** activities. The working groups on "pedotransfer functions (PTFs) and land surface parameterization" and "soil thermal properties" are preparing science roadmap papers. The first results of the Soil-Parameter Model Intercomparison Project (SP-MIP) thermal regime analysis show that changes in soil textural maps have a larger effect on soil temperature climatology than changes in hydraulic/thermal PTFs for some land surface models (LSMs), while the opposite is found for other LSMs. The SP-MIP hydrology analysis indicates that differences in treatment of infiltration processes are important to improve our understanding of the impact of soil maps on the hydrological responses, and that interactions between groundwater and soil water are important to consider. There were discussions on the emerging "soil-cloud cascade" initiative, and some preliminary studies are currently ongoing to investigate the cascading effects of different soil maps (and the PTFs) on spatiotemporal distribution (heterogeneity) of soil moisture content, surface temperature, and evaporative fraction, and how all these effects will subsequently impact the convective cloud formation processes.

Nicholas Parazoo introduced the new **Solar-Induced Fluorescence Model Intercomparison (SIF-MIP)** project. The global, multiscale remote sensing of vegetation solar induced fluorescence represents a major breakthrough in our ability to track the response of planetary photosynthesis to environmental change and carbon-climate feedback. SIF-MIP aims to characterize SIF process representation within land models, improve their performance compared to observations, and enable more accurate prediction of carbon-water-energy cycle interactions. Preliminary work focuses on forest locations in North America with well-calibrated SIF spectra. Future work will expand across the global tower network, leveraging forcing data from parallel projects such as the Protocol for the Analysis of Land Surface models (PALS) Land Surface Model Benchmarking Evaluation Project, Phase 2 (PLUMBER2).

Though the **Coupling of Land and Atmospheric Subgrid Parameterizations (CLASP)** is a new GLASS project, the effort began as a U.S.-based Climate Process Team jointly funded by the National Oceanic and Atmospheric Administration (NOAA), the U.S. Department of Energy (DOE), and NASA. Through GLASS, this project is now extending beyond the

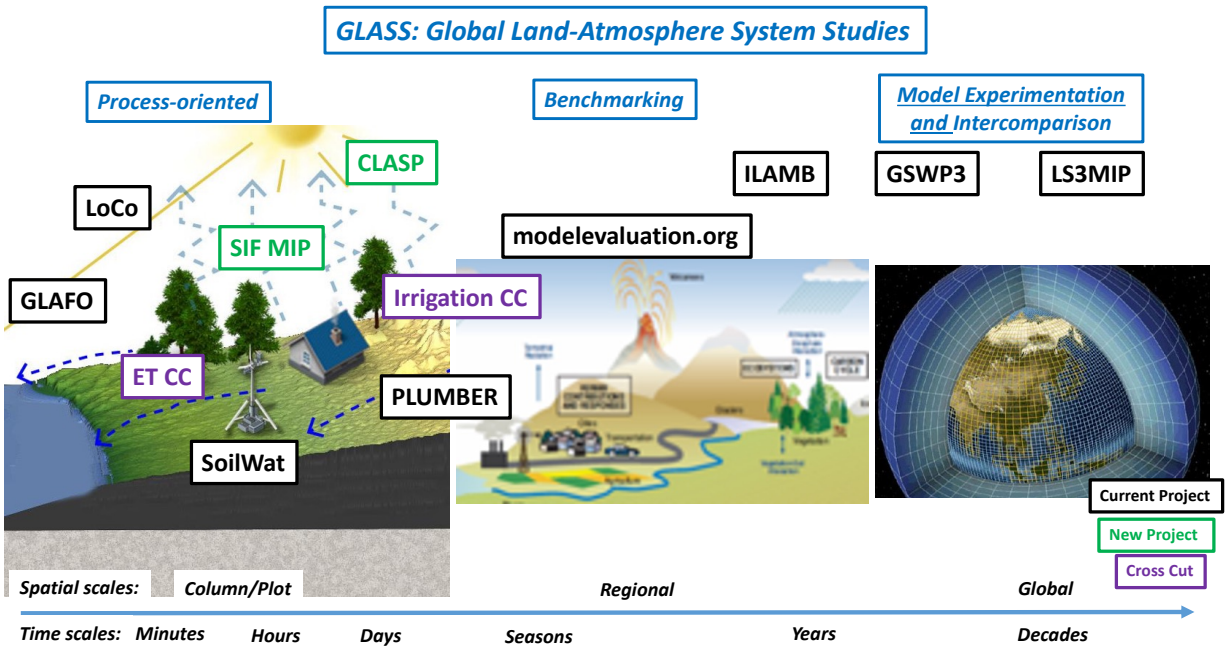

***Figure 1**. Current GLASS projects and the spatio-temporal scales they broadly address*

U.S. to include efforts in Germany and the UK; we hope to continue that international expansion and cross-pollination of ideas and strategies.

Nate Chaney provided updates on the status of CLASP's three themes. Two different approaches to parameterizing sub-grid land-atmosphere coupling through modifications of turbulence closure schemes have been implemented and tested by the participating modeling centers. The Cloud Layers Unified By Binormals (CLUBB)-based approach shows weak sensitivity to surface heterogeneity while the Eddy-Diffusivity/Mass-Flux (EDMF)-based approach shows appreciable global impacts. Understanding these differences (and similarities) is an active area of research. On the diagnostics side, there are ongoing efforts to define new metrics to assess the atmospheric response to sub-grid heterogeneity; these include coupling sensitivity scores, evaluating models at sub-daily time scales, leveraging mixing diagrams, and evaluating simulated spatial heterogeneity of land surface temperature. Finally, the Large Eddy Simulation efforts show the key role that surface heterogeneity can play in the development and enhancement of convection due to secondary circulations. Most notably, CLASP work shows that the formation of secondary circulations (and the related enhancement of cloud development) is driven by surface spatial variances and correlation lengths (particularly sensible heat fluxes) rather than spatial means of surface fluxes.

Gab Abramowitz reported that about 90% of the output submissions for the **PLUMBER2** intercomparison are complete and analysis is gathering pace. The driving and evaluation data sets, which involved quality control and gap-filling flux tower data specifically geared towards land model applications, have now been published and are publicly available. Overall, results appear qualitatively similar to those of PLUMBER in terms of the relationship between physically-based models and empirical approaches. However, the breadth of model submissions (including LSMs, ecosystem, and hydrology models), empirical approaches (out-of-sample cluster and regression, long short-term memory, random forest), and ecosystems and conditions involved (170 sites internationally) mean that the potential for data mining to identify the circumstances of poor model performance (and so the potential for model improvement) is greatly improved. While at least two manuscripts are in preparation involving the 40+ co-authors involved in this project, we ultimately hope that the PLUMBER2 data will represent a valuable community resource for process representation improvement over the coming years.

Dave Lawrence reported that the **International Land Model Benchmarking (ILAMB) project** results are featured in the Sixth Assessment Report of the United Nations Intergovernmental Panel on Climate Change (IPCC AR6) documenting general improvement in model performance from the Coupled Model Intercomparison Project, Phase 5 (CMIP5) to CMIP6 for most land variables. ILAMB continues to integrate new observational data sets, and is now ingesting 90+ global, regional, and site-level data sets spanning 35 variables across the hydrological, radiation and energy, and carbon cycles as well as land climate/weather forcing variables. These include new data sets developed by members of the GLASS community. ILAMB also continues to evaluate scoring methodologies and is evolving towards a method that gives better bias-to-score correspondence, provides a clearer meaning for the scores, and limits problems related to mass weighting and regional dominance.

Hyungjun Kim reported that several analyses have been carried out on the output of the "Land-hist" experiment connecting the **Land Surface, Snow and Soil Moisture Model**

Intercomparison Project (LS3MIP) and the **Global Soil Wetness Project, Phase 3 (GSWP3)**: i) overview and model benchmarking, ii) long-term balance and variability of the terrestrial water and carbon cycle, iii) land surface simulations of cold processes, and iv) global energy transport by the terrestrial hydrologic cycle. Also, land surface feedbacks on temperature and precipitation in Land Feedback Model Intercomparison (LFMIP) experiments have been investigated.

Some participants of the 2022 GLASS Panel Meeting

Cross-cuts and other efforts: Aaron Boone provided a brief overview of the Land surface Interactions with the Atmosphere over the Iberian Semi-arid Environment (LIAISE) field experiment and the Determining Evapotranspiration cross-cut (dET CC), which will be pockets of GLASS-GHP collaboration in the years ahead. We also received an update by John Edwards on the Global Atmospheric System Studies (GASS) project called the **GEWEX Atmospheric Boundary-Layer Study (GABLS)**, which has close connections with GLASS. Over the past two decades, the GABLS project has organized four successful intercomparisons of the atmospheric boundary layer. As these have grown in sophistication, interactions with the land have become a key theme. GASS is keen for the project to continue, with close connections to GLASS (e.g., via GLAFO).

GLASS interactions with other WCRP and WMO programs: Kirsten Findell shared the latest on the WCRP Lighthouse Activity "Explaining and Predicting Earth System Change", which she co-leads. Mike Ek provided an update on the Working Group on Numerical Experimentation (WGNE), with priorities on Earth system model development at all time scales and diagnosing and resolving shortcomings. WGNE is interested in GLASS activities related to improving land models in weather and climate models at the process level via studies such as land model benchmarking (e.g., PLUMBER) and land-atmosphere interactions (e.g., LoCo, GLAFO). WGNE activities relevant to GLASS include their 2019 Systematic Error Survey (surface fluxes, surface temperatures, and the diurnal cycle are noteworthy); the WGNE Surface Flux Intercomparison Project will have a future focus on land. WGNE is also keen to know when/whether GLASS will return to land and hydrology data assimilation. Anne Verhoef is the GLASS representative on the Science Steering Committee of the 6th WGNE Workshop on Systematic Errors in Weather and Climate Models, which took place at the European Centre for Medium-Range Weather Forecasts (Reading, UK) in early November 2022.

Looking ahead, there are clearly strong synergies between GLASS projects, as well as with activities in other GEWEX Panels and the wider WCRP community. These synergies can and should be leveraged to address current land model limitations, and to improve understanding and modeling capabilities. For example, discussions with GDAP representatives in Monterey focussed on the need to ensure that modeling systems are able to ingest remote sensing *observables* (e.g., SIF, optical spectra, brightness temperature, land surface temperature, etc.) as land data assimilation efforts move forward. Additionally, we want to strengthen our focus on the representation of heterogeneity in LSMs, via CLASP and GLAFO, and the new related initiatives on "soil-cloud cascades": a collaboration between CLASP, SoilWat, GLAFO, and members of the GDAP and GASS communities. This desire links well with the new GEWEX-wide "km-scale modeling" and "mesoscale organization of convection" themes.

We also discussed the importance of land-atmosphere interactions at diurnal and sub-diurnal scales; we aim to address this issue through GLAFO, CLASP, and in collaboration with GABLS. We agreed that to improve diurnal predictions, we need to replace Monin-Obukhov with a more suitable theory. Moreover, we need to continue to strive for full ecosystem process representation in our models, i.e., 3-D connections between groundwater, soil water, roots, vegetation, and the atmosphere (through water, heat, and CO_2 fluxes). This may result in cross-project activities (SIF-MIP/SoilWat/CLASP/GLAFO/ILAMB), ideally with an initial focus on the watershed scale. Here we need to strengthen our links with GHP (and together nurture our ET and irrigation CCs) and GDAP (considering suitable satellite data streams such as the Gravity Recovery and Climate Experiment, or GRACE). These envisaged activities fit well with the GEWEX regional-scale stores and fluxes themes. With this in mind, we would also welcome an increase in our current efforts on surface water, with an emphasis on lakes and reservoirs. This is also relevant to land surface heterogeneity, organization of convection, the dET and irrigation CCs, RHPs, the GEWEX km-scale theme, and the NASA Surface Water and Ocean Topography (SWOT) satellite launch. In all our efforts, we need to make best use of **existing observatories and observations** through joint project consolidation efforts, such as those data relating to the Southern Great Plains Observatory, GLAFOs, LIAISE, and the Tibetan plateau.

The GLASS Panel looks forward to an in-person meeting in August 2023 at the University of Hohenheim, and to gathering with the wider GEWEX and WCRP communities at the WCRP Open Science Conference in October 2023.