

Trillion-Pixel GeoAI Challenges 2024 GeoAI Workshop Report



Rahul Ramachandran – *NASA Marshall Space Flight Center*
Dalton Lunga – *Oak Ridge National Laboratory*
Budhu Bhaduri – *Oak Ridge National Laboratory*
Manil Maskey – *NASA Marshall Space Flight Center*
Valentine Anantharaj – *Oak Ridge National Laboratory*
Assaf Anyamba – *Oak Ridge National Laboratory*
Samantha Arundel – *United State Geological Survey*
Katie Baynes – *NASA Headquarters*
Carter Christopher – *Oak Ridge National Laboratory*
Forrest Hoffman – *Oak Ridge National Laboratory*
Aaron Kaulfus – *NASA Marshall Space Flight Center*
Dawn King – *National Geospatial-Intelligence Agency*
Tsengdar Lee – *NASA Headquarters*
Wenwen Li – *Arizona State University*
David Page – *Oak Ridge National Laboratory*
Beth Plale – *Indiana University*
Shubha Ranjan – *NASA Ames Research Center*
Sujit Roy – *University of Alabama in Huntsville*
Lexie Yang – *Oak Ridge National Laboratory*



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AI Foundation Models Powering Geospatial Digital Twins

Trillion-Pixel GeoAI Challenges Workshop Report

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
and
OAK RIDGE NATIONAL LABORATORY

September 2024

Prepared by
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
and
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, TN 37831
managed by
UT-BATTELLE LLC
for the
US DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

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ACKNOWLEDGMENTS

Session Speakers

Dr. Sambit Bhattacharya, *Fayetteville State University*
Dr. Sid Ahmed Boukabara, *Senior Program Scientist, NASA Earth Science Division*
Ms. Laura Carriere, *NCCS High Performance Computing Lead, NASA*
Mr. Mark Cygan, *Director, National Mapping Solutions*
Dr. Ahmed Eldawy, *University of California Riverside*
Dr. Kjersten Fagnan, *Chief Informatics Officer, DOE Joint Genome Institute*
Dr. David Hall, *Senior Data Scientist and Solution Architect, NVIDIA*
Dr. Jay Hnilo, *Program Manager, Department of Energy, Office of Science*
Dr. Hook Hua, *Jet Propulsion Laboratory / California Institute of Technology*
Dr. Neena Imam, *O'Donnell Data Science and Research Computing Institute, Southern Methodist University*
Mr. Todd Johanesen, *Director, Foundation GEOINT Group*
Dr. Mark Korver, *Director, Geospatial Data & Analytics, TGI*
Dr. Jitendra Kumar, *Oak Ridge National Laboratory*
Dr. Sujay Kumar, *Hydrological Sciences Lab, NASA*
Mr. Kyle Lamb, *Field CTO for HPC, VAST Data*
Mr. Zongyi Li, *California Institute of Technology*
Dr. Lingbo Liu, *Center for Geographic Analysis, Harvard University*
Dr. Dan Lu, *Senior Scientist, Oak Ridge National Laboratory*
Dr. Shawn Newsam, *University of California, Merced*
Ms. Laura Rogers, *Earth Science Technology Office Deputy Program Manager, NASA*
Dr. Johannes Schmude, *Senior Research Scientist, IBM Research*
Mr. Ian Schuler, *CEO, Development Seed*
Dr. Catherine Schuman, *The University of Tennessee, Knoxville*
Dr. Seetharami Seelam, *Principal Staff Member, IBM Research*
Dr. Daniel Selva, *Texas A&M University*
Dr. Ahmad Tavakoly, *US Army Engineer Research and Development Center*
Dr. Kunhikrishnan (Kunhi) Thengumthara, *Physical Scientist & Interagency Coordinator, ICAMS/CoRI*
Dr. Mike Tischler, *Director, National Geospatial Program*
Mr. Bijan Varjavan, *Scale AI*
Dr. Raju Vatsavai, *Center for Geospatial Analytics, North Carolina State University*
Dr. Venkat Vishwanath, *Argonne National Laboratory*
Dr. Renee Weber, *Chief Scientist, NASA Marshall Space Flight Center*
Dr. WenWen Li, *Arizona State University*
Dr. May Yuan, *The University of Texas at Dallas*
Dr. Chris Zimmer, *Oak Ridge National Laboratory*

ABSTRACT

This year's Trillion Pixel Challenge workshop delved into the use of artificial intelligence (AI) foundation models (FMs) to advance geospatial digital twins and enhance scientific research. The workshop effectively explored the integration of AI foundation models into scientific research, emphasizing practical strategies to embed these models into current systems and enhance collaborative efforts. The discussions laid groundwork for future innovations in utilizing AI to foster more effective and predictive scientific exploration, particularly within the realm of geospatial digital twins, where foundational models are expected to play a pivotal role.

Key Themes and Discussions

1. **Geospatial Digital Twins and AI Foundation Models:** The workshop tackled the challenges of integrating AI models with geospatial digital twins, emphasizing the need to handle data from diverse sources and improve predictive analyses. Participants highlighted AI's potential to enhance decision-making by optimizing digital twins for better scenario planning.
2. **AI Strategy for Open Science:** Developing a robust and scalable AI infrastructure was identified as critical for advancing AI models within scientific frameworks. Discussions also stressed enhancing AI literacy within the science community and promoting collaboration through data integration to streamline scientific workflows and promote open science practices.
3. **Predictive Modeling and Simulation:** The use of AI-driven predictive models for Earth science using Earth observation was a major focus. The workshop underscored the importance of these models in improving our understanding of Earth as a system. These models are key to improving our understanding of Earth's systems and planning for various environmental phenomena.

Ultimately, the event highlighted the transformative potential of AI foundation models in a wide array of fields, from disaster management to climate monitoring. However, significant concerns regarding resource allocation, transparency, and bias in AI systems remain. Continued research and collaboration between academic, industrial, and governmental sectors will be essential to addressing these challenges and maximizing the impact of AI in scientific research and real-world applications.

Key Challenges Identified

- Synchronizing diverse data sources
- Managing computational resources
- Ensuring transparency in AI models

AI models have significant potential in disaster management, climate change mitigation, and environmental monitoring. Enhancing traditional models with AI can improve efficiency in handling complex data, but challenges remain, particularly regarding:

- Resource allocation
- Explainability and trust
- Model biases

The workshop also underscored the need for further research to align foundational models with the evolving demands of digital twins. Challenges in power consumption, data integration, and long-term collaboration were key issues raised by participants.

Recommendations for Advancement

- Develop better evaluation metrics to identify biases
- Treat validation and verification metrics as a scientific discipline
- Address misinformation and trust issues
- Foster systematic partnerships for resource access
- Remedy the lack of annotated data and improve data provenance
- Increase explainability and transparency of AI systems

The workshop emphasized the necessity for collaboration across sectors and disciplines to drive innovation and tackle global challenges. Continued focus on technical, ethical, and infrastructural issues is vital for leveraging the potential of AI in digital twins for scientific discovery and practical applications.

SESSION 1: PROGRAMMATIC NEEDS

PRESENTATIONS

Dr. May Yuan's presentation explored the shift in geospatial research from traditional methods to the adoption of digital twins and foundation models. Historically, geospatial research relied on mathematical models and hypothesis-driven data collection to validate theories. The introduction of GeoAI digital twins, which prioritize extensive data collection for modeling and prediction over exploring physical processes, marks a significant departure from this approach. Yuan highlighted concerns about potentially sacrificing deeper scientific inquiry for predictive accuracy and emphasized the need to balance predictive models with physical process models. The presentation also covered various geospatial methodologies and trends, including Bayesian vs. frequentist approaches, knowledge graphs, and cloud computing. She noted the NSF's substantial investment in digital twin technology and urged the integration of social, behavioral, and economic factors into Earth system science.

Dr. Mike Tischler of the USGS detailed the agency's strategic vision for advancing scientific research through integrated geospatial data systems. The USGS aims to enhance its understanding of natural processes and human-environment interactions using 3D modeling and geospatial data. Key components of the USGS's core science systems include Landsat satellites, the 3D National Topography Model, the 3D Hydrography Program, and the 3D Elevation Program. The presentation also discussed future directions, such as developing a unified 3D data model to improve the understanding of Earth's surface and subsurface. This commitment reflects the USGS's focus on providing high-quality data to meet growing demands for detailed and accurate geospatial information.

Dr. Sid Boukabara's presentation on digital twins highlighted their growing importance in addressing complex national and global issues through real-time simulation and prediction. Digital twins are being adopted across various sectors, including agriculture, infrastructure, and public health, due to their ability to integrate diverse data streams and improve decision-making. Despite their advantages, challenges such as integrating existing data, quantifying uncertainty, and incorporating AI into traditional models remain significant.

Dr. Todd Johansen discussed the Foundation Digital Twin project, which aims to create a dynamic and authoritative geospatial model of Earth for critical applications, emphasizing real-time updates and automation. Lastly, Tsengdar Lee, presenting on behalf of NOAA, talked about leveraging AI for Earth observations. He underscored the transformative potential of AI in enhancing environmental monitoring,

prediction, and decision-making, with notable initiatives including the Trillion Pixel Challenge and recent AI/ML workshops.

QUESTION/ANSWER SESSION

The audience questioned whether foundational AI and digital twins represent a true shift in methodologies or if they are merely a reframing of established practices. Dr. Yuan responded that although these technologies do advance the field, they are built upon existing methods. For example, AI's ability to uncover patterns is useful for humans, whereas digital twins enhance these capabilities by integrating physical processes to predict patterns not yet visible in satellite imagery. This implies that although these technologies improve current methodologies, they may not drastically change the underlying approaches.

The discussion also clarified the differences between digital twins and feature mapping. Digital twins provide a comprehensive, interoperable view of data, whereas feature maps are designed for specific applications and are finely tuned for particular needs. Digital twins offer a dynamic, detailed approach to solving real-world problems including environmental changes and infrastructure needs, compared to static traditional maps. The conversation highlighted the importance of increased collaboration and funding, with a call for more systematic partnerships and inclusivity in accessing resources. Strategic leadership and effective use of substantial funding, such as the \$2 billion allocated to digital twins, are essential for addressing real-world problems and advancing geospatial technologies.

SESSION 2: ARTIFICIAL INTELLIGENCE

PRESENTATIONS

Professor Shawn Newsam elaborated on the distinction between geospatial digital twins and foundation models, highlighting how these concepts, although different, complement each other. Geospatial digital twins focus on mimicking natural processes and operate in real time, whereas FMs emphasize creating models based on data that are inherently static. Newsam noted that AI and FMs are crucial in realizing geospatial twins because they can handle multimodal data and integrate various geospatial models, although the effectiveness of a FM is constrained by the quality and quantity of training data. Dr. Raju Vatsavai explored the application of a FM in enhancing disaster management and resource planning, aiming to improve traditional models and support climate-smart practices in agriculture and forestry. His vision includes leveraging AI to address climate change challenges and inform policy while empowering carbon markets.

Dr. Dan Lu showcased the Oak Ridge Base Foundation Model for Earth System Predictability (ORBIT), an AI/FM model for weather prediction, which excels in short- and medium-term forecasts. ORBIT was a finalist for the Gordon Bell Prize in Climate Prediction. Similarly, Dr. Johannes Schmude introduced the Prithvi_WxC model, which focuses on downscaling weather data and forecasting hurricanes, with its [open-source release](#) planned for September 15, 2024. Dr. David Hall discussed the application of FM models in geospatial intelligence, mentioning FourCastNet and Stormcast, and addressing challenges such as hallucinations and memory issues. Lastly, Zongyi Li described the development of a weather prediction model using neural operators. Overall, the presentations highlighted the interplay between geospatial digital twins and foundation models, showcasing their applications across different fields.

QUESTIONS/ANSWER SESSION

In the Q&A session, discussion focused on the evolving role of AI in replacing traditional high-performance computing (HPC) simulations. AI models, once trained, offer efficiency and accuracy that

sometimes surpasses traditional simulations. However, there are pressing questions about the optimal allocation of resources between training and fine-tuning AI models. Explainability is a critical challenge, as AI systems need to be as transparent as physics-based models while potentially improving their accuracy. Strategies such as interpretable layers and hybrid models that combine data-driven approaches with physical laws are being explored to enhance both transparency and performance.

Audience questions also highlighted the integration of large language models (LLMs) with Geo AI models to broaden their application. Despite the potential of these advancements, academia is struggling to keep pace with them. Smaller models can achieve significant results if they utilize effective training techniques and high-quality data. The discussion raised concerns about whether LLMs can be trusted for precise predictions in highly nonlinear domains such as weather forecasting. Researchers are also exploring whether innovative model designs might replace the need for scaling up model size, which often leads to skepticism about the value of massive parameter increases.

Finally, the discussion addressed the need for improved efficiency in running large AI models and debated the value of scaling models from billions to trillions of parameters. The conversation touched on the practical limits of model size versus the diminishing returns in performance improvement. Balancing model size with accuracy and computational resources is crucial, as sometimes smaller, well-curated models can outperform larger ones. The discussion also considered future directions, emphasizing the importance of optimizing GPU use and exploring new techniques to advance AI capabilities without overwhelming resource constraints.

SESSION 3: DATA AND INFRASTRUCTURE

PRESENTATIONS

The presentations covered a range of topics centered around managing and utilizing vast amounts of data in various scientific fields. Kjersten Fagnan highlighted the challenges associated with human genome projects and other large-scale data initiatives. She emphasized issues such as the lack of annotated data, the need for structured ontologies, and maintaining data provenance. Fagnan referenced earlier concerns about data management and stressed the importance of unifying data access infrastructure to address these challenges effectively.

Ian Schuler focused on transforming data into actionable insights, particularly through the use of high-resolution imagery and end-to-end architectural patterns. He discussed the concept of "food twin" and the importance of bridging the gap between tools designed for researchers and those for end-users. Schuler also addressed the implications of geospatial data on infrastructure and the ongoing convergence of useful tools in the research and user communities.

Hook Hua and Laura Carriere both addressed the need for structured and efficient data management in their respective domains. Hua discussed foundational models and different types of data interactions, such as hindcasting and forecasting, and the role of community-based approaches in digital twin integration. Carriere focused on the challenges of managing petabyte-scale data, the importance of controlled vocabularies, and issues related to data access and duplication. Ahmed Eldaway proposed solutions for complex geospatial data preprocessing, and Jay Hnilo talked about advancing autonomous systems for atmospheric data and the role of repositories such as ESS-Dive and ESGF in managing diverse datasets.

QUESTIONS/ANSWER SESSION

In the panel discussion, several key topics were addressed regarding the integration and effectiveness of data management between edge and cloud environments. Laura Carriere highlighted the significance of operational AI/ML for robotics, emphasizing the efficiency of data processing on the edge. Hook Hua stressed the need for computational and cost efficiency, whereas Ian Schuler suggested empowering users to interrogate and compute data directly on their devices. As datasets scale, Jay Hnilo pointed out the challenges of coordination and international partnerships for federated data storage, with Kjersten Fagnan noting the limitations of distributed data and the necessity for standardized formats. Hook Hua questioned whether to optimize systems for storage or usage costs, advocating careful consideration of these factors.

The discussion also explored infrastructure needs for creating geospatial digital twins, with Jay Hnilo recommending large-scale solutions such as Destination Earth-2, whereas Kjersten Fagnan suggested focusing on software design and integration. Ahmed Eldaway proposed using multiple models within a marketplace approach rather than a single comprehensive model. The panel also discussed best practices to prepare data for AI and digital twins, with Laura Carriere mentioning the extensive data output from climate models and noting pervasive sampling biases. Ahmed Eldaway recommended standardizing metadata at the file system level to ensure consistency. Lastly, Kjersten Fagnan suggested investing in data quality improvement through compressive signatures for better searchability and indexing.

SESSION 4: PEOPLE AND PARTNERSHIPS

PRESENTATIONS

The People and Partnerships session focuses on the pivotal roles of individuals and collaborative efforts in progressing AI-enhanced geospatial tools within the Trillion Pixel Challenge. Topics include trustworthiness and dependability of AI-augmented tools, optimal user interface design, and the appropriate autonomy levels for AI-driven Digital Twins. The session brought a spotlight to existing community consortiums and forums for ongoing dialogue, effective ways to engage stakeholders, and emerging commercial partners in the geospatial AI field.

Panelists discussed a wide range of current and needed coordination efforts to develop robust partnerships among institutions, organizations, and businesses to be successful in advancing geospatial digital twins research. Mr. Mark Korver, representing the Taylor Geospatial Institute, discussed how the availability and use of open source software and data have become ubiquitous, noting that open information practices have changed how we think about and use data for large scale analysis. He also pointed out that building an open AI model for Earth will require significant collaboration to cover the financial resources required for compute.

Both Dr. Venkat Vishwanath (Argonne National Laboratory and Trillion Parameter Consortium) and Mr. Mark Cygan (Esri) described how their organizations foster cooperation in their respective research and policy formulation efforts. Vishwanath shared how the Trillion Parameter Consortium operates as an open, global community of researchers united in their commitment to define best practices in building the world's most powerful FMs for science. Cygan emphasized that the most successful approaches to advancing geospatial AI research and policies involve building and leveraging public-private partnerships and championing goals of innovation, inclusion, and implementation.

Similarly, Dr. Sambit Bhattacharya, expounded on the benefits of establishing a web of active partnerships between academia and other organizations. At the Intelligent Systems Lab at Fayetteville

State University, Bhattacharya and his team's work in the AI domain is powered by collaborations with federal agencies. Coming from a more technical perspective of fine tuning AI FMs through visual programming, Dr. Lingbo Liu of Harvard University framed collaborative methodologies as either centralized, decentralized, or recentralized, depending on how users engage in the process.

QUESTIONS/ANSWER SESSION

Following the presentations, most questions centered around addressing bias and safety in datasets. Asked whether organizations were tackling these problems head-on, Cygan emphasized that solving these problems is key to securing and maximizing funding in the future, and he highlighted his organization's efforts in reinvesting revenue into research and development. Vishwanath stressed the need for better evaluation metrics to identify biases and validate models, a sentiment echoed by Korver, who pointed out the ongoing challenge of understanding AI's "black box" nature. Bhattacharya added that collaboration with social sciences is essential to tackling these issues, and Liu stressed the importance of fine-tuning models and involving more people in the process.

The conversation then shifted to the topic of trust and misinformation, with Cygan expressing concerns about the integrity of AI-generated maps and Vishwanath noting the importance of guardrails in deploying AI technologies. The panelists also discussed job automation, acknowledging potential job losses while highlighting emerging roles in creative and scientific domains. Collaboration was identified as a key factor for success, with incentives such as faster innovation and greater trust driving teamwork across organizations.

SESSION 5: HARDWARE AND SOFTWARE ARCHITECTURES

PRESENTATIONS

The session featured a diverse lineup of presenters who explored advancements in high-performance computing (HPC), artificial intelligence (AI), and their applications across various fields. Mr. Chris Zimmer from Oak Ridge National Laboratory discussed the capabilities of the Discovery supercomputer, which boasts 1.19 exaflops and serves around 1,600 active users across 250 projects. He emphasized the integration of machine learning and digital twins into scientific workflows, aiming to enhance leadership modeling and simulation capabilities while addressing energy efficiency and storage limitations. Zimmer also highlighted the challenges posed by current GPU technologies and the necessity for innovative storage solutions to support the evolving demands of AI systems.

Dr. Neena Imam from Southern Methodist University presented the O'Donnell Institute's mission to integrate AI, ML, and data science into research. She outlined the complexities of digital twin systems, particularly regarding their robustness and validation. Imam introduced SMU's NVIDIA DGX SuperPoD, tailored for AI workflows, and described the Texoma Semiconductor Tech Hub's efforts in semiconductor research under the CHIPS Act. Additionally, she touched on the potential of neuro-symbolic AI, which combines knowledge graphs with large language models to enhance resilience and truthfulness in AI systems.

The presentations also included insights from industry experts such as Mr. Kyle Lamb from VAST Data, who addressed the importance of streamlining data pipelines for AI, and Dr. Seetharami Seelam from IBM, who focused on AI workflows and the significance of inference in model deployment. Mr. Bijan Varjavand from Hewlett Packard Enterprise highlighted the need for effective resource management in machine learning environments, whereas Dr. Catherine Schuman from the University of Tennessee explored the prospects of neuromorphic computing in GeoAI. Together, these presenters provided a

comprehensive view of current challenges and innovations in computational science, emphasizing the collaborative nature of advancing technology in various research domains.

QUESTIONS/ANSWER SESSION

The question and answer session focused on the challenges and advancements in leadership computing, particularly regarding resource utilization and software integration in high-performance computing (HPC) environments. Participants discussed the complexity of accessing and managing increasingly intricate systems, emphasizing the need for improved software stacks that cater to the scientific community. The conversation highlighted issues faced by researchers, such as the underutilization of new systems due to reliance on legacy code and established workflows. Attendees noted the importance of guiding users through standardized processes to enhance efficiency and better leverage computational resources.

Additionally, the discussion addressed the future of computing technologies, including neuromorphic and quantum computing. As Moore's Law slows down, promising alternatives including carbon nanotubes and superconductors can be explored, although large-scale implementations remain challenging. Attendees examined GPU utilization, revealing that many scientific users only harness a fraction of available resources. Solutions such as dynamic slicing and centralized monitoring systems were suggested to optimize GPU usage, while also acknowledging the limitations of current metrics such as power consumption in evaluating efficiency. Overall, the session underscored the need for innovative approaches to improve resource management in the evolving landscape of computational science.

SESSION 6: CLIMATE AND WATER SECURITY

PANEL DISCUSSION

The panelists explored the application of digital twins in understanding and mitigating water-related challenges under changing climate conditions. They discussed the integration of satellite data, the use of AI for predictive modeling, and the importance of continuously updating models to reflect non-stationary factors including human intervention. Key themes included the importance of interconnected models, autonomous sensors, and the need for better data accuracy and resolution.

The panel discussed the future and effectiveness of digital twins, focusing on their application, metrics for success, and user needs. Laura Rogers emphasized that digital twins must address uncertainties and adapt to varying questions and contexts. Sujay Kumar stressed that digital twins should capture local features to build user trust and accurately reflect impacts. Daniel Selva highlighted the importance of aligning models with stakeholder needs and end-user requirements. Overall, the panel emphasized the importance of integrating diverse data, improving model accuracy, and aligning models with practical needs and user expectations.

Ahmad Tavakoly introduced the USG global water strategy and emphasized the integration of AI in research to support warfighters in adapting to climate variability, highlighting the need for reliable large-scale hydrological models. Wenwen Li addressed the significance of digital twins for understanding the Earth's water system and showcased the AI foundation model NASA-IBM's Prithvi for efficient flood mapping, while stressing the necessity for multimodal data integration to tackle resource inequities. Jitendra Kumar focused on the complexities of digital twins in modeling hydrological and ecological processes, calling for enhanced resolution and the integration of field data with remote sensing. He provided examples of challenges in regions with limited data availability, such as modeling river ice breakup in Alaska.

QUESTIONS/ANSWER SESSION

The audience questioned the robustness of pixel-by-pixel uncertainties in foundation models. Panelists agreed that pixel-by-pixel analysis may not be ideal; instead, considering broader metrics and the impact of models is crucial. Sujay Kumar and Wenwen Li discussed the need for incorporating spatial uncertainties and quantifiable metrics. The discussion also touched on challenges in model training with non-stationary data and the difficulty in forecasting human decisions. Daniel Selva and Laura Rogers highlighted the need for autonomous, self-improving models and the potential for extreme autonomy in future systems.

Attendees discussed the metrics for defining success in digital twin models. Laura Rogers emphasized that success varies based on the specific questions the model aims to address and the uncertainties it tackles. Sujay Kumar pointed out the importance of the final solution's relevance and the need to capture local features to foster trust in models. Daniel Selva added that effectiveness should align with stakeholder needs, stressing the importance of understanding what decision-makers require from these models. Ahmad Tavakoly noted that considering a model's impact across various sectors could significantly enhance its utility.

Participants also highlighted areas that were overlooked during previous discussions about digital twin models. Laura Rogers suggested that sharing open-source code and datasets would advance the field, whereas Ahmad Tavakoly called for greater cross-disciplinary applications. Jitendra Kumar expressed a desire for more conversations about training and fine-tuning engines. Sujay Kumar advocated for more domain-specific discussions.

CONCLUSION

The Trillion Pixel Challenge 2024 workshop underscored the transformative potential of AI foundation models in advancing geospatial digital twins and enhancing scientific research. The presentations and discussions highlighted the integration of AI models with digital twins, which enables more accurate predictive analytics and decision-making. Key challenges identified included synchronizing diverse data sources, managing computational resources, and addressing issues of transparency in AI models. The workshop emphasized the importance of creating a robust AI infrastructure to support these advancements, particularly within the context of NASA's scientific initiatives.

The workshop also explored the broader implications of AI models in fields such as disaster management, climate change mitigation, and environmental monitoring. By leveraging foundation models, researchers can enhance traditional models, making them more efficient and capable of handling complex, multimodal data. However, issues related to resource allocation, explainability, and model biases remain pressing concerns that must be addressed through continued research and collaboration between academic institutions, industry, and government agencies.

A number of challenges were identified. Needs include:

- better evaluation metrics to identify biases and validate models;
- viewing validation and verification metrics as a science;
- addressing issues related to trust and misinformation;
- for more systematic partnerships and inclusivity in accessing resources;
- identifying remedies for the lack of annotated data, the need for structured ontologies, and maintaining data provenance; and
- increasing the explainability and transparency of AI systems.

Finally, the Trillion-pixel Challenge workshop emphasized the need for improved collaboration and partnerships across sectors to accelerate innovation and tackle global challenges. Participants called for more inclusive access to resources and systematic efforts to foster partnerships in geospatial AI research. Moving forward, the integration of AI models in digital twins holds immense potential for scientific discovery and practical applications, provided that the community continues to collaborate to address the technical, ethical, and infrastructural challenges.