

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

The TEAMx Observational Campaign



Selected instrumentation and observational activities during the TEAMx Observational Campaign [Photo credits (top left to bottom right): B. Saunders (Univ. Innsbruck), M. Breig (KIT), G. Nitti (Univ. Innsbruck), D. Corradini (Univ. Cologne), M. Rotach (Univ. Innsbruck), D. Anderson (FAAM), I. Stiperski (Univ. Innsbruck), A. Gohm (Univ. Innsbruck), M. Rotach (Univ. Innsbruck), C. Brun (Univ. Grenoble)]. Find more on TEAMx starting on page 4.

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Commentary

Peter van Oevelen

Director, International GEWEX Project Office

Reading and seeing the news nowadays, it is hard not to feel depressed, anxious, and even lost. The world is in turmoil, and so many of the things we took for granted are now being questioned: democracy, peaceful regime change, freedom of speech, liberty...things that could be considered part of the bedrock of western societies are no longer a given. For us in the weather, water, and climate research enterprise, it particularly points to the evaluation and validation of the work we do, and the contributions to society that we make. No longer is it as widely accepted that climate change is something we as a global community need to deal with. The support that was previously present is changing, often disappearing. Of course, there are many good reasons to address the current and emergent global issues (wars, economic instability, etc.) given their impacts, and that comes with changes in priorities. However, pretending or assuming climate change is no longer a global security threat in the broadest sense will be a costly and poorly-timed mistake. Much has been written on this already and there is no need to repeat it here. If you are reading this newsletter, no doubt I would be preaching to the choir.

One thing I would like to emphasize, though, is the continued need for basic or fundamental research in our field. Or maybe I should call it research where direct societal relevance is less apparent. It is often seen as curiosity-driven, the hobby of academics and far removed from any usefulness. However, this type of research is the cornerstone of understanding, examining why things function as they do, why they are as they are. It is the fundament of being able to describe and understand the processes that we study. In this day and age, where Artificial Intelligence (AI) and Machine Learning (ML) are making it quicker and easier than ever to produce (predictive) models with surprising results, it is even more important to understand. It is also something where AI and ML also can contribute in a variety of ways. The above is not at all meant as a suggestion to replace application-oriented research, merely as a reminder that without it, applied research will not progress and

can even regress. Speaking of ML, you can find highlighted on page 7 a relatively new GEWEX activity, Machine Learning for Land Modeling (ML4LM), which hosts monthly webinars. Recordings can be found on our GEWEX YouTube channel, https://www.youtube.com/@GEWEX_WCRP/videos, where you can watch other GEWEX-related videos and webinars!

Despite the numerous programs worldwide on early warnings, flood forecasting, risk reduction, etc., all depending heavily on observational data sets, it is still incredibly hard to support and continue any of these observational networks, particularly in situ networks. In that context, it is important to note that climate observations are more than just long-term observations of a single variable! I would like to commend the World Meteorological Organization (WMO) and its partners the United Nations Development Programme (UNDP) and the United Nations Environment Programme (UNEP) for its Systematic Observations Financing Facility (SOFF) program, which does address this need. I hope it will go beyond Global Basic Observing Network (GBON) compliance and its focus on atmospheric observation and also include hydrological observations.

Enjoy this newsletter and please let us know if you have any ideas for contributions!

Pan-GLASS 2026
*Back to the Drawing Board:
 From Fundamentals to
 Improved Models of the Coupled
 Land-Atmosphere System*
 6-9 July 2026 | Stuttgart, Germany

GLASS **GEWEX**

Register and visit <https://www.gewexevents.org/meetings/glass2026/> for more information!

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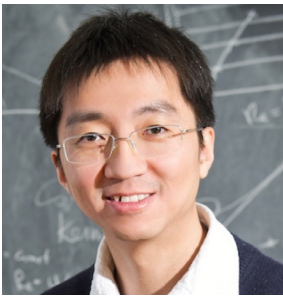
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New Panel Members



Dr. Bart Geerts (Atmospheric Science PhD, University of Washington, 1990), who recently joined the GEWEX Data and Analysis Panel (GDAP), is a Professor at the University of Wyoming. He conducts research into cloud-scale to meso-scale atmospheric processes through observations, aimed at improving our understanding of key processes

in clouds and at the land surface that are critical in the uncertainty of the climate system's response to anthropogenic change. Much of his research builds on targeted observations. Dr. Geerts has led several multi-institution field campaigns that deployed aircraft, ground-based remote sensors, and surface energy balance sensors. He has applied insights from field campaigns to the question of predictability of extreme events such as flash floods through km-scale convection-permitting regional climate simulations. He is a Fellow of the American Meteorological Society and currently serves as Editor of *Monthly Weather Review*.



Yi Huang is a Professor in the Department of Atmospheric and Oceanic Sciences at McGill University, Canada. He joins the GDAP Panel with strong interest in atmospheric water and energy. Yi obtained his degrees from Peking University (BS) and Princeton University (PhD) and was a Climate and Global Change Postdoctoral Fellow

at Harvard University before joining the faculty at McGill. He specializes in atmospheric radiation, such as the radiative transfer theories governing the energetic impacts of water vapor and other greenhouse gases. He also develops and deploys new remote sensing techniques measuring spectral radiation and retrieving atmospheric composition. He is the Science co-Lead of Canadian satellite, High-altitude Aerosols, Water vapor and Clouds (HAWC), which will contribute to the observation of global water and energy exchange.



Dr. Hsi-Yen Ma, an atmospheric scientist at Lawrence Livermore National Laboratory, is a new member of the GEWEX Global Atmosphere System Studies (GASS) Panel. His research interests mainly focus on clouds, precipitation, convection, and their representations in Earth system models. More broadly, his interests include high-resolution

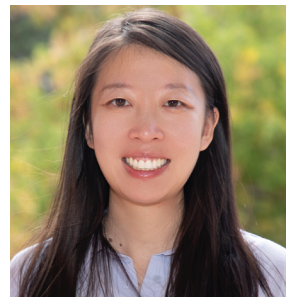
Earth system modeling, dynamics of coupled atmosphere-ocean-land interactions, modes of variability, monsoons, ex-

tremes, and the application of AI techniques to improve Earth system predictions. Dr. Ma is currently co-leading the GASS Phase II Diurnal Cycle of Precipitation (DCP) intercomparison project, with a focus on high-resolution regional and global models. Previously, he also co-led two GASS intercomparison projects to study the summertime warm surface air temperature biases over the central United States (CAUSES) and Phase I of DCP.



Dr. Florian Tornow is an Associate Research Scientist at Columbia University and joins GEWEX's Global Atmospheric System Studies (GASS) Panel. His research investigates microphysical cloud-aerosol-precipitation interactions that drive cloud regime transitions and their radiative impacts. He integrates field campaign and satellite

observations with large-eddy simulations to study these processes and improve their representation in Earth system models. He leads the Cold-air Outbreak in the Marine Boundary Experiment Model-Observation Intercomparison Project (COMBLE-MIP), studying a Norwegian Sea cold-air outbreak to assess model performance under mixed-phase cloud conditions. As part of National Aeronautics and Space Administration (NASA)'s ModelE team, he also develops a marine cold-air outbreak case library spanning a broader range of conditions observed during COMBLE and the Aerosol Cloud Meteorology Interactions over the western Atlantic Experiment (ACTIVATE) to advance model evaluation and development.



New GASS member Yang Tian is a Scientist at the U.S. National Center for Atmospheric Research (NCAR). Her research focuses on the multiscale coupling between moist convection and the large-scale circulation, with the goal of improving the physical realism of precipitation and extremes across weather-climate timescales in

models. She combines theory, large-eddy simulations (LES), convection-permitting regional and global modeling, and satellite/field observations to develop process-based diagnostics and physical constraints on cloud-environment mixing, up-draft dynamics, convective organization, and aerosol-cloud interactions. She currently leads the GEWEX GoAmazon km-scale Model Intercomparison Project (MIP) to benchmark model performance against GoAmazon observations and LES. This effort is designed to pinpoint where and why current convection-permitting models (CPMs)/cloud-resolving models (CRMs) diverge from observations and LES in representing congestus and convective organization, and to provide concrete targets for improving turbulence, microphysics, and gray-zone physics.

The TEAMx Observational Campaign

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TEAMx, the Multi-Scale Transport and Exchange Processes in the atmosphere over mountains – programme and experiment, is an international research program that aims at a better understanding of transport and exchange processes in the atmosphere over mountainous terrain and at evaluating and improving the representation of these processes in numerical weather and climate models (Ward and Rotach, 2021; Rotach et al., 2022). While the transport of energy, mass, and momentum in the atmospheric boundary layer over flat and horizontally homogeneous terrain is largely a result of vertical turbulent mixing, multiple processes contribute to the transport within the Mountain Boundary Layer (MoBL) and between the MoBL and the free atmosphere (Lehner and Rotach, 2018; Serafin et al., 2018). These processes range from turbulent transport both in the vertical and the horizontal direction over small-scale flows like slope winds to mesoscale processes such as the valley-wind circulation and mountain waves. Despite recent advances in computational resources and the associated increases in grid resolution, many of these processes can only be partly resolved in operational and research models and the impact of small subgrid-scale processes becomes increasingly important. In 2017, a number of researchers thus initiated the TEAMx research program, expressing the need for a joint international effort to address questions of transport processes over mountainous terrain. The resulting Memorandum of Understanding has been signed by more than 40 partner institutions in the meantime, and, in 2024–2025, more than 30 research groups participated in the TEAMx Observational Campaign (TOC).

The TEAMx Observational Campaign

The TOC was a one-year long measurement campaign between September 2024 and September 2025. Measurements took place in four target areas aligned in an approximately north-south transect through the European Alps from the northern Alpine foreland, Germany, to Lake Garda, Italy (Fig. 1). With the approximately east-west oriented Inn Valley north of the main Alpine crest (Inn Valley Target Area) and the approximately north-south oriented Adige Valley south of the main Alpine crest (Adige Valley Target Area), the domain included two major populated valleys of similar size, but differing orientation. The proximity to the Mediterranean Sea provides an ample supply of moisture, which allows us to study the transport of atmospheric moisture and the initiation of orographic convection. A climatological study conducted by the TEAMx Working Group on Convection in preparation for the TOC identified the Sarntal Alps in the Alpine Crest Target Area (Fig. 1) as a hotspot of convection initiation (Manzato et al., 2022).

The TOC domain has a dense operational measurement network, including networks of automated weather stations operated by national and regional weather and environmental services in particular. In addition, several of the TEAMx partner institutions in the TOC domain are operating long-term research stations; for example, the i-Box eddy-covariance network (Ro-

tach et al., 2017) and the Innsbruck Atmospheric Observatory (Karl et al., 2020) in the Inn Valley. This existing measurement network was supplemented with additional remote-sensing and surface stations for the duration of the TOC to sample the structure of the MoBL at multiple locations for an entire year.

The most intensive measurements were, however, conducted during two six-week long Extended Observational Periods (EOPs) in January/February 2025 (winter EOP, or wEOP) and in June/July 2025 (summer EOP, or sEOP). During the two EOPs, multiple research groups joined the TOC to deploy their instrumentation at strategically-selected sites throughout the four target areas to observe individual transport processes and their interactions in detail (Fig. 1). Activities included, for example, the deployment of suites of remote-sensing instruments (e.g., Doppler wind lidars, Raman lidars, microwave temperature and humidity profilers, and ceilometers) and eddy-covariance stations, airborne measurements with research aircraft and uncrewed aerial systems (UAS), radiosonde launches, and tethered-balloon measurements (see cover).

Three research aircraft participated during the sEOP: the Facility for Airborne Atmospheric Measurements (FAAM) BAe146 from the National Centre for Atmospheric Science (NCAS), the Cessna F406 from the Technische Universität Braunschweig (TUBS), and the Cessna Caravan from the German Aerospace Center (DLR). In total, 80 flights with more than 250 flight hours were conducted to sample the three-dimensional thermal structure, flow fields, and turbulence characteristics in the MoBL during undisturbed, dynamically-driven, and convective conditions. In addition to 100 Hz in situ probes, one of the three aircraft, the Cessna F406 from TUBS, was also equipped with a novel five-beam lidar system developed at the Karlsruhe Institute of Technology to measure the three-dimensional wind below the aircraft with a 100 m spatial resolution.

Observed Processes

In total, 18 and 24 Intensive Observational Periods (IOPs) were conducted during the wEOP and sEOP, respectively, during which the most personnel-intensive measurements were made, including aircraft flights, UAS operations, and radiosonde launches. With durations between 6 and 48 h, the IOPs focused on different atmospheric transport processes defined by the initial science goals and depending on the synoptic conditions and the available observational resources (e.g., the availability of the research aircraft). During both EOPs, the targeted science goals included the vertical structure and spatial variability of mean and turbulence characteristics in slope winds, the three-dimensional structure of both mean and turbulence properties of a valley atmosphere during synoptically undisturbed conditions and during conditions with weak dynamic forcing, and gravity-wave development and characteristics. The sEOP had an additional focus on valley-exit jets at the exit of the Inn Valley and on orographic convection and convection initiation over the Sarntal Alps.

As an example, slope winds were targeted both during the wEOP and the sEOP. During the wEOP, a steep, north-facing and snow-covered slope in the Inn Valley was instrumented

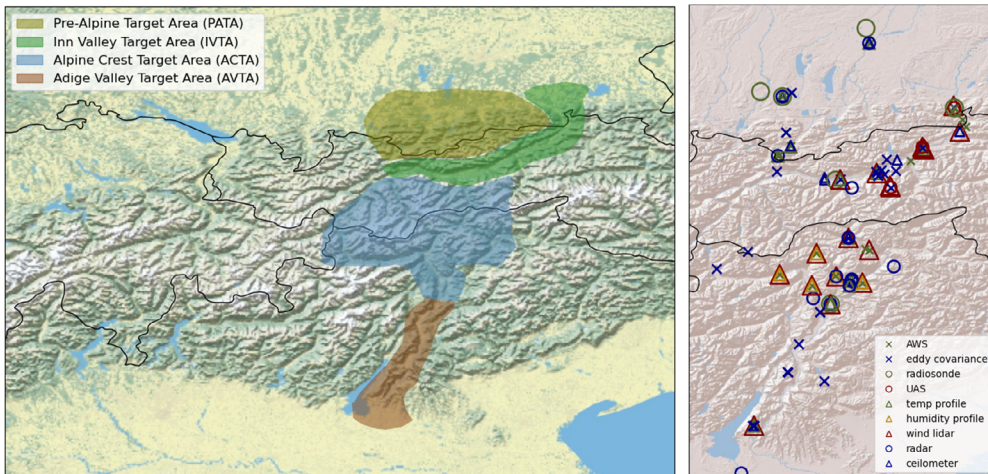


Figure 1. TEAMx observational domain with its four target areas (left), instrumentation during the summer EOP (right). The Sarntal Alps are located in the Alpine Crest Target Area, indicated by a cluster of red and yellow triangles (wind lidars and humidity profilers). See www.teamx-programme.org for an interactive map.

to observe katabatic winds. The vertical temperature and wind structure of the flow and its interaction with the valley wind aloft was observed using a Doppler wind lidar, a tethered balloon, and a UAS, while a network of eddy-covariance stations and a distributed temperature sensing system were deployed to observe the spatial variability of the turbulence characteristics and the small-scale temperature field along and across the slope. Measurements were conducted during a range of conditions from undisturbed, clear-sky nights with pure katabatic winds to dynamically-influenced conditions with foehn modifying the katabatic flow. During the sEOP, the full diurnal cycle of slope winds of both nighttime katabatic and daytime anabatic winds was targeted at a relatively homogeneous slope on Monte Baldo, Italy, near Lake Garda. Similar to the wEOP, the vertical flow structure and the turbulence characteristics were observed using Doppler wind lidars, a Raman lidar, a tethered balloon, and eddy-covariance stations. In addition, ozone and particulate matter were sampled at three locations to gain information about air-pollution transport by the slope winds. A more detailed synopsis of TOC activities will soon be published in the *Journal of the European Meteorological Society*.

Outlook

A wealth of data was collected during the one-year long TOC and the participating research groups are currently working on quality-controlling and post-processing their datasets. A TEAMx Data Management Plan has been produced, which outlines among other things the guidelines for sharing the TOC data within the TEAMx community and with the wider scientific community. Publication of all TOC datasets in public data repositories is envisaged until one year after the end of the TOC and, by that time, all published datasets should be accessible through the Earth Data Portal (<https://earth-data.de>).

The motivation behind this joint international effort was twofold: to collect a unique dataset that can be used both for gaining better process understanding and for evaluating and improving numerical weather and climate models. Several model intercomparison studies have already been started as part of the

TEAMx program using observational data from previous field campaigns, which can now be extended to TOC case studies. Ongoing TEAMx research projects also include studies focusing on the evaluation and improvement of model parameterizations (e.g., gravity wave drag and boundary-layer parameterizations) using observational data from the TOC, and plans exist to run a high-resolution (kilometer- to hectometer-scale) reanalysis for at least the two six-week long EOPs.

TEAMx is a bottom-up financed program, which means that all research groups financed their participation in the TOC through individual research grants from national and European funding agencies or through institu-

tional support. With some of these projects ending soon, new research proposals are being written continuously by members of the TEAMx community to fund further research. Collaborations within the TEAMx community for joint data analysis and modeling studies are being facilitated through ongoing work in six Working Groups focusing on different transport processes and though planned annual Workshops.

If you are interested in learning more about TEAMx, the TEAMx Observational Campaign, and other TEAMx activities, contact the TEAMx Programme Coordination Office (teamx-pco@uibk.ac.at) or visit the TEAMx website (www.teamx-programme.org).

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The Canadian HAWC: A Space Mission to Observe the Atmosphere from New Angles

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Water vapor, clouds, aerosols, radiation, and their interactions are crucial to the global energy and water exchange. At present, our understanding of the relevant physical processes and the accuracy of their representation in weather and climate models are limited by gaps in the observation of these critical climate variables.

In response to this imperative observational need, Canada has approved three innovative satellite instruments collectively called High-altitude Aerosols, Water vapour and Clouds (HAWC) to "improve extreme weather prediction, climate modelling, and monitoring of disasters" (<https://www.canada.ca/en/space-agency/news/2022/10/addressing-climate-change-with-satellites-canada-will-contribute-to-nasas-international-atmosphere-observing-system.html>).

HAWC uses a novel multi-instrument synergy, combining different viewing geometries (limb and nadir) to observe the atmosphere with unprecedented resolutions. The instrumentation includes:

- The **Aerosol Limb Imager (ALI)**, a limb-viewing multi-spectral, dual-polarization imager that measures scattered sunlight in the visible and near infrared to derive cloud and aerosol distributions in two-dimensional fields of view (vertical: 5–35 km; horizontal, cross-track: 300 km). It will capture fine cloud structures and aerosol properties with a vertical resolution of 0.5 km and a precision of 10%.
- **Spatial Heterodyne Observations of Water (SHOW)**, a limb-view spatial heterodyne spectrometer that measures scattered sunlight spectra in a micro-window in the water vapor vibrational absorption band near 1365 nm, to derive water vapor concentration profiles in the vertical range of 5–35 km, with a vertical resolution of less than 0.5 km and a precision of less than 1 ppmv.
- **Thin Ice Cloud and Far InfraRed Emission (TICFIRE)**, a nadir-viewing spectral imager with eight channels covering the energetically important spectrum (4–73 μm) of Earth's infrared thermal radiation and designed to maximize the information content of cloud microphysics. Its ground instantaneous field-of-view has a swath of 50 km and resolution of 1 km; its radiometric precision is 0.02 W/m²/sr and radiometric errors < 2%.

Combining nadir- (TICFIRE) and limb-views (SHOW and ALI), HAWC will make synergistic measurements of aerosols, water vapor, clouds, and their interactions with radiation, par-

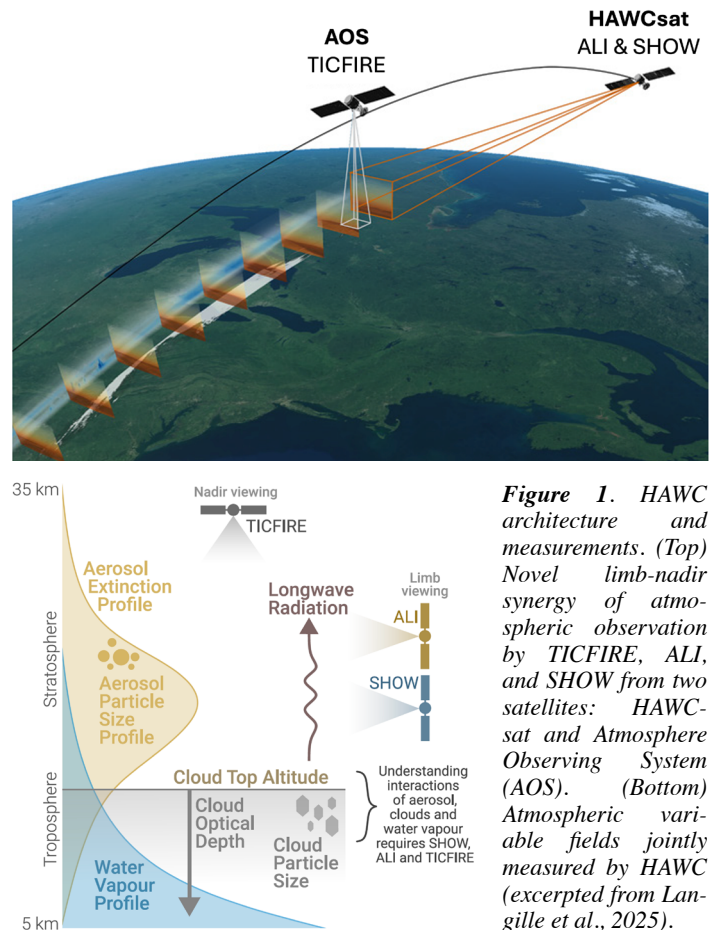


Figure 1. HAWC architecture and measurements. (Top) Novel limb-nadir synergy of atmospheric observation by TICFIRE, ALI, and SHOW from two satellites: HAWCsat and Atmosphere Observing System (AOS). (Bottom) Atmospheric variable fields jointly measured by HAWC (excerpted from Langille et al., 2025).

ticularly in cold and dry atmospheric regions such as over the Arctic and in the upper troposphere and lower stratosphere (UTLS). The synergy with complementary observations of other satellite(s), such as the National Aeronautics and Space Administration (NASA) Atmosphere Observing System, can provide more complete, whole atmosphere observations. The core products of HAWC include:

- UTLS water vapor
- UTLS aerosol extinction and particle size
- Cloud top altitude and optical depth
- Ice particle size and shape
- Longwave spectral radiance and irradiance

HAWC is scheduled to launch in the early 2030s and its development has been jointly led by a Canadian University Consortium, currently consisting of 15 universities across Canada, and the Canadian Space Agency, with contributions from other government agencies including Environment and Climate Change Canada and National Research Council Canada.

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Meeting/Workshop Reports

Advancing Machine Learning for Land Modeling: ML4LM 2025 Webinars and Workshop

10 December 2025
Online

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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.

Aligning with ML4LM Objectives

ML4LM is an initiative dedicated to exploring where and how machine learning can add value to land surface and Earth system studies. The project sits at the intersection of Earth system science, computer science, and data science, and is uniquely positioned to capitalize on:

- Rapid advances in high-performance computing and ML algorithms
- Increasingly accurate and diverse Earth observations, particularly satellite data
- A growing need for scalable, interpretable, and flexible land modeling approaches

Rather than viewing ML as a replacement for physical models, ML4LM emphasizes complementarity: identifying where ML can enhance existing land and Earth system models, improve process understanding, and enable new scientific insights.

As a GEWEX project, ML4LM also contributes toward the broader mission of evaluating and intercomparing modern ESM land models and supporting their application to major scientific and societal questions. This workshop aimed to scratch the surface of some of these aspects.

Reflections from the 2025 Webinar Series

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.

Where ML is already proving valuable is in targeted, science-driven applications, including:

- Benchmarking and model evaluation
- Parameter optimization and calibration
- Process understanding and hypothesis testing
- Ensemble generation and uncertainty quantification
- Data fusion across observations and models
- Remote sensing (RS) operators and observation-model links

Participants also 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.

Another recurring theme was modularity. Process-level modularization in land and Earth system models—where individual components can be swapped, augmented, or learned—could be strongly facilitated by ML, enabling more flexible experimentation and innovation.

The Central Challenges

Across all discussions, one message was clear: learning is only possible if we have data. However, data availability remains uneven.

Key questions raised during the workshop included:

- 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?

Addressing these questions is not just a technical challenge, but a scientific one that requires close collaboration between observational scientists, model developers, and ML practitioners.

To tackle these themes in depth, the ML4LM December 2025 Workshop was organized into four parallel sessions, each targeting a critical dimension of ML-enabled land modeling.

1. Data & Observations

This session focused on the foundation of all ML approaches: data. Topics included data availability and quality, integration of heterogeneous observations, infrastructure and workflows for large-scale data use, and identifying future data needs. Discussions emphasized the importance of community standards and open, well-documented datasets to enable reproducibility and shared progress.

2. Explainable AI and Physics-Informed Hybrid Modeling

Participants explored methods for interpreting ML models in the context of land processes. Talks and discussions addressed explainable AI, physics-informed and hybrid frameworks, and strategies for ensuring trustworthiness. A central goal was moving beyond black-box performance toward scientific insight, where ML helps reveal mechanisms rather than obscure them.

3. Benchmarking, Evaluation, and Uncertainty Quantification

This session addressed the need for common standards in ML4LM evaluation. How should ML-based land modeling approaches be compared fairly and rigorously? What are the unique challenges of uncertainty quantification in hybrid and data-driven models? The session also emphasized the importance of the lessons learned from other benchmarking projects such as the Land Surface Model Benchmarking Evaluation Project (PLUMBER2) and the International Land Model Benchmarking (ILAMB).

Discussions also linked technical evaluation to operational and societal relevance, emphasizing decision-making under uncertainty.

4. Extremes, Long-Range Prediction, and Transferability

The final session focused on some of the most demanding applications for ML in land and Earth system modeling: extremes, robustness under climate change, long-range prediction, and transferability across scales and regions. These challenges stress-test both data availability and model generalization, making them a critical proving ground for ML4LM approaches; they would also serve as the basis for future benchmarking of land and ESM ML-based models.

Looking Ahead

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. The schedule for the rest of 2026 can be found in the table below. We invite the community to join these seminars, share perspectives, and help shape the next phase of ML4LM*.

Acknowledgements

We would like to thank all speakers from the 2025 ML4LM webinar series (Dr. Peter Dueben, Dr. David Lawrence, Prof. Kei Yoshimura, Dr. Dan Lu, Prof. Christoph Rüdiger, Prof. Pierre Gentine, Dr. Nina Raoult, Prof. Nuno Carvalhais, Prof. Andrew Bennett, Prof. Gab Abramowitz) for sharing their expertise, insights, and time with the community, and to the GEWEX IPO for its support in coordinating the series. Their contributions played a key role in shaping the discussions at the December workshop. We are also grateful to everyone who participated in the workshop for sharing their ideas, experiences, and perspectives.

*Until the establishment of a dedicated ML4LM forum, interested speakers and those with suggestions are welcome to reach us through the GEWEX contact email, contact@gewex.org, with a mention of ML4LM in the subject line.

Schedule of Remaining 2026 ML4LM Webinars

Date and Time (UTC)	Title and Presenter
15 April 2026 15:30 UTC	Accelerating Land-Surface Modeling with Emulators: STEMMUS-SCOPE, Drought Detection, and SoilWat/ ISMC Updates <i>Prof. Yijian Zeng, University of Twente</i>
14 May 2026 15:30 UTC	Clustering Heterogeneity: The Opportunities It Enables for Land Surface Models <i>Prof. Nate Chaney, Duke University</i>
17 June 2026 15:30 UTC	Enhanced Land Surface Data Exploitation Using Machine Learning in Weather Prediction Systems <i>Dr. Patricia de Rosnay, ECMWF</i>
15 July 2026 14:30 UTC	Using ML to Identify Conditions of Underperformance in LSMs under the PLUMBER2 Framework <i>Dr. Jon Cranko Page, University of Oulu</i>
15 September 2026 15:30 UTC	Sparky – A Hybrid Fire Model for LSMs <i>Dr. Joe McNorton, ECMWF</i>
15 October 2026 15:30 UTC	Leveraging In Situ and Remote Sensing Observations to Support ML Modeling of Land Surface Processes <i>Prof. Marouane Temimi, Stevens Institute of Technology</i>
12 November 2026 14:00 UTC	Physics-Informed Machine Learning for Land Data Assimilation <i>Prof. Xin Li, Chinese Academy of Science, ITPCAS</i>
10 December 2026 15:30 UTC	Key Challenges and New Scientific Studies for Improving Our Understanding of the L-A System <i>Prof. Volker Wulfmeyer, University of Hohenheim</i>

Progress Towards a Better Understanding of Land Temperature Anomalies over Tibetan Plateau and Rocky Mountains as a New First-Order Source of the Global S2S Precipitation Predictability in Summer and Winter: GEWEX/LS4P-II Highlights

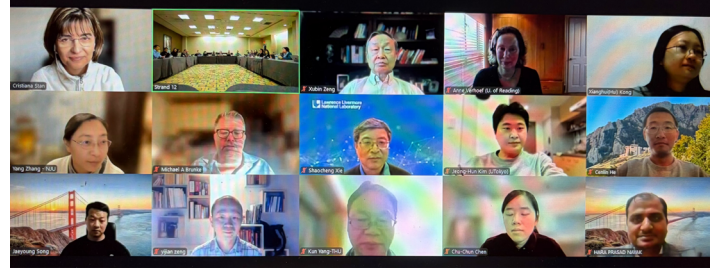
14 December 2025
New Orleans, LA, USA

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The GEWEX/Impact of Initialized Land Temperature and Snowpack on Sub-Seasonal to Seasonal Prediction (LS4P) Phase I study identified springtime land surface/subsurface temperature (LST/SUBT) anomalies over the high-elevation Tibetan Plateau (TP) as a first-order new source of subseasonal to seasonal (S2S) predictability of summer extreme hydroclimate events in global “hotspot” regions. LS4P Phase II, which started in 2023, has made substantial efforts to further advance this research in several areas. During the 2025 American Geophysical Union (AGU) Annual Meeting in New Orleans, the Sixth GEWEX/LS4P International Workshop was held on 14 December 2025 with 26 in-person attendees and 30 remote participants from 11 countries (<http://ls4p.geog.ucla.edu/meetings>). The workshop reviewed LS4P-related research and achievements over the past two years, reported on the status of the LS4P Phase II experiment, and presented its preliminary results. To gather broader community input for better planning of future LS4P activities, an LS4P Steering Committee was established, which includes, in addition to the LS4P Co-Chairs, Frédéric Vitart (European Centre for Medium-Range Weather Forecasts), Qi Tang (Lawrence Livermore National Laboratory, or LLNL), Yuhei Takaya (Meteorological Research Institute/Japan Meteorological Agency), and Jianping Tang (Nanjing University).

LS4P-I focused only on the effects of TP spring 2003 LST/SUBT on global summer 2003 precipitation. Since then, an expanded set of case studies has been conducted, including extreme precipitation events in July 2020 (Fan et al., 2024), June 2022 (Kong et al., 2025), June 2024 (Li et al., 2025), and June 1998 (Nayar et al., 2025) in East Asia and North America. All these case studies confirm the critical role of TP land surface heating in S2S summer prediction. The case study of the June 2024 extraordinary precipitation event began in June and concluded in July 2024, making it very close to a real-time prediction. Given the increase in extreme hydroclimate events in recent years, improved soil temperature data have been assimilated for TP LST/SUBT initialization for multi-



Online and in-person participants of the Sixth GEWEX/LS4P International Workshop

year hindcast experiments by groups participating in LS4P. The preliminary results are very promising. In addition, snow and soil moisture, their relationships with soil temperature, and their combined effects on monsoon prediction have also been investigated in several studies (e.g., Takaya et al., 2025).

Recent LS4P research has expanded from summer to winter case studies. During the winters of 2016/2017 and 2022/2023, California and adjacent regions received record-breaking precipitation, causing extraordinary damage and severe societal impacts. A fundamental lack of predictability for these events has been speculated, because they have not been successfully predicted at S2S scales by existing forecast systems or reproduced in hindcast/case studies. In addition, they occurred during La Niña conditions, which are traditionally associated with dry conditions in California. Based on combined observational analyses and global model experiments, a study found that anomalous heating over the TP during early winter played a key role in driving these two extreme events. After imposing a temperature mask during initialization over the TP in an LS4P Earth system model (ESM), it was found that catastrophic winter precipitation events in California and

adjacent regions were predictable from remote TP surface conditions, further identifying high-elevation terrestrial thermal anomalies as a new source of S2S predictability for winter hydroclimate extremes.

Comprehensive investigations in LS4P-II have been carried out to understand the mechanisms of remote, high-elevation land heating-atmosphere interactions. The Tibetan Plateau–Rocky Mountain Circumglobal (TRC) wave train has been identified as strongly associated with the global-scale influence of TP temperature anomalies. Its characteristics in observations and model simulations, including results from Coupled Model Intercomparison Project Phase 6 (CMIP6) experiments under different scenarios, have been comprehensively examined. Different responses of the TRC wave train to TP thermal anomalies in summer and winter seasons have been identified and investigated in diagnostic studies. The effect of orographic drag in modulating downstream Rossby waves and precipitation induced by TP land temperature anomalies was assessed. Initial results suggest that this may be an important process requiring careful consideration in LS4P studies. Furthermore, the LS4P-II temperature-perturbation experiment revealed that the models showed asymmetric sensitivity to warm versus cold perturbations. This warm–cold asymmetry, identified in several LS4P ESMs, appears to be associated with soil thermal processes—especially soil water–ice and snow phase changes, along with the corresponding impacts on effective soil heat capacity.

Preliminary results from LS4P-II ESM experiments have been analyzed within the framework of the GEWEX/LS4P Phase-II protocol (<http://ls4p.geog.ucla.edu>). The experiments focus on the year 1998, when a severe summer drought occurred in Texas and Oklahoma, with an extraordinary cold spring in the western U.S., and severe flooding in the Yangtze River Basin associated with an anomalously warm spring over the TP. In addition, 1998 was a strong El Niño year, implying that a strong sea surface temperature effect is expected; this will be compared with the impact of high-elevation LST/SUBT. Sixteen ESMs are participating in this coordinated experiment. Among them, six ESMs [the China Meteorological Administration Beijing Climate Center–Atmospheric General Circulation Model (CMA BCC-AGCM), the Centre National de Recherches Météorologiques contribution to CMIP6 (CNRM-CM6-1), the Indian Institute of Tropical Meteorology–Climate Forecast System (IITM-CFS), the Korea Institute of Atmospheric Prediction Systems/Korean Integrated Model–Noah Multiparameterization model (KIAPS-KIM/Noah-MP), the LLNL Energy Exascale Earth System Model (LLNL-E3SM), and the University of California, Los Angeles–Global Forecast System (UCLA-GFS)] have uploaded their results to the database, and another eight are actively conducting simulations. The preliminary analysis of six ESMs has shown encouraging results. Spring LST/SUBT anomalies over both the TP and western U.S. account for about 50% of observed summer precipitation anomalies in the Yangtze River Basin and southern U.S., demonstrating a strong teleconnection be-

tween East Asian and North American atmospheric circulation. Further analysis for individual ESM simulations reveals that models producing TP 2m temperature anomalies closer to observations generate more realistic precipitation anomalies in remote regions compared to models producing weaker TP 2m temperature anomalies. The LS4P Phase-II experiment is expected to be finished by the end of the summer of 2026. LS4P-II group papers are expected to be completed in 2027 or early 2028. LS4P-III, which, after the TP and Rocky Mountains land temperature investigation, will focus on the Andes LST/SUBT effect on Southern Hemisphere circulation, is expected to start in late 2028. Prototype research for LS4P-III is planned prior to its formal launch.

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Share your GEWEX experiences and activities, including scientific research results and other information associated with global water and energy cycle studies. Articles should be 800–2400 words (1–3 pages) and feature 1–2 figures. If you have an idea for a piece, please contact us at gewex@gewex.org.

Advancing Our Ability to Simulate Extreme Precipitation in Coastal and Tropical Regions

5-7 August 2025
Hong Kong

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The Ninth Convection-Permitting Climate Modeling (CPCM) Workshop was held at the Hong Kong University of Science and Technology in August 2025, bringing together more than 120 scientists from Asia, Europe, Australia, and North America (Figure 1). The meeting focused on how kilometer-scale atmospheric models, together with new observations and diagnostics, can improve understanding and prediction of extreme precipitation in regions that are increasingly vulnerable to climate-driven hydrometeorological hazards such as coastal, mountainous, and urban environments.

Extreme rainfall lies at the intersection of GEWEX science because it links atmospheric dynamics, cloud microphysics, land-surface processes, and hydrology, while directly shaping societal impacts such as flooding, landslides, and water-resource stress. Rapid urbanization in many tropical and subtropical regions further amplifies these risks, creating demand for climate information at short-duration and local scales. Convection-permitting models (CPMs), operating at grid

spacings of a few kilometers or less, now offer a promising pathway to address these challenges, but their capabilities and limitations remain active research topics.

A major theme of the workshop was progress in CPM simulations across a range of climates. Results from regional and global models showed that increasing horizontal resolution improves the representation of moist deep convective structures, rainfall intensities, and seasonal precipitation biases. In monsoon regions and tropical cyclone environments, finer resolution tends to produce more intense and better-organized extremes, consistent with theoretical expectations under warming. However, participants emphasized that resolution alone does not solve all problems. Biases in storm timing, diurnal cycles, and spatial clustering partly remain, particularly in the tropics, where boundary-layer processes, cold pools, and cloud microphysics strongly influence convective organization.

Beyond peak intensities, the meeting highlighted the importance of rainfall structure and duration. Short-lived, high-intensity convective bursts are key drivers of urban flash flooding, while longer-lasting, large-scale precipitation events produce widespread river flooding. Presentations showed how storm interactions, moisture transport, and orographic forcing shape extreme events, and how changes in storm clustering and persistence may be contributing to growing flood risks in some regions. Understanding and simulating the transition from isolated cells to organized, long-lived systems remain a central challenge for high-resolution modeling.

Progress in modeling is closely tied to advances in observations and diagnostics. Several contributions showcased expanding radar networks, denser rain-gauge arrays, and tar-



Figure 1. The in-person participants of the 9th CPCM workshop at the Hong Kong University of Science and Technology

geted field campaigns across East and Southeast Asia that provide the fine-scale data needed to evaluate CPMs. New analysis tools were introduced to quantify convective initiation, cold-pool dynamics, storm clustering, and rainfall intermittency, helping to move beyond bulk precipitation metrics toward more process-based model evaluation.

Machine learning is also becoming an important complement to modeling and analysis. Workshop presentations demonstrated applications ranging from statistical downscaling and bias correction to nowcasting of prediction and convective activity. Long, high-resolution CPM datasets and regional reanalyses were highlighted as valuable training resources for these methods, enabling hybrid approaches that combine physical realism with computational efficiency.

The meeting placed strong emphasis on societal relevance. Case studies from Hong Kong, Southeast Asia, and Australia illustrated how sub-hourly rainfall increasingly overwhelms urban drainage systems. Prototype early-warning systems that integrate CPM output with real-time radar and gauge data showed promise for improving short-lead-time flood forecasts. In mountainous regions, high-resolution simulations are helping to identify moisture-convergence hotspots and rainfall enhancement mechanisms that are critical for landslide and flood risk management.

Despite these advances, significant challenges remain in predicting fast-evolving, weakly-forced convective storms, which are often responsible for the most damaging sub-daily extremes in data-sparse tropical urban environments. These extremes are inherently difficult to simulate accurately due to their rapid evolution, strong sensitivity to local land-atmosphere interactions, and the lack of dense observational networks in many tropical cities. Computational constraints limit the length, ensemble size, and spatial coverage of kilometer-scale simulations, forcing difficult trade-offs between physical realism, robustness, and operational feasibility. Participants also emphasized the urgent need for standardized diagnostics, shared observational datasets, and coordinated model intercomparison efforts to ensure that model improvements are robust and transferable across regions.

Looking ahead, the CPCOM community identified priorities that align closely with GEWEX goals: expanding dense observation networks in vulnerable regions, coordinating CPM intercomparison projects focused on extremes, and developing open-source diagnostic toolkits. Capacity building through data sharing, training, and collaborative modeling was emphasized, as was the need to incorporate human influences such as urbanization, land-use change, and water management into high-resolution modeling frameworks. Together, these efforts will help translate scientific advances in kilometer-scale modeling into more reliable and actionable climate information for a warming world.

GEWEX/WCRP Calendar

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

13–17 April 2026—6th Baltic Earth Conference—Usedom Island, Germany

22–23 April 2026—9th GEWEX Water Vapor Assessment (G-VAP) Workshop—Copenhagen, Denmark

3–8 May 2026—EGU General Assembly 2026—Vienna, Austria, and Online

12–14 May 2026—4th Workshop on Central Asia—Osh, Kyrgyz Republic

20–22 May 2026—10th International Conference on Flood Management (ICFM10)—London, ON, Canada

1–5 June 2026—2nd GEWEX Earth's Energy Imbalance Assessment Workshop—Pasadena, CA, USA

22–26 June 2026—19th BSRN Scientific Review and Workshop—Palaiseau, France

22–26 June 2026—Summer School on Runoff Predictions in Ungauged Basins—Vienna, Austria

24–26 June 2026—2026 GHP Meeting—Medellín, Colombia

6–9 July 2026—2026 Pan-GLASS Conference—Stuttgart, Germany

10 July 2026—2026 GLASS Panel Meeting—Hohenheim, Germany

13–17 July 2026—ParaChute Conference—Reading, UK

14–16 July 2026—2026 GDAP Meeting—Montreal, Canada

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