Final Project Report

Conference: International Summit to Consider a Special-Purpose Computational System for Frontier Earth System Science and Climate Simulation & Projection

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Executive Summary

This NSF award supported a hybrid-participation, multi-sector and multidisciplinary international summit designed to catalyze transformative progress in Earth system science through global collaboration and innovative computational strategies. Convened at the University of Illinois Urbana-Champaign (UIUC) from September 29 – October 2, 2024, the summit involved over 120 leaders in science, technology, policy, and stakeholder communities across 10 countries. Recognizing that sophisticated Earth system models are unable to achieve their full potential owing to limitations in the computational resources available, the principal objective of the summit was to frame a specialized computational system that supports frontier Earth system simulations, integrated with artificial intelligence and machine learning capabilities, thereby enabling fine-scale, decision-relevant weather and climate information for a broad array of stakeholders.

Structured around plenary sessions, breakout discussions, and networking opportunities, the summit addressed three foundational challenges: defining a scientifically credible and societally relevant vision; identifying the research, data, and computational infrastructure needed to implement the vision; and exploring new models for governance and funding. Discussions emphasized the urgent need for a global modeling framework capable of kilometer-scale resolution built on a modular computational architecture, open data principles, and co-designed with stakeholders. Participants endorsed a two-phase approach: an initial focus on 10 km-resolution global modeling over a decadal timescale, followed by a second phase targeting 1 km resolution and 30- to 50-year simulations to capture both natural variability and anthropogenic signals.

Breakout sessions yielded clear priorities for action, including better integration of physical and AI-based models, creation of a specialized distributed but coordinated computational ecosystem, development of standardized model outputs and validation frameworks, and design of a stakeholder-driven translational infrastructure. The summit also highlighted the importance of governance mechanisms that ensure inclusivity, agility, and sustained investment. Cross-cutting themes included workforce development, open science, and the urgent need to engage philanthropic, public, and private funding partners.

The summit generated significant broader impacts by focusing on transformational climate modeling in service to society, and by providing mechanisms globally to participate in the summit and utilize its archived products. Through its comprehensive and forward-looking approach, the summit brought together a diverse, interdisciplinary community to co-develop a vision for next-generation, fine-scale climate information systems. By framing climate modeling as a global public good, the project promoted democratization of access, particularly for under-resourced regions and communities that are often most vulnerable to climate change yet lack adequate decision-support tools.

The summit concluded with consensus on several next steps: establishing working groups to refine scientific goals and computational infrastructure requirements; translating stakeholder use cases into model specifications; creating pathways for global engagement\; and launching targeted communication efforts to articulate the societal value of high-resolution Earth system modeling. Collectively, the summit laid the groundwork for a globally coordinated initiative to revolutionize Earth system science and support environmental resilience at all levels of society.

1. Motivation and Key Questions Addressed

This NSF award supported a hybrid-participation, multi-sector and multidisciplinary international workshop convened at the University of Illinois Urbana-Champaign (UIUC) from September 29 – October 2, 2024 (https://climatecomputer.ncsa.illinois.edu/). The purpose of this meeting (hereafter referred to as the summit) was to discuss the practicability of creating a specialized computational system to support frontier Earth system science research and climate projection at the spatial fidelity of today's numerical weather prediction (NWP) models (1 to 3 kilometers between locations in a global mesh at which calculations are made). Such detailed computer simulations using sophisticated global Earth system models (ESMs), integrated with artificial intelligence and machine learning (AI/ML) capabilities, are believed essential for understanding the local impacts of future events such as fine-scale extreme weather, as well as the two-way interactions between such events and larger/global-scale phenomena.

The summit was motivated by several challenges in applying fine-scale ESMs globally. First, ESMs not only solve equations similar to those of NWP models, i.e., representing atmospheric motion, thermodynamics, cloud and precipitation processes, radiation physics, surface/atmosphere interactions, vegetation, soil moisture and groundwater, and oceans, but they also model other highly nonlinear processes associated with atmospheric gases and particulates, biogeochemical cycles, ice sheets, marine ecosystems, and natural and anthropogenic forcings such as volcanic eruptions, variations in solar output, and human-induced greenhouse gas emissions. This increase in the complexity and sophistication of ESMs likewise increases their computational requirements.

Second, NWP models and ESMs are initialized differently. Because the former are used operationally, in most cases to capture the location and evolution of specific events on time scales ranging from a few hours to around two weeks (e.g., large-scale high- and low-pressure systems, frontal precipitation), their starting point, or initial condition, is the end state of a previous forecast into which the latest observations are assimilated. Thus, NWP largely is an *initial value problem* and, consequently, NWP model output is referred to as a *prediction* or forecast.

In contrast, ESMs applied to estimating long-term Earth system behavior begin not with a previous estimate and set of observations, but rather with a reference state. The models then are run for long periods of time until they reach quasi-equilibrium, after which various natural and anthropogenic "forcings" are applied over time to estimate how changes in greenhouse gas concentrations and other factors (e.g., volcanic eruptions, changes in solar activity and land-surface characteristics) affect the overall system. Because ESMs utilized in this fashion provide general characteristics of the Earth system over extended periods of time (many decades to centuries), they represent a largely *boundary-value problem,* and their output generally is referred to as *projections* rather than predictions. Being able to run ESMs at fine resolution globally will involve using observations in new ways, and also facilitate melding weather and climate modeling to allow seamless prediction and projection across scales.

Third, uncertainty always exists in NWP forecasts and ESM projections owing to shortcomings in the representation of physical processes, approximations made in numerical solution techniques, assumptions made in specifying future human and technological frameworks, errors in observations, uncertainty in initial conditions, and limitations in our understanding of the complexities of the Earth system (an additional and very important issue is model resolution, described below). As a result, rather than running a single NWP forecast or climate projection, an ensemble of them is created – sometimes numbering hundreds of runs – by thoughtfully varying model parameters, initial states and forcings, and by combining output from multiple models. Among other things, this approach allows for quantification of uncertainty and yields probability distributions that can be utilized in a wide variety of ways, especially for assessing risk. Ensembles also dramatically increase the computational resources required (an issue which may be addressed in some cases by AI/ML, as discussed during the summit).

Finally, and the principal motivation for the summit, all NWP models and ESMs are limited in their ability to spatially resolve features owing to how the physical systems they portray are represented in the computer. Typically, these representations involve discretization of the equations being solved on a mesh of various geometric characteristics. Computationally, a doubling of the spatial resolution (halving of the mesh spacing or its equivalent) increases computer memory requirements by a factor of 4 and computation time by a factor of 8. This exponential scaling leads to extraordinary computational system demands for fine-scale ESMs run over the entire globe for decades or more, where meshes can be 20 to 30 times finer than those typically used for national and international assessments.

Although others have examined approaches for accommodating fine-scale ESMs run globally, focusing on hardware-software co-design, recommendations largely were not implemented. Additionally, AI/ML had not yet been applied to NWP models and ESMs in the manner they have today, leading to proposed computational frameworks focused principally on traditional physics-based modeling strategies.

The UIUC summit took a notably different approach by placing the needs of practitioners – who rely on ESM-derived information for making decisions – as the driving force behind the design framework of a specialized computational system for Earth system science and climate projection. Example application areas include insurance and reinsurance, risk and catastrophe modeling, urban and coastal planning, infrastructure and resilience, energy, agriculture, transportation, communications, recreation, health, and land management. Such needs also motivate the research required to create the computational and modeling framework as well as the pioneering research that would result from it.

Because numerous efforts already are underway internationally to establish kilometer-scale ESMs,[1] addressing issues such as representations of physical processes, computational grids, and data frameworks, *the summit emphasized the other side of the coin: namely, creating a computational environment which would make multi-decade ensemble projections from fine-scale ESMs practicable*. More specifically, the summit sought to address the following question:

Will the evolution of computational systems, as presently envisioned, be sufficient to support large ensembles of kilometer-scale global climate simulations soon enough to help answer key scientific questions, and to support local and regional decision-making regarding climate change?

Summit organizers also proposed the following stretch goal:

Upon completion of a five-year development and construction effort, the special-purpose computational system will support the execution of 100 full-physics Earth system simulations of 100-year duration at 1 km effective global grid spacing.

The summit addressed additional questions, including but not limited to the following:

- How can challenges of running ESMs on current and future HPC systems best be overcome in hardware and application/system software, especially using AI?
- How can heterogeneities within ESMs, both in terms of the structure of equations being solved and the physical processes they represent, be leveraged to optimize performance in hardware and software?
- How can practitioners and stakeholders best utilize high-resolution information from ESMs, and what features and events need to be captured?

[1] Examples include but are not limited to the Earth Virtualization Engines project, Earthworks project, U.S. Department of Energy (DOE) Exascale Earth System Model (E3SM), European Union's Destination Earth and nextGEMS, Swiss EXCLAIM, and Japan's NICAM-GLES**.**

- What are the best approaches for mapping ESMs, now being converted to high spatial resolution, to special-purpose systems (e.g., languages, codes, and components to be used, roles of different organizations)?
- What functional requirements (e.g., computational time, memory, output storage, visualization, analysis) exist for fine-scale global ESMs, their ensembles, and integrative AI to produce meaningful many-decade to century-duration climate projections?
- How does model resolution impact ensemble size and related information for decision making, predictability limit estimation, etc?
- Is a computational system (which might consist of a system of systems), co-designed by scientists and engineers specifically for large ensembles of km-resolution ESM runs that also interacts with AI systems, technically feasible and the best approach to be taken?
- What innovations and research will be required (e.g., chips, interconnect, memory, I/O, operating system, memory hierarchy, networking, compiler, etc) to achieve this capability?
- Can such an effort be completed in five years, and how much would it cost?
- Would such a system be sufficiently stable to support innovative science and long-term global climate projections?
- What would be the effective lifetime of such a system, scientifically and structurally?
- Can the envisioned system be powered solely or mostly by renewable energy sources?
- What alternative technology pathways exist, both immediately and in the short-term (5-10 years), and how could they accelerate progress toward the stretch goal?
- Is it possible or even likely that advances in general-purpose computing capabilities, when coupled with AI, would provide the needed capability by the time a special-purpose computational system could become operational?
- How can the envisioned system be used to better understand interactions of Earth system phenomena across scales, particularly the mutual interactions between fine-scale/extreme weather (e.g., thunderstorms) and the larger/global scale environments in which they form?
- How should fine-scale ESMs applied globally be initialized? Do traditional data assimilation techniques apply?
- What can we learn about atmospheric predictability by running fine-scale ESMs globally?
- What changes are needed in model physics parameterizations to produce reliable and physically realistic solutions at fine scales globally?
- What roles can AI/ML play in fine-scale ESMs applied globally, including for producing ensembles?
- What organizational/administrative structure(s) would be most effective in developing and executing a plan for such a computational system, and what exemplars can be used as role models (e.g., CMIP, ITER, and even complex, multi-national manufacturing activities such as commercial airplanes)?
- How would such an effort be funded, and what organizations would be involved? How could the effort not detract from the necessary continued support of general-purpose computing for research, and also not have deleterious impacts on the research workforce needed to continue performing important climate research?
- What incentives exist for participation in an international initiative, especially by non-government funding organizations? What issues could arise with regard to intellectual property ownership for a system to which multiple organizations contribute proprietary capabilities?
- Would any of these issues inhibit the system from being fully open to international users and its output being made available without restriction? How will the output be shared?
- What would kilometer-scale global climate projections enable for society, and what technological spillover effects could be realized by academia, government, and the private sector that would not occur in the absence of such an effort? How could a special-purpose computational system be operated to most effectively meet both research and operational needs?
- In light of the CHIPS and Science Act of 2022, how would an effort to build a special-purpose computational system positively impact U.S. global competitiveness in microelectronics, AI, climate science, and high-performance computing?

- What educational benefits could be realized from such an effort, and how could it stimulate interest in STEM fields and broaden the participation of traditionally underrepresented groups in a merit-based competitive framework?
- How could such an effort benefit other disciplines?

2. Summit Planning and Structure

Held at the I Hotel on the campus of UIUC and hosted by the Department of Climate, Meteorology & Atmospheric Sciences, and the National Center for Supercomputing Applications (NCSA), the summit was organized by a 10-member Planning Committee (Table 1). The membership of 6 men and 4 women was drawn from a broad cross section of experts in Earth system science, meteorological and climate modeling, computational and computer science, artificial intelligence and machine learning, and computer system operations. Additionally, 29 other experts from the global research community, including end-user stakeholders, formed the Nucleus Team, described below.

Table 1. Summit Planning Committee

Name (alpha order)	Title & Organization	Expertise
Kelvin Droegemeier (Chair)	Professor of Atmospheric Sciences and Special Advisor to the Chancellor for Science and Policy, Department of Atmospheric Sciences, University of Illinois	Severe Storms, Numerical Weather Prediction, Data Assimilation, Computational Fluid Dynamics
Francina Dominguez	Professor of Atmospheric Sciences, Department of Atmospheric Sciences, University of Illinois	Land-Atmosphere Interactions, Hydrology and Climate Change
Barb Helland	Former Director, DOE Office of Science Advanced Scientific Computing Research program	High Performance Computing, Computational Science Education, Data Management
Ruby Leung	Chief Scientist of Energy Exascale Earth System Model, Pacific Northwest National Laboratory	Climate and Hydrologic Modeling, Climate Change Impacts
Maria Molina	Assistant Professor, Department of Atmospheric and Oceanic Science, University of Maryland	Application of Machine Learning to Climate & Extremes
Andreas Prein	Professor for High-Resolution and Climate Modeling, Federal Institute of Technology Zurich (ETH)	Modeling of Extreme Events in a Warming Climate
Dan Reed	Professor of Electrical and Computer Engineering and former Provost, University of Utah	High-Performance Computing, Policy, Education
John Shalf	Department Head for Computer Science, Lawrence Berkeley National Laboratory	High-Performance Computing, Customized Computer Platforms
Bjorn Stevens	Director and Member of Climate Physics Department, Max Planck Institute for Meteorology	Impacts of Water Vapor and Clouds on Climate Change
John Towns	Deputy Director, National Center for Supercomputing Applications	Making High-Performance Computing Resources available to the National Research Community, Data Management and Visualization

Summit participation took multiple forms. First, in-person participation was by invitation-only, given budgetary constraints. Invited individuals paid their own expenses, apart from Nucleus Team and Planning Committee members, who were funded by the NSF grant. Invitees who could not participate in person were allowed to participate as Zoom panelists (i.e., full interactivity). The second form of participation was by invitation as well, but only remotely as Zoom panelists. The Final form involved global participation via a free YouTube web stream. All participants were required to register.

Considerable effort was directed toward maximizing the breadth of participants both in the US and globally. Promotional material was sent to nearly 100 organizations, ranging from US Federal agencies, research centers (e.g., Climate Adaptation Science Centers, National Center for Atmospheric Research, NOAA organizations) to academic institutions, disciplinary professional societies, and organizations representing women, minorities, and traditionally under-resourced institutions.

Internationally, promotional materials were sent to operational and research weather and climate centers, UN organizations, and academic and independent research institutions. Table 2 shows the demographics of invitations to individual persons and their participation, as well as YouTube participants. The summit was announced via a press release and on the NCSA website

(https://www.ncsa.illinois.edu/international-summit-seeks-to-harness-supercomputing-power-for-climate-decision-making/), and the PI wrote a promotional article as part of the NCSA "Download" series (https://www.ncsa.illinois.edu/kelvin-k-droegemeier-on-working-toward-a-computational-framework-to-support-earth-system-science-and-climate-projection/). These links were included in invitations.

The summit was built around four Organizing Themes: (1) Practitioners and Stakeholders; (2) Earth System Models; (3) Computational Systems (Requirements for System Architecture and Operational Software); and (4) Artificial Intelligence and Machine Learning. To best prepare summit participants in advance and thus maximize the value of time spent in person during the summit, Planning Committee members led several Pre-Summit Intensives (PSIs) on each of the four themes during spring and summer, 2024. Each PSI had approximately two dozen participants, chosen by the PSI chairs/co-chairs. Several questions were provided in advance of each meeting and read-ahead summaries prepared and placed on the summit website.

Table 2. Summit Invitation and Participation Demographics

	Invited Participants (198)	Participating in Person (78)	Declined Invitation (120)	Participating via Zoom (44)	Watching on YouTube (84 Registered, 153 Views)
Sex					
Male	150	54	96	28	58
Female	48	24	24	16	26
Affiliation					
University	58	43	15	22	56
Federal Government	41	1	40	6	2
State Government	3	1	2	1	0
Private Sector	48	14	34	9	9
Other	48	19	29	6	17
Country					
USA	167	72	95	37	68
United Kingdom	12	1	11	2	3
Switzerland	6	3	3	1	0
Germany	9	1	8	4	1
Japan	3	1	2	0	0
Taiwan	0	0	0	0	6
India	0	0	0	0	1
Denmark	0	0	0	0	1
China	1	0	1	0	2
Poland	0	0	0	0	1
Colombia	0	0	0	0	cc

In addition to the Planning Committee, a group of 29 individuals (19 men and 10 women) composed the Nucleus Team (Table 3), the role of which was to serve as the primary discussants during the summit as well as to give presentations and co-lead breakout sessions. Nucleus Team members were drawn internationally from a broad array of academic, corporate, and non-profit organizations representing the four organizing themes of the summit. Most members attended the PSIs, with 22 attending the summit in person, 5 attending virtually, and 2 ultimately unable to attend.

To obtain a comprehensive assessment of fine-scale ESM model development activities underway globally, an extensive survey was made in advance of the summit. A total of eight responses were received from 10 invitations to submit. Materials from the survey, and from the PSIs, were synthesized and made available to all participants as read-ahead materials on the summit website (https://climatecomputer.ncsa.illinois.edu/read-ahead-materials/), as were all slides and videos from the summit. The materials are now archived on the University of Illinois Media Space system (https://mediaspace.illinois.edu/).

Table 3. Summit Nucleus Team Members and their Organizing Theme Categories

Earth System Models	Artificial Intelligence and Machine Learning
Jim Hurrell, Colo State/EarthWorks	Chris Bretherton, Allen AI Institute
Irina Sandu, ECMWF Destination Earth	Tapio Schneider, Caltech
Jon Petch, NCAR	Pierre Gentine, Columbia
Masaki Satoh, Tokyo University	Torsten Hoefler, ETH Zurich
Hayley Fowler, Newcastle University	Katie Dagon, NCAR
Peter Messmer, NVIDIA	Amy McGovern, U of Oklahoma
Christiane Jablonowski, University of Michigan	Laure Zanna, NYU
Computational Systems	**Practitioners and Stakeholders**
Jim Hack, ORNL Retired	Jeff Gall for Craig Tillman, Renaissance Re Risk Sciences
Cliff Young, Google	Josh Hacker, Jupiter Intelligence
Maria Estela Suarez Garcia (Estela Suarez), Julich/Bonn	Jean Brokish, Amer Farmland Trust
Mike Schulte, AMD	Edith Makra, Metro Mayors Caucus
Larry Kaplan, HPE	Ming Pan, Ctr for West Water/Wx Extremes
Michael Wehner, Berkeley	Glenn Heistand, Assn of St Flood Pln Mgrs
Irene Qualters, LANL	Dan Kirk-Davidoff, EPRI/Energy
	Trent Ford, IL State Water Survey

The summit was structured around a mixture of stage-setting presentations, breakout groups, and plenary sessions. By asking participants to become familiar with summit topics and goals via the PSI summaries in advance of the event, considerable time was devoted during the summit to formal discussion and informal interaction during extended breaks. Although an agenda was used to frame the summit, it was designed to be flexible so topics could be explored as they arose. In that regard, all participants (in-person and virtual) were able to submit comments and suggestions electronically throughout the summit. This information was captured and synthesized by the Planning Committee and used to determine topics in real time. For this reason, a “real time” agenda was used and is presented in Appendix B, with the original/starting agenda in Appendix A.

The summit utilized a code of conduct (see summit website), provided lactation facilities and special accommodation if requested, and made available information regarding local resources for caregiving. UIUC staff coordinated all travel arrangements for those funded by the NSF grant. Meals were provided onsite in accordance with NSF policies, and facility costs were paid by the NSF grant and supplemented by the UIUC Department of Climate, Meteorology & Atmospheric Sciences. The results from a post-summit satisfaction survey are available in Appendix C.

3. Day-1 Session Summaries

a. Welcome from UIUC President and NCSA Director

An icebreaker was held during the evening of September 29, 2024 at the summit venue, at which Dr. Timothy Killeen delivered welcoming remarks. A Member of the National Academy of Engineering, Dr. Killeen is President of the University of Illinois System and former Director of the NSF National Center for Atmospheric Research. He also served as NSF Assistant Director for Geosciences and thus is extremely familiar with the topic and importance of the summit. Dr. Killeen highlighted the history of UIUC research in atmospheric sciences, the importance of the summit to understanding the future of the Earth system, and the value of the international community collaborating to address pressing societal challenges.

Dr. Bill Gropp, Director of NCSA and Member of the National Academy of Engineering, provided welcoming remarks as well. He described the history of NCSA and its significant role in advancing atmospheric and climate sciences, noting the appropriateness of NCSA hosting the summit. He also

described issues in applying high performance computing to grand challenge-scale problems and that UIUC is an appropriate venue for supporting the type of computational system to be discussed at the summit.

b. Opening of the Summit and Keynote Presentation

The summit was formally opened by Dr. Robert J. Jones, UIUC Chancellor, and Dr. Susan Martinis, UIUC Vice Chancellor for Research and Innovation. Both provided strong support for the summit and noted that the topics to be discussed were top priorities in the UIUC research and education portfolio. They pledged their support to make both the summit and follow-on activities a success.

Summit chair and NSF grant PI, Dr. Kelvin Droegemeier, gave the opening keynote address titled "Engaging the Global Community in a Transformative Approach to Earth System Science Research, Education, and Climate Projection." Droegemeier emphasized the critical need for high-resolution global modeling capable of capturing extreme weather events, land-atmosphere interactions, and small-scale phenomena with far greater realism than is possible today. Drawing from recent scientific literature, he noted that although weather forecasting has evolved rapidly to kilometer-scale resolution, climate modeling has lagged due to the massive computational demands required for long-term simulations.

Acknowledging concerns about cost, energy consumption, workforce readiness, and the potential diversion of resources from other modeling strategies, Droegemeier argued that these challenges must be confronted directly through collaborative, interdisciplinary solutions. He pointed to the transformative role that AI/ML is already playing in weather prediction and emphasized the potential for these technologies to accelerate progress in climate modeling as well. Drawing inspiration from large-scale scientific initiatives like LIGO and the Event Horizon Telescope, he urged the community to embrace a similarly ambitious vision—one grounded in radical collaboration, mutual trust, and public benefit. The summit, he emphasized, is not simply about advancing the science of climate, but about reimagining the infrastructure, computational architecture, organizational models, and educational pipelines needed to deliver robust, stakeholder-relevant climate insights. He posed five central questions to guide the summit, focusing on stakeholder engagement, scientific and technical feasibility, AI integration, workforce development, and sustainable global coordination. In closing, Droegemeier underscored that while the path forward will be difficult, it is precisely such bold endeavors that lead to transformative outcomes for science and society.

c. Stage-Setting Panel on Current Physics- and AI-Based Model Development Activities

The first session of the summit was devoted to brief presentations from eight speakers on the status of global work in ESMs and AI/ML-based systems for weather and climate. The presenters included a mix of Planning Committee and Nucleus Team members. The purpose was to show the extraordinary capabilities of fine-scale ESMs and AI/ML-based models, and that the tremendous momentum behind the former warrants addressing the computational side of the coin.

Dr. Andreas Prein, ETH Zurich, summarized results from the global survey of km-scale model development activities. He noted that most efforts continue to use Fortran though some are transitioning to C++ or Python for GPU architectures. Simulated years per day (SYPD) range from 0.5 to 2, with NICAM and SCREAM leading performance benchmarks. Strong scaling remains a challenge due to communication demands, especially on GPUs. Common themes include the need for reduced precision, improved coupling, and porting to heterogeneous HPC systems. Efficiency metrics are lacking but deemed essential for guiding development priorities.

Drs. Nils Wedi (ECMWF) and Bjorn Stevens (Max Planck Institute for Meteorology) described the Destination Earth (DestinE) initiative as Europe's flagship effort to build operational digital twins of

the Earth system. The project has developed capabilities for climate change adaptation, and weather-induced extreme event prediction, using 5–10 km resolution global simulations (ICON, IFS-NEMO, IFS-FESOM). DestinE integrates AI/ML for on-demand inference, user-friendly indicators, and data compression. It features a one-pass algorithm for tailored indicators and real-time applications (e.g., wind farm performance). With EuroHPC access and phased deployments from 2022 to 2030, DestinE aims to provide seamless, regularly updated, and user-customized Earth system data at scale.

Dr. Stevens argued that increasing spatial resolution in ESMs is the most reliable and hierarchical path for improving their realism. High-resolution models address challenges of ensemble spread and complexity by reducing uncertainties in local and extreme events. Dr. Stevens emphasized that while resolution solves many problems (e.g., grey zone dynamics), it introduces new ones, such as computational scaling bottlenecks, data overload (Carroll's paradox), and unequal access to information. He advocated for the development of *Earth Virtualization Engines (EVE)* — federated, AI-enabled modeling centers leveraging tier-0 computing resources to democratize high-fidelity climate futures.

Dr. Masaki Satoh (University of Tokyo) described NICAM, Japan's high-resolution global model, noting it achieved the highest-resolution global simulation to date (220 m grid spacing), resolving deep convection through a "Global Large Eddy Simulation" (GLES) on the Fugaku computer (81,920 nodes). NICAM is central to several international collaborations, including DYAMOND and upcoming intercomparison projects. It supports multi-scale simulations (from 3.5 km to 220 m) and integrates EarthCARE satellite data. Upcoming experiments will explore +4K warming, annual cycles, and ensemble scenarios for future projections.

Turning to the U.S., Dr. Prein described three major U.S. physics-based modeling systems—SCREAM (DOE), X-SHiELD (NOAA/GFDL), and MPAS (NCAR) – all of which are progressing toward km-scale capabilities. SCREAM is GPU-optimized using C++/Kokkos; others are transitioning gradually. Ocean-atmosphere coupling remains limited but is under development. Each model has distinct strategies for architecture adaptation and physics improvements. SCREAM leads in high-resolution performance and is integral to DOE's exascale modeling framework (E3SM). Cross-center collaboration on coupling, downscaling, and ensemble generation is encouraged.

Dr. Stephan Hoyer (Google) described Google's *NeuralGCM*, which blends a spectral dynamical core with neural-network-based physics, trained on ERA5 reanalysis data. It delivers competitive weather forecasts (1–15 days) and realistic near-term climate simulations with low bias. Compared to 3 km storm-resolving models, NeuralGCM achieves better accuracy in metrics like precipitable water, while being more than 1000 times cheaper and faster (200 simulation years/day on 1 TPU). Its differentiability enables direct optimization against observations. Dr. Hoyer highlighted the role of AI as an accelerator, not a replacement, and emphasized the importance of benchmarks like WeatherBench for model development.

Finally, Dr. Karthik Kashinath (NVIDIA) described Earth-2, which is NVIDIA's initiative to revolutionize climate modeling through a fusion of simulation, AI emulation, and visualization. Dr. Kashinath presented the "three miracles" challenge: (1) ultra-efficient km-scale simulations, (2) full-state AI emulation for any region/time, and (3) real-time visualization. *FourCastNet* and *Spherical Fourier Neural Operators* (SFNO) achieve greater than a factor of 1000 speedup and more than 3000 times the energy efficiency over traditional NWP. For regional downscaling, *CorrDiff* diffusion models leverage generative AI to provide scalable, high-fidelity km-scale forecasts. These methods enable massive ensembles and probabilistic analysis of low-likelihood high-impact (LLHI) events, such as unprecedented heatwaves.

d. Practitioner/Stakeholder Panel

Having overviewed the extraordinary capabilities of fine-scale ESMs and AI-based systems, this session assembled individuals from local government, agriculture, reinsurance, and infrastructure to explore how fine-scale ESM/AI information can directly support decision-making across sectors.

Edith Makra (Metropolitan Mayors Caucus) emphasized the importance of localized climate data for driving regional collaboration on sustainability and resilience planning. In the Chicago metropolitan area, where over 9 million residents span multiple jurisdictions, municipalities are leveraging consensus frameworks like the Greenest Region Compact and localized risk assessments to inform climate action. She underscored the urgent need for data-informed infrastructure investments, citing the $1.45 billion alternative water source initiative in Joliet as an example of planning shaped by groundwater modeling and regional hydrologic trends.

From an agricultural perspective, Jean Brokish (American Farmland Trust) highlighted the operational and strategic value of climate data across a range of timescales. Farmers make daily to decadal decisions that depend on understanding precipitation patterns, soil moisture, crop suitability, and market infrastructure. Climate information, when translated effectively, can support field-level decisions like irrigation and tillage, help reduce risks to farm labor, and inform longer-term choices around crop rotations and water management infrastructure. She illustrated how changes in precipitation timing and intensity are already constraining spring planting windows in the Midwest and suggested that smart climate-informed tools could help optimize cover crop management, nutrient loss reduction, and farm profitability.

Jeff Gall (RenaissanceRe Risk Sciences) brought a financial and risk analytics lens to the conversation, pointing to the growing demand within the insurance and reinsurance sectors for scientifically- grounded, globally-consistent, and high-resolution hazard simulations. He explained that traditional catastrophe models often simulate one peril-region combination at a time, missing key correlations across regions. In contrast, global Earth system models can simulate simultaneous peril events—such as hurricanes in the U.S., typhoons in Asia, and flooding in Europe—enabling the assessment of interdependencies that are crucial for pricing risk and managing capital exposure. Gall also described the potential of high-resolution modeling for seasonal forecasting, real-time event response, and climate risk quantification, all of which are critical to narrowing the global insurance gap.

Rounding out the session, John England (U.S. Army Corps of Engineers) underscored the necessity of modernizing the estimation of extreme precipitation—known as Probable Maximum Precipitation (PMP)—for critical infrastructure such as dams and levees. Current methods are outdated. England advocated for a phased transition to model-based PMP estimation using kilometer-scale Earth system simulations that can account for uncertainty and evolving hydrologic extremes. He highlighted the benefits of model-based approaches for site-specific safety evaluations and infrastructure design, emphasizing that such methods could become standard within the next decade if supported by sustained research and interagency collaboration.

Collectively, the panel presentations revealed a clear and urgent need across sectors for high-resolution, decision-ready climate information. Practitioners seek not only better data, but also more interpretable, timely, and actionable insights that reflect the scale and complexity of their operations. The session underscored the importance of aligning advances in Earth system modeling with the practical requirements of users on the ground—municipal leaders, farmers, insurers, and engineers alike—through sustained partnerships, iterative tool development, and clear communication of risk and uncertainty.

e. Discussion of Thoughts, Questions, and Ideas Submitted Electronically

This session involved a plenary discussion of materials submitted to this point on Day-1 of the summit, synthesized using ChatGPT. Participants engaged in a rich exchange that surfaced key technical, strategic, and collaborative priorities. A dominant theme was the need to establish clear scientific drivers for fine-scale modeling, particularly in terms of the societal outcomes it aims to support. Participants emphasized that articulating specific use cases—such as regional climate resilience, hazard prediction, or agriculture planning—would help shape technical objectives and better justify investments.

A strong call was made to create a common framework or vision that could unify international and cross-agency efforts, with several participants referencing existing initiatives such as Earth Virtualization Engines (EVE), Destination Earth (DestinE), and DOE's E3SM. These included recommendations to standardize terminology, share best practices in model development and data dissemination, and promote open, reproducible science. Many contributors stressed the importance of defining meaningful benchmarks and metrics for evaluating model performance—beyond conventional accuracy scores—to better reflect the practical utility of outputs for downstream users.

The discussion also addressed technical challenges such as computational scalability, coupling of Earth system components, and the integration of AI/ML with physics-based modeling. Some advocated for modular, interoperable platforms that could evolve over time, while others emphasized the need to ensure that emerging hybrid models maintain transparency and trust. Concerns were raised about the massive data volumes produced by high-resolution simulations, and a shared recognition emerged that next-generation data services must prioritize discoverability, accessibility, and usability for both expert and non-expert users.

Participants expressed strong support for the co-production of climate information with stakeholders, recommending iterative engagement with end users, including those in government, industry, and the public sector. Education and workforce development were also highlighted as critical components of any long-term strategy, especially in building technical capacity for running, interpreting, and applying outputs from km-scale models. Finally, several individuals called for bold, collaborative initiatives that go beyond incremental advances—suggesting moonshot-style projects or challenge programs that could galvanize innovation, align incentives, and accelerate progress across disciplines and sectors. Overall, the Day 1 discussion revealed broad enthusiasm for the transformative potential of fine-scale modeling, tempered by a pragmatic focus on building shared infrastructure, aligning with user needs, and delivering societal value through sustained investment and collaboration.

f. Recap of the Pre-Summit Intensives

Leveraging the previous presentations and discussions, this session recapped key points from the four pre-summit intensives. Presentation of this material was intentionally delayed until the end of Day-1 so participants would have an appropriate context. With this information, participants were asked to think overnight about key questions and topics for breakout sessions on Day-2.

Co-Chaired by Dr. Francina Dominguez (UIUC) and Frank Nutter (Reinsurance Association of America, retired), the Practitioner and Stakeholder Pre-Summit Intensive engaged practitioners from agriculture, urban systems, water resources, energy, and insurance/reinsurance. The discussions emphasized that the most at-risk communities are those lacking resources to adapt to climate impacts—rural areas, the elderly, and marginalized systems like healthcare and agriculture. Practitioners generally rely on derived products from climate models (e.g., flood or energy simulations), rather than on raw model output, and demand high-resolution (km-scale), hourly data for decision-making. Current projections are too coarse, necessitating statistical or dynamical methods.
Strong emphasis was placed on uncertainty quantification, transparent communication, and the need

for a democratized climate information system accessible to all. Timescales of interest span from real-time to 20–30 years, constrained by planning horizons and regulatory frameworks. None of the stakeholders said they consider impacts beyond 30 years. Participants urged sustained collaboration with scientists and policy communities and expressed concern over proprietary data and for-profit climate information providers undermining transparency.

Chaired by Dr. Andreas Prein, the Earth System Model Pre-Summit Intensive focused on the design and development of next-generation coupled ESMs at kilometer-scale resolution. The community broadly agreed on the benefits of moving to km-scale grid spacing, noting significant improvements in the representation of processes such as convection, severe weather, and orographic precipitation. Participants called for stronger community coordination, enhanced public-private partnerships, and greater integration with the weather prediction community. Open research questions include trade-offs between model resolution and complexity, validation of high-resolution simulations, coupling of ESM components, ensemble design, and uncertainty quantification. Concerns were raised about the high energy consumption of future exascale computing systems, the difficulty of major code rewrites, and the scarcity of observations in key regions, particularly in the Global South. The need to build an inclusive, efficient, and sustainable modeling ecosystem was a recurring theme.

Chaired by John Shalf (Lawrence Berkeley National Laboratory), the Computational Systems Pre-Summit Intensive translated the requirements of fine-scale ESMs into concrete system architecture specifications. It did not make prescriptive technology choices (e.g., CPU vs GPU) but instead developed an analytic spreadsheet model to evaluate memory, communication, and I/O demands based on strawman fine-scale ESMs. A representative model assumed 10 prognostic variables, 125–256 vertical layers, 1.25 km horizontal mesh spacing, and ensemble sizes up to 100, with throughput targets ranging from 10 to 100 simulated years per day. Key hardware constraints centered on **memory** bandwidth, not compute power, with memory bandwidth requirements projected in the tens of petabytes per second. IO subsystems were also highlighted as potential bottlenecks, with 160 TB/s ingest rates needed for hourly output. The PSI emphasized that many optimizations (e.g., loop fusion, concurrent chemistry/dynamics) would depend on matching software design to hardware capabilities. Further profiling, validation, and community input were identified as the necessary next steps.

Chaired by Dr. Maria Molina (University of Maryland), the AI/ML Pre-Summit Intensive explored how AI and ML can accelerate or complement fine-scale physics-based Earth system modeling. Participants recognized AI's current skill in simulating extremes and ensembles, its potential to replace physical parameterizations, and the importance of integrating stakeholder needs and ease of use into AI-powered systems. Although some viewed fully AI-based models (bypassing traditional data assimilation) as a viable long-term goal, others stressed the need for physics-informed AI and cautioned against discarding the traditional dynamical core/solver of ESMs. The ability of AI to downscale, explore, or interpolate fine-scale ESM output was seen as a significant opportunity, along with the role of AI in optimizing sensor placement for better observations. Open questions included why only some AI models extrapolate to extremes effectively, how their predictability compares to that of traditional models, and the optimality of ensemble configurations for uncertainty quantification. Key issues include AI development outpacing infrastructure planning, model validation challenges, and the ability to ensure equitable access to data and computational tools.

g. Special Presentation on Model Uncertainty

Dr. Tim Palmer (Oxford University) delivered a compelling and provocative presentation on the fundamental sources of ESM uncertainty, arguing that the conventional approaches to representing uncertainty—particularly multi-model ensembles (MMEs) and perturbed parameter ensembles (PPEs)—are conceptually flawed and practically inadequate. He emphasized the need for a paradigm shift toward stochastic parameterizations and greater coordination in the modeling community to advance fine-scale modeling.

Dr. Palmer grounded his talk in the mathematics of fluid dynamics, highlighting the importance of scaling symmetry in the Navier-Stokes equations. This symmetry implies self-similarity across scales in turbulent flows. However, when these equations are solved numerically, computational truncations break that symmetry—especially at the grid scale—leading to both systematic and random errors that propagate upscale. This is not only a numerical artifact but rather a fundamental source of model uncertainty, akin to Lorenz's "real butterfly effect."

Parameterizations in weather and climate models assume subgrid processes resemble ensemble behavior and are thus amenable to deterministic statistical treatment. But, due to the power-law nature of atmospheric dynamics, subgrid processes are dominated by a few large structures, not a multitude of small ones, making them inherently unparameterizable in the conventional sense. Thus, uncertainty is not just due to lack of knowledge (epistemic) but reflects a fundamental inadequacy (ontological) in how we conceptualize and represent unresolved physics.

Transitioning to fine-scale ESMs run globally will enhance the resolution of key phenomena and possibly reduce some forms of error (e.g., better resolving gravity waves), but will not eliminate uncertainty. Instead of building dozens of high-resolution models, Palmer suggested investing in a small number of coordinated, high-quality models that integrate stochastic parameterizations and establishing international collaborations, akin to CERN or ITER, to share computing resources and modeling frameworks.

Palmer concluded by challenging the community to rethink the value of supporting large M.Mus. Given finite human and computational resources, he asserted that stochastic approaches within a unified modeling framework offer a more promising, scientifically grounded, and operationally viable path forward—especially as we pursue the ambitious goal of kilometer-scale climate simulation.

4. Day-2 Session Summaries

a. Reflections on Day-1 and Plans for Day-2

The principal goal for Day-2 of the summit was to develop a deeper shared understanding of key issues, identify points of agreement and disagreement, clarify needed research and remaining questions, and begin to create a consensus regarding a path forward. To set the stage for the day, Dr. Droegemeier delivered a provocative presentation that called for a radical transformation in how the global scientific community approaches climate modeling, stakeholder engagement, and administrative coordination. He noted it is far easier to ask questions than to give answers, and that the summit was about both asking questions and providing answers.

His central message emphasized the point that, although current efforts in climate science are meaningful, they are insufficient for the scale of the societal and environmental challenges ahead. What is needed, he argued, is not incremental change, but a bold leap—analogous to building an "Airbus or Boeing" rather than relying on the metaphorical "regional jets" of current scientific and computational efforts.

He posed foundational questions to frame the conversation:

- *What if we do nothing?*
- *What if we do nothing more?*
- *What story do we want to write? And how will we sell it?*

He showed a mock headline, dated October 2, 2024, to serve as a conceptual anchor, describing an international announcement of a bold new framework that integrates artificial intelligence with traditional Earth system modeling. The vision detailed:

- A specialized computational system designed not as a single-purpose supercomputer, but as a virtual environment tethered to AI and machine learning tools.
- Generation of fine-scale, statistically reliable, and minimally biased climate information, made available to all sectors of society.
- An aggressive five-year implementation plan, which is expected to yield unanticipated benefits, such as those which accrued from the Apollo program to land humans on the moon.
- Broad societal impact, including equity, inclusion, economic stability, and reduced climate risk in insurance and finance sectors.
- A non-traditional, adaptive funding and administrative model to accelerate development and implementation.

The overarching vision articulated by Droegemeier was: "A global society that makes decisions regarding our changing climate using statistically reliable, minimally biased, fine-scale information that is available to all, and that is delivered in ways that support practical decision making across the entire range of stakeholders involved."

Droegemeier argued that although research is critical, the summit was about something bigger—mobilizing the global community to pursue a vision beyond individual scientific projects. This vision must unify scientific ambition with societal responsibility and global collaboration. The idea is to create a new computational ecosystem—adaptive, scalable, and infused with AI—not limited to academic research but extending to practical decision-making and public accessibility. Droegemeier stressed that real progress would be uncomfortable. If the path forward feels familiar, it is probably insufficient. He encouraged participants to think in terms of writing the headlines of tomorrow—how the work they undertake now could affect the world decades into the future (e.g., climate impacts to 2070), particularly for finance, insurance, and underserved communities.

Following Droegemeier's presentation, the discussion that ensued reflected broad enthusiasm for the call to launch a bold, globally coordinated climate modeling initiative. Participants explored the implications of that concept, emphasizing the need for a unifying scientific mission that could galvanize the international research community. Many echoed the importance of anchoring the effort in a compelling grand scientific challenge—such as resolving persistent uncertainties in cloud feedbacks, reproducing observed climate trends, and assessing tipping points like the potential collapse of the Antarctic ice sheet. These scientific objectives, it was argued, would provide the initiative with both intellectual legitimacy and practical relevance, especially for attracting engagement from U.S. researchers and global partners.

A recurring theme throughout the discussion was the centrality of societal stakeholders—not only as consumers of climate information, but as key drivers of the effort itself. Participants stressed that the envisioned modeling system must deliver reliable, fine-scale, and minimally biased information that supports practical decision-making at local and regional levels, particularly through 2070. Yet that information typically does not flow directly from model to stakeholders, but rather through intermediary "translators," such as companies that add value and understandability to model output (often customized to a specific sector or user). The discussion noted that inclusion of translators in the overall structure going forward is critically important.

Strong support existed for ensuring that under-resourced communities and nations outside the traditional climate science power centers play a meaningful role in shaping and benefiting from the initiative. While some participants questioned the extent to which ultra-fine resolution is necessary for all applications, the group generally agreed that actionable, accessible data is essential. Innovative ideas were offered for democratizing this information, including immersive visualization tools and user-friendly platforms that would make climate projections intuitive and engaging for non-experts.

Building such an ambitious effort, many argued, will require more than technological advancement; it demands the creation of a new kind of collaborative ecosystem. Participants described the need for an inclusive and integrated community that bridges disciplines and sectors, bringing together climate scientists, artificial intelligence experts, computational architects, policymakers, and diverse societal stakeholders. Drawing analogies to the early days of computational science, some noted that forging such cross-disciplinary partnerships will not be easy, but is essential for success. There was a shared recognition that traditional funding models and administrative structures are unlikely to be adequate. Instead, the group called for new, creative mechanisms that enable agility, inclusiveness, and long-term commitment.

Communication emerged as another major focal point. Participants discussed the critical importance of framing the initiative in ways that resonate with broad audiences, including policymakers, the public, and the private sector. One participant introduced the metaphor of a "computational time machine," capable of revealing alternative climate futures based on different policy choices—a framing that was widely praised for its imaginative and accessible appeal. Others built on this idea, suggesting that the community should think in terms of crafting headlines for the future, making the potential societal benefits of the effort vivid and compelling. There was consensus that clear, powerful storytelling—grounded in human experience and aspirational outcomes—will be necessary to sustain momentum and support.

Underlying these discussions were several productive tensions. Participants acknowledged the challenge of balancing scientific ambition with practical impact, and long-term vision with near-term feasibility. They also debated how narrowly or broadly to define the project's scope, with some warning against diluting focus by trying to solve too many problems at once. Still, despite these complexities, the tone of the discussion remained optimistic and forward-looking. There was a shared conviction that the climate science community stands at a pivotal moment—one that demands imagination, courage, and collective action to write a new chapter in how the world prepares for and responds to climate change.

b. Summary of Breakout Sessions #1

The first set of five breakout sessions dealt with the following topics: (1) A New Approach for the International Community; (2) Crosscutting Topics; (3) Earth System Models and AI/ML; (4) Computational Systems; and (5) Practitioners, End-Users and Stakeholders. The discussions spanned scientific, technical, organizational, and stakeholder-oriented themes, offering a multifaceted roadmap toward realizing the proposed vision.

Breakout Group #1 focused on international collaboration and a novel approach to mobilizing global expertise and infrastructure. Participants stressed the need for a shared vision that is clearly articulated and strategically framed to galvanize political and financial support. Central to this vision is a commitment to democratizing access to high-resolution climate information, advancing model development (e.g., 1km resolution), and ensuring appropriate engagement across geographic regions and societal sectors. The group underscored the importance of designing a flexible institutional

framework that can support co-development, inclusive governance, and rapid innovation without being hindered by existing bureaucratic structures.

Breakout Group #2 addressed several cross-cutting issues, including model development, stakeholder needs, communication strategies, and research priorities. The group advocated for robust validation frameworks, stakeholder-driven performance benchmarks, and the incorporation of human and ecological dimensions into modeling systems. A recurring theme was the necessity of "climate interpreters"—human or AI intermediaries capable of translating model output into actionable information for a range of users. The group also emphasized the need for compelling narratives and demonstrable societal benefits to secure funding and political will. Specific focus on extreme and compound events such as droughts, heat waves, wildfires, and precipitation – as well as longer-term information about water availability – were highlighted as focal points for advancing both science and public value.

Breakout Group #3 examined the integration of Earth system models with artificial intelligence and machine learning (AI/ML). The group emphasized that km-scale models must be nested within a hierarchy of modeling frameworks to ensure scalability and robustness. AI tools were seen as instrumental for model calibration, emulation, and data assimilation, especially over seasonal to decadal timescales. Participants discussed the need for flexible, modular modeling platforms that support diverse grid resolutions and leverage high-level programming languages to future-proof the system and attract early-career talent. The group also identified critical challenges in computational infrastructure, particularly in terms of data storage, model tuning, and the co-design of software and hardware systems. The summit highlighted challenges related to programming language choices and code portability. Although many legacy models use Fortran, a growing shift exists toward C++, Python, and Julia to enable cross-platform flexibility. Porting large codes like CESM to GPU-accelerated Python was estimated to require 100 FTEs. Frameworks such as Kokkos and GT4Py were recommended to facilitate this transition.

Breakout Group #4 concentrated on the computational infrastructure required to support the initiative. Participants agreed that although the goal of 1km resolution models is scientifically justified, the computational and data workflows to support them must be explicitly mapped and optimized. They highlighted the importance of understanding software requirements and leveraging existing tools where appropriate, but also acknowledged the likely need for novel solutions tailored to AI-augmented modeling. The group discussed the distinct needs of physical and AI-driven models and the necessity of building systems capable of supporting both. Workflow design, including rapid response capabilities for stakeholder "what-if" scenarios, was identified as critical to the success and utility of the platform.

Breakout Group #5 focused on the scientific, technological, and human capital investments needed to build a next-generation climate modeling system. The group proposed that km-scale models should deliver credible forecasts from days to decades, with improved simulation of precipitation, clouds, and extremes. To achieve this, addressing unresolved processes like boundary-layer clouds, microphysics, and biogeochemical cycles is essential. The group also discussed the need for robust evaluation tools and standardization of outputs rather than internal APIs. A key long-term goal is to design an open, accessible modeling environment that integrates storage and compute capabilities while supporting workforce development. Several participants emphasized the importance of locating compute resources close to data storage. The Japanese strategy of allowing remote access to co-located data, and GFDL's practice of cloud-based coarse-grained sharing, were highlighted as promising models. Online diagnostics, real-time compression, and encoding/decoding optimization were identified as necessary to manage the vast output from fine-scale simulations. The group acknowledged the tension

between unifying around a single modeling framework and enabling innovation across diverse modeling platforms.

Collectively, these breakout sessions laid the groundwork for a transformative international initiative that aspires not only to push the boundaries of Earth system modeling but also to deliver climate information that is scientifically credible, societally meaningful, and globally inclusive. Participants stressed that success hinges on a bold, coherent vision, sustained investment in human and computational resources, and transparent, adaptive governance structures capable of evolving with scientific and societal needs.

c. Summary of Breakout Sessions #2

Discussions from the first breakout session illustrated the need for emphasis on additional topics for the second breakout session, notably (1) Use Cases; (2) A Research and Development (R&D) Agenda; and (3) Data and Tools.

Breakout Group #1 centered its discussion on defining high-impact use cases and variables necessary for climate-informed decision-making. The group emphasized the critical importance of stakeholder trust in model outputs and highlighted the need to generate reliable, actionable projections of short-duration, extreme weather events—particularly those relevant to engineering design, insurance, agriculture, and municipal infrastructure planning. Participants pointed to specific requirements, such as the ability to simulate 10-, 100-, and 500-year return period events at high spatial and temporal resolution, and stressed the need to tailor products to varying stakeholder needs (e.g., hourly forecasts for financial markets, seasonal precipitation for agriculture). Complex compound events—like heat following windstorms or droughts coinciding with pest outbreaks—were identified as high-priority phenomena requiring improved simulation capabilities. The group also called for integrating data assimilation, probabilistic outputs, and rigorous uncertainty characterization to build trust across user communities.

Breakout Group #2 focused on the research and development agenda needed to build km-scale models capable of reliable seasonal to decadal climate projections. The group prioritized advancing the physical realism of models, particularly in terms of precipitation processes, cloud feedbacks, and extreme event simulation. A major objective is to enable forecasts across timescales—from weather to climate—with a unified modeling framework. The group also highlighted technical challenges, including evaluating coupling schemes at 1km resolution and representing land surface processes accurately. Key recommendations included focusing on climate feedbacks, using satellite simulators for model evaluation, and standardizing model outputs and test protocols rather than APIs. Investment in human expertise—especially in subgrid parameterization—was seen as critical to reducing uncertainty and sustaining innovation.

Breakout Group #3 addressed the design of data systems and analytical tools to support the climate modeling framework. The group emphasized that data infrastructure must support reproducibility, uncertainty quantification, provenance tracking, and explainability of results. They advocated for integrating compute resources close to data to accommodate the massive size of climate model output and to avoid unsustainable data transfer practices. A tiered access and governance model was proposed to balance equity, agility, and operational needs, with attention to differing user requirements—from researchers to policymakers. Notably, participants called for the establishment of “climate interpreters” who can help translate complex outputs into meaningful guidance for diverse users. They underscored that many consumers need synthesized information rather than raw data, and that interfaces should be stratified to reflect varying levels of expertise and use cases.

Taken together, the second set of breakout discussions advanced a more refined and operationally grounded vision for the climate modeling initiative. Although the groups explored different facets—from model physics and computational tools to governance and stakeholder applications—they converged on key principles: stakeholder-driven design, scientific rigor, operational agility, democratization of access, and global collaboration. The outcomes offer a comprehensive framework for aligning innovative climate science with the urgent needs of society.

4. Day-3 Discussions

The principal goal for the final day of the summit was to summarize key points of agreement and remaining questions, and to (1) develop a consensus regarding a computational environment and modeling framework that address stakeholder needs; (2) identify key research questions that need to be addressed to achieve reliable model results; and (3) frame an administrative structure, facilities concept, and funding model for executing a global initiative that leverages community resources to achieve a whole that is astonishingly greater than the sum of its parts.

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a. Consensus on a Computational Environment and Modeling Framework to Address Stakeholder Needs

Participants generally agreed on a two-phase strategy for building a global climate modeling infrastructure capable of delivering high-resolution, stakeholder-relevant information. The first phase focuses on achieving global simulations at ~10 km grid spacing over decadal timeframes (about 10 years), allowing the system to begin capturing natural climate variability and provide meaningful outputs for many decision contexts. This phase assumes rapid advances in computational capabilities and leverages ongoing international modeling efforts.

The second phase targets ~1 km global grid spacing over ~30-year periods to better capture both natural variability and anthropogenic effects. A key architectural innovation in this phase is the development of an ECMWF-like structure for the community—a shared, modular modeling framework capable of evolving with scientific progress. This system would not be fully plug-and-play, but would incorporate sufficient variability (e.g., multiple dynamical cores and physics options) to support ensemble modeling and integrate advances from multiple research groups. Participants emphasized that the envisioned system should support a flexible, hierarchical modeling architecture capable of spanning LES-scale research to coarse-resolution operational runs. A single modeling framework that can operate across a wide range of resolutions and incorporate AI at various levels—from physical parameterizations to hybrid and fully AI-driven approaches—was seen as a desirable long-term goal.

Additional R&D needs emphasized during summit discussions include process representations not yet adequately resolved even at kilometer scales. These include lateral groundwater flow, cloud microphysics, and aerosol-cloud-radiation interactions. Significant attention must also be paid to improving turbulence parameterizations, shallow and deep convection, and biogeochemical coupling in the ocean. Advancing these capabilities is essential to ensure the physical credibility of next-generation ESMs.

Stakeholder needs are further addressed through the prioritization of use cases (e.g., compound extremes, infrastructure planning, financial risk management), integration of data assimilation and reanalysis capabilities, and development of translation tools that convert raw model output into actionable information. The importance of tailored information delivery—such as return period statistics, probabilistic event characterization, and uncertainty quantification—was emphasized

repeatedly, along with the recognition that both expert users and non-experts must be served through expert translators of the science to the practitioners, tiered data interfaces and visualization systems.

b. Key Research Questions to Ensure Reliable Model Results

To produce trusted and decision-relevant outputs, several foundational scientific questions must be addressed. Chief among these is the representation of clouds, precipitation, and feedback processes at km scales, as these directly impact the simulation of extreme events and compound hazards. Improved coupling between atmosphere, ocean, land surface, and ice systems at high resolution is critical, especially given the timescale goals of the initiative.

A recurring theme was the importance of bridging the weather-climate continuum through unified modeling frameworks that can reliably simulate both short-term and long-term phenomena. Advancing subgrid parameterizations, especially for convection and boundary-layer processes, is seen as essential to reduce uncertainty. Participants also identified the need for robust model evaluation frameworks that move beyond traditional skill metrics to assess reliability, reproducibility, and stakeholder relevance. Trust in km-scale model outputs will depend upon rigorous validation using real-time observations and clearly communicated uncertainty bounds. Stakeholders from sectors such as insurance and infrastructure emphasized the need for high-resolution simulations of rare events (e.g., 15-minute precipitation totals, 10,000-year event modeling) to support probabilistic decision-making. Incorporating satellite simulators and standardized test protocols is expected to play a significant role in this validation work.

Another major scientific priority involves the co-evolution of AI and physics-based models. Emulators, surrogate models, and machine learning-assisted parameterizations must be tightly coupled with traditional methods to both accelerate simulations and enhance fidelity. This requires innovative approaches to uncertainty quantification and to characterizing emergent behaviors in hybrid modeling systems.

c. Administrative Structure, Facilities Concept, and Funding Model for a Global Initiative

The summit concluded with a shared understanding that delivering this ambitious vision will require not only scientific and technical innovation, but also a bold rethinking of institutional, organizational, and funding structures. There was widespread support for forming a globally coordinated framework akin to ECMWF, but tailored to the unique demands of km-scale modeling and open science. This would involve standing up a core international facility—or distributed network of facilities—that brings together computing infrastructure, modeling expertise, stakeholder engagement teams, and translational workforce capacity.

Importantly, participants rejected the notion of business-as-usual administration. Instead, the group advocated for a flexible, adaptive governance model that empowers global participation, facilitates co-development, and encourages innovation without fragmentation. Special emphasis was placed on democratization, particularly involving scientists and institutions from the Global South. Structures must be intentionally inclusive of under-resourced communities and build capacity where needed.

Regarding funding, the discussion envisioned a multi-source model that begins with rapid mobilization of philanthropic and non-governmental resources to launch the initiative, followed by sustained public sector investment. The idea is to create a catalytic “super-model” effort that can initially augment existing national capabilities but eventually provide operational and scientific value far beyond what individual countries could achieve alone.

Support for such a model will depend on the articulation of a compelling narrative for multiple audiences—governments, industry, foundations, and the public. This includes not only the scientific benefits of km-scale modeling, but its transformative impacts on sectors like agriculture, energy, disaster preparedness, finance, and public health. Messaging should emphasize the creation of a community of practice, and not simply a technical system.

d. Priorities and Next Steps

The final discussions outlined a set of priorities to translate summit momentum into action. These include:

- Finalizing the two-phase modeling framework and its stakeholder-informed performance goals.
- Establishing working groups to develop a coordinated research agenda, data management strategies, and use-case translation pathways.
- Designing an administrative prototype for a global facility or consortium, with active outreach to existing entities like WCRP and Digital Earth.
- Developing strategic funding pitches to philanthropic and government agencies, using high-value use cases to illustrate impact.
- Creating pathways for inclusive participation, especially for under-resourced scientists and regions, through education, workforce development, and co-leadership roles.
- Initiating a communication strategy focused on the value proposition of km-scale modeling to society, emphasizing both climate resilience and economic opportunity.

e. Post-Summit Communication

A key to maintaining momentum developed during the summit is continuous communication with the organizations involved, the addition of other organizations, creating a leadership structure and building and executing a strategic plan, and establishing increasingly strong linkages with the stakeholder/practitioner community. Efforts are underway on each of these topics.

5. Summit Products

a. Informal Publications

Droegemeier, K.K., 2024. Working Toward a Computational Framework to Support Earth System Science and Climate Projection. The Download, National Center for Supercomputing Applications, University of Illinois Urbana-Champaign. Available at https://www.ncsa.illinois.edu/kelvin-k-droegemeier-on-working-toward-a-computational-framework-to-support-earth-system-science-and-climate-projection/.

b. Invited Publications

Droegemeier, K.K. and Co-authors, 2025: A global community approach for transforming Earth system science and climate projection. In *Pathways to Sustainability: Collaborative Solutions for a Resilient Future*. D. Killeen, D. Wuebbles, and J. Lane Eds. University of Illinois Press, 285 pp.

c. Planned Publications

The summit Planning Committee intends to publish a summary of the summit in an archive journal.

d. Archived Materials from Summit

All videos and presentation slides from the summit are archived on the University of Illinois Urbana-Champaign Media Space system (https://mediaspace.illinois.edu/).

8. Appendix A – Original Summit Agenda

International Summit on a

Computational System for Frontier Earth System Science and Climate Simulation & Projection

AGENDA

Sponsored by the National Science Foundation (NSF) Under Grant 24-10910
and
National Center for Supercomputing Applications (NCSA)
Department of Climate, Meteorology & Atmospheric Sciences University of Illinois Urbana-Champaign

Sunday, September 29 – Wednesday, October 2
I Hotel and Illinois Conference Center
1900 South First Street
Urbana, IL 61820 USA

Sunday, September 29, 2024 (ALL TIMES ARE CENTRAL DAYLIGHT TIME)

6:00 pm	Registration and Reception at the Chancellor's Ballroom, I Hotel and Conference Center. Refreshments provided with cash bar. Welcome by Dr. Timothy L. Killeen, President, University of Illinois System. Overview of the National Center for Supercomputing Applications (NCSA) by Dr. William D. Gropp, Director.

Monday, September 30, 2024 (Day-1) (ALL TIMES ARE CENTRAL DAYLIGHT TIME)

Principal Goals for the Day: Help everyone become familiar with the purpose and rationale for the summit, overview drivers and thoughts obtained to date on core topics, and prepare issues/questions for discussion on Day-2.

7:30 – 8:30 am	Arrive at the I Hotel and Conference Center and check-in at the summit registration table outside the Chancellor's Ballroom. Continental breakfast provided.
8:30 – 9:00 am	Welcome by Dr. Robert J. Jones, Chancellor, and Dr. Susan Martinis, Vice Chancellor for Research and Innovation, University of Illinois Urbana-Champaign.
9:00 – 9:15 am	Introductions, goals of the summit, and logistics. (Kelvin Droegemeier, University of Illinois Urbana-Champaign).
9:15 – 9:45 am	Engaging the Global Community in a Transformative Approach to Earth System Science Research, Education and Climate Projection. (Kelvin Droegemeier).
9:45 – 10:15 am	Break with refreshments provided; networking; sharing of initial thoughts electronically.
10:15 am - noon	Panel Session: Progress in Fine-Scale Earth System Modeling Around the World and AI-Based Systems for Weather and Climate. Co-Chaired by Ruby Leung, DOE Pacific Northwest National Laboratory; Bjorn Stevens, Max Planck Institute for Meteorology; and Maria Molina, University of Maryland. ● km-Scale Model Survey Results (Andreas Prein, ETH Zurich). ● Europe: Destin-E/IFS/ICON (Nils Wedi, European Center for Medium Range Weather Forecasts) and EVE (Bjorn Stevens, Max Planck Institute for Meteorology). ● Asia: NICAM (Masaki Satoh, Tokyo University). ● United States: SCREAM/SHIELD/MPAS (Andreas Prein, ETH Zurich) and NeuralGCM (Stephan Hoyer, Google).

- AI/ML: NVIDIA AI for Weather and Climate (Karthik Kashinath, NVIDIA) and GraphCast (TBD, Google).

Noon – 2:00 pm — Working Lunch (provided) and Practitioner/Stakeholder Panel Session: Needs as Drivers of Fine-Scale Climate Information. Chaired by Francina Dominguez, University of Illinois Urbana-Champaign.

- Jeff Gall, RenaissanceRe Risk Sciences
- Edith Makra, Metropolitan Mayors Caucus.
- John England, U.S. Army Corps of Engineers.
- Jean Brokish, American Farmland Trust.

2:00 – 2:15 pm — Silent brainstorming and electronic submission of thoughts for discussion.

2:15 – 3:15 pm — Discussion of thoughts, questions, and ideas submitted electronically. Co-Chaired by Dan Reed, University of Utah and Maria Molina, University of Maryland.

3:15 – 3:30 pm — Break with refreshments provided.

3:30 – 5:00 pm — Recap of pre-summit intensives and discussion of possible breakout topics. Co-Chaired by Barb Helland, US Department of Energy (Retired) and John Towns, University of Illinois Urbana-Champaign. Submit additional thoughts electronically about questions needing to be addressed in breakouts.

- Practitioners and Stakeholders, Francina Dominguez.
- Earth System Models, Andreas Prein.
- Computational Systems, John Shalf.
- Artificial Intelligence and Machine Learning, Maria Molina.

5:00 – 5:20 pm — Why are models uncertain and how can uncertainty best be quantified? Tim Palmer, University of Oxford.

5:30 pm — Adjourn – Dinner on your own and think about breakout topics.

Planning Committee meets for dinner at 6:00 pm.

Tuesday, October 1, 2024 (Day-2) (ALL TIMES ARE CENTRAL DAYLIGHT TIME)

Principal Goals for the Day: Develop a deeper shared understanding of key issues, identify points of agreement and disagreement, clarify needed research and remaining questions, and begin to create a consensus regarding a path forward.

7:30 – 8:30 am	Arrive at I Hotel and Conference Center. Continental breakfast provided.
8:30 – 9:00 am	Recap of Day-1 and plans for Day-2, including breakouts and use of Challenge Sets (Kelvin Droegemeier).
9:00 – 10:30 am	Plenary discussion of pre-summit intensive materials and presentations from Day-1, with participants making suggestions electronically regarding key questions/issues needing to be addressed in the breakout sessions. End with 15 minutes of silent brainstorming. (Planning Committee, Nucleus Team).
10:30 – 11:00 am	Break with refreshments provided and networking.
11:00 am – 12:30 pm	Breakout Sessions #1 (Nucleus Team).
12:30 – 1:15 pm	Lunch provided.
1:15 – 2:45 pm	Breakout Sessions #2 (Nucleus Team).
2:45 – 3:00 pm	Break with refreshments provided and return to plenary (Nucleus Team).
3:00 – 4:00 pm	Report of breakout discussions in plenary (Nucleus Team).
4:00 – 5:30 pm	Cross-cutting Challenge Sets in breakout groups (Nucleus Team).
5:30 pm	Adjourn – Dinner on your own.
	Planning Committee meets for dinner at 6:00 pm.

Wednesday, October 2, 2024 (Day-3) (ALL TIMES ARE CENTRAL DAYLIGHT TIME)

Principal Goals for the Day: Summarize key points of agreement and remaining questions; (1) develop a consensus regarding a computational environment and modeling framework that address stakeholder needs; (2) identify key research questions that need to be addressed to achieve reliable model results; and (3) frame an administrative structure, facilities concept, and funding model for executing a global initiative that leverages community resources to achieve a whole that is astonishingly greater than the sum of its parts.

7:30 – 8:30 am	Arrive at I Hotel and Conference Center. Continental breakfast provided.
8:30 – 9:00 am	Logistics for Day-3 and thoughts from informal discussions overnight (Kelvin Droegemeier).
9:00 – 10:30 am	Report out from Challenge Sets and other discussions toward achieving the three principal goals for the day (Nucleus Team).
10:30 – 11:00 am	Break with refreshments provided.
11:00 am – 1:00 pm	Structured discussion, guiding principles, possible anonymous polling on key issues, how to maintain momentum and key next steps (Nucleus Team, Planning Committee).
1:00 – 2:00 pm	Box lunch provided, summit survey, and wrap-up (those needing to leave can take a box lunch with them).
2:00 pm	Summit adjourns.
3:00 – 6:00 pm	Planning Committee meets to discuss summit, next steps, and report to NSF.

Summit Planning Committee

Summit Planning Committee		
Name (alpha order)	**Title & Organization**	**Expertise**
Kelvin Droegemeier (Chair)	Professor of Atmospheric Sciences and Special Advisor to the Chancellor for Science and Policy, Department of Atmospheric Sciences, University of Illinois	Severe Storms, Numerical Weather Prediction, Data Assimilation, Computational Fluid Dynamics
Francina Dominguez	Professor of Atmospheric Sciences, Department of Atmospheric Sciences, University of Illinois	Land-Atmosphere Interactions, Hydrology and Climate Change
Barb Helland	Former Director, DOE Office of Science Advanced Scientific Computing Research program	High Performance Computing, Computational Science Education, Data Management
Ruby Leung	Chief Scientist of Energy Exascale Earth System Model, Pacific Northwest National Laboratory	Climate and Hydrologic Modeling, Climate Change Impacts
Maria Molina	Assistant Professor, Department of Atmospheric and Oceanic Science, University of Maryland	Application of Machine Learning to Climate & Extremes
Andreas Prein	Professor for High-Resolution and Climate Modeling, Federal Institute of Technology Zurich (ETH)	Modeling of Extreme Events in a Warming Climate
Dan Reed	Professor of Electrical and Computer Engineering and former Provost, University of Utah	High-Performance Computing, Policy, Education
John Shalf	Department Head for Computer Science, Lawrence Berkeley National Laboratory	High-Performance Computing, Customized Computer Platforms
Bjorn Stevens	Director and Member of Climate Physics Department, Max Planck Institute for Meteorology	Impacts of Water Vapor and Clouds on Climate Change
John Towns	Deputy Director, National Center for Supercomputing Applications	Making High-Performance Computing Resources available to the National Research Community, Data Management and Visualization

Summit Nucleus Team

Practitioners and Stakeholders	
Jean Brokish	American Farmland Trust
Trent Ford	Illinois State Water Survey
Jeff Gall	RenaissanceRe Risk Sciences
Josh Hacker	Jupiter Intelligence
Dan Kirk-Davidoff	Electric Power Research Institute
Edith Makra	Metropolitan Mayors Caucus
Ming Pan	Center for West Water &Weather Extremes
Earth System Models	
Hayley Fowler	Newcastle University
James Hurrell	Colorado State University
Christiane Jablonowski	University of Michigan
Peter Messmer	NVIDIA
Jon Petch	National Center for Atmospheric Research
Irina Sandu	ECMWF Destination Earth
Masaki Satoh	Tokyo University
Computational Systems	
Jim Hack	Oak Ridge National Laboratory (Retired)
Larry Kaplan	HPE
Irene Qualters	Los Alamos National Laboratory
Michael Schulte	AMD Corporation
Estela Suarez	University of Bonn
Michael Wehner	Lawrence Berkeley National Laboratory
Cliff Young	Google
Artificial Intelligence and Machine Learning	
Chris Bretherton	Allen AI Institute
Katie Dagon	National Center for Atmospheric Research
Pierre Gentine	Columbia University
Torsten Hoefler	ETH Zurich
Amy McGovern	University of Oklahoma
Tapio Schneider	California Institute of Technology

9. Appendix B – Real Time Summit Agenda

International Summit on a

Computational System for Frontier Earth System Science and Climate Simulation & Projection

*REALTIME AGENDA

Sponsored by the National Science Foundation (NSF) Under Grant 24-10910
and
National Center for Supercomputing Applications (NCSA)
Department of Climate, Meteorology & Atmospheric Sciences
University of Illinois Urbana-Champaign

Sunday, September 29 – Wednesday, October 2
I Hotel and Illinois Conference Center
1900 South First Street
Urbana, IL 61820 USA

*This agenda reflects changes made to the program during the course of the summit.

Sunday, September 29, 2024 (ALL TIMES ARE CENTRAL DAYLIGHT TIME)

6:00 pm	Registration and Reception at the Chancellor's Ballroom, I Hotel and Conference Center. Refreshments provided with cash bar. Welcome by Dr. Timothy L. Killeen, President, University of Illinois System. Overview of the National Center for Supercomputing Applications (NCSA) by Dr. William D. Gropp, Director.

Monday, September 30, 2024 (Day-1) (ALL TIMES ARE CENTRAL DAYLIGHT TIME)

Principal Goals for the Day: Help everyone become familiar with the purpose and rationale for the summit, overview drivers and thoughts obtained to date on core topics, and prepare issues/questions for discussion on Day-2.

7:30 – 8:30 am	Arrive at the I Hotel and Conference Center and check-in at the summit registration table outside the Chancellor's Ballroom. Continental breakfast provided.
8:30 – 9:00 am	Welcome by Dr. Robert J. Jones, Chancellor, and Dr. Susan Martinis, Vice Chancellor for Research and Innovation, University of Illinois Urbana-Champaign.
9:00 – 9:15 am	Introductions, goals of the summit, and logistics. (Kelvin Droegemeier, University of Illinois Urbana-Champaign).
9:15 – 9:45 am	Engaging the Global Community in a Transformative Approach to Earth System Science Research, Education and Climate Projection. (Kelvin Droegemeier).
9:45 – 10:15 am	Break with refreshments provided; networking; sharing of initial thoughts electronically.
10:15 am - noon	Panel Session: Progress in Fine-Scale Earth System Modeling Around the World and AI-Based Systems for Weather and Climate. Co-Chaired by Ruby Leung, DOE Pacific Northwest National Laboratory; Bjorn Stevens, Max Planck Institute for Meteorology; and Maria Molina, University of Maryland. ● km-Scale Model Survey Results (Andreas Prein, ETH Zurich).

- Europe: Destin-E/IFS/ICON (Nils Wedi, European Center for Medium Range Weather Forecasts) and EVE (Bjorn Stevens, Max Planck Institute for Meteorology).
- Asia: NICAM (Masaki Satoh, Tokyo University).
- United States: SCREAM/SHIELD/MPAS (Andreas Prein, ETH Zurich) and NeuralGCM (Stephan Hoyer, Google).
- AI/ML: NVIDIA AI for Weather and Climate (Karthik Kashinath, NVIDIA) and GraphCast (TBD, Google).

Noon – 2:00 pm — Working Lunch (provided) and Practitioner/Stakeholder Panel Session: Needs as Drivers of Fine-Scale Climate Information. Chaired by Francina Dominguez, University of Illinois Urbana-Champaign.

- Jeff Gall, RenaissanceRe Risk Sciences
- Edith Makra, Metropolitan Mayors Caucus.
- John England, U.S. Army Corps of Engineers.
- Jean Brokish, American Farmland Trust.

2:00 – 2:15 pm — Silent brainstorming and electronic submission of thoughts for discussion.

2:15 – 3:15 pm — Discussion of thoughts, questions, and ideas submitted electronically. Co-Chaired by Dan Reed, University of Utah and Maria Molina, University of Maryland.

3:15 – 3:30 pm — Break with refreshments provided.

3:30 – 5:00 pm — Recap of pre-summit intensives and discussion of possible breakout topics. Co-Chaired by Barb Helland, US Department of Energy (Retired) and John Towns, University of Illinois Urbana-Champaign. Submit additional thoughts electronically about questions needing to be addressed in breakouts.

- Practitioners and Stakeholders, Francina Dominguez.
- Earth System Models, Andreas Prein.
- Computational Systems, John Shalf.
- Artificial Intelligence and Machine Learning, Maria Molina.

5:00 – 5:20 pm — Why are models uncertain and how can uncertainty best be quantified? Tim Palmer, University of Oxford.

5:30 pm — Adjourn – Dinner on your own and think about breakout topics.

Planning Committee meets for dinner at 6:00 pm.

Tuesday, October 1, 2024 (Day-2) (ALL TIMES ARE CENTRAL DAYLIGHT TIME)

Principal Goals for the Day: Develop a deeper shared understanding of key issues, identify points of agreement and disagreement, clarify needed research and remaining questions, and begin to create a consensus regarding a path forward.

7:30 – 8:30 am	Arrive at I Hotel and Conference Center. Continental breakfast provided.
8:30 – 9:00 am	Recap of Day-1 and plans for Day-2, including breakouts and use of Challenge Sets (Kelvin Droegemeier).
9:00 – 10:30 am	Plenary discussion of pre-summit intensive materials and presentations from Day-1, with participants making suggestions electronically regarding key questions/issues needing to be addressed in the breakout sessions. End with 15 minutes of silent brainstorming. (Planning Committee, Nucleus Team).
10:30 – 11:00 am	Break with refreshments provided and networking.
11:00 am – 12:30 pm	Breakout Sessions #1. Group 1: A New Approach for the International Community Group 2: Crosscutting Topics Group 3: Earth System Model and AI/ML Group 4: Computational Systems Group 5: Practitioners, End Users & Stakeholders
12:30 – 2:00 pm	Lunch provided and report-out from Breakout Sessions #1
2:00 – 2:30 pm	Break with refreshments provided
2:30 – 4:00 pm	Breakout Sessions #2. Group 1: Use Cases Group 2: R&D Agenda Group 3: Data and tools
4:00 – 5:30 pm	Report-out from Breakout Sessions #2.
5:30 pm	Adjourn – Dinner on your own. Planning Committee meets for dinner at 6:00 pm.

Wednesday, October 2, 2024 (Day-3) (ALL TIMES ARE CENTRAL DAYLIGHT TIME)

Principal Goals for the Day: Summarize key points of agreement and remaining questions; (1) develop a consensus regarding a computational environment and modeling framework that address stakeholder needs; (2) identify key research questions that need to be addressed to achieve reliable model results; and (3) frame an administrative structure, facilities concept, and funding model for executing a global initiative that leverages community resources to achieve a whole that is astonishingly greater than the sum of its parts.

7:30 – 8:30 am	Arrive at I Hotel and Conference Center. Continental breakfast provided.
8:30 – 10:00 am	Plenary discussion of key issues (Planning Committee)
10:00 am – 10:45 am	Break and refreshments provided
10:45 am – noon	Continue discussion; identify next steps.
Noon	Summit adjourns and box lunch provided.
1:00 – 2:30 pm	Planning Committee meets to discuss summit, next steps, and report to NSF.

9. Appendix C – Post-Summit Satisfaction Survey

An online survey was used to assess participant views of the summit and the results are presented below.

Total submissions: 17 Status:
running
Type: PDF Summary with Answers ID:
146203390

1. How satisfied are you with the overall experience of the summit?	*Percent*	*Count*
Very Satisfied	**47%**	**8**
Satisfied	**53%**	**9**
Neutral	**0%**	**0**
Dissatisfied	**0%**	**0**
Very Dissatisfied	**0%**	**0**

2. Was the time you spent participating worthwhile?	*Percent*	*Count*
Very Worthwhile	**76%**	**13**
Somewhat Worthwhile	**24%**	**4**
Neutral	**0%**	**0**
Not Worthwhile	**0%**	**0**

3. How effective was communication leading up to the event (e.g., registration process, agenda details)?	*Percent*	*Count*
Very Effective	**71%**	**12**
Somewhat Effective	**24%**	**4**
Neutral	**0%**	**0**
Not Effective	**6%**	**1**

4. Were the read-ahead materials from the Pre-Summit Intensives useful in preparing you for the summit?	*Percent*	*Count*
Very Useful	**53%**	**9**
Somewhat Useful	**41%**	**7**
Neutral	**6%**	**1**
Not Useful	**0%**	**0**

5. How satisfied are you with the logistical support you received, if appropriate (e.g., travel, lodging, local transportation)?	*Percent*	*Count*
Very Satisfied	**53%**	**9**

Satisfied	**18%**	**3**
Neutral	**18%**	**3**
Dissatisfied	**0%**	**0**
Very Dissatisfied	**0%**	**0**

6. How satisfied are you with the extent to which you were able to provide input during the summit?	*Percent*	*Count*
Very Satisfied	**59%**	**10**
Satisfied	**29%**	**5**
Neutral	**6%**	**1**
Dissatisfied	**6%**	**1**
Very Dissatisfied	**0%**	**0**

7. Do you feel the goals of the summit were clearly explained?	*Percent*	*Count*
Very Clear	**18%**	**3**
Clear	**59%**	**10**
Somewhat Confusing	**24%**	**4**
Very Confusing	**0%**	**0**

8. Do you feel the goals of the summit were achieved?	*Percent*	*Count*
Definitely Achieved	**24%**	**4**
Mostly Achieved	**53%**	**9**
Somewhat Achieved	**24%**	**4**
Unlikely Achieved	**0%**	**0**
Definitely Not Achieved	**0%**	**0**

9. Do you believe the international community should pursue the initiative discussed at the summit?	*Percent*	*Count*
Strongly Agree	**82%**	**14**
Mostly Agree	**18%**	**3**
Somewhat Agree	**0%**	**0**
Somewhat Disagree	**0%**	**0**
Strongly Disagree	**0%**	**0**

10. How relevant we the summit's themes (NWP, ESM, AI/ML, Practitioners and Stakeholders) to your work or research interests?	*Percent*	*Count*
Highly Relevant	**76%**	**13**

Somewhat Relevant	**18%**	**3**
Neutral	**6%**	**1**
Not Relevant	**0%**	**0**

11. What themes should have been included but were not?		*Count*
	Answered	**4**
	Skipped	**13**

2. Trade-offs of resolution vs other ways to achieve verisimilitude

6. We should have spent more time discussing requirements and desired features for the Climate Computer.

7. high performance computing and computer architecture

13. overview of international activities; current issues of global km-scale models

12. Were the number of presentations appropriate?	*Percent*	*Count*
Very Appropriate	**65%**	**11**
Somewhat Appropriate	**35%**	**6**
Neutral	**0%**	**0**
Not Appropriate	**0%**	**0**

13. Were the number of breakout and discussion sessions appropriate?	*Percent*	*Count*
Very Appropriate	**53%**	**9**
Somewhat Appropriate	**41%**	**7**
Neutral	**6%**	**1**
Not Appropriate	**0%**	**0**

14. How effective were the breakout sessions in fostering discussion on the key issues?	*Percent*	*Count*
Very Effective	**29%**	**5**
Effective	**59%**	**10**
Neutral	**6%**	**1**
Ineffective	**6%**	**1**

15. Please rate the quality of the summit's presentations.	*Percent*	*Count*
Excellent	**65%**	**11**
Good	**35%**	**6**
Fair	**0%**	**0**
Poor	**0%**	**0**

16. How would you rate the clarity and accessibility of information presented on complex topics (e.g., high-resolution ESMs, AI/ML in climate modeling)?	*Percent*	*Count*
Extremely Clear	**53%**	**9**
Clear	**41%**	**7**
Somewhat Clear	**6%**	**1**
Not Clear	**0%**	**0**

17. • Importance of high-resolution ESMs:	*Percent*	*Count*
1	**12%**	**2**
2	**0%**	**0**
3	**0%**	**0**
4	**35%**	**6**
5	**53%**	**9**

18. • Role of AI/ML in weather and climate modeling/projection:	*Percent*	*Count*
1	**6%**	**1**
2	**6%**	**1**
3	**12%**	**2**
4	**41%**	**7**
5	**35%**	**6**

19. • Global and local impacts of climate modeling:	*Percent*	*Count*
1	**6%**	**1**
2	**6%**	**1**
3	**12%**	**2**
4	**41%**	**7**
5	**35%**	**6**

20. • Computational infrastructure challenges:	*Percent*	*Count*
1	**6%**	**1**
2	**12%**	**2**
3	**18%**	**3**
4	**41%**	**7**

5	24%	4

21. • Integration of stakeholders and decision-makers:	*Percent*	*Count*
1	**0%**	**0**
2	**24%**	**4**
3	**29%**	**5**
4	**24%**	**4**
5	**24%**	**4**

22. How valuable were the Panel Discussions in offering insights into the future of Earth system modeling and computational advancements?	*Percent*	*Count*
Very Valuable	**47%**	**8**
Somewhat Valuable	**53%**	**9**
Neutral	**0%**	**0**
Not Valuable	**0%**	**0**

23. How valuable were the Challenge Sets in providing potential pathways toward achieving the proposition of a computational system for globally fine-scale Earth system models?	*Percent*	*Count*
Very Valuable	**24%**	**4**
Somewhat Valuable	**65%**	**11**
Neutral	**12%**	**2**
Not Valuable	**0%**	**0**

24. How would you rate the opportunities for networking and collaboration during the summit?	*Percent*	*Count*
Excellent	**82%**	**14**
Good	**12%**	**2**
Fair	**6%**	**1**
Poor	**0%**	**0**

25. • Virtual platform (if applicable):	*Percent*	*Count*
Excellent	**24%**	**4**
Good	**12%**	**2**
Fair	**6%**	**1**
Poor	**0%**	**0**

26. • In-person venue (if applicable):	*Percent*	*Count*
Excellent	**65%**	**11**
Good	**18%**	**3**
Fair	**0%**	**0**

Poor	**0%**	**0**

27. • Technical and logistical support:	*Percent*	*Count*
Excellent	**47%**	**8**
Good	**29%**	**5**
Fair	**6%**	**1**
Poor	**0%**	**0**

28. What did you find most valuable about the summit?		*Count*
	Answered	**17**
	Skipped	**0**

1. Great insights and discussions!

2. Catching up on the state of the art of high resolution climate modeling.

3. Very important topic. Opportunity to engage with experts in important topic and make significant progress

4. Discussion topics

5. level setting and networking

6. It brought together a diverse group of experts to begin planning for an international collaboration on climate modeling and the resources needed to enable this.

7. knowing the community needs better

8. I now have a better understanding of what is possible.

9. Excellent discussions on state-of-the-art and ambitious goals

10. The organization of topics.

11. Need for km scale models was clearly stated

12. Getting a better grasp on the current state of large-scale collaboration in the ESM community.

13. gathering US global km-scale communities

14. The holistic and high-level focus

15. The interactions with others who were committed to solving the same global challenges

16. Networking - having the right people!

17. Open forum for discussing specific physical and computational issues related to km-scale modeling

29. What areas of the summit could be improved for future events?	*Count*
Answered	**8**
Skipped	**9**

2. more specific discussion of how data would help practitioners

5. better organization of focused breakouts

6. It would be useful to have more detailed analysis and more concrete planning in future events. This conference was an excellent first step.

8. It could have been done in less time -- probably 2 days.

9. more in-depth pre-reads would have been useful

11. I felt that my breakout (hardware/software) was ineffective. A few high level manager types had visions from 30000 feet up and don't understand what climate science or stakeholders actually do. I am a climate scientist who has worked with stakeholders. But they didn't listen particularly well. There are relevant activities underway now within USGCRP and associated agencies, but not being in the field, they had no idea. In particular, the revamped ESGF at ORNL is the resource for big climate data distribution and analytics. So i viewed this breakout as essentially irrelevant. I suggest more people from the trenches and less managers.

13. connection of operational centers, weather and climate

16. Not much actually

30. What topics would you like to see covered in future summits related to Earth system modeling,	*Count*
Answered	**10**
Skipped	**7**

5. specific elements of the mapping from use cases thought requirements to implementations

6. Computational system requirements. Strategies to combine physics and AI models. Strategies for international collaboration.

8. Which model.

9. more focus on data challenges - production rate, archive, access, etc.

10. Perhaps more emphasis on data assimilation and its role in km-scale simulations.

11. What we expect to learn

13. scientific issues of global km-scale model simulations

14. Specific opportunities for collaboration; use cases and implications

15. Algorithm design

16. Specifics on sup-topics such as HW-SW co-design

31. How likely are you to support future activities related to the summit goals?	*Percent*	*Count*
Very Likely	**82%**	**14**
Likely	**18%**	**3**
Neutral	**0%**	**0**
Unlikely	**0%**	**0**
Very Unlikely	**0%**	**0**

32. Please share any other comments or feedback.		*Count*
	Answered	**6**
	Skipped	**11**

5. In discussion with other attendees, the quality of the breakouts varied, some more focused while others were a bit more scattershot

6. Overall, this was a very productive Summit. I learned a lot.

8. I have not received a receipt for my lodging.

11. The focus on 5-30 years is misguided in my opinion. 5 years is essentially today. 30 years is the beginning of the relevant period where we can say something statistically significant. Longer term projections, expressed at global warming levels to be scenario independent are high relevant to public decisionmakers. The dams that nearly failed in Helene are 125 years old! So public infrastructure decisions can be on much longer time scales than private industry timescales (but I realize that is where the $ is)

14. The tone was highly conducive and constructive to the type of open dialogue which lays the foundation for more in depth and specific focus topics.

16. Big thanks to Kelvin and the team!