GLASS Report for the 38th GEWEX SSG Meeting 2026

Full Panel Name (Acronym) : Global Land-Atmosphere System Studies Panel
Reporting Period : 01 January - 31 December 2025
Starting Date : ….
End Date (where appropriate) : N/A
URL : https://www.gewex.org/panels/global-landatmosphere-system-study-panel/

Membership

Chair(s) and Term Dates : Nathaniel Chaney, 2024 – Present
Volker Wulfmeyer, 2025 – Present

Members and Term Dates : Souhail Boussetta, 2018 – Present
Marc Calaf 2025 – Present
Laura Condon, 2022 – Present
John Edwards, 2014 – Present
Marina Hirota, 2023 – Present
Patricia Lawston-Parker, 2022 – Present
Xianhong Meng, 2019 – Present
Vimal Mishra, 2023 – Present
Jon Cranko Page 2025 – Present
Nicholas Parazoo, 2024 – Present
Joshua Roundy, 2016 – Present
Asaminew Teshome Game, 2023 – Present
Anne Verhoef 2018 – Present
Yijian Zeng, 2020 – Present
Yunyan Zhang, 2021 – Present

Panel Objectives, Goals and Accomplishments during Reporting Period

Programmatic changes to the panel - I have added this section for this year because there are significant changes that are currently ongoing within the panel that do not fit anywhere within the rest of the report and are critical to enumerate and to understand the ongoing efforts within the panel.

- The panel has been reconfigured into Working Groups and the classical "projects" now fall inside and between these working groups. The current working groups that have been defined as of the last panel meeting include: 1) Land atmosphere interactions over heterogeneous surfaces; 2) Surface exchange and ABL processes; 3) Anthropogenic influences in the water and energy cycles; 4) Benchmarking; 5) Soil, vegetation, and Water (SoilWat); 6) Observations. These initial working groups are meant to leverage the existing strengths in the panel and will evolve. New ones will emerge as the panel continues to change over the coming years. There are other priorities that were also identified and these will be a driver for new panel members. The rest of the report is framed with regards to the classic projects; however, starting 2027, the project reports will become working group reports and the overall GLASS report will be framed accordingly.
- The terms of references of panel membership were updated because of these changes. Being a panel member now involves co-leading a working group where the first order goal of the working group is to create global community around themes that are seen as critical for advancing the GLASS panel current goals. These working groups aim to then spin-off projects similar to what classic GLASS projects have been in the past. However, these projects are specifically meant to be led by

researchers in the field that are not a current GLASS panel member. This approach allows us to maintain a small and nimble GLASS panel and does not limit the number of GLASS projects; this will be led and decided by the global community's engagement with the core themes/goals of the working groups.

- The amount of time that a single panel member is on the panel has also been more properly defined and will be followed moving forward. A panel member will be on the panel for three years with a possible extension to five years depending on interest and engagement; and again, every panel member will be co-leading a working group during this time. The only exception will be co-chairs who preferably should emerge from the working group co-leads. The time limit on the panel for the co-chair will automatically be extended by four years; and once their time as chair is over, they will rotate off the panel. Given the long time that many have been on the panel, a two-year buffer was added to those interested to help minimize a "shock" to the panel membership.

Overall Panel Objective(s)

- Improve the understanding and representation of bio-geophysical processes in land-atmosphere models, especially over heterogeneous surfaces
- Develop and apply cutting-edge metrics and methods to confront land-atmosphere model performance
- Leverage novel developments, i.e., machine learning techniques, and comprehensive 4-D in-situ and remotely sensed observations of the L-A system

List of Panel Goals

- **Programmatic**
  - Leverage the new working group format to more heavily and directly engage with the global land-atmosphere interactions community.
  - Have new projects emerge from the new working groups; these projects are meant to be led by people outside of the GLASS panel but in the larger GLASS community.
  - Organize conferences and workshops such as the new Pan-GLASS Conference in Stuttgart, Germany, July 6-9, 2026 (see https://www.gewexevents.org/meetings/glass2026)
- **Thematic**
  - Leverage Machine Learning techniques, and comprehensive 4-D in-situ and remotely sensed observations of the Earth's critical zone* and atmospheric states
  - Improve understanding and representation of mechanistic processes in land-atmosphere models, especially over heterogeneous surfaces, with a focus on turbulence parameterisations (including MOST), surface flux partitioning, as well as vegetation and soil processes
  - Improve and develop cutting-edge metrics and methods to confront land model performance with a focus on diurnal cycles

List of 2 to 3 Key Results

Adjust yearly with respect to goals

PLUMBER-2

- Second PLUMBER2 paper has been published with the key finding that LSMs are outperformed by machine learning benchmarks in "meteorological edge conditions". https://doi.org/10.5194/bg-23-263-2026
- Sustained development of modelevaluation.org has seen significant new features and improvements in the website.

SIF-MIP

- SIF-MIP Phase 2 paper, titled "Multi-Model Evaluation of Simulated SIF and Its Coupling with GPP Across Multiple Evergreen Forests" is circulating with 21 co-authors, with contributions from at least seven modeling groups (BEPS, CLiMA, CLM-PNNL, CLM-UVA, JULES, TECs, ORCHIDEE). Submission expected by end of March
- Models continue to show high spread in the simulation of SIF, GPP, and their ecological relationships
- Results were presented by Haoran Liu at the 2026 FLEX Workshop in Bonn, Germany

GLAFO

- Established Huancayo in Peru as the first GLAFO over Southern America
- Operated enhanced GLAFO synergy during the vegetation period in 2025 at the Land-Atmosphere Feedback Observatory (LAFO) of the University of Hohenheim (see https://lafo.uni-hohenheim.de and https://lafi-dfg.de) including using fiber-optic distributed systems (FODS), energy balance instrumentation, drones, and scanning lidar systems
- Research on ET, land-surface heterogeneity, and entrainment using synergetic measurements on L-A processes

CLASP

- Ongoing efforts continue to implement and test the multi-plume approach to parameterizing sub-grid heterogeneity in the atmospheric response in EDMF. These efforts continue at GFDL and NCAR. Multiple publications have emerged recently around this work.
- Last year, CLASP began exploring how observed thermal heterogeneity from satellite remote sensing and mesoscale networks of Doppler Lidars can be used to measure the role of thermal heterogeneity on secondary circulations.
- A large-scale analysis using locally (sub 60 km) heterogeneous and locally homogenous 3 km WRF simulations examined the role of surface heterogeneity in atmospheric response. Results show large increases (200 mm and higher) in precipitation in moisture-limited regions of CONUS, a persistent increase in precipitation bias when compared to observations, and a near universal increase in evaporative fraction. A publication emerged from this work last year.

Other Science Highlights

Not part of the 2-3 key results

SIF-MIP

- Most of the model results in the Phase 2 paper are based on the classic Ball-Berry photosynthesis model which has limitations simulating photosynthesis and fluorescence under variable light vs stress limiting conditions. The modeling groups have been working with Co-I Jen Johnson to implement a new leaf-level model of photosynthesis, called the Johnson-Berry model (JB), with an improved representation of the temperature responses of electron transport, carbon metabolism, and stomatal conductance. We expect follow up work to focus on understanding sensitivity of SIF MIP results to this new scheme. It is expected to reduce range and improve simulation of stress events.

GLAFO

- Ultrahigh resolution water-vapor and temperature profiling for the determination of turbulent transport processes and entrainment
- Separation of E and T using water vapor isotope measurements
- Turbulence-permitting simulations over LAFO
- Coordination of LAFO measurements with GABLS5
- Monin-Obukhov Similarity Theory (MOST) must be considered as disproved based on SPG and MOL-RAO data! This requires urgent research on ET and surface flux partitioning

CLASP

- A large ensemble of modeling experiments highlights the poor performance of land surface models in simulating the observed space-time patterns of land surface temperature (LST) over the Contiguous United States. Furthermore, a sensitivity analysis of this ensemble brings to light the important role that turbulence parameterizations will play in this performance. Further analysis also brings to light how the spatial resolution of the forcing dataset (specifically downward longwave radiation) can have a very important role in the spatial organization of LST. These results point towards a need to do a model intercomparison of LST space-time patterns; the advantage of the parameterizations that emerge from CLASP otherwise will be limited.
- The modeling of subsurface flows between tiles at local, intermediate, and regional scales can lead to large differences surface states and fluxes including soil moisture, land surface temperature, latent heat fluxes, sensible heat fluxes, and upward longwave radiation (Guyumus-Preciado, D. et al., 2025). This has also been formally tested within the GFDL model environment at more local scales (Hong, M., et. al., 2025).

ML4LM

- In an end-of-year workshop, the message that data is central to progress was clear. Some key questions emerged during the workshop including:
    - For which land processes do we actually have sufficient and suitable data?
    - Which surface fields can we realistically observe, constrain, and learn?
    - How can learned models be applied in data-poor regions, both spatially and temporally?
    - How do we assess whether ML models are genuinely generalizing or merely interpolating?
    - How do we quantify confidence when extrapolating to new climates or future conditions?

Panel Activities during Reporting Period

List of Panel Activities and Main Result

GABLS

- We have selected the period of the 11th-13th August 2025 as the basis for a case and are developing simulations based on this period.
- A repository on GitHub has been set up to share code.
- Prototype single-column and convective-scale simulations based on our selected period are being set up.

PLUMBER2

- The second PLUMBER2 paper was published in Biogeosciences, with the key finding that LSMs are outperformed by ML benchmarks in “meteorological edge conditions”.
- Substantial work on modelevaluation.org has taken place. A new analysis page has been developed for wider integration of benchcab and meorg within the LSM community, and Fluxnet Shuttle’s API is being integrated into a pipeline for automated flux observation data updating.

SoilWat

- In 2025, SoilWat’s main achievement was the joint ISMC–GEWEX workshop in Reading, which consolidated progress since the first Leipzig meeting and sharpened the scientific roadmap for improving soil and subsurface representation in land, weather, and climate models. The workshop brought together work on SP-MIP, soil thermal and hydraulic parameterization, root water uptake, plant hydraulics, vapor flow, infiltration, groundwater interactions, and land–atmosphere coupling, with the clear message that legacy static soil formulations are no longer sufficient.
- A common storyline is emerging in SoilWat via synthesis and related presentations, several priorities became clear: the need for environmental covariates and better soil maps, explicit treatment of dry-end processes such as adsorbed water and film flow, dynamic rather than fixed soil properties, and closer integration of soil physics with plant hydraulics and remote sensing. This built directly on the 2024 SoilWat agenda, which had already advanced SP-MIP hydrological and thermal analyses, the unified hydraulic–thermal theory effort, and the Vegetation as a Soil Sensor concept.

- In terms of publications, 2025 mainly capitalized on strong papers and syntheses initiated in 2024 and carried into the 2025 agenda. Key examples include the hydro-pedotransfer-function roadmap, the soil-plant digital twin / soil health synthesis, work on root–soil hydraulics, and studies on evaporation and soil hydraulic estimation. Together, these outputs strengthened SoilWat's role as the interface between soil physics, land modelling, and the broader soil–plant–atmosphere continuum community.

CLASP

- Virtual seminar series focused on expanding CLASP to the global community
- Devising new spin-off projects around 1) revisiting MOST (under land-ABL coupling processes WG) and 2) a MIP of LST space-time patterns.
- CLASP is being sunset this year and will be absorbed by the new heterogeneous land-atmosphere interactions working group within GLASS. There is still a lot of interest in the objectives of CLASP; however, given that CLASP began as a US project only; it is not the right avenue to grow the community.
- Members of the team have received new heterogeneous L-A-related funding including developing metrics to evaluate space-time patterns of LST in the land surface models and observe the existence of thermally-driven secondary circulations over the new ARM AMF3-BNF site in northern Alabama in the United States.
- Land surface modeling sessions are being held regularly at AGU around land surface modeling with a continued focus on improved modeling of surface heterogeneity and its impact on surface fluxes. These continued activities will be a key focus for the renewed efforts to improve the modeling of surface turbulent fluxes.
- Multiple presentations of the team members occurred at EGU, AMS, and AGU over the year. Multiple publications form the team were published over the year and multiple are either in preparation or in review.
- Short term goals are to write up a perspective/review paper that summarizes the efforts of CLASP over the past five years and provides a lessons learned perspective to provide context on the future directions of heterogeneous coupling in coupled land-atmopshere models.
- We envision to merge CLASP with LAFI and LIAISE to join forces on studies of L-A interaction

SIF-MIP

- Nicholas Parazoo, Haoran Lu, and Rong Li have had regular tag ups to update modeling protocols, synthesize results, and discuss paper progress
- Parazoo, Lu, and Jen Johnson attended 2026 FLEX Workshop to present results and discuss modeling plans

GLAFO

- Evaluation of parameterizations of entrainment fluxes using ARM SGP data
- Application of this approach to LAFO data in Stuttgart, Germany
- Studies of the impact of land-surface heterogeneity on the energy balance closure
- Application of machine learning methods to MOL-RAO tower data of DWD
- Exploration of further GLAFO sites such as over Southern Africa and Tibet
- Harmonization of data sets using the obs4MIPs format

List of New Projects and Activities in Place and Main Objective(s)

Irrigation CC

Several new projects/initiatives have been emerging:

- Climate Change Initiative – Anthropogenic Water Use (CCI-AWU)
    - Lead: Luca Brocca and others

    - Irrigation focused project funded by ESA, started in 2023
    - Details available at this link: https://climate.esa.int/en/projects/anthropogenic-water-use/
- CAS-Climate: To Irrigate or Not? Assessing Climate Change Adaptation for Sustainable Water-Agriculture Systems in the Mississippi River Basin
    - Leads: Yadu Pokhrel (PI), Kaiyu Guan (Co-I), Norman Bowman (Co-I), Bridget Scanlon (Co-I)
    - Three year project, Oct 2023 – Sept 2026
    - The project objectives are to:
        1. Assess the need, potential, and feasibility of irrigation expansion in the eastern Mississippi River Basin (MRB) to sustain food production under climate change
        2. Quantify water scarcity under sustained irrigation and future climate in the western MRB
        3. Assess plausible agricultural adaptation strategies to reduce water stress across the high plains aquifer
        4. Quantify the changes in green, blue, and gray water footprints across the entire MRB under various adaptation and climate change scenarios.

PLUMBER-2

- Collaboration between PLUMBER2 and NCAR remains a key objective, with a final goal of a collaborative modelevaluation.org-based benchmarking platform that is LSM-agnostic. Such a platform will ultimately be extendable to further organisations (such as UKMO and ECMWF amongst others).
- Work continues for a 3rd PLUMBER2 paper focused on ground heat flux, with contributions from GLASS community, UKMO, and others in reconciling site-specific instrument calibration.

SIF-MIP

- Submission of Phase 2 paper
- Analysis and publication model results using JB model
- Initial plans for Phase 3 activities, focused on wider range of sites (using Plumber2 forcing)

GLAFO

- The Land-Atmosphere Feedback Initiative (LAFI), the Collaborative Research Unit (RU) 5639 of the German Research Foundation (DFG) performed a General Observations Period (GOP) and several imbedded Intensive Operations Periods (IOPs) at the LAFO during the vegetation period of 2025

SoilWat

- SoilWat is now translating the Reading outcomes into a more structured program of follow-up work. The current core activities are organised around five themes: unified hydrothermal parameterisations; dynamic soil properties and pore-size distributions; soil–surface–atmosphere interface processes; root dynamics and plant hydraulics; and blended soil property estimation, including Vegetation as a Soil Sensor. These themes define SoilWat's present scientific focus and give the initiative a clearer operational structure than before.
- A major ongoing activity is the continuation of model intercomparison and benchmarking, especially through SP-MIP and related analyses of hydrological and thermal regime behaviour. The key objective is no longer only to compare flux outputs, but to understand how soil maps, PTF choices, runoff and evaporation formulations, and process parameterisations shape model behaviour and uncertainty. This remains central to SoilWat's contribution to next-generation land modelling.

ML4LM

- Throughout 2025, ML4LM hosted a webinar series featuring in-depth talks from leading experts on the application of machine learning in land and Earth system science. Insights from these webinars helped shape the workshop discussions. One clear takeaway was that ML capabilities for Earth

system science are already surprisingly mature. Machine learning models capable of data assimilation and even aspects of climate modeling now exist and are actively being explored.

- At the same time, participants emphasized the need for realism and nuance. For example, pure land model emulation -replacing a land surface model entirely with an ML surrogate- may not yet be particularly helpful in isolation. Land models are relatively inexpensive to run compared to other Earth system components, and emulation alone does not automatically yield new understanding. This caveat, however, applies less to more computationally-expensive components of Earth system modeling
- Participants highlighted the vast, still largely-untapped potential of hybrid modeling, in which ML components are embedded within or alongside physical models. Such approaches offer promising avenues for improving predictability, diagnosing model behavior, and exploring emergent processes.

List of New Projects and Activities Being Planned, including Main Objective(s) and Timeline, Lead(s)

Irrigation CC

- Proposal submitted to the Taylor Geospatial Institute to use NASA satellite remote sensing data to improve crop models in collaboration with farmers (PI: Jess Erlingis-Lamers, Co-I Patricia Parker).
- Co-Chair Parker and member Ehsan Jalilvand are collaborating with Michael Brody and Peter Van Oevelen on plans for a Central Asia RHP workshop in Kyrgyzstan and potential research projects in the region that can be done in coordination with the irrigation group.

PLUMBER-2

- Incorporation of automated alerting and plotting for site PIs when new flux data is uploaded to modelevaluation.org. This will bridge the modelling and observation communities, increasing two-way communication to improve benchmarking efforts on flux data.

GLAFO

- A new GABLS is in preparation oriented around LAFO and ARM SGP. The unique observations at these sites will be used in combination with runs of L-A system models such as the UK Met Office Unified Model, ICON-JSBACH, WRF-NOAHMP-Gecros, WRF-NOAHMP-Hydro-Iso, and PALM. It is envisioned to start with coordinated and dedicated activities in Fall 2026. The results will be applied for L-A system process understanding and model verification.
- Realize a GLAFO over Tibet and southern Africa
- SoilWat

- The main proposal now in development is **ISPHERE** (led by Anne Verhoef). It aims to improve land–atmosphere representation by developing harmonised soil hydraulic and thermal datasets across scales, a unified hydro-thermal framework that includes both capillary and adsorbed water, global parameter maps, dynamic soil-property representations, and multi-model testing in offline and coupled modes. In essence, ISPHERE is the most direct implementation vehicle of the SoilWat 2025 roadmap.
- More broadly, SoilWat continues to strengthen links with GEWEX, ISMC, LS4P, land-surface modelling centres, and digital-twin / physics-informed ML efforts. The initiative is increasingly positioned not just as a soil working group, but as a cross-disciplinary platform connecting soil physics, plant hydraulics, remote sensing, data assimilation, and Earth system prediction.

ML4LM

- The December 2025 ML4LM Workshop highlighted that machine learning for land modeling is no longer speculative, it is already contributing to real science. At the same time, it stressed the need for careful, community-driven development, grounded in data realities, physical understanding, and transparent evaluation.
- As ML4LM continues under the GEWEX umbrella, the focus remains clear: identify where ML truly adds value, build shared tools and datasets, and foster collaborations that advance land modeling as a core component of Earth system science. Central to this effort is creating space for open exchanges between earth system modelers, ML researchers, and observational scientists.
- Looking ahead, the 2026 ML4LM seminar series will build on this momentum with an exciting line-up of new speakers working at the forefront of machine learning and Earth system science. We invite the community to join these seminars, share perspectives, and help shape the next phase of ML4LM*.

Science Issues and Collaboration during Reporting Period

Contributions to Developing GEWEX Science and the GEWEX Imperatives.

a. Data Sets

Irrigation CC

- Satellite-derived Irrigation Water Use (IWU) data sets over the Ebro basin (Spain), Po valley (Italy), and the Murray-Darling basin (Australia) available at: https://zenodo.org/records/7341284. The products are an output of the ESA Irrigation+ project.
- Long-term IWU data set developed by leveraging satellite data within the ESA CCI-AWU data sets to be delivered soon. Targeted areas: CONUS, India, Murray-Darling basin, Ebro basin.

PLUMBER-2

- *Modelevaluation.org collates both observed flux data and machine learning benchmark datasets, improving ease of LSM benchmarking.*
- *SIF-MIP*
- Worked with Dave Bowling at University of Utah to curate tower flux and met data
- Worked with Zoe Pierrat at Jet Propulsion Laboratory to curate tower SIF data

GLAFO

- New data sets on the L-A system are available from the Stuttgart LAFO and Huancayo GLAFO sites. Advanced data processing schemes and sophisticated research data management are ongoing, e.g., in collaboration with NDFI4Earth (https://www.nfdi4earth.de) and obs4MIPs. This contains soil moisture and temperature, vegetation parameters and variables, canopy profiling (at LAFO), surface layer profiles and fluxes, in the future also isotope measurements and fiber-optical distributed sensors, profiles up to the lower troposphere using a ceilometer (Huancayo) as well as Doppler, advanced Raman and differential absorption lidar at Stuttgart LAFO.

CLASP

- Datasets of summarized space-time behavior of land surface temperature over the Contiguous United States (GOES 16/17) and global (Copernicus LST). These data derived from km-scale LST hourly data provide insights into the diurnal cycle of thermal spatial patterns. This data is then being explored in the context of evaluating land surface models to revisit how these models represent thermal heterogeneity.

b. Analysis

PLUMBER-2

- The PLUMBER2 framework provides robust benchmarking analysis, which has so far resulted in two papers with another in an advanced state of production.

SIF-MIP

- Haoran Lu (U Wisconsin) has taken over Phase 2 leadership and led most of the analysis and paper writing.

GLAFO

- Data processing and quality control of a synergy of observations such as surface fluxes, surface energy balance closure, and turbulence profiles in the ABL as well as their relations to soil and vegetation parameters and variables. All data will become available in obs4MIPs format.

CLASP

- Building on the derived space-time data from the LST global data, analysis of a model ensemble is being explored to understand how meteorology and structural uncertainties inform the simulated diurnal LST space-time patterns. This analysis is highlighting the poor performance of contemporary models to simulate realistic space-time patterns of surface temperature. It also presents an opportunity to potentially explore a model intercomparison to understand the performance of space-time patterns of LST across global land surface models. The work to evaluate model performance of space-time patterns of LST in the GFDL was recently funded by NOAA.
- The project is looking to provide a stronger measurement evidence for the results that have emerged from the LES experiments. Ongoing analysis is leveraging the available Doppler Lidars over the Southern Great Plains site (SGP) in Oklahoma and the LST data from GOES 16/17 to understand if the early day thermal setup has an influence in the emergence of dispersive kinetic energy in the afternoon.

c. Processes

SIF-MIP

- Implementation of JB model is expected to provide much deeper insight into ecological relationships across evergreen tower sites.

GLAFO

- Studies of relations between fluxes, ABL development and soil and vegetation states as well as the effects of heterogeneities. This includes turbulent transport in the convective boundary layer, entrainment, evapotranspiration, sensible heat flux, ground heat flux, radiative transfer, cloud formation, and morning transition and afternoon decay.

d. Modeling

GABLS

- Initial discussions on single-column modelling have taken place and a prototype file of driving data Is being developed for distribution to collaborators In the spring of 2026.

SIF-MIP

- JB model has been implemented but not yet analyzed

GLAFO

- Simulation of the L-A system in heterogeneous terrain from meso- down to turbulence-permitting scales for studying scale interaction and scaling laws as well as the effect of micro-scale flow on surface and PBL properties
- Combination with single-column models and LES with homogeneous surface
- Mostly multi-nested design under realistic large-scale forcing including data assimilation

CLASP

- New funding for the heterogenous L-A interactions working group is focuing on setting up LES experiments over the new AMF3-BNF site in northern Alabama. This work aims to better understand surface thermal heterogeneity driven secondary circulations. These experiments will be compared to the available Doppler Lidars at the AMF3-BNF site which is already mostly suitable as a GLAFO site. This work will complement efforts of the new GABLS as well as the efforts in SoilWat and GLAFO.

e. Application

PLUMBER-2

- Continued development of modelevaluation.org to automate the PLUMBER2 benchmarking framework. Automation, generalization, and new analyses are key aspects of design direction.
- SIF-MIP
- Results have potential to improve use of SIF for drought monitoring.

GLAFO

- New parameterizations of surface fluxes, ABL turbulence, and stomatal resistance for crops
- NWP from short- to medium-range including the assimilation of new observations
- Sub-seasonal to seasonal simulations
- Advanced km-scale regional climate projections by incorporation of better representation of L-A feedback and vegetation properties

f. Technology Transfer

GLAFO

- Operational application of new remote sensing systems at observatories
- Operational turbulence-permitting forecasting
- Operation of advanced instrumentation at sites like Huancayo as well as in the future in Southern Africa, and Tibet

g. Capacity Building

GLAFO

- LAFI summer and fall schools for students, PhD students, and postdocs
- Incorporation of GLAFO science in educational BSc and MSc programs

- Collaboration with forecast centers
- Collaboration with developing countries such as Ethiopia and Zimbabwe
- Educational efforts planned at all sites to demonstrate the measurement methodology, operation, maintenance and processing of GLAFO data, also in Peru and other future sites

CLASP

- Over the past few years, many PhD students and postdoctoral research associates have been funded through CLASP and associated projects.
- Interaction with the MOSAI project in France and the LAFI project in Germany that are "cousin" projects to CLASP. These interactions will continue in the coming year with possibilities of joint projects emerging down the road. This is one of the primary reasons behind the plan to sunset CLASP and replace it with a heterogeneous L-A working group.
- Collaboration with climate modeling centers in their development and evaluation of sub-grid coupling parameterizations.

List contributions to the GEWEX Science Goals and plans to include these.

Goal # 1 (GS1): Determine the extent to which Earth's water cycle can be predicted. This Goal is framed around making quantitative progress on three related areas posed in terms of the following questions:

1. Reservoirs:

What is the rate of expansion of the fast reservoirs (atmosphere and land surfaces), what is its spatial character, what factors determine this and to what extent are these changes predictable?

Irrigation CC

- Irrigation modifies natural 'fast' reservoirs at the surface (through soil moisture then land-atmosphere interactions) as well as slower reservoirs like surface water (through diversion) and groundwater. Although the irrigation project emphasizes the land-atmosphere component, it is inseparable from considerations of human water management and the social dimension of irrigation water usage.

SIF-MIP

- Our data assimilation experiments will evaluate impacts of SIF and other joint vegetation, carbon and water constraints on the water **pools including plant available and unavailable water in soils**. These experiments range in scale from a few towers in high latitude and high altitude environments, to global and long term.

2. Flux exchanges:

To what extent are the fluxes of water between Earth's main reservoirs changing and can these changes be predicted and if so on what time/space scale?

Irrigation CC

- The irrigation effort includes scientist whose research includes mapping irrigated areas using remote sensing data. Recent advances in tools and computational power have allowed for the creation of annual maps of irrigated areas, which has and will continue to improve our understanding of time-varying changes to irrigation acreage (and therefore SM/surface reservoirs). The irrigation effort also includes members working on the ESA + irrigation project that seeks to estimate irrigation water use from space.

SIF-MIP

- Our data assimilation experiments will evaluate impacts of SIF and other joint vegetation, carbon and water constraints on the water **fluxes including evapotranspiration and runoff**. These experiments will focus on a few towers in high latitude and high altitude environments.

GLAFO

- Lots of studies already ongoing with LAFO and MOL-RAO surface energy balance measurements that disproved MOST for ET

CLASP

- The sensitivity of LST space-time patterns to turbulence parameterizations highlights the critical role that turbulent surface fluxes play in the space-time organization of thermal heterogeneity and thus the micro to mesoscale coupling between the land surface and atmosphere. The sub-diurnal modeling of surface fluxes is deficient and needs to be addressed for the purposes of modeling cumulus clouds and convection in numerical weather prediction and climate models.

3. **Precipitation Extremes***:*

How will local rainfall and its extremes change under climate change across the regions of the world?

SIF-MIP

- Our modeling protocol currently does not account for land surface feedbacks to the atmosphere, but this is an interesting and important direction for SIF-MIP

GLAFO

- No contribution expected here but studies of the pre-convective environment available and its relation to convection initiation

CLASP

- Representation of km-scale heterogeneity over the land surface shows a clear impact on model predictability as illustrated via surface homogeneous vs heterogeneous WRF experiments over the Contiguous United States.

Goal # 2 (GS2): Quantify the inter-relationships between Earth's energy, water and carbon cycles to advance our understanding of the system and our ability to predict it across scales:

1. **Forcing-feedback understanding:**

How can we improve the understanding of climate forcings and feedbacks formed by energy, water and carbon exchanges?

SIF-MIP

- Our data assimilation experiments will evaluate impacts of different observational constraints on energy, water, and carbon exchanges. Data assimilation systems will look for a solution which is most consistent with diverse model processes and observational constraints. For example, we may find that assimilating only water variables, such as soil moisture, has a difference set of impact on energy, water and carbon exchanges than joint assimilation of carbon and water variables.

GLAFO

- This is a key research subject of GLAFO and the entire GLASS Panel. GLAFO will investigate L-A feedbacks with long-term measurements. The results will contribute to the understanding of the L-A feedback chains over the regime of soil moisture conditions, vegetation properties and in dependence of large-scale forcing as well as permit studies to quantify the effects of land use and land cover changes (LUCC) on regional weather and climate

2. ABL process representation:

To what extent are the properties of the atmospheric boundary layer (ABL) defined by sensible and latent energy and water exchanges at the Earth's surface versus within the atmosphere (i.e., horizontal advection and ABL-free atmosphere exchanges)?

GABLS

- The project will utilize the advanced capabilities of the GLAFO sites to assess how well models represent the detailed turbulent structure of the atmospheric boundary layer.

SIF-MIP

- Our modeling protocol currently does not account for land surface feedbacks to the atmosphere, but this is an interesting and important direction for SIF-MIP

GLAFO

- This is another fundamental subject of GLAFO research. For this purpose, the Stuttgart LAFO provides worldwide unique profiling of mean, gradient, and turbulent quantities, e.g., for TKE, momentum, heat, and latent heat flux profiling. First results are available from the LAFI GOP-IOPs. Also, new metrics will be available to investigate the feedback between surface fluxes and ABL development including entrainment

CLASP

- Under convective boundary layers, cloud development is enhanced when there are strong surface thermal gradients. This effect is caused primarily by the thermal gradients driving the development of the secondary circulations that then enhanced the cloud production. Implementation of these types of approaches in global models will facilitate an improved understanding of the role of surface heterogeneity on ABL processes and thus cloud development.

3. Understanding Circulation controls:

To what extent are exchanges between water, energy and carbon determined by the large-scale circulations of the atmosphere and oceans?

SIF-MIP

- Our modeling protocol currently focuses on single point runs, but eventually will be more regional and global and nature, and which point large-scale circulation impacts can be examined.

GLAFO

- Some contributions expected in the regions of the GLAFOs because advection can be estimated by ABL budget analyses

4. Land-atmosphere interactions:

How can we improve the understanding of the role of land surface-atmospheric interactions in the water, energy and carbon budgets across spatiotemporal scales?

GABLS

- The project will exploit the comprehensive observations at the GLAFO sites, including the state of the land surface to assess the physics of land-atmosphere coupling and the role of surface heterogeneities.

SIF-MIP

- We have envisioned approaches for examining land-atmosphere interactions by coupling a subset of our models to atmospheric models, such as the Climate Modeling Alliance (CLIMA)

CLASP

- There is a growing recognition that the community should focus around how surface heterogeneity impacts turbulence and mean advection at the surface and thus its impacts on surface fluxes which remains a persistent weakness in land surface models. The role of microscale circulations and how moisture and heat are transferred between sub-grid units is seen as the next frontier in these efforts.

Goal # 3 (GS3): Quantify anthropogenic influences on the water cycle and our ability to understand and predict changes to Earth's water cycle.

1. Anthropogenic forcing of continental scale water availability:

To what extent has the changing greenhouse effect modified the water cycle over different regions and continents?

….

2. Water management influences:

To what extent do water management practices and land use change (e.g., deforestation) modify the water cycle on regional to global scales?

….

3. Variability and trends of water availability:

How do water & land use and climate change affect the variability (including extremes) of the regional and continental water cycle?

….

Other Key Science Questions

List 1 – 3 suggestion that you anticipate your community would want to tackle in the next 5-10 years within the context of a land-atmosphere project

SIF-MIP

- A major goal continue to be to understand the extent to which SIF can be used for drought monitoring and early warning in crop, forest, and rangeland ecosystems. Ongoing and planned modeling experiments will contribute to chip away at this goal.

GLAFO

- How do the L-A feedback chains work over different GLAFOs, in dependence of large-scale forcing, and over different regimes of soil moisture conditions, vegetation properties?
- What is the effect of land use and land cover changes (LUCC) on regional weather and climate in the regions of the GLAFO sites?

- How can be improve the parameterization of L-A system processes and how does their implementation in L-A system models improve the simulation of extreme events?

Contributions to WCRP including the WCRP Light House Activities

Briefly list any specific areas of your panel's activities in particular to the WCRP Light House Activities (Digital Earth, Explaining and Predicting Earth System Change, My Climate Risk, Safe Landing Cimates and WCRP Academy) https://www.wcrp-climate.org/lha-overview.

GLAFO

- Process understanding and improved parameterizations for L-A system models, which we consider fundamental to make process in model performance, verification of model output from turbulence to km-scales

Cooperation with other WCRP Projects, Outside Bodies and links to applications

e.g. CLIVAR, CliC, SPARC, Future Earth, etc.

GLAFO

- WWRP RCP TeamX
- LIAISE
- AmeriFlux
- Critical Zone Observatories
- NASA Hydrological Testbed

Workshops and Meetings

List of Workshops and Meetings Held in 2025

- Meeting title, dates and location.
-

Irrigation CC

- Virtual Meeting - 30 June

GLAFO

- BALTEX Meeting, Hamburg, February 4, 2025
- ESMO GLASS Meeting, virtual, February 12, 2025
- Lighthouse Activity Meeting, virtual, April 1, 2025
- Presentation of GLASS results at EGU, Vienna, April 27, 2025
- Presentation of GLAFO at the University of Zimbabwe, Harare, virtual, July 23, 2025
- Visit of Huancayo Observatory and several other research institutes in Peru, August 2025
- NFDI4Eearth Meeting, Bremen, September 22, 2025
- ANDEX meeting, virtual, October 14, 2025
- 11th WMO Scientific Conference on Weather Modification, Pune, India, GLASS Panel Meeting in Reading, UK, from July 16-18, 2025
- WGNE meeting, virtual, November 3, 2025

CLASP

- CLASP virtual seminar series – 03/2025

SoilWat

- In 2025, SoilWat's main achievement was the joint ISMC–GEWEX workshop in Reading, which consolidated progress since the first Leipzig meeting and sharpened the scientific roadmap for improving soil and subsurface representation in land, weather, and climate models. The workshop brought together work on SP-MIP, soil thermal and hydraulic parameterisation, root water uptake,

plant hydraulics, vapour flow, infiltration, groundwater interactions, and land–atmosphere coupling, with the clear message that legacy static soil formulations are no longer sufficient.

ML4LM

- After a series of successful webinars, the Machine Learning for Land Modeling (ML4LM) community held its first online workshop in December 2025. The main focus of the workshop was on exploring how modern machine learning (ML) can support land surface and Earth system modeling (ESM) in general. The discussions centered on using ML to improve process understanding, better connect observations and models, and ultimately strengthen prediction. Drawing on recent advances in high-performance computing, Earth observations, and AI, the workshop explored both the opportunities and the real-world challenges of integrating ML into ESM and land modeling frameworks.

List of Workshops and Meetings Planned in 2026 and 2027

- Pan-GLASS 2026: travel support needed:
  The main focus of 2026 is the Pan-GLASS meeting. We are aiming for over 200 researchers to attend and present and to more robusly populate the different working groups. A follow-up to this meeting will then be for each working group to lead review/opinion papers to build our their communities and spin-off new GLASS projects.

- GABLS
- An abstract for a presentation about the project Is being submitted for the Pan-GLASS conference In July, when It Is hoped further discussions about the project will take place and results from the prototype simulations will be presented

Irrigation CC

- Quarterly virtual meeting – March 2026
- Quarterly virtual meeting – June 2026
- Quarterly virtual meeting – September 2026
- Quarterly virtual meeting – December 2026

  Virtual meetings – no travel support needed

SIF-MIP

- FLEX Workshop in Bonne (Mar 3-7)
- Pan-GLASS Conference in Stuttgart, German (6-9 July, 2026)
- Fall AGU (Dec 2026)

GLAFO

- GLASS Panel Meeting, Stuttgart, Germany, July 10, 2026
- 1st Pan-GLASS Conference, Stuttgart, Germany, July 6-9, 2026
- Presentations of GLASS Panel results at EGU, EMS, etc.

ML4LM

- Looking ahead, the 2026 ML4LM seminar series will build on this momentum with an exciting line-up of new speakers working at the forefront of machine learning and Earth system science. We invite the community to join these seminars, share perspectives, and help shape the next phase of ML4LM.

Publications during Reporting Period

List of Key Publications

Irrigation CC

Boone, A., J. Bellvert, M. Best, J. K. Brooke, G. Canut-Rocafort, J. Cuxart, O. Hartogensis, P. Le Moigne, J. R. Miró, J. Polcher, J. Price, P. Quintana Seguí, J. Bech, Y. Bezombes, O. Branch, J. Cristóbal, K. Dassas, P. Fanise, F. Gibert, Y. Goulas, J. Groh, J. Hanus, G. Hmimina, L. Jarlan, E. Kim, V. Le Dantec, M. Le Page, F. Lohou, M. Lothon, M. R. Mangan, B. Martí, D. Martínez-Villagrasa, J. McGregor, A. Kerr-Munslow, N. Ouaadi, A. Philibert, J. Quiros-Vargas, U. Rascher, B. Siegmann, M. Udina, A. Vial, B. Wrenger, V. Wulfmeyer, M. Zribi, 2025: The Land Surface Interactions with the Atmosphere over the Iberian Semi-Arid Environment (LIAISE) Field Campaign. J. Europ. Meteorol. Soc., 2, 100007, https://doi.org/10.1016/j.jemets.2025.100007.

Fan, Y., Yang, Z., Lo, MH. et al. Deciphering the capricious precipitation response: irrigation impact in the North China Plain. npj Clim Atmos Sci 8, 211 (2025). https://doi.org/10.1038/s41612-025-01063-3.

Jiménez, Maria A., Joan Cuxart, Aaron A Boone, Patrick Le Moigne, Tanguy Lunel, Jordi Mercader, Josep R Miró, Martin Best, Jennifer K Brooke, 2025: Land-surface interactions with the atmosphere over the Iberian Semi-arid Environment (LIAISE): First mesoscale modelling intercomparison. Q. Journal of the Royal Met. Soc., 151, 796, e4949.

Lunel, T. R., Marti, B., Boone, A., and Le Moigne, P.: Systematic overestimation of evapotranspiration over irrigated areas by an offline land surface model, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2024-3562, 2025.

PLUMBER-2

Cranko Page, J., De Kauwe, M. G., Pitman, A. J., Towers, I. R., Arduini, G., Best, M. J., Ferguson, C. R., Knauer, J., Kim, H., Lawrence, D. M., Nitta, T., Oleson, K. W., Ottlé, C., Ukkola, A., Vuichard, N., Wang-Faivre, X., & Abramowitz, G. (2026). Land surface model underperformance tied to specific meteorological conditions. Biogeosciences, 23(1), 263–282. https://doi.org/10.5194/bg-23-263-2026

SIF-MIP

Haoran Liu, Min Chen, Rong Li, Camille Abadie, Cédric Bacour, David R. Dave Bowling, Natalie Douglas, Jennifer Johnson, Dalei Hao, Troy Magney, Fabienne Maignan, Alexander J Norton, Zoe Amie Pierrat, Tristan Quaife, Mingjie Shi, Yujie Wang, Mousong Wu, Xi Yang, Yelu Zeng, Yongguang Zhang, Nicholas C Parazoo, SIF-MIP Phase 2: Multi-Model Evaluation of Simulated SIF and Its Coupling with GPP across Multiple Evergreen Forests, Manuscrip in Prep for Remote Sensing of Environment

GLAFO

Schwitalla, T., Jach, L., Wulfmeyer, V. and Warrach-Sagi, K., 2025: Soil moisture-atmosphere coupling strength over central Europe in the recent warming climate. Natural Hazards and Earth System Sciences, 25(4), pp. 1405–1424. DOI:10.5194/nhess-25-1405-2025

Lange, D., Behrendt, A., Senff, C., Wagner, T.J., Späth, F. and Wulfmeyer, V., 2025: Using ground-based lidar data to investigate the water–vapor budget in the daytime atmospheric boundary layer. Bulletin of Atmospheric Science and Technology, 6 (1), art. no. 24. DOI:10.1007/s42865-025-00110-4

Wulfmeyer, V., Jach, L., Branch, O. and Breil, M. 2025: Das Land-Atmosphäre-System der Erde: Die „Erdung“ von Wetter- und Klimaprozessen. Physik in unserer Zeit, 56, pp. 80-88. DOI:10.1002/piuz.202401716

Minz, J., Kleidon, A., Imberger, M., and Badger, J., 2025: Evaluating the Impact of Kinetic Energy Removal by Wind Turbines on the Technical Wind Energy Potential of the German Bight, Meteorologische Zeitschrift. DOI:10.1127/metz/2025/1215

Li, Y., Huang, B., Rechid, D., Hoffmann, P., Jach, L., Warrach-Sagi, K., Breil, M., Mooney, P. A., Toelle, M., Cardoso, R. M., Rust, H. W., 2025: Impacts of deforestation on drought patterns across multiple time scales in Europe: Insights from LUCAS regional climate models, Journal of Hydrology, 133781, ISSN 0022-1694. DOI:10.1016/j.jhydrol.2025.133781

CLASP

1. Guyumus, D., Torres-Rojas, L., Bacelar, L., Xu, C., & Chaney, N. (2026). HydroBlocks-MSSUBv0. 1: a multiscale approach for simulating lateral subsurface flow dynamics in Land Surface Models. Geoscientific Model Development, 19(1), 477-504.

2. Waterman, T., Dirmeyer, P., & Chaney, N. (2025). Surface Flux Homogenization and Its Impacts on Convection across CONUS. Journal of Hydrometeorology, 26(6), 709-724.

3. Hong, M., Chaney, N., Malyshev, S., Zorzetto, E., Preucil, A., & Shevliakova, E. (2025). LM4-SHARC v1. 0: resolving the catchment-scale soil–hillslope aquifer–river continuum for the GFDL Earth system modeling framework. Geoscientific Model Development, 18(7), 2275-2301.

4. Waterman, T. S., Stiperski, I., Chaney, N., & Calaf, M. (2025). Evaluating anisotropy-based Monin–Obukhov similarity theory over canopies and complex terrain [manuscript under review]. QJR Meteorol Soc. https://d oi. org/1 0, 4(8), 5.

5. Ghannam, K., Malyshev, S., Shevliakova, E., Tan, Z., Bou-Zeid, E., & Chaney, N. W. (Accepted). Coupling Subgrid-Scale Surface Heterogeneity to the Convective Boundary Layer in the GFDL Global Model (AM4. 0-LM4. 0): Parameterization Development and Climate Impacts. Journal of Advances in Modeling of Earth Systems.

SoilWat

1. Guyumus, D., Torres-Rojas, L., Bacelar, L., Xu, C., & Chaney, N. (2026). HydroBlocks-MSSUBv0. 1: a multiscale approach for simulating lateral subsurface flow dynamics in Land Surface Models. Geoscientific Model Development, 19(1), 477-504.

2. Waterman, T., Dirmeyer, P., & Chaney, N. (2025). Surface Flux Homogenization and Its Impacts on Convection across CONUS. Journal of Hydrometeorology, 26(6), 709-724.

3. Hong, M., Chaney, N., Malyshev, S., Zorzetto, E., Preucil, A., & Shevliakova, E. (2025). LM4-SHARC v1. 0: resolving the catchment-scale soil–hillslope aquifer–river continuum for the GFDL Earth system modeling framework. Geoscientific Model Development, 18(7), 2275-2301.

4. Waterman, T. S., Stiperski, I., Chaney, N., & Calaf, M. (2025). Evaluating anisotropy-based Monin–Obukhov similarity theory over canopies and complex terrain [manuscript under review]. QJR Meteorol Soc. https://d oi. org/1 0, 4(8), 5.

5. Ghannam, K., Malyshev, S., Shevliakova, E., Tan, Z., Bou-Zeid, E., & Chaney, N. W. (Accepted). Coupling Subgrid-Scale Surface Heterogeneity to the Convective Boundary Layer in the GFDL Global Model (AM4. 0-LM4. 0): Parameterization Development and Climate Impacts. Journal of Advances in Modeling of Earth Systems.