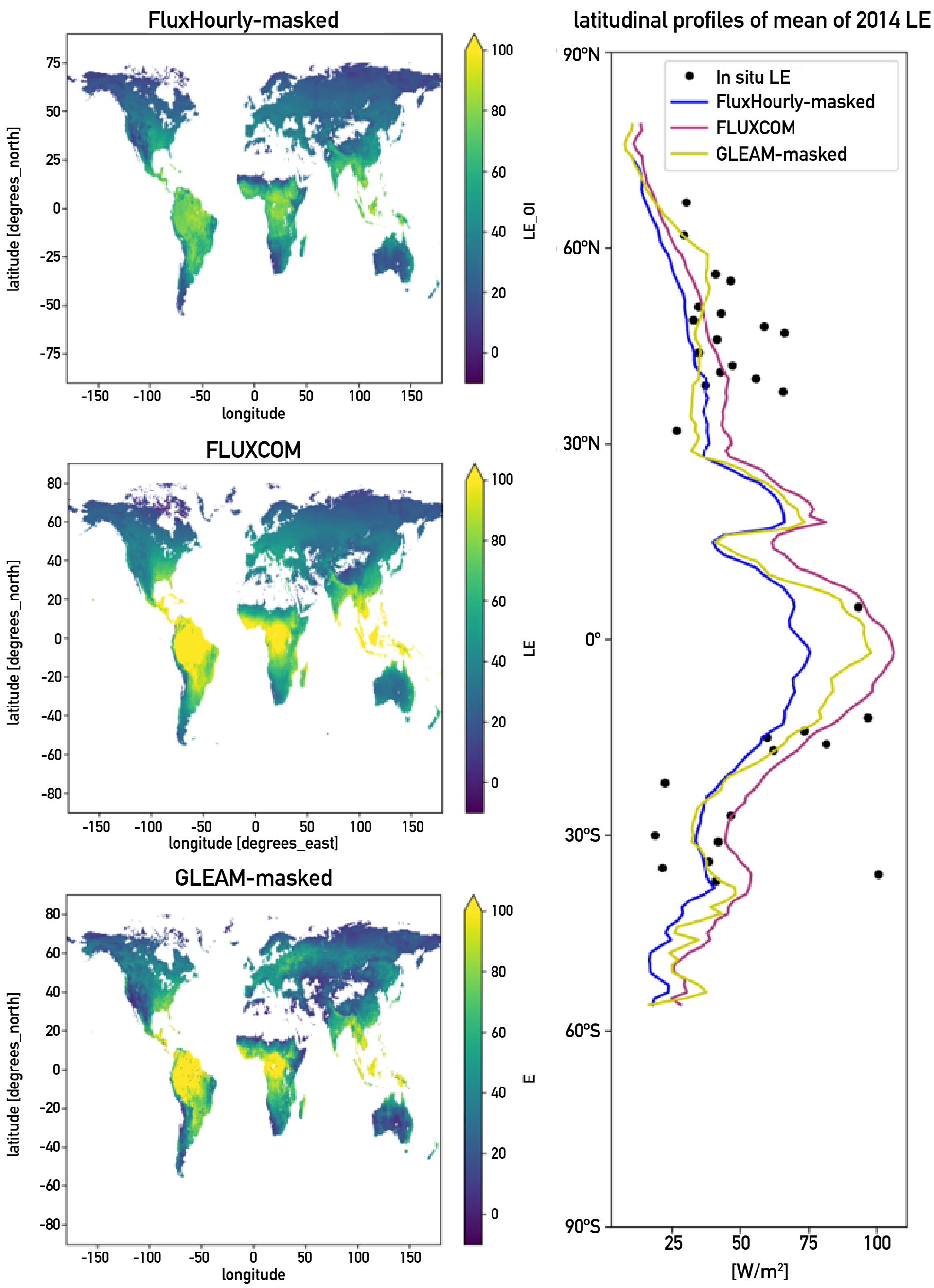
GEWEX QUARTERLY

WCRP

Vol. 36, No. 2 | Quarter 2 2026

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

Phase II of the Determining Evapotranspiration Initiative



Annual average values of daily latent heat flux (LE) predicted by FluxHourly, FLUXCOM, and GLEAM in 2014 (Han et al., 2025). See Jia et al. on pg. 6 for more.

Inside This Edition

Commentary

General

Save the Date

The 4th Pan-Global Atmospheric System Studies (GASS) meeting, *Understanding and Modelling Atmospheric Processes* (UMAP 2027), will take place in Bremerhaven, Germany from 5–9 July 2027. Check out the details on page 13 or visit *https://www.gewexevents.org/meetings/umap2027/* for more information!

Commentary

Jason Evans
Co-Chair, GEWEX Scientific Steering Group

It is easy, at present, to feel that the world is moving backwards. Wars are destroying lives, livelihoods, and infrastructure. Anti-science rhetoric is being used politically in many countries. For many Earth system scientists, this is a dispiriting moment. But this is not the full story, and positive changes are occurring too.

The global energy system is changing at a scale that would have seemed unlikely not long ago. Ember's *Global Electricity Review 2025* found that renewables plus nuclear supplied 40.9% of global electricity in 2024, with renewables increasing fast. This is an industrial-scale transformation of the infrastructure that underpins modern society. The momentum is expected to continue: the International Energy Agency (IEA) projects global renewable power capacity to increase by almost 4,600 GW between 2025 and 2030, roughly double the previous five years.

Transport is electrifying just as rapidly. Electric vehicles were a small fraction of the global car market in 2020; by 2025, they accounted for more than 25% of new car sales. In China, the world's largest car market, electric and plug-in hybrid vehicles passed 50% of new car sales in 2025. We are living through a transformation of road transport on a scale not seen since the car replaced the horse and cart.

Energy investment tells the same story. The IEA estimates that global energy investment reached a record US $3.3 trillion in 2025, with about US $2.2 trillion going to clean energy technologies. This matters because capital expenditure is a leading indicator of future energy systems and emissions pathways. Grids, batteries, solar modules, wind turbines, heat pumps, and electric vehicles are now major economic sectors, not simply climate aspirations.

These developments are also reflected in our own modeling community. The Coupled Model Intercomparison Project Phase 7 (CMIP7) Scenario Model Intercomparison Project (ScenarioMIP) emissions scenarios include a high-emissions pathway notably lower than the high-end pathway used in CMIP6. Van Vuuren et al. note that "the CMIP6 high emission levels [quantified by Shared Socio-economic Pathway 8.5 (SSP5-8.5)] have become implausible, based on trends in the costs of renewables, the emergence of climate policy and recent emission trends". This is recognition that policy, technology, and economics have shifted the plausible envelope of future emissions.

There is also reason for optimism within the science itself. The exceptional warmth of 2023 and 2024 has sharpened attention on Earth's energy imbalance (EEI) and the possibility that the rate of warming may be changing. For GEWEX, these findings connect planetary energy imbalance, surface fluxes, circulation variability, ocean heat content, and regional hydroclimate impacts into a single evolving picture of climate change. Some of this was discussed at the 2nd GEWEX EEI Assessment Workshop: *https://www.gewexevents.org/meetings/eei2026/*.

Kilometer-scale climate modeling is another important advance. By resolving deep convection and representing topography, coastlines, storms, and land–atmosphere contrasts more realistically, these simulations reduce our dependence on some long-standing parameterizations. They reveal how organized convective systems shape tropical rainfall, how mesoscale circulations influence clouds and precipitation, and how extremes emerge from interactions among moisture, radiation, turbulence, and surface fluxes. For GEWEX, this brings the water and energy cycles into sharper focus, improving our ability to study intense precipitation, atmospheric rivers, mountain precipitation, etc. These models also expose remaining uncertainties in cloud microphysics, aerosol-cloud interactions, and land-surface processes.

It would be better if the energy transition were faster, and if climate science received more sustained funding and public attention. But progress is happening. The highest-emission futures have become less plausible, clean technologies are being deployed at unprecedented scale, and our scientific tools are improving. Many unresolved questions remain about the global water and energy cycles, extremes, feedbacks, and regional change. But for a moment, it is worth recognizing that change is underway. We should celebrate that and face the scientific challenges ahead with determination and optimism.

[1]Van Vuuren, D.P.; O'Neill, B.C.; Tebaldi, C. et al. The Scenario Model Intercomparison Project for CMIP7 (ScenarioMIP-CMIP7). *Geoscientific Model Development* **2026,** *19* (7), 2627–2656. doi:https://doi.org/10.5194/gmd-19-2627-2026.

Table of Contents

Essential Water Variables (EWVs) Survey: Results and Analysis

Sushel Unninayar[1, 2], Richard Lawford[4], John Bolton[1], George Huffman[1], Angelica Gutierrez[3], and Jared Entin[5]

[1]Goddard Space Flight Center, Greenbelt, MD, USA; [2]Morgan State University, Baltimore, MD, USA; [3]GEO Secretariat–GEOGLOWS, WMO Geneva, Switzerland; [4]University of North Dakota, Grand Forks, ND, USA; [5]National Aeronautics and Space Administration, Washington, DC, USA

Introduction

Essential Water Variables (EWVs) are a set of fundamental variables that are critical for monitoring, understanding, and managing the Earth's water resources. The concept is analogous to Essential Climate Variables (ECVs) and is crucial for addressing global and regional water cycle challenges. The requirements for these variables are designed to ensure that the data collected is relevant, feasible, and cost-effective for a wide range of users, from scientific researchers to water resource managers and policymakers. We issued a survey to over 500 Earth Observation (EO) researchers and practitioners across multiple disciplines, with an estimated 10% response rate, to determine user perspectives around EWVs. Results provide valuable insights into user needs for water-related data across various sectors, providing a basis for informing future observing systems and data distribution mechanisms.

For a water variable to be considered "essential," it must meet several key criteria. These criteria are established through community consensus, often led by organizations like the Group on Earth Observations (GEO) (*https://earthobservations.org/*). The primary considerations include:

Relevance: The variable must be critical for characterizing the state and changes in the water cycle. This includes its role in scientific understanding, as well as its importance for policy and decision-making.

Feasibility: It must be technically and economically possible to observe the variable on a global or regional scale using established and scientifically sound methods.

Accuracy and Precision: Measurements must accurately represent real-world conditions.

Cost-Effectiveness: The cost of implementing, maintaining, and archiving the data for the variable should be justifiable.

Sustainability: Long-term monitoring commitment is essential.

The survey, built on concepts from the Global Earth Observation System of Systems (GEOSS) Water Strategy Report (*https://ceos.org/document_management/Ad_Hoc_Teams/WSIST/WSIST_GEOSS-Water-Strategy-Full-Report_Jan2014.pdf*) and the Global Water Sustainability (GEOGLoWS) Initiative (*https://www.geoglows.org/*), was conducted using a Google Form (*https://forms.gle/C4DKtwhTVf6qpmbx8*) during 2023–2025. Initial results were presented at the American Geophysical Union 2024 Fall Meeting and the American Meteorological Society 2025 Annual Meeting to gather additional feedback and improve statistical representation.

Survey Participation by Discipline/Sector

The survey reached a diverse array of water-related disciplines and sectors:

Discipline/Sector	Responses	Percentage
Hydrological (surface and groundwater)	33	66%
Climate change (UN-FCCC, IPCC, etc.)	29	58%
Agricultural (including forests)	24	48%
Environmental (including urban)	23	46%
Meteorological (atmospheric, weather, climate)	22	44%
Land surface/vegetation, forests & ecosystems	20	40%
Sustainable development (UN-SDGs)	16	32%
Renewable energy (wind, solar, hydroelectric, etc.)	14	28%
Cryospheric (snow/ice, glaciers, etc.)	12	24%
Health (air pollution, air/water/vector borne disease)	6	12%
Chemical engineering, waste management	1	2%
Mining impacts on the hydrological cycle	1	2%

Key Insights:

- Disciplines or sectors that deal with one or more elements of the atmosphere-ocean, land-vegetation water cycle dominate respondent profiles, with hydrological work being most common (66%)
- Climate change and agricultural sectors show strong representation (58% and 48% respectively)
- Strong representation also exists in environmental and meteorological fields (mid-40% range)
- Specialized areas like health and Earth observations are underrepresented as are advanced engineering and specific geosciences

Primary Essential Water Variables

Respondents identified which Primary EWVs they either currently use or plan to use:

Rank	Essential Water Variable	Responses	Percentage
1	Precipitation	40	80%
2	Groundwater	32	64%
3	Evapotranspiration	30	60%
4	Snow	30	60%
5	Runoff/Streamflow/ River discharge	27	54%
6	Evaporation	26	52%
7	Water quality	24	48%
8	Surface water extent	23	46%
9	Lake/Reservoir levels & storage	19	38%
10	Soil moisture	13	26%
11	Water use/demand	11	22%

Additional variables (each with 1 response/2%): Water stress, Water vapor variations, Wastewater/energy/nutrients, Fertilizers, Surface water storage, Solar irradiance/photosynthesis

Key Insights for primary variables:

- Core hydrological cycle components dominate, with precipitation being most widely used (80%)
- Despite surface water variables having strong representation, groundwater ranks second (64%), highlighting its importance
- Both atmospheric (evapotranspiration) and cryospheric (snow) components show equal importance (60%)
- Emerging or indirect factors have minimal adoption, possibly due to data limitations or perceived relevance

Supplemental Essential Water Variables

In addition to primary EWVs, respondents identified complementary, supplemental variables as:

Rank	Essential Water Variable	Responses	Percentage
1	Land cover, vegetation	37	74%
2	Land use	36	72%
3	Surface meteorology	28	56%
4	Elevation/topography	26	52%
5	Surface & atmospheric radiation	16	32%
6	Clouds & water vapor	15	30%
7	Surface altimetry	12	24%
8	Permafrost	12	24%
9	Geological stratification	9	18%
10	Bathymetry	8	16%
11	Aerosols	7	14%

Additional variables (each with 1–2 responses): Pandemic disease outbreaks, Other unspecified variables (2%)

Key Insights for secondary variables:

- Land-based variables are essential, with land cover/vegetation (74%) and land use (72%) leading by a significant margin
- Meteorological and topographic data are crucial for hydrological assessments
- Specialized variables like geological stratification, bathymetry, and aerosols see limited uptake
- Health-related variables have minimal representation

Preferred Spatial Resolutions

Both space and time resolutions are dependent on the variable. Some, for example, rain, can include both short variations and longer time scales while ground water varies more slowly and weekly or even longer time scales might be appropriate.

Respondents indicated their preferred spatial resolutions for EWVs:

Spatial Resolution	Scale	Preference (%)
L3 (100 m–1 km)	Local	50.0%
L2 (10 m–100 m)	Local	47.8%
R/G1 (1 km–10 km)	Regional/Global	47.8%
L1 (1 m–10 m)	Local	37.0%
R/G2 (10 km–100 km)	Regional/Global	28.3%
R/G3 (100 km–250 km)	Regional/Global	19.6%
R/G4 (>1000 km)	Regional/Global	4.3%
Both Local & Regional/Global	Mixed	2.2%

Key Insights:

- Strong preference for local-scale resolutions, particularly in the 100 m to 1 km range (50%), and 10 m to 100 m range (47.8%)
- Regional scales (1 km–10 km) remain important (47.8%), suggesting system-wide analysis needs
- Interest declines significantly for coarser resolutions beyond 100 km
- Results indicate prioritization of detailed plot-scale analysis capabilities

Preferred Temporal Resolutions

The survey examined preferred time resolutions for EWVs:

Time Resolution	Responses	Percentage
T3: 1–10 days	28	36.8%
T2: 3 hr–1 day	25	34.2%
T4: 10 days–1 month	20	26.3%
T1: 1 hr–3 hr	16	21.1%
T5: 1 month–3 months	15	19.7%
T6: 3 months–1 year	12	15.8%
T7: 1 year–10 years	8	10.5%
T8: >10 years	3	3.9%

Key Insights:

- Intermediate time scales (1–10 days) are most preferred (36.8%)
- Sub-daily to daily temporal resolutions are also highly valued (34.2%)
- Preferences follow a bell-shaped distribution, with declining interest toward both finer and coarser extremes
- Results support the principle that local spatial scales require finer temporal resolutions

Preferred Data (Availability) Latency

Respondents indicated their requirements for data distribution timeliness:

Time Latency Category	Description	Responses	Percentage
TL4	1 week	23	48.9%
TL6	1 month	21	44.7%
TL1	3 hours	15	31.9%
TL2	3–24 hours	13	27.7%
TL5	10 days	12	25.5%
TL8	1 year	12	25.5%
TL3	1 day	11	23.4%
TL7	3 months	5	10.6%
TL10	10+ years	5	10.6%
TL9	5 years	3	6.4%

Key Insights:

- Distribution shows bimodal preferences: weekly (48.9%) and monthly (44.7%) latencies
- Significant interest exists for very short latencies (3 hours: 31.9%)
- Results confirm that different applications require varied latency capabilities
- Data systems should implement multi-tiered distribution to meet diverse user needs

Preferred Data Forms/Formats

Respondents indicated their preferred data formats for EWVs:

Rank	Essential Water Variable	Responses	Percentage
1	Time series	32	65.3%
2	Grid fields	28	57.1%
3	Maps	25	51.0%
4	Tables	21	42.9%
5	Digital	20	40.8%
6	Graphical	12	24.5%
7	Specialized formats (Netcdf, Raster)	2	4.0%

Key Insights:

- Temporal data (time series) are most valuable, selected by nearly two-thirds of respondents
- Spatial data (grid fields and maps) are also highly valued by more than half of respondents
- Raw/structured data formats are generally preferred over graphical representations

Most users require multiple data formats, suggesting that flexibility in data delivery systems is important.

Summary and Key Takeaways

This international survey on Essential Water Variables (EWVs) highlights a growing consensus around the core requirements for observing and managing the global water cycle. The survey reached a broad and diverse set of stakeholders across scientific disciplines, application sectors, and geographical regions.

The majority (>50%) of respondents self-identified their discipline or sector as (dominantly) from hydrology (66%) and climate change (58%), followed by strong interest (>40%) from agriculture (48%), environment (46%), meteorology (44%), and land surface/vegetation (40%). The distribution tapers off with sustainable development (32%), renewable energy (28%), cryosphere and snow/ice (24%), and health (12%). It is noted that the "respondent" distribution may impact the results of the survey in, for example, the choice of the variables, their space/time resolutions, and latency requirements.

Key insights include:

1. **Strong Demand for Standardization and Accessibility**: Respondents emphasized the need for consistent data formats and open-access repositories to support interoperability and broad usage across sectors.
2. **Core EWVs Prioritized Across Sectors**: A majority (>50%) of respondents identified the most important variables as precipitation (80%), groundwater (64%), evapotranspiration (60%), snow (60%), runoff/streamflow

(54%), and evaporation (52%). Other variables also highlighted, though to a somewhat lesser degree, include: water quality (48%), surface water extent (46%), lake/reservoir levels (38%), soil moisture (26%), and water use/demand (22%). The primary supplemental variables chosen (>50%) were land cover/vegetation (74%), land use (72%), surface meteorology (56%), and elevation/topography (52%). Supplemental variables are frequently needed in conjunction with primary EWVs for assessing and managing water resources. There is a need to better coordinate in situ observing networks combined with satellite data to be able to deliver end products that are useful to a broad, multi-sectoral clientele. Data assimilation techniques would play a key role in data and information delivery systems.

3. **Spatial Resolution Requirements Vary by Use Case**: Local-scale applications (e.g., flood forecasting) require high spatial and temporal resolution, while broader climate assessments can accommodate coarser resolutions and longer data latency. Typically, the 100 m–1 km scale is used for detailed analysis while the 1 km–10 km scale is chosen for regional to global system-wide assessments.

4. **Balanced Temporal Resolution**: Intermediate time scales (1–10 days) were identified as the most important for multi-purpose research and applications, while sub-daily measurements are critical for some end-user needs.

5. **Tiered Data Latency Distribution**: Observing and data systems need to be capable of delivering integrated products combining in situ and satellite data (e.g., through data assimilation techniques) at different latencies such as:
   - Daily to weekly or 10-day updates for most applications
   - Near-real-time (3-hour to 1 day) delivery for time-sensitive uses

6. **Flexible Data Formats**: The provision of multiple data formats was considered necessary with emphasis on time series, gridded fields, and map representations.

7. **Observational Context Integration**: Supplementary data on land cover/use, among other data, was considered important to make available alongside core water variables. Often, models and decision-making systems require multi-parameter analysis that integrates a broader context than any one individual observation type, e.g., water stress, water budgets, and water resources management.

8. **User-Specific Customization**: It is important to build flexible data delivery systems that allow users to specify their required data or product resolution, latency, and format.

These findings could provide valuable guidance for the design of future Earth observation systems and data assimilation products focused on water resource monitoring and management.

Acknowledgements

The support from NASA WSB# 281945.02.14.05.19 is gratefully acknowledged.

Determining Evapotranspiration (dET): Call for Contributions to the Second Phase of a GEWEX Cross-Cut Initiative

Li Jia[1], Bob Su[2], Volker Wulfmeyer[3], Nathaniel Chaney[4], Tristan L'Ecuyer[5], Paola Arias[6], Rowan Fealy[7], and Peter J. van Oevelen[8]

[1]State Key Laboratory of Remote Sensing and Digital Earth, Aerospace Information Research Institute (AIR), Chinese Academy of Sciences (CAS), Beijing, China; [2]Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, Enschede, The Netherlands; [3]Institute of Physics and Meteorology, University of Hohenheim, Stuttgart, Germany; [4]Duke University, Durham, NC, USA; [5]University of Wisconsin, Madison, Wisconsin, USA; [6]Universidad De Antioquia, Medellín, Colombia; [7]Maynooth University, Maynooth, Co. Kildare, Ireland; [8]International GEWEX Project Office, George Mason University, USA

Why Is It Important to Accurately Determine ET?

Evapotranspiration (ET) is a fundamental process linking Earth's water, energy, and carbon cycles. It accounts for roughly 60% of land precipitation returning to the atmosphere and is crucial for predicting water cycle changes, managing agricultural water use, modeling climate extremes, and informing adaptation strategies. Accurate ET quantification is therefore essential for addressing GEWEX's core science goals related to water cycle prediction and understanding anthropogenic influences.

What Were the Previous GEWEX Activities Related to dET?

GEWEX's engagement with ET began with informal discussions at the 2018 Open Science Conference in Canmore, followed by a reflection paper in *GEWEX News* (Cuxart et al., 2019) outlining four key challenges: definition and understanding, in situ measurement, parameterization, and remote sensing and catchment-scale estimation. This led to the first Determining Evapotranspiration (dET) workshop in October 2019 with five themes (Verhoef at al., 2020): open water, landscape-scale, interception, transpiration, and soil evaporation. A second, innovative online workshop in February 2021 consolidated community priorities (Hartogensis et al., 2021) and directly paved the way for the formal launch of the Crosscutting project on determining EvapoTranspiration (CC-dET) under the GEWEX Hydroclimatology Panel (GHP) in 2022. CC-dET is also considered a joint activity with the Global Land-Atmosphere System Studies (GLASS) Panel, and contributes to key sessions of the first international Pan-GLASS Conference (*https://www.gewexevents.org/meetings/glass2026*) occurring this July. A major milestone for the dET initiative was the 1st Land surface Interactions with the Atmosphere over the Iberian Semi-arid Environment (LIAISE) Conference and dET CrossCut Workshop in Lleida, Spain, in March 2023, which served as a key synthesis point for early campaign results and community planning (Boone et al., 2023).

What Are the Components of ET and How are They Defined?

ET is an aggregate flux comprising distinct physical processes:

- Transpiration: water vapor release through plant stomata during photosynthesis
- Soil Evaporation: direct vaporization from soil surfaces
- Interception Loss: evaporation of water intercepted by vegetation canopies (from rain, dew, fog)
- Open-Water Evaporation: evaporation from lakes, reservoirs, and rivers
- Sublimation: direct phase change from solid (snow or ice) to water vapor without passing through a liquid phase.

Strictly speaking, sublimation is not a component of ET, as ET traditionally excludes phase change from solid to vapor. However, sublimation represents a significant land–atmosphere water vapor flux over snow- and ice-covered surfaces. Given the dET initiative's goal to close the terrestrial water vapor budget comprehensively, sublimation is explicitly included as an additional flux to be quantified alongside ET components.

A core challenge in dET is to accurately measure and model these components separately, as they respond differently to environmental drivers and human management.

How Do We Measure These Components from Local or Leaf Scale to the Earth System Scale?

Measurement strategies are scale-dependent:

- Leaf/Plant Scale: sap flow sensors, gas exchange chambers, isotopic tracers
- Field Scale: eddy covariance (EC) towers (the principal source for benchmark data), lysimeters, and scintillometers. For sublimation from snow or ice, EC towers and profile measurements are also applicable over snow-covered surfaces
- Landscape to Regional Scale: remote sensing [thermal, optical, Solar-Induced Chlorophyll Fluorescence (SIF)], airborne campaigns, and networked flux data [FLUXNET, the Integrated Carbon Observation System (ICOS)]
- Global Scale: satellite-derived ET products and reanalysis data

A flagship activity for multi-scale measurement integration was the LIAISE field campaign in 2021. It provided a rich dataset to study ET contrasts between irrigated and natural landscapes. This project has been extended by the Land-Atmosphere Feedback Initiative (LAFI, *https://lafi-dfg.de*), a collaborative Research Unit of the German Research Foundation. During the LAFI field campaign, almost all of the measurements mentioned above were performed in synergy. Suitable long-term measurements are emerging from the GEWEX Land-Atmosphere Feedback Observatories (GLAFOs, Wulfmeyer et al., 2020), from both sites that are operational and those that are under development.

How Do We Model ET Currently?

ET modeling employs a hierarchy of approaches:

- Physically-Based Models: Penman-Monteith, Priestley-Taylor, Monin-Obukhov Similarity Theory (MOST), photosynthesis models such as the Ball-Berry model, as well as surface energy balance (SEB) models, including two-source (TSEB) formulations
- Remote Sensing-Driven Models, which use satellite data to constrain surface fluxes and compute ET via residual energy balance or hybrid methods
- Land Surface Models (LSMs), which incorporate ET modules within Earth System Models, simulating soil-plant-atmosphere interactions
- Data-Driven Models, which employ machine learning and deep learning algorithms trained on surface data, including flux towers in combination with other sensors, and satellite data

Recent advances focus on improving ET partitioning, integrating plant hydraulic stress, and representing anthropogenic effects like irrigation.

Sublimation is typically modeled using:

- Physically-based snow approaches: bulk aerodynamic and surface energy balance methods are adapted for snow/ice surfaces
- Land surface models (LSMs): sublimation is treated as part of snowpack routines within Earth System Models
- Satellite-driven models: remote sensing of snow cover, albedo, and surface temperature are used to estimate sublimation at regional scales

Recent advances focus on improving the representation of blowing snow sublimation and canopy-intercepted snow sublimation. Challenges remain in validating sublimation fluxes due to scarce measurements over snow and ice, especially in high latitudes and mountain regions.

What Are the Current Global Datasets and Their Challenges?

Key datasets include EC network releases (FLUXNET), remote sensing products [Moderate Resolution Imaging Spectroradiometer (MODIS)-based, Global Land-surface Evaporation Amsterdam Methodology (GLEAM), Penman-Monteith-Leuning (PML), EvapoTranspiration Monitor (ETMonitor)], and reanalysis outputs [e.g., European Centre for Medium-Range Weather Forecasts Reanalysis v5-Land (ERA5-Land)]. However, significant challenges persist in in situ data, models, and model products. Eddy covariance data, considered the ground truth, suffer from extensive gaps (up to 70% missing hourly data) and limited long-term records, hindering trend analysis and model validation (Li et al., 2025).

Monin-Obukhov Similarity Theory (MOST) has been disproved over crops (Wulfmeyer et al., 2023), so it is essential to develop more accurate similarity theories. Comprehensive intercomparisons (Tang et al., 2024; Zheng et al., 2025) show that machine-learning and hybrid products generally outperform others, but large discrepancies remain in magnitude, trends, and ET partitioning—especially in arid regions—with reanalysis products tending to overestimate and some remote-sensing products to underestimate ET. Moreover, the Protocol for the Analysis of Land Surface models (PALS) Land Surface Model Benchmarking Evaluation Project, Phase 2 (PLUMBER2, Abramowitz et al., 2024) reveals that even state-of-the-art land surface models often fail to beat simple out-of-sample empirical models, pointing to fundamental shortcomings in process representation. Furthermore, a 2025 evaluation of 13 global diagnostic ET products revealed they generally perform poorly in capturing observed long-term trends, often underestimating the magnitude and even misidentifying the direction of change in over 30% of basins studied (Ruan et al., 2025). Sublimation fluxes over snow and ice are even more difficult to quantify, with no operational global datasets and minimal in situ validation.

Recent efforts are addressing these gaps. For instance, a new benchmark dataset (2000–2022) has been developed using a bias-corrected machine learning approach to gap-fill and prolong EC data from 64 global sites, providing a more continuous record for analysis and model validation (Li et al., 2025). Work is also ongoing to perform multi-scale assessments, the energy balance closure using advanced sensor synergies, and fuse existing global ET datasets to create more robust products and extend to water use efficiency, gross primary productivity as well SIF signals (Jiang et al., 2025; Han et al., 2025). New opportunities are also emerging from novel satellite observations, such as using SIF as a proxy for vegetation leaf water potential to better understand plant water stress (Su and Zeng, 2025).

What Are the Remaining Challenges?

- Measurement and Validation: persistent surface energy balance non-closure, scaling discrepancies from point to region, and difficulty in partitioning E and T
- Model Limitations: inadequate representation of plant water stress, transpiration, irrigation, cold-region processes (e.g., snow/ice sublimation, freeze-thaw dynamics), and surface heterogeneity
- Lacking theories: flux-driver relationships must be improved, particularly over crops
- Data Gaps: lack of long-term, continuous benchmark observations and inconsistent validation protocols, especially in critical regions like mountains, arid zones, and irrigated croplands
- Trend Uncertainty: as noted, major discrepancies exist in the magnitude and even sign of ET trends across different products, complicating climate impact assessments
- Anthropogenic Integration: effectively accounting for water management, land use change, and CO_2 fertilization effects in models

Why Concentrate New Efforts on Determining ET Now?

ET is central to contemporary climate challenges. With increasing water scarcity and hydrological extremes, improved ET knowledge is critical for water security, food production, and climate resilience. The dET Crosscut is specifically designed to tackle this interdisciplinary challenge. Building on the foundation of Phase I, the second phase is structured into five focused Working Groups (WGs) to foster targeted collaboration and address core research gaps:

Working Group	Primary Focus
WG1: In situ measurement	Quantify the accuracy of different in situ measurement methods in coordination with the new GLASS WG on Observations
WG2: ET components	Inventory and recommend methods for separating evaporation (soil) from transpiration (plants) for positive fluxes, and for determining the contribution of non-rainfall water (dew, fog deposition, and adsorption) to negative (or net) ET fluxes
WG3: ET scaling	Develop nested ET products, involving points-scale methods, Earth observations via a range of platforms (satellite, unmanned aerial vehicle, proximal remote sensing), and modeling
WG4: ET dynamics	Understand plant water stress dynamics using new remote sensing signals like SIF and indicators of leaf water potential
WG5: ET products	Evaluate long-term, relevant data products for applications; assess trends and uncertainties

This structure facilitates progress on the GEWEX Imperatives (*https://www.gewex.org/about/science/seven-gewex-imperatives/*) and supports international programs like the World Climate Research Programme (WCRP)'s Lighthouse Activities and the Global Climate Observing System (GCOS).

A Call to Action and Participation

The second phase of the CC-dET project actively invites and encourages researchers across disciplines—remote sensing, hydrology, ecology, atmospheric science, and modeling—to engage. Current and planned activities include Model Intercomparison Projects (ET-MIPs), the analysis of campaigns like LIAISE, and preparation for the 4th ET Conference in China in October 2026. The community contributes to and benefits from ongoing synthesis publications and special collections. By joining a Working Group, participating in workshops, and contributing to open data efforts, scientists can help transform our capacity to observe, understand, and predict evapotranspiration across all scales.

To contribute, please contact **Li Jia** (*jiali@aircas.ac.cn*) or **Bob Su** (*z.su@utwente.nl*), indicating your preferred Working Group(s) and potential contributions.

References

Abramowitz, G.; Ukkola, A.; Hobeichi, S. et al. On the predictability of turbulent fluxes from land: PLUMBER2 MIP experimental description and preliminary results. *Biogeosciences* **2024**, *21* (23), 5517–5538. doi:https://doi.org/10.5194/bg-21-5517-2024.

Boone, A.; Bellvert, J.; Best, M. et al. The 1st LIAISE Conference & dET CrossCut Workshop (2023). *GEWEX Quarterly* **2023**, *33* (3), 9–11. https://www.gewex.org/gewex-content/uploads/2024/05/Q32023.pdf.

Cuxart, J.; Verhoef, A.; Marthews, T.R. et al. Current Challenges in Evapotranspiration Determination. *GEWEX News* **2019**, *29* (1), 5–8. https://www.gewex.org/gewex-content/uploads/2024/02/1551991026Q1_2019.pdf.

Han, Q.; Zeng, Y.; Wang, Y. et al. FluxHourly: global long-term hourly 9 km terrestrial water-energy-carbon fluxes. *Earth System Science Data* **2025**, *17* (12), 7101–7117. doi:https://doi.org/10.5194/essd-17-7101-2025.

Hartogensis, O.; Cuxart, J. Workshop reports from the Second Determining Evapotranspiration Workshop. *GEWEX Quarterly* **2021**, *31* (2), 11–13. https://gewex.org/gewex-content/files_mf/1633983474Q22021.pdf.

Jiang, M.; Zheng, C.; Jia, L. et al. A 20-year dataset (2001–2020) of global cropland water-use efficiency at 1-km grid resolution. *Scientific Data* **2025**, *12* (1). doi:https://doi.org/10.1038/s41597-025-04904-1.

Li, W.; Yao, Z.; Qu, Y. et al. A benchmark dataset for global evapotranspiration estimation based on FLUXNET2015 from 2000 to 2022. *Earth System Science Data* **2025**, *17* (8), 3835–3855. doi:https://doi.org/10.5194/essd-17-3835-2025.

Ruan, F.; Yang, Y.; Tu, Z. at al. Global evaluation of terrestrial evaporation trend from diagnostic products. *Journal of Hydrology* **2025**, 655, 132979. doi:https://doi.org/10.1016/j.jhydrol.2025.132979.

Su, Z.; Zeng, Y. Photosynthesis and water potential: A new perspective for coupling water, energy, and carbon cycles. *The Innovation Geoscience* **2025**, *3* (3), 100156–100156. doi:https://doi.org/10.59717/j.xinn-geo.2025.100156.

Tang, R.; Peng, Z.; Liu, M. et al. Spatial-temporal patterns of land surface evapotranspiration from global products. *Remote Sensing of Environment* **2024**, *304*, 114066–114066. doi:https://doi.org/10.1016/j.rse.2024.114066.

Verhoef, A.; Cuxart, J.; Marthews, T. et al. Report on the First Determining Evapotranspiration Workshop, Sydney, Australia, 8-10 October 2019. *GEWEX Quarterly* **2020**, *30* (1), 16. https://www.gewex.org/gewex-content/uploads/2024/02/1583952472Feb2020.pdf

Wulfmeyer, V.; Manuel, J.; Otte, S., et al. Estimation of the Surface Fluxes for Heat and Momentum in Unstable Conditions with Machine Learning and Similarity Approaches for the LAFE Data Set. *Boundary-Layer Meteorology* **2022**, *186* (2), 337–371. doi:https://doi.org/10.1007/s10546-022-00761-2.

Wulfmeyer, V.; Späth, F.; Behrendt, A. et al. The GEWEX Land-Atmosphere Feedback Observatory (GLAFO). *GEWEX Quarterly* **2020**, *30* (1), 6–11. https://www.gewex.org/gewex-content/uploads/2024/02/1583952472Feb2020.pdf.

Zheng, C.; Jia, L.; Hu, G. et al. How much water vapour does the Tibetan Plateau release into the atmosphere? *Hydrology and Earth System Sciences* **2025**, *29* (2), 485–506. doi:https://doi.org/10.5194/hess-29-485-2025.

A New Explorer for Climate Science: The Far-infrared Outgoing Radiation Understanding and Monitoring (FORUM) Mission

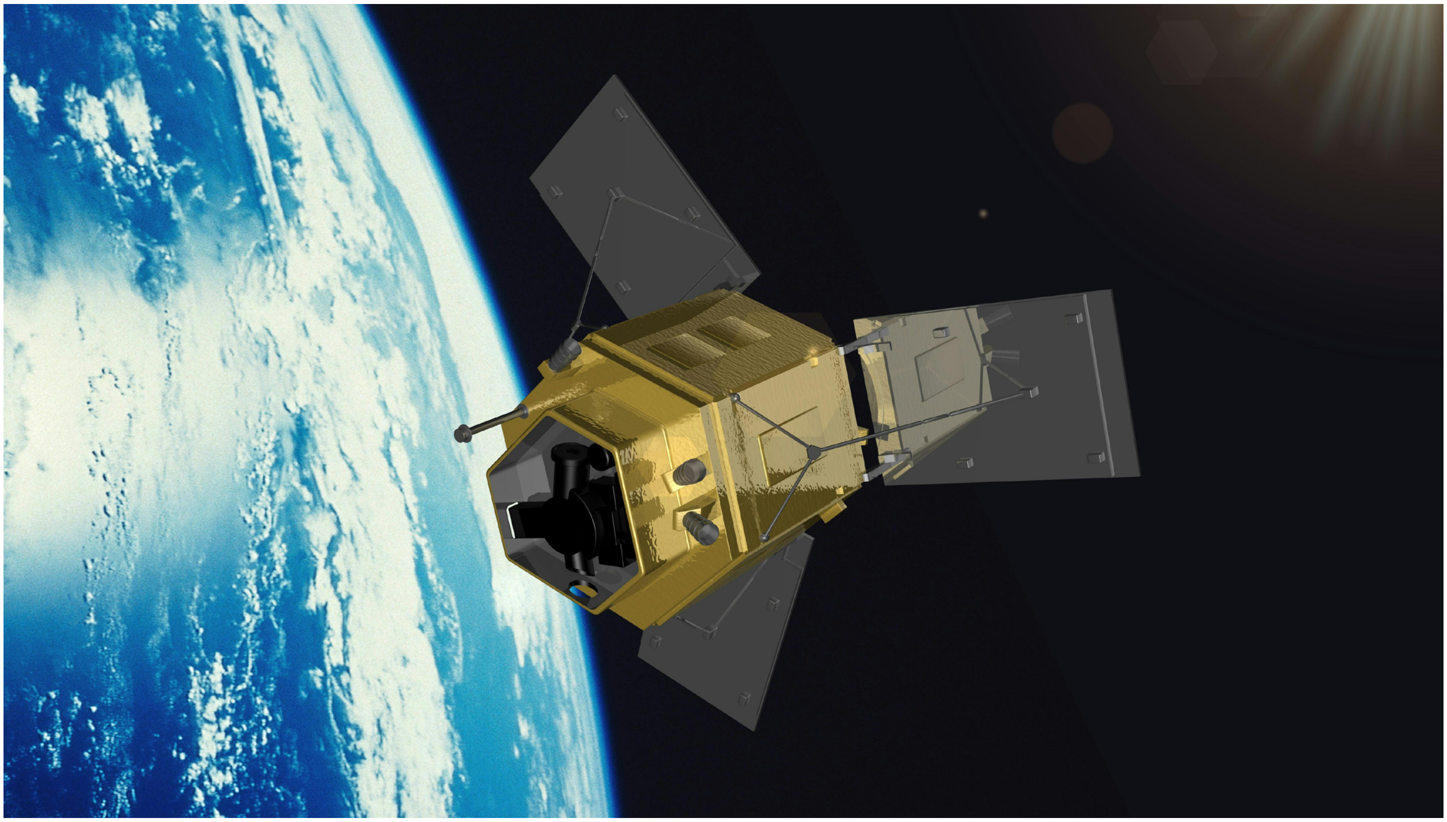
Helen Brindley
Imperial College London, London, UK

Scheduled for launch in 2028, the European Space Agency (ESA)'s 9th Earth Explorer, FORUM, will be the first mission to make global measurements of the Earth's outgoing longwave energy spectrum in the far-infrared, defined here as wavelengths between 15–100 µm, with high spectral resolution and accuracy. The overarching mission goals are to evaluate how energy transfers in the far-infrared shape Earth's current climate and to use information contained in the far-infrared spectrum to reduce uncertainty in predictions of future climate change (Palchetti et al., 2020).

We expect FORUM to make a significant contribution to all seven of the GEWEX Imperatives (https://www.gewex.org/about/science/seven-gewex-imperatives/). The mission will provide new insights into the distribution and variability of water vapor, particularly in the upper-troposphere lower-stratosphere (Panditharatne et al., 2025a); allow improved detection of thin ice clouds and better constrain the microphysics of ice and mixed-phase clouds (Maestri et al., 2019; Panditharatne et al., 2025b); provide novel information on the composition of dust aerosols (Di Biagio et al., 2026); and enable unique retrievals of surface emissivity in the far-infrared (Ben-Yami et al., 2022). Critically, FORUM will also quantify how variability in these parameters couples to their radiative spectral signature, providing information that can be exploited to directly evaluate and improve climate models (Della Fera et al., 2025).

These research goals will be achieved through a payload consisting of two instruments, the FORUM Sounding Instrument (FSI) and the FORUM Embedded Imager (FEI). The FSI is a Fourier transform spectrometer, designed to measure from 100–1600 cm^{-1} (6.25–100 µm) with a nominal spectral resolution of better than 0.5 cm^{-1}. The instrument ground footprint has a diameter of 15 km. It employs a stop and stare technique to build up sufficient signal to noise in each measurement such that the along-track sampling distance is ~100 km. The target radiometric accuracy is better than 0.1 K (3-σ) for all scenes. With a ground field of view of 36 km^2 and pixel resolution of 0.6 km, co-located measurements from the FEI, a single channel narrow-band radiometer centered at 10.5 µm, are designed to provide context for each FSI observation.

To optimize scientific benefit, FORUM will fly in "loose formation" (time difference < 1 minute) with the Meteorological Operational Satellite–Second Generation-A (MetOp-SG-A) in sun-synchronous orbit (0930 Local Solar Time descending mode). Measurements from the Infrared Atmospheric Sounder Interferometer–New Generation (IASI-NG; spectral range of 645–2,760 cm^{-1}) will complement those from FORUM, allowing cross-calibration, synergistic retrievals, and measurements of the full top-of-atmosphere outgoing far-to-mid



Artist's impression of the FORUM satellite in orbit (©Airbus Defence and Space)

infrared spectrum. Insights from other MetOp-SG-A instrumentation, including the Micro-Wave Sounder (MWS; temperature and humidity profiles), Multi-viewing Multi-channel Multi-polarization Imager (3MI; aerosols), and Meteorological Imager (METImage; cloud, land surface), will also further the FORUM objectives.

Currently FORUM is in "Phase D" (verification and testing) and ESA's scientific activities are focused on testing and finalizing the end-to-end simulator, which is used as a test-bed for the generation of Level 1 and 2 products. The baseline Level 1C product will be the calibrated and geolocated radiance spectra from FORUM. Target Level 2 products include vertical profiles of temperature and water vapor, surface spectral emissivity, and ice cloud properties including cloud top height, base, ice water path and effective diameter. A further development will see the generation of spectral top of the atmosphere outgoing longwave fluxes. It is envisaged that Level 2 products will be derived using "FORUM only" observations and via the synergistic use of "FORUM + IASI-NG" observations.

These are exciting times for FORUM, and we actively encourage all interested members of the GEWEX community to engage with us in ensuring that the mission's scientific potential is fully realized. Please contact Professor Helen Brindley, *h.brindley@imperial.ac.uk*, or the FORUM Mission Scientist, Dr. Hilke Oetjen, *h.oetjen@esa.int*, if you would like further information on how to get involved.

References

Ben-Yami, M.; Oetjen, H.; Brindley, H.E. et al. Emissivity retrievals with FORUM's end-to-end simulator: challenges and recommendations. *Atmospheric Measurement Techniques* **2022**, *15* (6), 1755–1777. doi:https://doi.org/10.5194/amt-15-1755-2022.

Della Fera, S.; Fabiano, F.; Raspollini, P. et al. Reproducing and Attributing IASI Radiance Trends with EC-Earth Climate Model Simulations. *Journal of Climate* **2025**, *38* (23), 6943–6959. doi:https://doi.org/10.1175/jcli-d-25-0034.1.

Di Biagio, C.; Bru, E.; Orta, A. et al. Mid- and far-infrared spectral signatures of mineral dust from low- to high-latitude regions: significance and implications. *Atmospheric Chemistry and Physics* **2026**, *26* (2), 1079–1091. doi:https://doi.org/10.5194/acp-26-1079-2026.

Maestri, T.; Cossich, W.; Sbrolli, I. Cloud identification and classification from high spectral resolution data in the far infrared and mid-infrared. *Atmospheric Measurement Techniques* **2019**, *12* (7), 3521–3540. doi:https://doi.org/10.5194/amt-12-3521-2019.

Palchetti, L.; Brindley, H.; Bantges, R. et al. FORUM: Unique Far-Infrared Satellite Observations to Better Understand How Earth Radiates Energy to Space. *Bulletin of the American Meteorological Society* **2020**, *101* (12), E2030–E2046. doi:https://doi.org/10.1175/bams-d-19-0322.1.

Pandítharatne, S.; Brindley, H.; Cox, C., et al. Retrievals of water vapour and temperature exploiting the far-infrared: application to aircraft observations in preparation for the FORUM mission. *Atmospheric Measurement Techniques* **2025a**, *18* (3), 717–735. doi:https://doi.org/10.5194/amt-18-717-2025.

Panditharatne, S.; Cox, C.; Song, R., et al. Exploiting airborne far-infrared measurements to optimise an ice cloud retrieval. *Atmospheric Chemistry and Physics* **2025b**, *25* (17), 9981–9998. doi:https://doi.org/10.5194/acp-25-9981-2025.

Convection Tracking Initiative

Hanii Takahashi[1] and Juliet Pilewskie[2]
[1]Jet Propulsion Laboratory, Pasadena, California, USA; [2]Colorado State University, Fort Collins, Colorado, USA

Understanding **why convective storms, heavy precipitation, and clouds form precisely when and where they do**—identified as one of the key challenges in the Decadal Survey (National Academies, 2018)—remains a fundamental problem in weather research. Addressing this challenge requires improved understanding of convective and precipitation processes through systematic tracking of convective clouds, monitoring storm lifecycles, and examining how storms interact with their surrounding environment as they evolve. Such life cycle-based analyses provide critical insight into the mechanisms that control storm development, organization, and intensity.

In this context, the development and application of cloud-tracking algorithms [e.g., Tracking Of Organized Convection Algorithm through 3D segmentatioN (TOOCAN), Tracking and Object-Based Analysis of Clouds (tobac), Integrated Multi-satellitE Retrievals for the Global Precipitation Measurement Mission (GPM)–Convection Tracking (IMERG-CT); Fig. 1], combined with Lagrangian analyses of clouds and other atmospheric phenomena, provide a powerful framework for examining the full life cycle of convective systems. These approaches support GEWEX's broader objective of improving the measurement and prediction of global and regional energy and water cycles through better integration of observations and models. Such capabilities are becoming increasingly important as new satellite missions designed to advance process-level understanding of convection [e.g., the Earth Cloud Aerosol and Radiation Explorer (EarthCARE), Polar Radiant Energy in the Far Infrared Experiment (PREFIRE), the INvestigation of Convective UpdraftS (INCUS) mission, the Polarized Submillimeter Ice-cloud Radiometer (PolSIR), Precipitation Measurement Missions (PMM), the Convective Core Observations trOugh Microwave Derivatives in the trOpics (C^2OMODO) mission, and Wind Velocity Radar Nephoscope (WIVERN)] come online. In addition, this activity is particularly timely given the GEWEX Data and Analysis Panel (GDAP)-sponsored Next Generation of the International Satellite Cloud Climatology Project (ISCCP-NG) dataset, a newly developed, intercalibrated global 11-channel cloud record (60°N–60°S) designed to support cloud and convective lifecycle studies (Heidinger et al., 2026).

Building on recent community activities, including the Convection Tracking Workshop held at the Goddard Institute for Space Studies (GISS) in 2024 (Fig. 2, next page), the need for a coordinated convection-tracking initiative has become clear. This effort aims to create a collaborative platform where researchers can share methodologies, datasets, and ideas. The initiative will also help identify the geophysical "products" needed to better characterize cloud objects, examine the processes associated with their formation and evolution, and develop toolkits capable of tracking both shallow and deep convection.

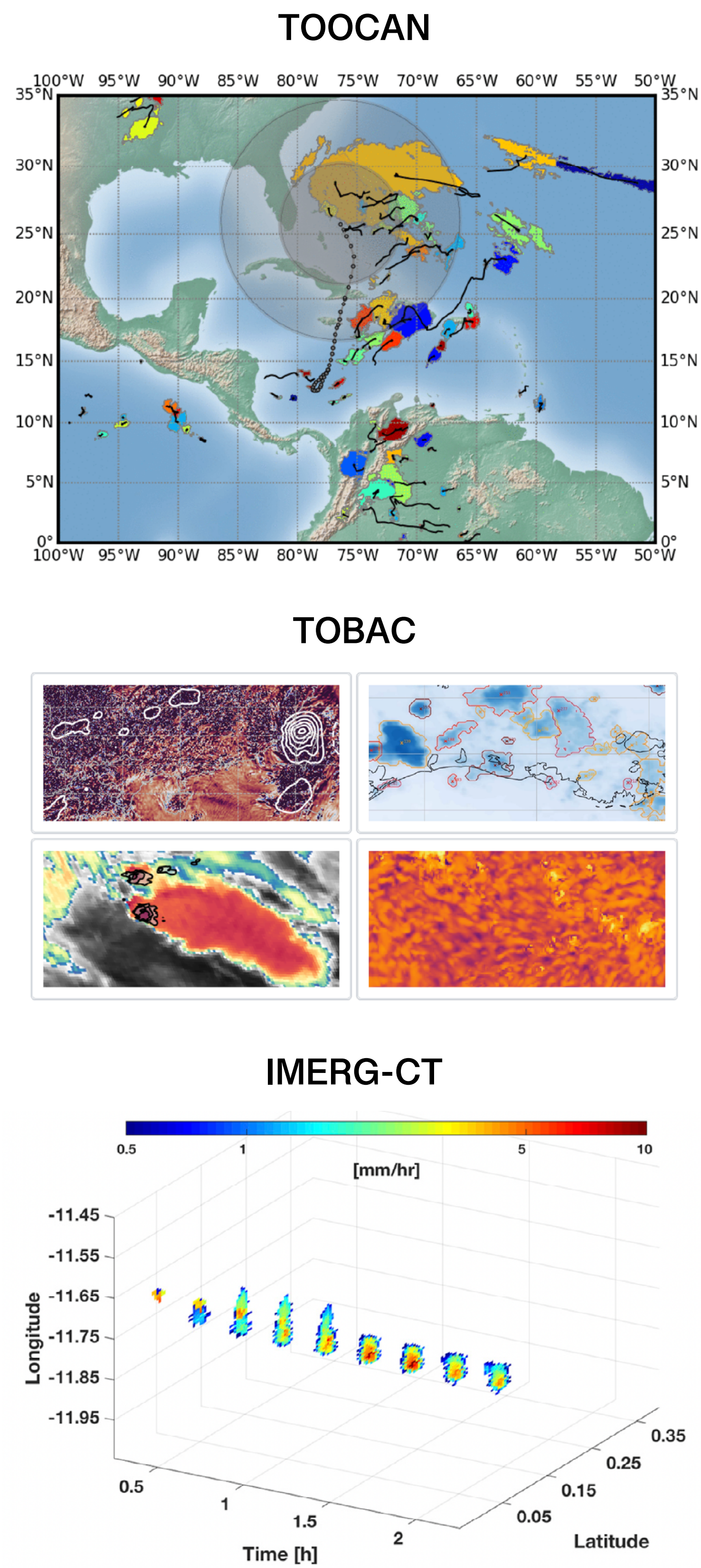


***Figure 1**. Examples of different cloud-tracking methods/algorithms: TOOCAN (https://toocan.ipsl.fr/), tobac (https://tobac.readthedocs.io/en/latest/), and IMERG-CT (Takahashi et al., 2021)*

Subgroup	Topic	Key Focus
1. Intercomparison Study	1.1 Inter-Algorithm Comparison	Evaluating different tracking algorithms using the same datasets
	1.2 Inter-Model Comparison	Evaluating different models using the same tracking method
	1.3 Inter-Scale Comparison	Assessing model performance across different temporal and spatial scales using the same tracking method
2. Multivariable Tracking	2.1 Multivariable Tracking	Evaluating different variables and thresholds for tracking convection; assessing the capability to identify the origin of convection that develops into deep convection
3. Environmental Influence	3.1 Storms/Deep Convection	Identifying key environmental properties that influence deep convection development; assessing the capability of reanalysis data for environmental analysis
	3.2 Shallow to Deep Convection	Identifying key environmental properties that influence shallow convection development
	3.3 Anvil Development	Identifying key environmental properties that influence anvil development

***Table 1**: Subgroups of Convection Tracking Initiative*

To support these activities, several subgroups are being organized around key scientific themes (Table 1). These coordinated efforts will help advance our understanding of storm evolution and improve our ability to predict extreme weather events.

Our long-term goal is to develop a collaborative platform for the convection tracking community that can produce assessment reports and assemble datasets in a common format that can be freely shared with the broader scientific community. To achieve this goal, we plan to establish the subgroups described above and facilitate regular meetings and workshops to exchange ideas, discuss progress, and identify future research activities. We explicitly welcome participation from the broader community at all career stages. In addition to contacting the leads, interested individuals are encouraged to register their interest via a sign-up form (*https://www.gewex.org/convection-tracking/*) to join the initiative, participate in subgroups, and receive updates through a mailing list.

Updates on convection tracking activities will be shared through the GEWEX/GDAP website (*https://www.gewex.org/convection-tracking/*) as well as the Convection Tracking Algorithms and Science Workshop website (*https://sites.google.com/view/convection-tracking-workshop/*).

References

Heidinger, A.; Stephens, G.; Schulz, J. et al. A GEO-Ring of Spectral Radiances: Toward a Next Generation of the International Satellite Cloud Climatology Project (ISCCP-NG). *Bulletin of the American Meteorological Society* **2026**, *107* (2), E291–E308. doi:https://doi.org/10.1175/bams-d-24-0161.1.

National Academies of Sciences, Engineering, and Medicine. *Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space*; The National Academies Press: Washington, DC, USA, 2018.

Takahashi, H.; Lebsock, M.; Luo, Z.J. et al. Detection and Tracking of Tropical Convective Storms Based on Globally Gridded Precipitation Measurements: Algorithm and Survey over the Tropics. *Journal of Applied Meteorology and Climatology* **2021** *60* (3), 403–421. doi:https://doi.org/10.1175/jamc-d-20-0171.1.

***Figure 2**. Group photo from 2024 GISS Convection Tracking Workshop*

UMAP2027 aims to bring together weather and climate scientists, including both observationalists and modelers, to discuss the key issues of atmospheric science. UMAP 2027 will cover atmospheric processes at the microphysical, turbulence, and mesoscales that control the atmospheric boundary layer, clouds, precipitation, and radiation balance.

The conference will be organized around the following topics:

- Convective organization and mesoscale circulations across cloud regimes
- Microphysical processes (including aerosol-cloud interactions) controlling cloud phase and precipitation
- Extratropical and cold clouds and their energy and moisture budgets
- Interactions between land, clouds and precipitation: processes, impacts and predictability

Mark your calendar for this upcoming event. Visit *https://www.gewexevents.org/meetings/umap2027/* for important updates and details.

Submit an Article to the GEWEX QUARTERLY

Share your GEWEX experiences and activties, 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*.

GEWEX/WCRP Calendar

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

1–9 August 2026—46th Scientific Assembly of the Committee on Space Research (COSPAR)—Florence, Italy

2–7 August 2026—Asia Oceania Geosciences Society (AOGS) 2026—Fukuoka, Japan

4–6 August 2026—Advancing Understanding of Land–Atmosphere Interactions and Processes for S2S Predictability—Boulder, CO, USA

8 August 2026—AsiaPEX AMY-II Brainstorming Workshop—Fukuoka, Japan

31 August 2026–4 September 2026—International School on Satellite Meteorology (ISSM) 2026—Sicily, Italy

7–11 September 2026—3rd International Conference on Subseasonal to Seasonal to Decadal Prediction (S2S2D)—Reading, UK

7–9 September 2026—2026 Annual INARCH Workshop—Kananaskis, AB, Canada

15–19 September 2026—5th International Soil Modeling Consortium Conference (ISMC 2026)—Rio de Janeiro, Brazil

18 October 2026—Mini-Workshop on “Climate Forcing, Response, and Recovery in a State-Dependent System”—Taipei, Taiwan

19–22 October 2026—2026 Cloud Feedback Model Intercomparison Project (CFMIP) Meeting—Taipei, Taiwan

7–11 December 2026—AGU 2026—San Francisco, CA, USA

10–14 January 2027—107th AMS Annual Meeting—Denver, CO, USA and Online

GEWEX QUARTERLY

Published by the International GEWEX Project Office

Peter J. van Oevelen, Director
Shannon Macken, Editor

International GEWEX Project Office
c/o George Mason University
111 Research Hall, Mail Stop 6C5
4400 University Drive
Fairfax, VA 22030 USA

E-mail: *contact@gewex.org*
Website: *http://www.gewex.org*