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9th Global Energy and Water Exchanges Open Science Conference
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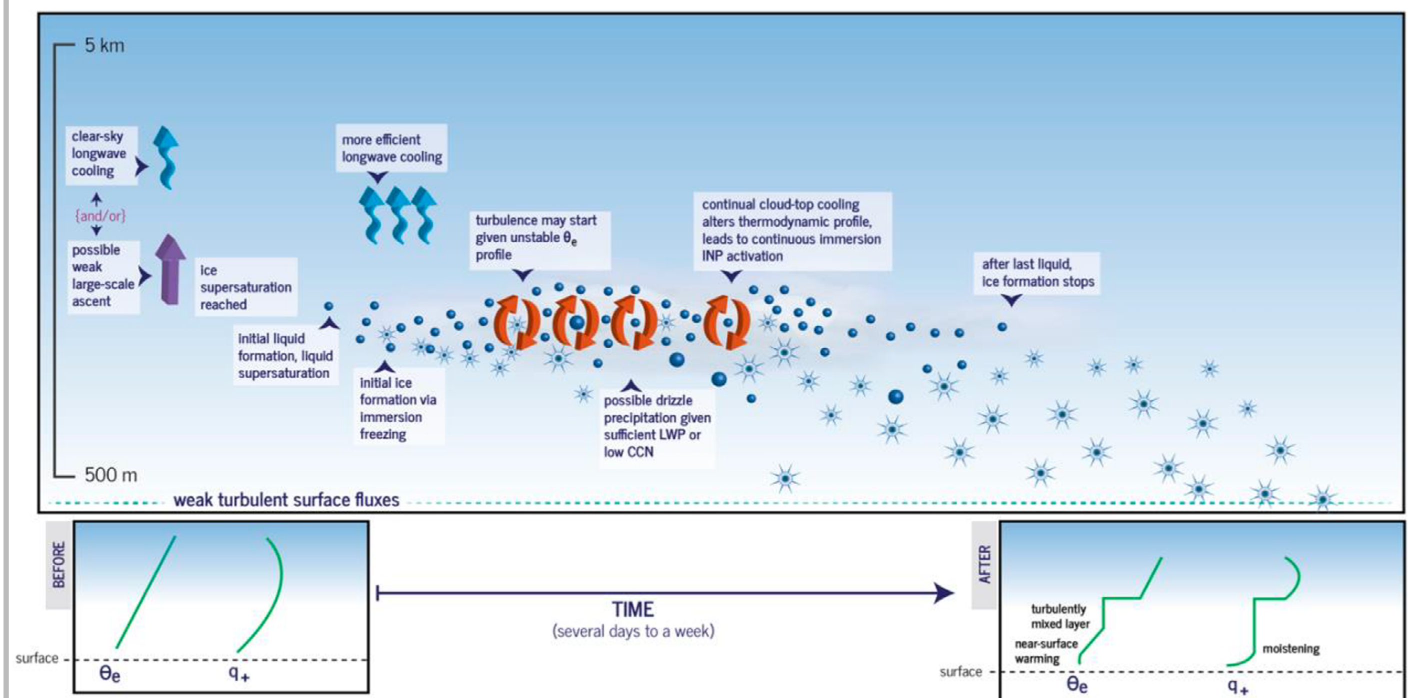
SCAN ME



An illustration of the thin, low cloud processes central to Arctic Radiation-Cloud-Aerosol-Surface-Interaction eXperiment (ARCSIX) science. ARCSIX aims to advance understanding of the Arctic climate by addressing the key influences of radiation-cloud-aerosol-sea ice coupling. See Taylor and Schmidt on page 8 for more.

Inside This Edition

Commentary

Jan Polcher
Co-Chair, GEWEX Scientific Steering Group

The World Climate Research Programme (WCRP) and the Global Climate Observing System (GCOS) organized jointly last June in Paris a workshop on Earth's energy, water, and carbon cycles and budgets. The objective was to evaluate how the observations of Essential Climate Variables (ECVs) performed under the umbrella of GCOS could support the research activities sponsored by WCRP and how our research could improve the quantification of the uncertainties and, more generally, the usage of the ECVs. This workshop brought together experts of the various components and cycles of the Earth system from the research community. GEWEX has a key role to play in this endeavor. Closing the energy and water cycle over catchments was given as a priority task to GEWEX by its founding fathers. Our program made some important advances over the Mississippi basin with the GEWEX Continental Scale International Project (GCIP) and over other catchments with the subsequent Regional Hydroclimate Projects. These results were then generalized to the globe during the National Aeronautics and Space Administration (NASA) Energy and Water Cycle Study (NEWS) program.

The workshop highlighted that although all were talking about the continuity equation of conserved quantities within the Earth system, the vocabulary and assumptions made are quite different. Each discipline within the geosciences has adopted different terms to designate the same quantities or concepts, and thus some fundamental misunderstandings exist. It can be illustrated with the "Earth Energy Imbalance" term. The continuity equation for a conserved quantity just translates the fact that nothing is lost or gained, but is redistributed within the balance. In that sense, the Earth energy cycle cannot be in "imbalance". It has become non-stationary. The increasing amount of greenhouse gasses has modified the distribution of energy within the closed system. In the same way, we all understand what is meant with the term "energy cycle", when in fact the conserved quantity is enthaply, or internal energy. These are just vocabulary issues and do not question the important results obtained by the various groups within WCRP. Communication is just made a little more difficult. It thus seems important at this stage to anchor the various terms and assumptions used by the climate community to the fundamental concepts of physics we all share.

In an effort to try and bring the research activities on the energy, water, and carbon cycles into the same reference system and allow for a closer interaction, some original ideas were expressed during the workshop. There is a consensus that by using the ECVs, we should be able to close the continuity equations for all three conserved variables (internal energy, water, and carbon mass) over the four components of the Earth system (ocean, land, cryosphere, and atmosphere). Attempting to balance all the fluxes and store variations of each component will provide an evaluation of these estimates within their error bars. If, as demonstrated by the GEWEX community within the NEWS program, the closure can be achieved within the assumed errors, it will provide greater confidence in the observational data. It will also allow to quantify if and when the trends within the various variables start to be significant. We will monitor the the non-stationarity of all three cycles.

This objective can be achieved relatively simply: for each global estimate of a flux or storage change within the three cycles, report the annual spatial integrals over each of the four compartments (ocean, land, cryosphere, and atmosphere). These values can then be used to attempt to close the twelve continuity equations at the annual scale. Obviously not all variables within the continuity equations are observed. The community will have to either agree to neglect these terms or on a method to derive them from other quantities. This effort will allow us to move to a common vocabulary and ensure that all better understand the assumptions made. We will evolve towards a common understanding of how our three conserved quantities can be monitored and how the associated errors need to be understood. This will strengthen the communication to the general public of WCRP's and GCOS's observations and how they allow the documentation of the non-stationarity of the energy, water, and carbon cycles in a changing climate.

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AGU H3S Fall Highlights: Webinars, AGU Fall Meeting, and New Member Applications

Danyka Byrnes[1] and Paige Becker[2]

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As we close the chapter on our current American Geophysical Union (AGU) Hydrology Section Student Subcommittee (H3S) activities, a whirlwind of excitement and preparation propels us toward the AGU Fall Meeting!

Elevator Pitch Workshop

Do you find yourself stumbling over your words when someone asks you, "what do you do?" Learn how to summarize your research in a concise and engaging "elevator speech", designed to effectively communicate the importance of your work and persuade the audience! We are hosting a workshop on November 30th at 12pm EST. Register at *https://tinyurl.com/H3SElevatorPitch*.

AGU Fall Meeting: Events and Sessions

We have lots of exciting events and sessions happening at the AGU Fall Meeting 2023 in San Francisco! Join us for our annual ECR & Student Trivia Night on Monday, December 11th. Tickets are available now on the Fall Meeting Registration portal.

We also have four sessions organized by H3S or colleagues:

- Communicating Science Beyond the Paper: Thinking Outside the Boxplot (INV13)
- Building your Network—Sharpening the Soft Skills of Science
- Inclusion in Earth Science: Fostering Diversity, Equity, and Inclusion through Community Building and Knowledge Sharing (INV51C)
- Where and How Can AGU Assist? Discussion About the Future of Early-Career and Student Members within AGU

Become a Part of AGU-H3S

Want to contribute to a positive community for students and early career researchers in the hydrologic sciences? We are seeking students and early career researchers (<5 years post-terminal degree) to join our team. As a member, you'll help create a supportive environment where knowledge is shared and connections are made. Apply at *https://forms.gle/4ME6AGMrFF1kiqAu9* by December 31st, 2023.

Stay connected! Subscribe to our newsletter on our website (*http://agu-h3s.org*) or follow us on X (*http://twitter.com/AGU_H3S*), Facebook (*http://tinyurl.com/h3s-faceb*), or LinkedIn (*http://tinyurl.com/h3s-linkedin*).

YESS Reporting on Active Engagement at International Science Meetings

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

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***Global Inequalities in Environmental Research**:* The Young Earth System Scientists (YESS) community looks back at active engagement at the World Climate Research Programme (WCRP) Open Science Conference (OSC) in Kigali, where it was involved in the organization of Town Hall meeting #3, "*Early-Mid Career Perspectives on South-North Inequalities: Fair Collaborative Research as a Way of Reducing Them*" (*https://wcrp-osc2023.org/side-event-th03*). This meeting addressed research collaborations between Global North and Global South, which can be difficult because of an unequal distribution of resources and other factors. In some cases, the research is dominated by the Global North and collaborators from the Global South are mostly executing the research or not substantially involved. These obstacles and potential solutions were discussed in the meeting and YESS is committed to contribute to those solutions.

***Balancing Data-Intensive and Foundational Climate Research**:* YESS was also involved in another Town Hall meeting of the WCRP OSC in Kigali: Town Hall meeting #9, "*Community Discussion on Balancing Data-Intensive and Other Foundational Climate Research Activities*" (*https://wcrp-osc2023.org/side-event-th09*). The session started with a short presentation on data-intensive research in climate sciences, followed by a panel discussion with speakers Bjorn Stevens, Julie Arblaster, Romaric Odoulami, and Silvina Solman. The meeting was inspired by an article, led by former YESS ExeCom member Shipra Jain, on the role of early career researchers in data-intensive research (*AGU Advances*, *https://doi.org/10.1029/2022AV000676*). Feedback from this meeting and responses to the survey linked in the original paper will be used for a follow-up article that is currently being drafted.

***Progress in Regional Climate Modeling**:* The International Conference on Regional Climate-Coordinated Regional Climate Downscaling Experiment (ICRC-CORDEX 2023, *https://icrc-cordex2023.cordex.org/*) was held at the end of September in Trieste, Italy. There was also an Early Career Scientist Event where participants from across the world came together to discuss science while establishing new contacts or strengthening existing connections. Such events at science meetings are excellent opportunities to network for early career researchers and YESS aims to support this in future meetings.

Get Involved! YESS is inviting early career researchers (Master's students, Ph.D. candidates, postdoctoral scholars, or researchers within 7 years of highest obtained degree) in the Earth system sciences to become a member and participate in our activities. See *https://www.yess-community.org/* for more information and a sign-up link.

In Memoriam: Prof. Dr. Ehrhard Raschke

Thank you to Hans-Jörg Isemer, former head of the International BALTEX Secretariat, for the initial draft, with contributions of Johannes Schmetz, Jerzy Dera, Sirje Keevallik, Markus Meier, Anders Omstedt, Markus Quante, Marcus Reckermann, Burkhardt Rockel, Thomas Vonder Haar, Paul Stackhouse, and William Rossow.

Ehrhard Raschke, a pioneer in satellite determinations of radiation exchanges in Earth's climate, an early advocate of and participant in GEWEX, and one of the initiators of the Baltic Sea Experiment (BALTEX), passed away on 24 August 2023 at the age of 87.

Ehrhard studied geophysics at the Bergakademie Freiberg and at the University of Mainz and received his Ph.D. in meteorology from the University of Munich, supervised by Fritz Möller, who was a pioneer in atmospheric radiation research. In 1973, Ehrhard became full professor and head of the Institute for Geophysics and Meteorology at the University of Cologne. While there, he established the institute as a center for satellite meteorology and the science of atmospheric radiative transfer. From 1989 to his formal retirement in 2001, he first headed the Institute of Physics, later the Institute of Atmospheric Physics, both at the GKSS Research Center (now the Helmholtz-Zentrum Hereon) in Geesthacht, Germany. He continued his research activities after his retirement, collaborating internationally and leading the GEWEX Radiative Flux Assessment, to end a career spanning 50 years of original research.

In Cologne, he expanded his seminal work with Thomas Vonder Haar, a lifelong collaborator, on the radiation budget at the top of the atmosphere to determining solar irradiance at the surface from satellite data. Several papers document the progress from one of the earliest satellite radiation budget results (Raschke and Bandeen, 1970) to Moeser and Raschke (1984), which included the most important contributions to the first surface solar radiation atlas for Europe issued by the European Commission. We remember well that he advocated for making use of incoming solar energy; in a way, he was ahead of his time.

For many years after his time in Munich, Ehrhard's research interests focused on improving our understanding of the atmospheric radiation balance and the quantification of related processes, which included remote sensing and in situ experiments of clouds and precipitation. He worked internationally right from the beginning of his career. His research with William Bandeen of the National Aeronautics and Space Administration (NASA) Satellite Research Laboratory, Thomas Vonder Haar, and three others formed the Nimbus-3 Medium-Resolution Infrared Radiometer (MRIR) Earth Radiation Budget (ERB) Science Team. This research led to the publications of the Nimbus-3 ERB methodology, a NASA Technical Note, and an early pioneering publication that quantified "The Annual Radiation Balance of the Earth-Atmosphere System during 1969–1970 from Nimbus 3 Satellite Measurements" (Raschke et al., 1973).

Ehrhard was involved in the World Climate Research Programme (WCRP) through its Working Group on Radiative Fluxes (WGRF), one of the first two active research arms of WCRP's Joint Scientific Committee. The three priorities of WGRF—the need for improved modeling of clouds; better knowledge of cloud radiative properties; and global observation of the amount, height, and types of clouds on Earth—became threads of much of Ehrhard's research throughout the remainder of his career.

His efforts with his colleagues to implement a global cloud observation system led to the development of the International Satellite Cloud Climatology Project (ISCCP) in 1982. He also initiated and coordinated the International Cirrus Experiment (ICE; Raschke et al., 1990), which was a joint effort of research groups in four different European countries to investigate the physical properties of cirrus clouds and their role in the climate system, with major field experiments in 1987 and 1989. ICE was continued by the European Cloud and Radiation Experiment (EUCREX), again coordinated by Ehrhard and co-financed by the European Union from 1989-1992. Both experiments supported ISCCP.

Once ISCCP was underway, the logical next step was to exploit the results from ISCCP to determine surface radiation. Ehrhard led the planning for the Surface Radiation Budget (SRB) project to use satellite observations to calculate surface fluxes, and, together with Atsumu Ohmura and Ellsworth Dutton, to check these calculations with a newly-organized Baseline Surface Radiation Network (BSRN).

Ehrhard's broadening research interests in the entire energy and water cycles of the atmosphere found a home in GEWEX. He served as a member of the GEWEX Scientific Steering Group (SSG) shortly after the program's start in 1989–1990, with a tenure stretching from 1992 to 1997. With ISCCP, SRB, BSRN, and other activities underway as GEWEX was beginning, projects were in place to determine cloud properties and their effects on top-of-atmosphere and surface radiative fluxes, one major component of the global energy and water cycle. Ehrhard returned to the results of this undertaking after it had matured over the 1990s and 2000s, and with the advent of Clouds and the Earth's Radiant Energy System (CERES), he led the GEWEX Radiative Flux Assessment (Raschke et al., 2016). Thus by the 2010s, the precipitation, clouds, and radiative fluxes determined in several global products had been assessed against each other and against global climate models.

Ehrhard also chaired the GEWEX Hydrometeorology Panel (GHP; today the GEWEX Hydroclimatology Panel) in the early 1990s. After several years of preparational work at the European and international levels, he succeeded in getting BALTEX officially approved as one of five initial Continental Scale Experiments (CSE) within GHP, together with the GEWEX Continental-Scale International Project (GCIP), the Large Scale Biosphere-Atmosphere Experiment in Amazonia (LBA), the GEWEX Asian Monsoon Experiment (GAME), and the Mackenzie GEWEX Study (MAGS). Ehrhard co-chaired, until his retirement, the BALTEX SSG, together with Lennart Bengtsson.

The outstanding BALTEX feature among the GEWEX CSEs at that time—and for years to come—was the inclusion of dedicated oceanographic experimental and modeling research components, in addition to meteorological and hydrological disciplines, which dominated the other CSEs.

After two phases of experiments and modeling, the BALTEX program successfully ended in 2013 and was followed by the Baltic Earth program, a longstanding GEWEX Regional Hydroclimatology Project. While the objectives of Baltic Earth have changed compared to BALTEX, the establishment of the new program had been significantly facilitated by the existence of BALTEX as the well-implemented and well-known precursor. The interdisciplinary cooperation dedicated to climate research around the Baltic Sea and its catchment benefitted from Ehrhard's decade-long initiatives.

Ehrhard was also committed to his students. He was always ready to seek opportunities for scientific research, creating chances for his students to grow. Most of his students can say that Ehrhard gave them the chance to learn through international collaboration. That was not only very successful, but also very enjoyable for his disciples, if not always easy. Ehrhard is remembered as a mentor who was instrumental in paving his students' way to a good career, and he will always have a place in their hearts.

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Integrated Human-Earth System Modeling by Coupling E3SM and GCAM

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1. Importance of Human-Earth System Interactions for Human Impacts and Climate Feedbacks

Human and natural Earth systems are intricately intertwined. Human activities have significantly altered, perturbed, and even reshaped the Earth system since the industrial revolution. Anthropogenic greenhouse gas (GHG) emissions are the main driver of global warming, with an elevated global surface temperature of 1.1°C from 1850–1900 to 2011–2020 (IPCC, 2023). Human-driven aerosol emissions from industrial and biomass burning activities have also contributed to air pollution, with important impacts on the climate, hydrological cycle, and cryosphere (Hao et al., 2023). Human-related ignitions play a part in increasing wildfire events (Philip et al., 2023). Human-driven land use change (e.g., agricultural expansion, urbanization, deforestation, and afforestation) exerts significant biochemical effects on the global carbon cycle, as well as biophysical effects on surface albedo and evapotranspiration. On the other hand, the Earth system provides essential resources and conditions for human society. Throughout history, climate has influenced energy use, agricultural production, forest management, and water resource availability (Ljungqvist et al., 2021); weather and climate extremes can also have catastrophic impacts on human health and socioeconomics (Ebi et al., 2021). In response to changing climate and environment, different adaptation and mitigation policies and strategies adopted by human societies will fundamentally determine the future evolution of the global climate.

2. Separate Representation of Human and Earth System (IAM vs ESM)

Traditionally, modeling human and natural Earth systems has been undertaken separately by two distinct communities. Integrated assessment models (IAM), e.g., the Global Change Analysis Model (GCAM) (Calvin et al., 2019), have been developed to represent the social and economic processes of human society, while Earth system models (ESMs), e.g., the Energy Exascale Earth System Model (E3SM) (Golaz et al., 2019), have been tailored to simulate the physical, chemical, and biological processes of the atmosphere, land, ocean, river, and cryosphere. In the current practices of climate simulations and projections (e.g., the Coupled Model Intercomparison Project Phase 5 and 6 experiments), these two types of models are one-way coupled in a non-dynamic, unidirectional, asynchronous manner (Collins et al., 2015). Specifically, IAMs generate anthropogenic GHG and aerosol emissions and land use change under diverse socioeconomic and climate scenarios, and these IAM-derived "forcings" are then used to drive the climate projections of ESMs. However, such one-way coupling excludes the impacts of the changing Earth system on the human system (e.g., the managed ecosystem productivity and crop yield), and the subsequent feedback to the Earth system via land use and energy activities (Calvin and Bond-Lamberty, 2018; Thornton et al., 2017). Neglecting the dynamic feedbacks between human and Earth systems will thus bias the future climate and carbon cycle projections from ESMs as well as energy, agriculture, and land use projections from IAMs regionally and globally (Thornton et al., 2017).

3. Survey of ESM Human/Management-Focused Developments

Due to the strong linkage between human and Earth systems, ESMs are increasingly representing human systems. For example, several land model components of ESMs are now simulating major crops. In addition to agriculture representation, agricultural management practices of fertilization, irrigation, and crop rotation are increasingly included in ESMs (Lombardozzi et al., 2020; Sinha et al., 2023). Transient land use change capturing afforestation, deforestation, expansion of cropland, and urban land are also being increasingly used in the land models. River routing and water management models are being coupled with the land model components to accurately simulate streamflow, reservoir operations, and irrigation water supply (Zhou et al., 2020). More broadly, the IAM and ESM modeling communities are exploring different strategies for coupling their respective modeling systems (Calvin and Bond-Lamberty, 2018), including an ongoing effort by the E3SM team that we describe below.

4. Brief Overview of the Coupled Model

4.1. Design of GCAM-E3SM

The E3SM-GCAM includes the human systems component as an E3SM model component on the same level as the other components (e.g., land, atmosphere, etc.; Fig. 1). This facilitates data transfer between the human component and all other components and allows for future coupling with other components. For example, in the future, GCAM can exchange information with E3SM's river-routing component by adding information on variables to be exchanged between these two components. The system currently has active couplings between GCAM and both the E3SM land (ELM) and atmosphere (EAM) components.

4.2. GCAM-ELM Coupling

In our GCAM-ELM coupling, terrestrial plant productivity is passed from ELM to GCAM and used to adjust the agricultural yield and carbon density parameterizations of GCAM, allowing the human-systems model to "see" climate change effects on the land carbon stocks due to, e.g., CO_2 fertilization. GCAM in turn passes information on land use/land cover change and anthropogenic CO_2 emissions (see section 4.3 on GCAM-EAM coupling) back to the E3SM land and atmosphere components. The information exchange from GCAM occurs every five years and is interpolated to annual values; we also convert the outputs from regional to gridded scale and vice-versa as GCAM and E3SM operate at different spatial scales. In addition, GCAM crop types are converted to ELM plant functional types (PFTs), and when data flows from the land model to GCAM, ELM gridded outputs and PFTs are converted to GCAM regions and crop types.

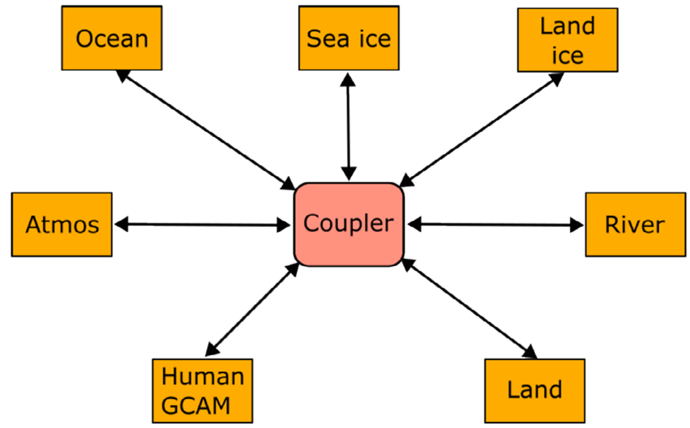

Figure 1*. Schematic of the GCAM-E3SM model and its major component models*

4.3. GCAM-EAM Coupling

In the GCAM-EAM coupling, the GCAM regional CO_2 emissions are downscaled by the human component to a spatial grid at monthly time intervals and then passed to EAM via the coupler at the beginning of each year. Two downscaling methods are being explored: 1) a simple linear scaling based on base-year gridded emissions and 2) a more detailed convergence-based downscaling that further adjusts future spatial patterns based on the assumptions of the convergence of national emission intensity [i.e., emission per gross domestic product (GDP)] to the regional average. Method 1 may produce unrealistic results when there are large differences among countries within the same region, while method 2 explicitly considers the dependence of country-level CO_2 emissions to future population growth and income levels. We also disaggregate GCAM's surface, international shipment, and aircraft CO_2 emission outputs separately, and the aircraft CO_2 emission is disaggregated into multiple vertical layers for input to EAM.

5. Example Run of the Coupled System

During a model run for the Shared Socioeconomic Pathways 2 (SSP2) scenario, 21st-century changes in climate and CO_2 concentrations, among other factors, affect plant productivity in ELM. This change is passed to GCAM and impacts agricultural yield, crop prices, and profit rates that in turn impact the total cropland area needed by the model to feed Earth's population. In our preliminary analysis, the above ground scalars are larger than 1 for the majority of grassland, shrubland, and cropland regions—i.e., carbon density tends to increase for these land types (Fig. 2).

6. Conclusion and Future Directions

The coupling of human and Earth system models is a cutting-edge area of ESM research generally, and crucial for E3SM's science goals of exploring the effect on the climate systems and the food-energy-water nexus and feedback under various

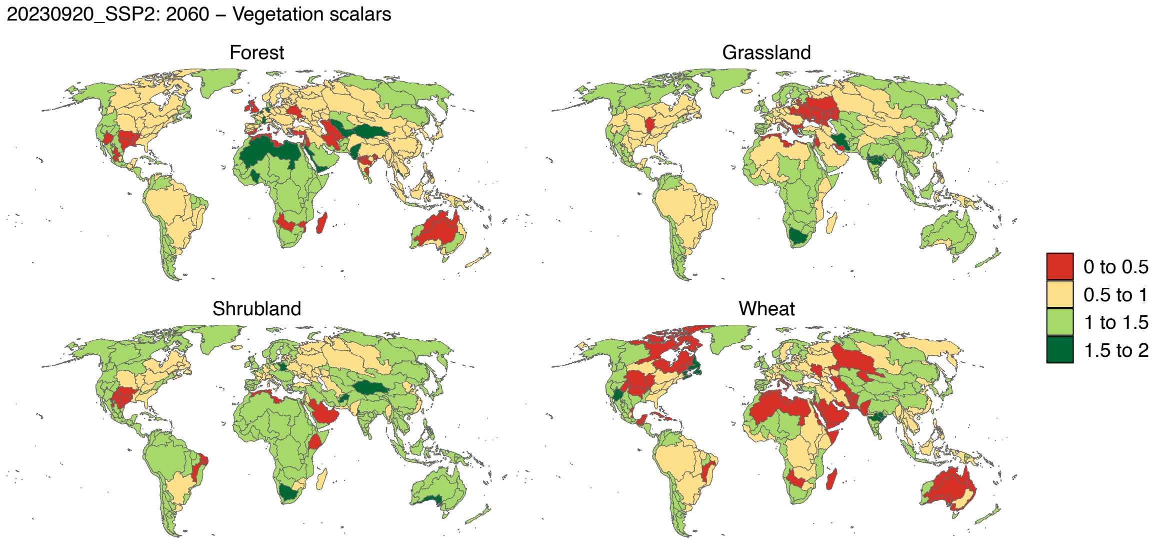

***Figure 2**. Aboveground or vegetation scalars for forest, grassland, shrubland, and wheat crop for year 2060. These scalars represent change in net primary production (NPP). Scalar values above one (green) represent an increase in NPP and values below one (red) represent decrease in NPP.*

decarbonization scenarios. Our actively-coupled model system, currently being assessed and documented in preparation for science simulations, represents an exciting opportunity for achieving this science goal. The coupled model will be used for future simulation campaigns that will study the impact of different U.S. decarbonization scenarios on U.S. regional climate and on the biogeochemical cycles. Future work can also involve coupling GCAM to the river routing model, the Model for Scale Adaptive River Transport-Water Management (MOSART-WM). The EAM-GCAM coupling can be further extended to include the emissions of other GHG (e.g., CH4) and air pollutants (e.g., black carbon).

The findings from the science simulations using our actively coupled human and Earth system model will be presented in "Coupled Human-Earth System Modeling" session at the GEWEX Open Science Conference in July 2024.

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The Arctic Radiation-Cloud-Aerosol-Surface-Interaction eXperiment (ARCSIX)

Patrick C. Taylor[1] and Sebastian Schmidt[2]

[1]NASA Langley Research Center, Hampton, VA, USA; [2]University of Colorado-Boulder, Boulder, CO, USA

The Arctic climate system is amidst a transition. Over the last 40 years, the Arctic sea ice pack has transformed from a predominantly thick, multi-year sea ice to a predominantly thin, seasonal sea ice, termed the "New Arctic". The observed rapid changes in the Arctic sea ice pack are an integral part of the Arctic Amplification phenomenon and represent a response to and a feedback on global climate change. As a result, the role of the Arctic within the global climate system is changing. Substantial uncertainty exists in our understanding of the atmosphere-surface interactions within the Arctic system, limiting our knowledge of the Arctic's role in the future climate.

Advancing our understanding of the Arctic climate system requires (1) measurements of the coupling between radiative processes and sea ice surface properties during summer sea ice melt; (2) measurements of the processes controlling the predominant Arctic cloud regimes and their properties (Fig. 1); and (3) improvements in the ability to monitor Arctic cloud, radiation, and sea ice processes from space. A key challenge is that thin, low clouds that are radiatively important to the Arctic surface energy budget can go undetected (Fig. 1).

The Arctic Radiation-Cloud-Aerosol-Surface-Interaction eXperiment (ARCSIX) is an airborne campaign based at the Pituffik Space Base in Greenland from May-August 2024 sponsored by the National Aeronautics and Space Administration (NASA) to address these needs. ARCSIX consists of two airborne measurement campaigns taking place in two 3-week intervals during the early and late sea ice melt season: late May through early June and late July through early August, respectively.

ARCSIX science is guided by three broad science questions that encapsulate the key influences of radiation-cloud-aerosol-sea ice coupling and a remote sensing and modeling objective:

Science Question 1 (Radiation): What is the impact of the predominant summer Arctic cloud types on the radiative surface energy budget?

Science Question 2 (Cloud Life Cycle): What processes control the evolution and maintenance of the predominant cloud regimes in the summertime Arctic?

Science Question 3 (Sea Ice): How do the two-way interactions between surface properties and atmospheric forcings affect the sea ice evolution?

Remote Sensing and Modeling Objective: Enhance our long-term space-based monitoring and predictive capabilities of Arctic sea ice, clouds, and aerosols.

ARCSIX science is focused on quantifying the two-way interactions between the atmosphere and sea ice and their influence on sea ice melt. This focus aligns with GEWEX Science Goal #2 to quantify the inter-relationships between Earth's energy and water cycles. ARCSIX will provide data sets to investigate the controls on cloud phase in Arctic low clouds and improve satellite radiation flux and cloud property data sets over sea ice, relevant to the Global Atmospheric System Studies (GASS) and GEWEX Data Analysis Panel (GDAP) activities, respectively.

To accomplish ARCSIX, the NASA Langley G-III and Wallops Flight Facility P-3 will fly in coordination. The G-III—the high-flyer—serves as a bridge to satellite observations by surveying with remote sensing instruments from above while the P 3—the low-flyer—acquires in situ aerosol, cloud, atmospheric, and surface properties along with radiation below, above, and inside cloud layers. The overarching goal of ARCSIX is to quantify the contributions of surface properties, clouds, aerosol particles, and precipitation to the Arctic summer surface radiation budget and sea ice melt. For the most up-to-date information see our website: https://espo.nasa.gov/arcsix/content/ARCSIX.

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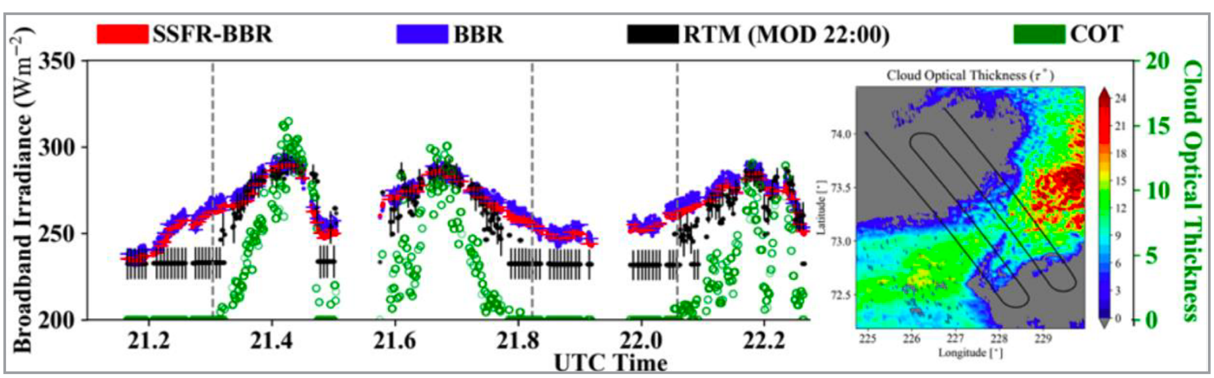


***Figure 1**. Thin, low Arctic cloud processes and detection challenges: (see cover) an illustration of the thin, low cloud processes central to ARCSIX science and (bottom) a pixel-by-pixel inter-comparison from Chen et al. (2021) of broadband upwelling solar irradiance above clouds overlying snow/ice with collocated imager-derived values [Moderate Resolution Imaging Spectroradiometer (MODIS) cloud optical thickness (COT)]. The irradiance was sampled by the Broadband Radiometer (BBR) and the Solar Spectral Flux Radiometer (SSFR) during the Arctic Radiation - IceBridge Sea and Ice Experiment (ARISE) campaign (September 2014).*

Meeting/Workshop Reports

Highlights of the GEWEX SSG-35

Santiago, Chile
1–4 May 2023

Peter van Oevelen[1], Xubin Zeng[2], and Jan Polcher[2]

[1]Director, International GEWEX Project Office; [2]GEWEX Scientific Steering Group Co-Chair

GEWEX held the 35th session of its Scientific Steering Group (SSG) hybrid meeting from May 1–4, 2023 in Santiago, Chile, generously hosted by René Garreaud and the Universidad de Chile.

The SSG meeting is our yearly recurring event where, aside from discussing our GEWEX Science Plan and its implementation as well as the strategy for the years ahead, our Panels can present the progress, strategic plans, new member nominations, and issues and challenges of each activity and receive feedback from the SSG. It is worthy to note that we strongly believe as an organization that the SSG and the International GEWEX Project Office (IGPO) are very much support structures for our community.

For the SSG Co-Chairs and IGPO, this meeting is also the primary avenue to collect information to present to the World Climate Research Programme (WCRP) Joint Scientific Committee (JSC) later in the year. The 2023 meeting, JSC-45, was held in Brussels, the week after SSG-35.

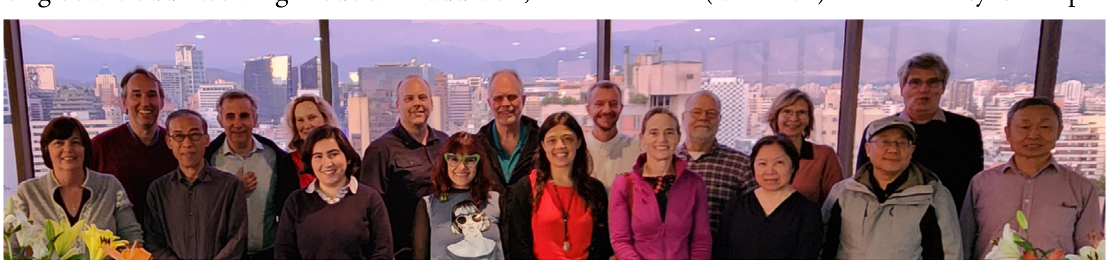
This year's meeting was back to a standard format where the Panels gave presentations as well as the various agencies and other partners including our WCRP counterparts, core projects, and Lighthouse Activity (LHA) representatives. As the full report will be prepared later as a WCRP publication (e.g., see previous year's reports at *https://www.gewex.org/resources/scientific-steering-group-and-panel-reports/*), here we provide a few highlights only.

The Global Atmospheric System Studies (GASS) Panel is starting three new projects: the Elucidating the Role of Clouds-Circulation Coupling in Climate-Model Intercomparison Project (EUREC4A-MIP) on mesoscale organization of shallow convection, the (Shallow) Cumulus Friction Experiment, and the DYnamics of the Atmospheric general circulation Modeled On Non-hydrostatic Domains (DYAMOND) project, an intercomparison of global cloud-resolving models. In addition, three other projects are in preparation: Organization of Deep Convection; the Cold-Air Outbreaks in the Marine Boundary Layer Experiment (COMBLE), which examines convective clouds during Artic cold-air outbreaks; and nudged climate model runs to facilitate comparisons between simulations and observations [e.g., the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAIC)]. Also emphasized was the continuation or strengthening of collaborations with the Cloud Feedback Model Intercomparison Project (CFMIP), the Working Group on Numerical Experimentation (WGNE), the GEWEX Data and Assessments Panel (GDAP), and Digital Earth. A co-located meeting was organized in Paris this year between the GASS Panel and CFMIP.

GDAP is also starting three new projects: a land water and energy closure assessment, the GEWEX Water Vapor Assessment (G-VAP) Phase II, and the Earth Energy Imbalance (EEI) Assessment. Also mentioned was the move of the International Soil Moisture Network (ISMN) from the Vienna University of Technology to the International Centre for Water Resources and Global Change (ICWRG) in Koblenz. The World Radiation Monitoring Center (WRMC)-Baseline Surface Radiation Network (WRMC-BSRN) has become a Global Climate Observing System (GCOS) affiliated network.

The GEWEX Hydroclimatology Panel (GHP) has start several new projects: ANDEX and the Third Pole Environment-Water Sustainability (TPE-WS) study are now officially initiating RHPs. The Asian Precipitation Experiment (AsiaPEX) is expected to follow in the latter part of this year, and the US Regional Hydroclimate Project (US RHP) achieved initiating RHP status at the end of the summer, after the SSG meeting. The Determining Evapotranspiration (dET) Crosscutting Project is a new effort with GLASS, and the Global Flood Crosscutting Initiative is now officially getting underway. There are also two new initiatives on 1) groundwater (a Crosscutting effort) and 2) surface water.

The Global Land Atmosphere System Studies (GLASS) has started three new initiatives: the Solar Induced Chlorophyll Fluorescence-Model Intercomparison Project (SIF-MIP), the Coupling of Land and Atmospheric Subgrid Parameterizations (CLASP), and a new Irrigation Crosscutting Project with GHP (along with dET). Also briefly discussed were the Land surface Interactions with the Atmosphere over the Iberian Semi-arid Environment (LIAISE) field experiment and dET, where it was stressed that evapotranspiration (ET) does not currently have a reference network, yet many ET products exist. The GEWEX/GLASS Land Atmosphere Feedback Observatories (GLAFOs) show a steady development.



Participants of the 35th GEWEX Scientific Steering Group Meeting

An important topic on the agenda was the organization of the 9th GEWEX Open Science Conference to be held in Sapporo, Japan from July 7–12, 2024. A short overview was presented on the location and venue as well as first ideas on the program and side events. Much more on this event online at *https://www.gewexevents.org/meetings/gewex-osc2024/*.

GEWEX continues to have a strong working relationship with the World Weather Research Program (WWRP), mainly through GASS. We hope to further develop similar strong relationships with the World Meteorological Organization (WMO)-Hydrology Program. The coordination with the LHAs and the new core projects was also discussed. All these recent developments are seen in a positive light, yet several participants expressed concerns regarding the resources needed for all these activities while also not overburdening our volunteer community.

The 35th GEWEX SSG turned out to be a very a successful and pleasant meeting with special thanks to our hosts and René Garreaud and his student Monica Zamora Zapata, who took care of the many practical issues including organizing a wonderful group dinner.

9th Global Energy and Water Exchanges Open Science Conference

Sapporo, Japan | 7–12 July 2024

Water · Climate | 水 · 気候

GEWEX Open Science Conference Program

The conference is organized around three themes:

1 Water, Climate, Anthropocene
2 Extremes and Risks
3 Water, Energy, and Carbon Processes

In the context of these themes, the sessions will focus on research that contribute to the following areas:

- Determination of the extent to which Earth's water cycle can be observed and predicted
- Quantification of the inter-relationships between Earth's energy, water, and carbon cycles to advance our understanding of the system and our ability to predict it across scales
- Quantification of the anthropogenic influences on the water cycle and our ability to understand and predict changes to Earth's water cycle
- Extremes in the water cycle and risks to society

An overview of each research area with associated topic(s) and the full list of sessions can be found at **https://www.gewexevents.org/meetings/gewex-osc2024/program/themes-and-sessions/**.

Important Dates

Abstract submission and registration open:	Late November 2023
Abstract submission closes:	1 February 2024
Travel support application closes:	1 February 2024
Abstract acceptance notification:	19–23 February 2024
ECR Workshop acceptance notification:	26 February–1 March 2024
Travel support notification:	4–8 March 2024
Early bird registration closes:	4 March 2024 at 24:00 UTC

The 2023 GLASS Panel Meeting

Hohenheim, Germany
15–17 August 2023

Anne Verhoef[1] and Kirsten Findell[2], GLASS Panel Co-Chairs
[1]University of Reading, Reading, UK; [2]Geophysical Fluid Dynamics Laboratory, Princeton, NJ, USA

For three lovely, hot days in the middle of August, the Global Land-Atmosphere System Studies (GLASS) Panel met on the beautiful campus of the University of Hohenheim in Germany, graciously hosted by Volker Wulfmeyer. We are grateful to Volker, Andreas Pyka (Vice President for International Affairs at the University of Hohenheim), Volker's research group, and especially his assistant Elisabeth Ott for the myriad ways they rolled out the red carpet for our GLASS community.

This year's meeting focused on the importance of observations to assess model behavior, improve parameterizations, and understand how land-atmosphere interactions are changing in a warming world. We considered how we might expand ongoing projects focused on ecological and hydrological processes, and grow new projects that highlight the role of humans in the global energy, water, and carbon cycles.

We kicked off our meeting with a welcome and introductory talk by GLASS Co-Chairs Kirsten Findell and Anne Verhoef. The first day focused on observing and understanding sub-daily processes in the land-atmosphere system, from soils to vegetation to the atmospheric boundary layer. We heard in-depth progress reports from five GLASS projects: **GEWEX Land/Atmosphere Feedback Observatories** (**GLAFO**), **GEWEX Soil and Water Initiative** (**SoilWat**; jointly sponsored by the International Soil Modeling Consortium, ISMC, and presented by Yijan Zeng), **Coupling of Land and Atmospheric Subgrid Parameterizations** (**CLASP**; led by Nate Chaney, presented by Meg Fowler), **Local Land-Atmosphere Coupling** (**LoCo**) Working Group (led by Joe Santanello, with Kirsten Findell contributing portions of the update), and **Solar Induced Fluorescence Model Intercomparison Project** (**SIF-MIP**; led and presented by Nick Parazoo).

Additionally, we heard about the progress of a few cross-cutting initiatives between GLASS and the other GEWEX Panels. Anne Verhoef filled us in on the Impact of Initialized Land Temperature and Snowpack on Sub-seasonal to Seasonal Prediction (LS4P-II) project (a Global Atmospheric System Studies, or GASS, Panel project; slides kindly provided by Aaron Boone, who co-leads the LS4P project with Yongkang Xue) and the **Determining Evapotranspiration** (**dET**) project (a cross-cut with the GEWEX Hydroclimatology Panel, or GHP; Anne co-leads this initiative with Oscar Hartogensis and Aaron Boone). She included a summary of high-resolution modeling efforts proposed by the Land surface Interactions with the Atmosphere over the Iberian Semi-arid Environment (LIAISE) team. We also heard about the research of new GLASS member Marina Hirota from the Federal University of Santa Catarina, Brazil, who looks at disturbances, impacts, and the resilience of tropical ecosystems. Her work includes Amazon basin-wide ecological and physiological field studies, as well as remote sensing, to ultimately help determine if models can represent the high heterogeneity present in Amazonian ecosystems. She challenged the reliability of climate-vegetation feedbacks simulated, given the heterogeneity we can see on the ground for these ecosystems, especially during their transitions, or when they reach eco-climatic "tipping points". The topic of heterogeneity fits nicely with our GLAFO and CLASP project aims, so some potential avenues for collaborations were discussed during our meeting. The GLAFO project update included highlights of two GLAFO observational platforms: the Land-Atmosphere Feedback Observatory (LAFO) near Hohenheim, Germany (set in a highly heterogeneous agricultural landscape), and the Cabauw Atmospheric Research Station (situated near Utrecht, the Netherlands on a large, relatively homogeneous managed grassland area affected by shallow groundwater), operated by The Royal Netherlands Meteorological Institute (KNMI). The Cabauw highlights were shared by Arnoud Apituley, who was invited to our meeting to underscore the common interests between his research team overseeing the Cabauw research station (part of the Ruisdael Observatory; *https://ruisdael-observatory.nl/cabauw/*) and the GLAFO project.

During the evening, we were treated to a beautiful quatremains professional piano recital in the ornate ballroom of Hohenheim Palace.

Day 2 of our GLASS Panel meeting focused on benchmarking models against observations, assessments of global model performance, and expanding our scope of hydrological projects. We heard progress reports from the remaining five GLASS projects: Gab Abramowitz filled us in on **Protocol for the Analysis of Land Surface models** (**PALS**) **Land Surface Model Benchmarking Evaluation Project, Phase 2** (**PLUMBER2**) and **modelevaluation.org**; Dave Lawrence discussed **The International Land Model Benchmarking** (**ILAMB**); and Hyungjun Kim spoke about **The Global Soil Wetness Project, Phase 3** (**GSWP-3**) and the **Land Surface, Snow and Soil Moisture Model Intercomparison Project** (**LS3MIP**), which were both tightly coupled to the Coupled Model Intercomparison Project Phase 6 (CMIP6) cycle and are therefore nearing completion.

The PLUMBER2 project has revealed that mechanistic land models (including land surface models, ecosystem and hydrology models) perform poorly in the prediction of turbulent fluxes against out-of-sample empirical benchmarks, including regression models and machine learning approaches. This is particularly true for sensible heat flux. Land surface models tend to significantly outperform other mechanistic models at flux prediction, including carbon flux prediction. These results are discussed in a manuscript that will be submitted by the end of the year.

ILAMB continues to gradually evolve, adding data sets and new metrics. A focus this year was on incorporation of hydrology metrics and some simple metrics that evaluate land-atmosphere interactions (terrestrial coupling strength and critical soil moisture metrics). A new scoring methodology aims to make errors from different areas of the globe comparable.

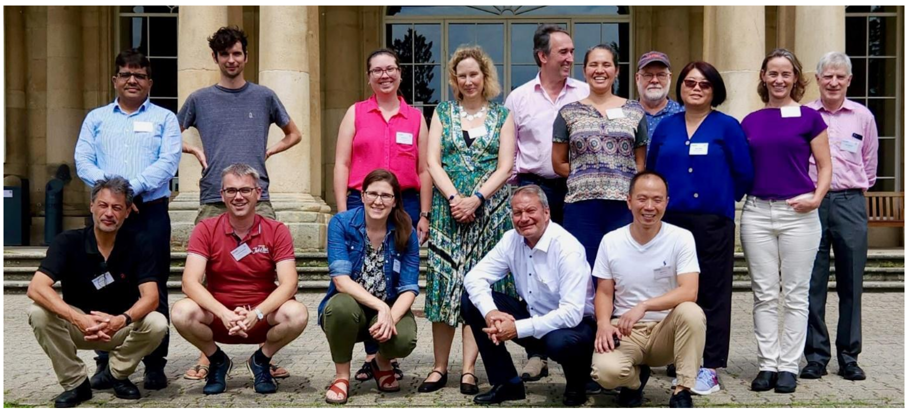
On Day 2 we also learned about projects with connections to the GEWEX Data and Analysis Panel (GDAP) from our GDAP liaison, Yunyan Zhang, and about projects with connections to GHP from our Panel members Laura Condon, Tricia Parker-Lawston, and Josh Roundy (our GHP liaison). Laura spoke about the **Groundwater cross-cut** led by Laura and Stefan Kollet, Tricia spoke about the **Irrigation cross-cut** she leads, and Josh spoke about the proposed cross-cuts on surface water and floods. We then heard about the research and scientific views of new GLASS member Vimal Mishra (from IIT Gandhinagar, India) on data and land surface modeling-related challenges in South Asia. He posed a range of pertinent questions relating to land surface hydrology in South Asia, with a key one being "how the interplay between climate and human interventions (e.g., aerosols, land use/land cover change, irrigation) affects the changes and variability in the summer monsoon". Finally, he highlighted the critical importance of shifting some of our collective attention to the urgent needs of climate services with the aim of developing pathways to bridge science and solutions.

A tour of the heavily instrumented LAFO field site, led by Volker and his colleagues, provided us all with observational inspiration at the end of this second day. Some of our modelers were particularly intrigued and grateful to see the intricate 3-D atmospheric scanning equipment in action, given their heavy reliance on these important observations.

In the evening, we visited Hohenneuffen Castle for a guided tour and medieval banquet. Apart from wonderful food and entertainment, this provided a great bonding experience for our Panel members and invited collaborators.

The morning of Day 3 shifted to potential collaborations with some of the initiatives in the broader World Climate Research Programme (WCRP) sphere. We heard from colleagues at the Integrated Land Ecosystem-Atmosphere Processes Study (iLEAPS; presented by Xianhong Meng) and three of the WCRP Lighthouse Activities: *Safe Landing Climates* (presented by Hyungjun Kim), *Explaining and Predicting Earth System Change* (presented by Kirsten Findell), and *Digital Earth*. Discussions are already underway between GLASS and Digital Earth's efforts on urban modeling (kindly presented by Gyorgy Zoltan Nagy, in lieu of Dev Nyogi, who was not able to attend) and high-resolution land modeling (led and presented by Min-Hui Lo). Gert-Jan Steeneveld, our GLASS Panel member representing urban modeling and monitoring efforts, gave a brief overview of recent developments in this arena.

An important focal point of the last day was provided by our local hosts: Lisa Jach shared results from her investigations of interannual variability of land-atmosphere coupling in Europe, and Hans-Stefan Bauer provided highly informative visualizations indicating the power of large eddy simulations of the region surrounding the LAFO field site. This site is providing data that will be at the heart of the next phase (GA-



***Top left**: GLASS Meeting participants at the LAFO field site. **Top right**: meeting attendees are treated to a piano recital at Hohenheim Palace. **Bottom left**: GLASS Meeting participants. **Bottom right**: a closer look at LAFO field site instrumentation. Thanks to Arnoud Apituley for the top two and bottom right photos.*

BLS5) of the long-standing GEWEX Atmospheric Boundary Layer Study (GABLS) initiative, which gained great momentum during our Panel meeting, based on a discussion following the presentation by John Edwards, with inputs from Mike Ek and Volker. The Panel was enthusiastic about the idea of reviving the GABLS project to focus on boundary-layer turbulence and land-atmosphere interactions, making use of the detailed observations available from GLAFO and capitalizing on synergies with CLASP. Initial simulations of a diurnal cycle have been performed by modeling groups at the University of Hohenheim and the UK Met Office at convection-permitting and large eddy simulation (LES) resolutions over domains centered on the GLAFO site at Hohenheim. We intend to develop a definitive case over the coming year. In the longer term, we envisage extending the project to encompass other sites.

During the final part of the afternoon, we reflected on how GLASS has been steadily re-adjusting its course, e.g., through better representation of the carbon cycle (via projects such as SIF-MIP and recent appointments to the Panel) and by ensuring we consider the multi-faceted problem of modeling human intervention in the Earth system, together with the other GEWEX Panels and WCRP initiatives. We also touched upon the topic of how to best collaborate and interact with the recently-established International Land Modeling Forum (ILMF), which focuses on the technological challenges that land modeling centers face, and how they can share best practices (*https://hydro-jules.org/international-land-modeling-forum-ilmf*). The ILMF (led by Dave Lawrence and Eleanor Blyth) is growing, with over 200 members spanning most major land modeling groups and a wide range of expertise. The ILMF is hosting a series of webinars this fall to kick start international collaborative activities on (1) sharing modules across land models, (2) parameter estimation, and (3) integrating humans more deeply into next generation land models. During the final part of our GLASS meeting, we also discussed potential new initiatives. In this context, worthy of particular mention are a working group on alternatives to the Monin-Obukhov Similarity Theory (MOST), and closer collaborations with GDAP and GASS (via LS4P-II) on the use of (remotely sensed) land surface temperatures (LSTs) in the context of land model verification and development. As seen in the results of PLUMBER2 mentioned above, our models are struggling with the prediction of sensible heat flux, in which LST plays a dominant role. These discussions also inspired some of our propositions for GLASS (co-)chaired sessions at the 9th Global Energy and Water Exchanges Open Science Conference, in Sapporo, Japan, from 7–12 July, 2024.

As we closed out the meeting, the urgency of the climate crisis motivated our discussion as we considered how GLASS can continue to grow and diversify to make sure we keep honing our models and increasing our observational capabilities to meet the societal needs of this Anthropocene Era.

This GLASS meeting was Kirsten's final meeting as co-chair, so we convey our heartfelt thanks for her dedicated and inspired services throughout the past 5 years. Nate Chaney will be taking over as co-chair from 1 January 2024 onwards.

Convection-Permitting Modeling for Mountainous and High Latitudes: A Summary of the 7th Convection-Permitting Modeling Workshop

Stefan Sobolowski[1,4], Andreas F. Prein[2], Stephanie Mayer[1,4], Asgeir Sorteberg[3,4], and Roy Rasmussen[2]

[1]NORCE Norwegian Research Centre AS, Bergen, Norway; [2]National Center for Atmospheric Research (NCAR), Boulder, CO, USA; [3]Geophyiscal Institute, the University of Bergen, Bergen, Norway; [4]The Bjerknes Center for Climate Research, Bergen, Norway

The seventh installment of the Convection-Permitting Modeling (CPM) Workshop series was held in hybrid format between 29–31 August 2023 in Bergen, Norway, and online. Bergen is home to the Bjerknes Center for Climate Research, the University of Bergen's Geophysical Institute, the Norwegian Research Centre (NORCE), and a vibrant weather and climate research community.

The workshop attracted 101 in-person and 26 online participants from 33 countries and all continents (except Antarctica). It featured six keynote talks, four plenary oral sessions, three panel discussions, two poster sessions, and three breakout groups focused on topics ranging from challenges in km-scale modeling over mountainous and high latitude regions, extremes and impacts, model development, CPM for society, and taking stock of what we have learned, and where, as a community, we wish to go. Given the overarching theme, the workshop had a strong observational component to go with discussions on model advances and expanding our physical understanding of the impacts of climate change at local scales. The workshop brought together members from different communities including the ANDEX project (*https://www.gewex.org/project/andex/*), several Coordinated Regional Climate Downscaling Experiment Flagship Pilot Study (CORDEX FPS) efforts such as the Convection-Permitting Third Pole (CPTP) group (which held a meeting after the workshop, *http://rcg.gvc.gu.se/cordex_fps_cptp/*), and the TeamX working group on mountain climate (*http://www.teamx-programme.org/workgroups/mountain_climate/*).

In-person participants of the 7th CPM workshop

A central theme of discussions was the need for high-resolution observations to help verify, validate, evaluate, and improve our high-resolution model simulations. Keynote talks emphasized the need to gain process-level understanding at even "snow drift" and "alpine valley" scales. Multiple presentations highlighted the importance of improving land-surface processes in km-scale models to reduce biases in key variables such as near-surface temperature, precipitation, and snow accumulations. We also saw results from some of the first transient convection-permitting climate modeling (CPCM) ensemble simulations, which indicate the emergence of increased variability around the middle of the century right around the time that summer sea ice disappears in the global climate models (GCMs). Further work is needed to confirm if these are related or a coincidence. Also, significant time was set aside at this workshop to reflect on what we have learned over recent years and where we wish to go. To this end, we saw evidence of how multi-model ensemble-based approaches allowed us to confirm the long-hypothesized convergence of climate change signals and improve our physical understanding of projected climate impacts.

The three breakout sessions focused on key Earth system components to integrate into our system; better linking to the Vulnerability, Impacts, Adaptation, and Climate Services (VIACS) community; and a five-year prioritization plan. The first set out a prioritization for the community that included interactive/evolving aerosols, vegetation, terrestrial hydrology, and urban components as these elements are already quite mature. For some regions, however, it is recognized that components like glaciers and coupled oceans are important and will need to be included in short order. The second suggested a focus on applications in order to improve the relevance of CPM for society while acknowledging that sustained engagement is needed for robust climate services co-production. Therefore, the CPM community needs to seek synergies and partnerships with established climate services providers. The third breakout group emphasized the need for coordinated efforts that address the promise of deep learning, improve process/physical understanding, and build/expand the community. The outcomes from these sessions will form a community perspectives paper and help inform community strategies around CPM, e.g., within the context of the CORDEX Flagship Pilot Studies.

Looming in the background of the workshop, as with many activities in 2023, was the mainstreaming of AI. What this means for the CPCM community is unclear. But there are many groups applying AI and machine/deep-learning techniques on topics as diverse as hybrid local-scale downscaling, extreme events, parameterization estimation, forward integration of projections, and more. There was a strong desire expressed to include a session on the topic in the next year's workshop.

In summary, some of the key messages from this workshop are:

- The use of km-scale models for downstream climate services is here now. The community has a shared responsibility to ensure that these outputs are used responsibly.
- With the first of the CORDEX FPSs making its output available via the Earth System Grid Federation (ESGF), we are able to look back and assess some lessons learned from these exercises that will serve us well in the age of AI and climate model streaming. They are: ensembles matter for understanding uncertainty; community efforts matter for gaining insight over diverse regions, processes, and scales; and physical understanding matters for building confidence in projected changes. All three are essential to advance knowledge.
- Advances continue in the area of coupling km-scale atmospheric models with other Earth system components. In this meeting, we aimed to make a prioritization based on readiness, scientific necessity, and societal needs. The most pressing components to include are terrestrial hydrology, vegetation, and urban effects.
- Advanced hybrid techniques that combine dynamical modeling with cutting-edge machine/deep-learning approaches are beginning to appear in the context of CPM and high-resolution climate modeling more generally.
- The increasing data volume from km-scale models continues to create inequalities in data accessibility, particularly for researchers in the Global South. Initiatives have started to reduce these inequalities by allowing researchers to analyze the data at the storage location. But at the same time, data volumes are set to explode with the upcoming outputs from Digital Twins.

The coordination of the workshop in Bergen was made possible through the herculean efforts of Beatriz Balino, WCRP, and the Bjerknes Centre for Climate Research. Generous support for local logistics was provided by NORCE, the University of Bergen, and the Bjerknes Centre. Travel support for early career scientists and scientists from low- to medium-income countries was provided by the National Center for Atmospheric Research (*https://ncar.ucar.edu/*) and GEWEX (*https://www.gewex.org/*).

More information on the 7th CPCM workshop can be found on the workshop website at *https://cpm2023.w.uib.no/*. The organization of the 8th CPCM workshop has already started, which will be held as a hybrid event in September 2024 in Fort Collins, Colorado, USA. Please subscribe to the CPCM email list (*ral-cpcm@ucar.edu*) for more information.

Land Surface Models: Current Trends, Future Needs, and Opportunities

Cologne, Germany
1–2 February 2023

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On February 1 and 2 in Cologne, Germany, a land surface modeling (LSM) workshop was organized by Geoverbund and the DETECT (Regional Climate Change: Disentangling the Role of Land Use and Water Management) project. Geoverbund is a regional center for geosciences and DETECT a large project funded by the German Science Foundation on regional scale climate modeling and the role of land use change and human water use on regional climate change and the terrestrial water, energy, and carbon cycles. The University of Bonn and Research Centre Jülich are the two main project partners in DETECT. The workshop had in total 24 invited talks and a few discussion rounds. We focus here on the main messages from the workshop and its highlights.

A land surface model (LSM) is an important component in an atmospheric circulation model, as the lower boundary condition not only has a major impact on the development of the boundary layer on diurnal timescales (and thereby influences the weather forecast), but also has the ability to carry some memory for longer timescales (or accumulate errors over longer periods). **Linda Schlemmer** from the **German Weather Service** (**DWD**) highlighted that for numerical weather prediction applications, there is a delicate balance between the number of processes that are represented, and the available computing time. Thus, the LSMs in usage are often quite simple, with a focus on a few important aspects, but together with a soil-moisture analysis, a good land surface boundary condition can be found. There is a potential for using high-resolution data sets as input (e.g., for soil properties or land use) and better initial conditions for the atmospheric model with the extended land-surface data assimilation. **Sönke Zaehle** from the **Max Planck Institute for Biogeochemistry** (**MPI-BGC**) detailed the further planned development of the Icosahedral Nonhydrostatic Weather and Climate Model (ICON)-Land, the LSM of the new numerical weather prediction (NWP) model of DWD. It will incorporate parts of the existing LSMs JSBACH (Jena Scheme for Biosphere-Atmosphere Coupling in Hamburg) and TERRA, as well as the QUINCY (Quantifying the Effects of Interacting Nutrient Cycles on Terrestrial Biosphere Dynamics and their Climate Feedbacks) model, which provides more comprehensive ecological processes and is still under development. As Linda Schlemmer indicated, a central question is the degree of complexity to be included for specific applications. On the other hand, **Rainer Helmig** (**University of Stuttgart**) pointed to the need for thermodynamically consistent coupling processes to better simulate water and energy exchange between land and atmosphere, with the need for better handling of the very different scales at which processes are acting, for surface roughness, and for fluid-solid phase changes like salt precipitation. **Jasper Denissen** emphasized that the European Centre for Medium-Range

Weather Forecasts (**ECMWF**) focuses the Integrated Forecasting System and the land surface model component of it, ECland, on simulations at a very high spatial resolution of 1 km. Current implementations focus on the representation of snow, river discharge, and flood modeling, water tile mapping, and urban tile mapping. **Simon Dadson** from the **UK Centre for Ecology and Hydrology** indicated that current work with the LSM Hydro-JULES model includes the development of a high-resolution groundwater model for the British Isles to be integrated in the LSM used by the UK Met Office. For **Benjamin Fersch** (**Karlsruhe Institute of Technology**, or **KIT**), the inclusion of lateral groundwater flow processes in the Noah-Multiparameterization (Noah-MP) LSM is a main research focus, besides the coupling to the WRF (Weather Research and Forecasting) model and improved assimilation of soil moisture measurements to better characterize the land surface. **Ben Smith** from **Western Sydney University** in Australia gave an overview of developments in the LPJ-GUESS (Lund-Potsdam-Jena General Ecosystem Simulator) LSM. He highlighted the dynamic global vegetation model that is included, and is based on an individual and patch-based representation of vegetation structure, composition, and dynamics, and the mutual feedbacks between vegetation and atmospheric conditions, pointing to season-dependent impacts of land use change. Further ongoing developments will, for example, include the phosphorus cycle and improved modeling of N_2O emissions.

Other presentations were centered on the ongoing development of LSMs, without focusing on the coupling to atmospheric models. **Dave Lawrence** (**National Center for Atmospheric Research**, or **NCAR**) stressed the need to support actionable science with the Community Land Model (CLM) (e.g., predictions, terrestrial contribution to net zero emissions, water and food security, and evaluation of impacts on ecosystem services). In this context, the quantification of the impact of parameter uncertainty and calibration was stressed (the parameter perturbation experiment), lateral water redistribution and improved representation of land management. The experiments show biome-dependent parameter sensitivities, and stress that care should be taken to select sensitive parameters correctly; for example, parameters that show increased sensitivity under future climate conditions. **Philippe Peylin** (**National Research Institute for Agriculture, Food and the Environment**, or **INRAE**) presented current developments in the ORCHIDEE (Organizing Carbon and Hydrology In Dynamic Ecosystems) LSM and stressed the increasing importance of parameter estimation for increasingly complex models. For parameter estimation, different approaches are now considered, such as calculating the tangent linear and adjoint model of any ORCHIDEE version, ensemble based methods (which are, however, very expensive), and emulator-based approaches. Philippe also pointed to the importance of nitrogen deposition and biological fixation, modeling dynamic canopy development, and modeling forest disturbance (e.g., infestations, fire). **Ralf Kiese** (**KIT**) presented the Landscape DeNitrification-DeComposition (LandscapeDNDC) model, which can simulate water, carbon, and nitrogen cycles from local to global scales as well as greenhouse gas emissions. He stressed the importance of a detailed representation of management processes in LSMs, such as intercropping or fertilizer application, for simulating greenhouse gas emissions and crop yield. **Rosie Fisher** (**Centre for International Climate and Environmental Research**, or **CICERO**) presented the Functionally Assembled Terrestrial Ecosystem Simulator (FATES), which represents vegetation demography, and allows the simulation of, for example, individual traits, time lags between climate change and vegetation adaptation, and regrowth after disturbance, so that it is potentially closer to observations. In this presentation, strategies for parameter estimation were also discussed, like emulator-based approaches. On the other hand, **Luis Samaniego** (**Helmholtz Centre for Environmental Research**, or **UFZ**) focused on an evaluation of the performance of LSMs and stressed that complex LSMs do not simulate a variable like discharge better than models with a much simpler model structure and fewer parameters. This contributed to the discussion of whether future LSMs should include even more processes and unknown parameters, and whether enough experimental data are available to estimate parameters of those models.

A group of presentations focused on the representation of drought stress and soil and plant hydraulics in LSMs. **Andrea Carminati** (**ETH Zürich**) highlighted that soil hydraulic conductivity is the first hydraulic limit to transpiration globally and that the soil thresholds range strongly from field capacity in sandy soils (critical matric potential -100 hPa), to almost wilting point in clay soils (critical matric potential -0.1 to -1 MPa). In summary, the variations in soil hydraulic properties (within each textural class) have a large impact on soil water thresholds. **Andrea Schnepf** (**Research Centre Jülich**) indicated that a 3D root hydraulic architecture can be upscaled and embedded in a 1D soil model by means of a simple function with two parameters, the root system conductance and the standard uptake fraction vector. This formulation allows for hydraulic redistribution and root water uptake compensation and could easily be implemented in LSMs. A low soil hydraulic conductivity in a dry perirhizal zone can further limit root water uptake and transpiration. It can be accounted for by an additional simple function that is derived from an approximate analytical solution of the 1D radial Richards equation that accounts for the development of water potential gradients between root surface and bulk soil. **Mauro Sulis** (**Luxembourg Institute of Science and Technology**, or **LIST**) pointed out that the plant hydraulic system (PHS) implemented in CLM5.0/the Community Terrestrial System Model (CTSM) and many other LSMs opens the opportunity for better characterizing the simulated transpiration response across different ecosystems and tree species based on experimental evidence reported in a large scale database (e.g., Xylem Functional Traits). Specifically, the PHS provides a way of characterizing the inter- and intra-specific variability of the vulnerability/resilience to drought of different tree species across a selected environmental gradient. Furthermore, the plant hydraulic parameter controlling the water transport capacity (i.e., maximum xylem conductance) is key for an improved simulation of water use strategies of different tree species. The values of this emerging parameter are, however, loosely connected to experimental measurements of specific xylem conductance, showing dependency on factors other than vegetation type in the current model formulation. There was an animated discussion on whether soil or plant hydraulics are more important in controlling the flow of water from soil to atmosphere. **Yijian Zeng**

(**University of Twente**) presented the current efforts in integrating plant hydraulics with photosynthetic processes at leaf-canopy levels based on the STEMMUS-SCOPE (Simultaneous Transfer of Energy, Momentum and Mass in Unsaturated Soil-Soil Canopy Observation, Photochemistry, and Energy fluxes) model, and highlighted the Digital Twin concept as a technology to push the boundaries for LSM development (in terms of incorporating holistically-relevant soil-plant processes into LSMs). He also stressed the use of machine learning and deep learning to develop LSM emulators, and to apply data assimilation technology to assimilate Earth observation data to update soil-plant system states.

Other presentations described specific developments or studies with LSMs, focusing on data assimilation, parameter uncertainty, irrigation, representation of vegetation, and peat. **Bibi Naz** (**Research Centre Jülich**) presented work on the assimilation of remotely-sensed soil moisture in the continental-scale CLM3.5 LSM, and showed that assimilation improved soil moisture characterization, but hardly other variables like discharge. **Anne Springer** (**University of Bonn**) pointed to satellite gravimetry observations from the Gravity Recovery and Climate Experiment (GRACE)/GRACE-Follow On (GRACE-FO) missions as information on large scale changes of continental water storage. She discussed how land-surface models can benefit from these observations through data assimilation and highlighted specific challenges related to the GRACE observation type. **Gabrielle de Lannoy** (**KU Leuven**) highlighted the integration of the AguaCrop model in the National Aeronautics and Space Administration (NASA) Land Information System (LIS) framework with data assimilation capacity, which can be used to estimate irrigation, given the strong link between crop yield and soil moisture in water-limited regions. However, this requires a high spatial resolution. **Arianna Valmassoi** (**DWD**) presented the inclusion of an irrigation routine in the atmospheric model WRF and showed that this improved the modeling of several variables like soil moisture content and air temperature. **Michel Bechtold** (**KU Leuven**) presented on current progress and challenges in integrating peatland processes into global land surface models. The need for structural model changes to account for peatland-specific features has been recognized by the land use modeling community and various modeling frameworks have introduced related modules. **Theresa Boas** (**Research Centre Jülich**) presented the implementation of winter wheat and a cover cropping subroutine in CLM5.0, as well as parameter estimation for several crops, which led to substantial improvements in simulating energy fluxes, leaf area index, net ecosystem exchange, and crop yield at the point scale. This framework was applied in combination with seasonal weather forecasts for predicting regional-scale crop yields. **Olga Dombrowski** (**Research Centre Jülich**) introduced perennial deciduous woody crops as a new plant functional type in CLM5.0. The model development includes a new crop phenology subroutine that captures the typical development of fruit trees and includes new management practices such as transplanting of tree seedlings, pruning of woody biomass, and orchard rotation and replanting. Additionally, carbon and nitrogen allocation were adapted and a new apple plant functional type was parameterized.

In summary, the workshop provided very interesting presentations and animated discussions, also in the breaks and at the evening dinner. The presentations highlighted the trend towards LSMs making use of higher-resolution input data and including more processes, especially concerning vegetation (e.g., plant hydraulics, vegetation demography, increasing number of vegetation types), human management (e.g, irrigation, fertilization), lateral flows, and improved coupling to the atmosphere. On the other hand, including more processes does not necessarily lead to better simulations or predictions, and this concern was also expressed in the meeting. An increased focus on land surface parameter estimation can be observed, along with the exploration of new methods in this context like the development of LSM emulators to make computing-intensive parameter estimation feasible.

Sandrine Bony Receives the Buys Ballot Medal

Sandrine Bony, Co-Chair of the GEWEX Global Atmospheric System Studies (GASS) Panel, has been awarded this year's Buys Ballot Medal for meteorology by the Royal Netherlands Academy of Arts and Sciences. Her work is credited with helping to clarify the interaction between clouds and circulation and reducing uncertainty about the effect of clouds on climate change.

New Abbreviations and Acronyms List Now Online

The new abbreviations and acronyms list is now available at *https://www.gewex.org/abbreviations-acronyms/*.

GEWEX/WCRP Calendar

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

27 November–1 December 2023—Hydrospace 2023—Lisbon, Portugal

11–15 December 2023—AGU Fall Meeting—San Francisco, CA, USA, and Online

28 January–1 February 2024—104th AMS Annual Meeting—Baltimore, MD, USA

13–17 May 2024—5th Baltic Earth Conference—Jūrmala, Latvia

7–12 July 2024—9th Global Energy and Water Cycle Open Science Conference—Sapporo, Japan

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