



The GeoConvergence Workshop was hosted by the American Geographical Society in support of the National Science Foundation's Convergence Accelerator from May 18-20, 2021, as a virtual event. The GeoConvergence concept animating this workshop was inspired by the many different ways in which different sectors of society, different academic disciplines, and different industries have all come to embrace and advance geospatial innovations of many different kinds - each in their own way. In these different contexts, humanity has time and time again found new ways to harness the power of X, Y, Z & T, to advance various fields of applications - drawing on insights from many different academic disciplines and fields of science and technology. Yet, the lack of collaboration, coherence and cohesion across these various approaches to harnessing the power of geo has unnecessarily raised barriers that have prevented a more rapid, efficient, interoperable, and effective GeoConvergence that could benefit us all.

This workshop was designed to identify and forge collaborations between a diverse, global community of thinkers, innovators, and practitioners to help identify the common problems we face, the solutions that might be explored, the potential collaborations that could be forged, and the solutions that could be crafted to help remove the barriers that are currently hindering the acceleration of GeoConvergence as it relates to our society's grand challenges. In the end, the AGS sought to achieve a more robust community understanding of these challenges, with the goal of sketching a roadmap for collectively realizing a GeoConvergence vision, in an ethical, just and empowering manner.



To spur conversation, we began the workshop with a working definition for GeoConvergence that all participants could challenge with their own ideas, based on their own experiences and perspectives.

Attendees were then treated to the 5 major themes driving Day 1’s keynotes and panels (see Appendix A for more detail):

1. The Sciences and Technologies of GeoConvergence
2. Reshaping the Social and Natural Landscape
3. Implications of GeoConvergence for Disciplines
4. GeoConvergence Across Fields of Applications
5. Ethical Implications of GeoConvergence

And, the opportunity to participate in 25 different workshops themes, which broadly clustered into the following 5 categories:

Geo Tech	High Tech	Bio/Physical/Health	Social	Ethical
Sensor Tech	Cloud Computing	Climate Change	The Future of Work	Ethics
Satellites/Space	AI/ML/CV	Conservation/Natural Habitats	National Security	Diversity, Equity & Inclusion
Remote Sensing	Autonomy/Robotics	Public Health	Transportation	Vulnerable & Marginalized Groups
Digital Twins	IoT	Oceans	Barriers to Collaboration	Social Equity & Environmental Justice
GPS	Modeling/Simulation	Disaster Mitigation	Public Policy	
			Smart Cities	

The initial registration demonstrated more interest in some of these workshop themes than others. For instance, Climate Change, MLC/CV and Remote Sensing received far more interest than Weather Systems and Materials/Energy (themes from registration that were eventually eliminated). But, given the critical mass in registration in each of these 25 sessions, we received consistently valuable feedback from participants from industry, government, academe, and the social sector. All workshop participants were asked to provide their ideas around the **PROBLEMS** that a particular workshop theme might pose that could be addressed by the GeoConvergence; **SOLUTIONS** that some aspect of the GeoConvergence might offer to a given theme’s challenges; **COLLABORATIONS** that are nascent within the GeoConvergence that could transform how we address a given theme; and **DELIVERABLES** that a given collaboration might be able to provide, if funded by the National Science Foundation. All of these inputs,

which were provided via the online collaborative Q&A app Sli.do (and are available upon request) help inform the following questions.

WHAT IS THE GEOCONVERGENCE AGENDA?

The “GeoConvergence Agenda” has 5 main thrusts:

- 1) Forge a common, interoperable 4D geospatial (spatio-temporal) framework that allows all of the sciences and social sciences to interface and contribute their insights and observations in a manner that facilitates inter-disciplinary/multi-disciplinary/trans-disciplinary collaboration that brings answers to our nation’s grand challenges.
- 2) Bring disparate fields of technological innovation together within a common interoperability framework, to remove barriers to collaboration, help synchronize capabilities, and accelerate the progress toward more fulsome GeoConvergence.
- 3) Leverage the unique power that AI/ML/CV can bring when combined with geo - developing GeoAI models for various complementary sensing modalities, at different scales, and from various vantage points around a known set of objects and phenomena to help increasingly autonomous platforms navigate ever changing environments, & cataloging change on Planet Earth, at all scales, with spatio-temporal precision and accuracy to address everything from climate change to the more sustainable operation of our cities.
- 4) Build community insight and understanding around the ethical implications of the GeoConvergence, to ensure that these powerful capabilities are used responsibly to the benefit of our most vulnerable and marginalized communities, as they empower us all to engage in “Geo for Good” that benefits our planet and our species.
- 5) Harness the sensemaking and visualization powers of the GeoConvergence to help translate complex phenomena into policy-relevant insights at local, state, federal, regional and global levels - addressing the biggest challenges facing humanity and our planet.

WHAT IS THE OPPORTUNITY/POTENTIAL FOR FORMING ENABLING PARTNERSHIPS?

The GeoConvergence workshop highlighted countless opportunities for forming enabling partnerships. One way to cluster these partnership opportunities is as follows:

AI/ML/CV Training Set Partnerships: There is a fascinating swirl of activity around the advancement of AI/ML/CV training sets for different aspects of the challenges inherent in the GeoConvergence that could benefit from newly formed partnerships. At the federal level, the NSF shares common cause with the National Geospatial-Intelligence Agency, NASA, NOAA, USGS, and even the US Census on issues of AI/ML/CV training sets for extracting features from satellite and drone remote sensing. The DoD's Joint AI Center (www.AI.mil) also plays a role in this mix, as a strategic investor that has demonstrated an interest in the intersection of Geo and AI.

There is also an interesting existing set of relationships around the Radiant Earth Foundation, a non-profit launched to help develop AI/ML/CV training sets for space-based remote sensing, which has already enlisted the support of the Bill and Melinda Gates Foundation, Omidyar Network, Schmidt Futures, McGovern Foundation, NASA and others. Similarly, there is an interesting existing set of relationships around the SpaceNet initiative initiated by In-Q-Tel's Cosmiq Works, on similar AI/ML/CV training sets and algorithms for extracting particular classes of features from remotely sensed data. This initiative already enjoys an existing set of partnerships with Maxar Technologies, and the other partners: Amazon Web Services (AWS), Capella Space, Topcoder, Institute of Electrical and Electronics Engineers (IEEE) Geoscience and Remote Sensing Society (GRSS), the National Geospatial-Intelligence Agency (NGA) and Planet.

But, there is a long way to go in building algorithms and training these processes for extracting information and even meaning from the ever changing mix of geospatial (spatio-temporal) datasets collected from space, and many other vantage points. The ability to collect observations from all vantage points, from space down to ground observations, to ground truth remote sensing observations when possible, is essential to accelerating the GeoConvergence. And, many partnerships will need to be forged to make this happen. This includes between the many commercial companies and academic units each taking on their own parts of this challenge. Large companies such as Google and Microsoft are playing key roles. Non-obvious companies such as Snapchat are poised to take leadership roles on making sense of street-level observations. And companies like Arturo.ai are working to voraciously consume and make sense of any and all geospatial/spatio-temporal observations to create real business value within their industry vertical - insurance. Within the academy, Arizona State University has already organized a consortium of academic GeoAI players, including George Washington University, Harvard, and Clark University that had already forged partnerships with ESRI, Facebook, Microsoft (commercial); USAID, USGS, ORNL (government), and the AGS and the Humanitarian Open Street Map team

(non-profit) (See bit.ly/trustworthygeoai for more). Many other universities, companies, agencies, and non-profits have capabilities that could contribute to such collaborations.

4D Sensor Interoperability Partnerships: The GeoConvergence will require the removal of barriers to 4D Sensor interoperability so that observations from all sensors can be brought together into a common 4D framework for visualization, advanced geoprocessing, and interaction with the real-world. Space-based, airborne, mobile, in situ, and terrestrial remote sensors of all phenomenologies (e.g., EO, IR, MSI, HSI, LiDAR, SAR, CBRNE, RF, acoustic, etc.) have long lived in their own stovepipes, and the GeoConvergence demands that they all work together within a common 4D framework.

There are many partnerships that already exist in this space that the NSF could harness and accelerate. The Open Geospatial Consortium (www.OGC.org), as an international non-profit organization focused on geospatial innovation, interoperability and standards, has forged an international standards-based architecture called the OGC Sensor Web Enablement (OGC SWE) architecture, as well as its sister-specification - the SensorThingsAPI (OGC STA). The OGC and its 500+ member organizations from all around the world - across industry, government, academies and non-profits - all contribute in their own ways to the integration of sensors in to a common geospatial or spatial-temporal framework - whether 2D, 2D+Time, or 4D. The OGC community has generated open source API's such as OpenSensorHub (www.OpenSensorHub.org) as well as commercial products that help all producers of Sensors, Things and Robots - whether commercial, government or academic - integrate their observations, processing, visualization and actuation within a common 4D framework.

Countless university research units, government agencies, and commercial companies are building sensors that could and should interoperate within X, Y, Z, & T, with geospatial/spatio-temporal precision and accuracy. Removing this barrier to the GeoConvergence would advance science, industry, and public missions.

Modeling and Simulation Partnerships: Modeling and simulation in true geospatial 4D at every spatial and temporal scale, for the complex phenomena at the heart of our nation's (and our planet's) grand challenges will require powerful partnerships that cross every sectoral, disciplinary, and industrial boundary of the GeoConvergence. Bringing modeling and simulation frameworks from different disciplines and different fields of application into a common 4D framework that allows them to consume real world 4D data at every scale, and contribute their results into a common 4D framework would improve our ability to link micro, meso, and macro level models. But, it would require significant investment in new partnerships.

In the realm of human scale phenomena, and the built environment, there are existing partnerships to be harnessed, such as those between the Open Geospatial Consortium and the Khronos Group, that are enabling standards-based interoperability. Web based geospatial implementers such as Cesium are partnering with gaming industry players like Epic Games, through the Epic Foundation's grant program, creating the ability for all innovators using the Unreal gaming engine to utilize real world high-resolution 3D data of the built and natural environment - above ground, below ground, and in motion. Maxar/Vricon is an example of a major industry player creating global scale data for feeding such environments. Countless other organizations are specializing in particular aspects of Digital Twins that can continually enrich these modeling and simulation environments with geospatially precise and accurate real world data. And, the US Army, Special Operations Command (SOCOM) and the NGA are all heavily invested in seeing this particular ecosystem of partnership succeed. Other similar variants, of course, could exist also.

Global scale models of climate change, developed by Columbia's Earth Institute and other major academic centers, as well as by NOAA and other public agencies, operate on a completely different scale, yet still demand an interoperable 4D framework so that models can be compared, multi-scalar data feeds can be interoperably published for consumption, and impacts can be modeled from global dynamics down to regional and local scales. The same dynamic is true for complex economic models, which draw on large scale global dynamics which we expect to understand in terms of their regional and local impacts, such as geographic/economic inequality.

There are also meso-scale models, such as El Niño Southern Oscillation (ENSO) models that span multiple regions, and operate on inter-annual scales, but which are essential at informing both longer term, global models as well as geographically local impacts and granular moments in time. It is often overlooked that detailed micro-scale 4D models of regions, whether urban or wildernesses, can generate impacts that can feed the larger macro-scale system by contributing to meso-scale 4D processes. This is one of the most exciting areas of forging collaborations within the GeoConvergence.

Intersectional GeoConvergence Partnerships: So many challenges our nation faces are due to a mosaic of different kinds of geographic divisions that are often overlapping. GeoConvergence keynote Dr. Parag Khanna spoke of the overlapping differences in Physical, Biological, Human, and Functional Geographies. Social, cultural, political, economic, legal, technological, natural physical, and biological boundaries overlap in non-obvious, geographically and temporally specific moments. Within the GeoConvergence, there are opportunities for rich inter-disciplinary/multi-disciplinary/

trans-disciplinary collaborations among researchers and policymakers to investigate how such intersectional boundaries can create intractable challenges, and how knowledge of them can enable creative strategies for creating progress.

The GeoConvergence workshop led to many suggestions of potential collaborations, often focused on marginalized and vulnerable populations that have been divided, excluded, or constrained by geographic boundaries, whether political boundaries, boundaries created by infrastructure, naturally occurring boundaries, boundaries born of emergent risks, or some other man-made boundary. Monitoring, modeling, and making sense of these complex geographic spaces over time - and how they impact real human lives - is a fertile area for research that can help unwind grievous and chronic geographic inequalities.

The same, of course, holds true for precious natural places that are under siege and are at risk from humans or human-induced pressures. Vulnerable natural spaces and natural resources are similar to vulnerable and marginalized communities in that they often lack the resources to advocate for themselves. And, when it comes to indigenous communities, these two realities often intersect, further exacerbating geographically intensified inequalities. To address such intersectional challenges, interesting partnerships were suggested between indigenous communities, indigenous/MSI/community colleges, regional conservation and rewilding organizations, and organizations with remote sensing resources. The same could be done with at-risk communities, HBCU/MSI & community colleges, social services and activist organizations, and organizations generating local geospatial data.

Ethical GeoConvergence: The GeoConvergence Workshop generated lots of interest in collaborations around the ethical implications of geospatial science and technology innovations, for human health and well-being, and the fate of our natural world. The Locus Charter and the EthicalGEO initiative provide useful platforms that help frame collaborative interests in the ethical and responsible use of geospatial data and technology. How to infuse the larger peer review process, and the conduct of research with these larger GeoEthics considerations was discussed broadly during many tracks of the workshop. The same is true of the feedback from commercial innovators and participants from government agencies. How exactly this would manifest is unclear.

WHAT ARE THE IMPACTFUL DELIVERABLES OF THE GEOCONVERGENCE?

The scope of impactful deliverables that could be provided by GeoConvergence projects over a 3 year timeframe is staggering.

AI/ML/CV Deliverables: One impactful deliverable would be a federally funded consortium and online framework for developing and sharing geospatially and spatio-temporally relevant AI/ML/CV training sets that address the many objects, features, and phenomena at the heart of our nation's grand challenges. Year One would be the stand-up of a small team, the development of a Concept of Operations (CONOP), and validating the approach by workshopping with all Federal stakeholders, and the wider GeoConvergence community.

Year Two and Year Three would lead to the development of different training data for each domain and libraries that are sensor-, region-, ecology- and even climate-specific. This should include a means for developing validation processes or tools for communities/local governments to confirm, challenge, improve model estimates. This would include open source geospatial data lake of observations from vantage points valuable for autonomous platforms. This community could help maintain score cards for different models, to help collectively determine how well they perform. These training data repositories would be built around principles of equity derived from the EthicalGEO and Locus Charter initiatives. This consortium would offer training sessions for faculty, postdocs, and students, and help build a community of practice around a suite of GeoAI APIs and algorithm libraries.

Sensor Interoperability & Integration Deliverables: In Year One, we would develop sensor interoperability & integration cookbooks, workshop these recipes, hold hackathons to demonstrate them, and run plugfests demonstrating the Art of the Possible.

In Year Two and Three, all manner of commercial, academic, and government sensors would be transformed in to location-enabled, geographically-aware, web-accessible services that conform with a common 4D interoperability framework, with rigorous mechanisms for encoding the provenance of the data generated by different chains of sensors and processes. This would ultimately leave us with training sets, tied to classes of sensors, tied to specific instances of sensors, tied to sensor standards, tied to missions challenges. Also, ideally, this would provide some infrastructure framework and computing workflows "from the dirt to the Cloud" that would cover the entire lifecycle of sensor observation data from its degraded-network or offline data capture to online collaborative manipulation and analysis in the Cloud. This would provide simple integration points for these very different complex backends. Ideally this would include some sort of shared sensor equipment center where instances of different sensors are available, and can be tested against shared high quality datasets, shared algorithms and code, examples of interdisciplinary data integration and use, and standard data processing workflows. When deployed for different purposes, it would be helpful to also

have an online catalog of discoverable sensors that provide near-real time view of sensors around specific use cases (ie., meteorological conditions in a city), with an interactive dashboard.

Modeling & Simulation Deliverables: In Year One, there would be a community process for defining an integrated data/model/simulation framework that would be easier for everyone to use. This would include tools allowing researchers with other specializations, as well as the public to explore model outputs geospatially, and spatio-temporally. That was the biggest demand of the participants in the GeoConvergence Workshop when discussing this topic.

In Year Two and Year Three, establish a modeling incubator that uses Agile development processes to iteratively integrate federal missions with industrial, academic, and open source modeling capabilities that integrate spatial, quantitative, and qualitative data at every scale. This would include the definition of harmonized broad scale datasets on our natural wildernesses (both terrestrial and marine), human behavior, our built environment, and human uses of nature that can be commonly used in various modeling and simulation environments. And, in support of future-casting methods, this modeling incubator will establish methods for consuming real-time monitoring data to continuously update the models. Since ecosystems and many human processes do not abide by political borders, we would strongly recommend that this modeling incubator be funded alongside international partners, and where necessary with US funding of international partners. In order to achieve the ease of use demanded by the workshop participants, this modeling incubator would provide cross-disciplinary training resources for graduate students working in different fields; fellowships and postdocs focused on transfer/sharing of GeoConvergence modeling and simulation approaches; coordinated data sharing and infrastructure strategy for NSF GeoConvergence research.

Bridging GeoConvergence into Policy Deliverables: In Year One, conduct short burst research program and publishing of high level frameworks for understanding the value of geo-enabled policy and decision-making, leading to location-enabled and geographically-aware quantitative estimates of benefits and costs; and, analysis of how the GeoConvergence can inform public, private, and social sector organizations in place-based policy development and implementation. This would all be done with an eye for the well being of our society's most vulnerable and marginalized.

In Year Two and Year Three, interdisciplinary and intersectional teams would help develop more detailed templates for helping scientists from within and around the GeoConvergence better communicate their insights regarding specific issues around

specific geographies to policymakers. These could include climate change, coastal exposure to natural hazards, city and regional planning, conservation and rewilding of land and ocean, health and wellbeing, and combating insecurity and instability, and many other topics. This process should provide feedback into where geospatial and spatio-temporal data gaps persist, where automation could help, and where bias might be removed from the science-to-policy process - when we anchor this process in place. The development of such frameworks should give planners/economists/politicians of the future a greater understanding of the long term effects of their decisions on specific places, so they can better think about long term solutions and who and where they affect, or overlook.

Intersectional Place-Based Research & Innovation Deliverables: The changes to our fast changing world are inherently geographical, and we must always be vigilant as to the negative impacts of this change on the marginalized and the most vulnerable, who often serve as a “canary in the coal mine,” where processes may soon come to negatively impact the general public. Geographic inequalities can emerge, be reinforced, or even exacerbated by deliberate or unintentional human action, as well as naturally occurring hazards and human induced processes such as climate change. Since change is the only constant in this world, we believe that there would be power in having 3 years of rigorous, spatial, quantitative, and qualitative studies of intersectional place-based challenges that could serve as pathfinders about how the GeoConvergence could help us better anticipate such pernicious geographic inequalities, and identify pathways to a more equal world. This could involve studying mobility and transportation systems in different urban, suburban, exurban, or rural communities - treating them as living labs - that can provide insights on various intersectional geographic inequalities. This could involve the geoenabling of a comprehensive table of integrated geo-analytical and social, environmental, and accessibility information to aid in better health outcomes in a particular geography or community. This could involve working with indigenous communities to better understand the impacts of climate change on historic wildernesses, waterways, or croplands and adaptation strategies that can work within the borders of their sovereign lands. A library of such studies, and their use of geospatial and spatial-temporal data from sensors and various field work methods could help inform future work by those within the GeoConvergence.

EthicalGEO Deliverables: In Year One, the GeoConvergence community would be develop a cookbook on how to introduce EthicalGEO considerations in to research and innovation, and recommend changes to the peer review process to improve representation, diversity, equity and inclusion in the formulation of GeoConvergence research ideas, and their consideration and selection. This will be done with the goal of

establishing frameworks for evaluating the broader impacts of NSF proposals that consider the principles of social justice and environmental justice, including equity, access and diversity.

In Year Two and Year Three, we would develop a set of GeoEthics resources for training stakeholders in GeoConvergence projects, including a mixture of traditional white papers, video clips, and workshops. This activity would work in concert with other projects to anticipate the unintended consequences that might grow out of GeoConvergence research and innovation, to the detriment to marginalized and vulnerable populations. A long list of such ideas was provided for this during the course of the GeoConvergence Workshop, and are captured in the notes.

WHAT WOULD A COHORT OF PROJECTS LOOK LIKE?

Within the GeoConvergence, there is a great potential for a cohort of projects that together would create a whole that is larger than the sum of its parts.

Climate Change: Mitigation, Adaptation and Restoration: This project would bring together physical, biological and human geographical perspectives - integrated through geospatial S&T - for the purpose of framing climate change & ecosystem destruction at micro-, meso-, and macro- scale. The project would focus on complex transboundary issues (natural boundaries, human boundaries, legal boundaries, etc.) and the identification of potential climate mitigation, adaptation and restoration strategies available at local, regional, and global scales. A wide range of sensor strategies and appropriate AI/ML/CV capabilities would be used, with an eye for the ethical blind spots they might engender. Identifying geographic interventions based on proven restoration strategies would be a particular focus of this effort.

Oceans: Total Ecosystem Aquaculture Approach: This project would see the development and application of a dynamic 4D framework for modeling and monitoring for a total ocean ecosystem aquaculture approach that accounts for all inputs and outputs, nutrients and wastes, monitoring not only for seaweed, shellfish, and fin fish, but down to the bacteria and microbes that occupy the space. This project would accelerate ocean observations information models, adding more ocean sensing/observation platforms/technologies beyond those of the blue economy, with an emphasis on research for carbon capture and storage since oceans are getting saturated and are acidifying.

Hazards, Risk, and Inequality: This project would see the adaptation of the geospatial data strategies of the World Bank's Global Facility for Disaster Reduction and Recovery

to better characterize and communicate risk to vulnerable and marginalized populations that stand to suffer the most in the face of natural and human induced hazards. By researching, modeling and providing a framework for understanding likely human responses in the path of various risks as they unfold, this research would help anticipate adverse human reactions, and provide useful strategies to shape human response in ways that mitigate acute inequality in the impacts of hazards in particular geographies.

Smart Cities, Urban Resilience, and Sustainability: This project would focus on the development and integration of complete smart cities information models for creating, living, interoperable Digital Twins at the intersection of a city's ever evolving natural (e.g., physical and biological) geography, human geography, and functional geography. These models would be tuned for enabling resilience and sustainability strategies across mobility, energy, food systems, and human wellbeing in the face of discontinuous change caused by emergent hazards. In examining different Sensor/Thing/Robotics strategies, and the attendant AI/ML/CV innovations, this project would shed light on the benefits of a more intelligent city, as well as the ethical implications of the resulting surveillance infrastructure. This project will situate Smart Cities within their larger regions, and their connectivity with larger supply chains and other networks on which they depend.

Health - Geospatial support system for mosquito borne disease control: This project would focus on the millennia old chronic health problem of mosquito borne disease control to expand the Open Geospatial Consortium's Health Spatial Data Infrastructure Concept Development Study, to spatial-temporally enable interdisciplinary monitoring and data collection that could better enable prevention, response, and recovery over complex developing world physical, biological and human terrains.

Conserving and Rewilding Natural Habitats: This project would build bridges between the various biogeographical methodologies, including an EcoRegions Level IV detailed delineation of ecoregions worldwide to help inform conservation and rewilding initiatives that could help restore crucial ecosystems, climate, watersheds, natural barriers to hazards, etc in the face of ever expanding human geographies, built geographies, functional geographies and the attendant human ecological footprints that are undermining our planet's ability to support our species. The full range of space-based, airborne, mobile, in situ and terrestrial remote sensors of all phenomenologies - and the AI/ML/CV required to make sense of them - will contribute to this dynamic give and take between our biogeography and our growing human footprint. This would further enable nature based solutions premised upon giving space back to nature.

Combatting Instability and Insecurity: This project would convene a MEDEA-Style initiative (e.g., controlled access by the scientific community to sensitive national security data/assets) researching critical issues in conflict zones and potential hotspots of instability and insecurity around conflict/environment interactions, peace building approaches in a changing climate environment, and population/environment/health dynamics that precipitate human insecurity. This will include access to all manner of sensor observations, as well as the artificial intelligence training sets required to make sense of them.

IMPROVING NSF PROCESS

There were quite a few inputs provided around ways to improve the NSF's processes to better embrace and advance the GeoConvergence.

Satellite Imagery Access: Improved satellite imagery access is something NSF should think of providing as a general utility, since it is an acute pain point for researchers of so many disciplines. This came up time and time again in different ways. Some researchers asked that NSF arrange for access to an imagery web service that provides consistent and standardized imagery nationwide and globally, through OGC standard web service interfaces. This data would be standard in terms of pixel size, beyond individual images, would provide cloud free mosaics of electro-optical imagery, as well as data from other phenomenologies. This should include a Catalog API for discovering all accessible space based remote sensing data bought by the USG.

Since there are so many projects that work with and support developing-country government and organizations, there is a need to help train them on how to understand, access and utilize satellite imagery/data for these projects to be successful.

Educational Grants: While the technologies and data of the GeoConvergence are valuable to a wide variety of disciplines and professional fields, there is a large chasm between the capabilities that are available and the level of awareness about them. As such, many GeoConvergence Workshop participants suggested that NSF invest in educational resources about GeoConvergence capabilities, as well as their inclusion in scientific outreach programs to schools, public science fairs, and collaborations between educators and scientists.

Building Linkages: Since there is such an explosive growth in commercial GeoConvergence capabilities, many recommended that NSF create grant schemes aimed specifically at building linkages between industry and academics, including local, small funding pots to cover the costs of starting collaborations or engaging with industry to explore potential collaborations. It was suggested that a series of workshops be run specifically to invite interested parties in academia to learn about pathways toward collaboration with industry and government through GeoConvergence. It was also suggested that guidelines and resources be provided for pre-service teachers about how to harness the GeoConvergence to drive superior educational outcomes. On the other end of the spectrum, several participants commented on the value of educating public sector decision makers about the benefits of GeoConvergence technologies and data to public policymaking and improved governance.

Appendix A: Day 1 Workshop Themes

Theme 1: The Sciences and Technologies of the GeoConvergence

This theme would address the wide range of technologies that are colliding in a variety of interesting, yet often problematic and inexact ways where the nuance and detail of how geospatial and temporal resolution, precision, and accuracy are dealt with really matter. These include Artificial Intelligence/Machine Learning/Computer Vision, Modeling & Simulation, Augmented Reality/Virtual Reality/Mixed Reality, Sensors, Internet of Things, Robotics & Autonomy, GIS & Remote Sensing etc. Different combinations of these technologies have been converging in fits and starts over many years and as the scientific, technical, interoperability and policy barriers have been overcome, we have seen fundamentally new capabilities unleashed. In exploring the technologies of the GeoConvergence, this session will surface a diverse set of issues and insights that could inform future investment.

Theme 2: GeoConvergence Across Various Fields of Application

This theme would address the diversity of different fields of application that GeoConvergence is impacting. Different industries, different public sector missions, different communities of use. This could include everything including climate change, sustainability, urban resilience, mobility and intelligent transportation, national security and more. With GeoConvergence, we are seeing particular combinations of technologies being used to solve practical problems geospatially within one field, only to become adopted in completely different fields of use that have similar functional requirements. As innovations occur, and technologies co-evolve, we see this process, in fits and starts, inspiring similar use in widely different kinds of companies, government agencies, community organizations, and everyday citizens.

Theme 3: Implications of GeoConvergence for Disciplines

GeoConvergence has enormous implications for a wide variety of academic disciplines, and the landscape of multi-disciplinary and interdisciplinary collaborations and knowledge creation. GeoConvergence brings disciplines like computer science, aerospace engineering, remote sensing, and agronomy together with economic forecasting, food policy, and climate science. GeoConvergence brings disciplines like electrical engineering, robotics, cognitive science, and optics/sensors together with transportation modeling, urban planning, and social work. GeoConvergence brings together international affairs, immigration studies, and humanitarian policy studies together with remote sensing, Geographic Information Science, and hazard risk analysis. These disciplinary mashups are proliferating with the increasing geospatial enablement of the social and policy sciences, as GeoConverged technologies and data

sources become more widely available to answer common questions that bridge different disciplines.

Theme 4: Reshaping the Social and Natural Landscape

GeoConvergence is driving unprecedented social change, and transmogrification of the natural world. It is also providing new weapons to combat inequity and social ills, as well as ecological destruction. Too often, we focus on the functional benefits that GeoConvergence provides our businesses and government missions, while ignoring the negative implications for our social and natural landscape. How can we think about, monitor, and characterize the effects of GeoConvergence on our social fabric and the well being of our natural environment? How can we think about, monitor, and characterize the effects of GeoConvergence on our natural landscape? And, what steps can we take to mitigate such negative impacts while we strive to maximize its benefits?

Theme 5: Ethical Implications of GeoConvergence

As with the introduction or evolution of any technology, GeoConvergence demands that we proactively explore the ethical implications of these technologies as they are applied to different fields of use. This swirl of technologies promises to remake the landscape of issues surrounding our 5 P's: privacy, politics, people, planet and property. The geospatial resolution, precision, and accuracy of these increasingly dense observations of our world are spurring deep concerns around location privacy and individual rights, the rise of surveillance capitalism and the surveillance state. GeoConvergence is generating volumes of such data that challenges our assumptions about freedom and democracy, and how this data is used to advantage and disadvantage us politically. Vulnerable communities of people are seeing GeoConverged data and technologies exacerbate the risks that they are suffering from, though there are ample opportunities to leverage these technologies to benefit them. Our planet's natural habitats and complex natural systems are being negatively impacted by aggressive use of GeoConverged data and technologies, while they could be used to heal our planet. And, our global patchwork of property rights systems are increasingly enabled by GeoConvergence, for both good and bad ethical implications.

Appendix B: Participant Statistics and Interests

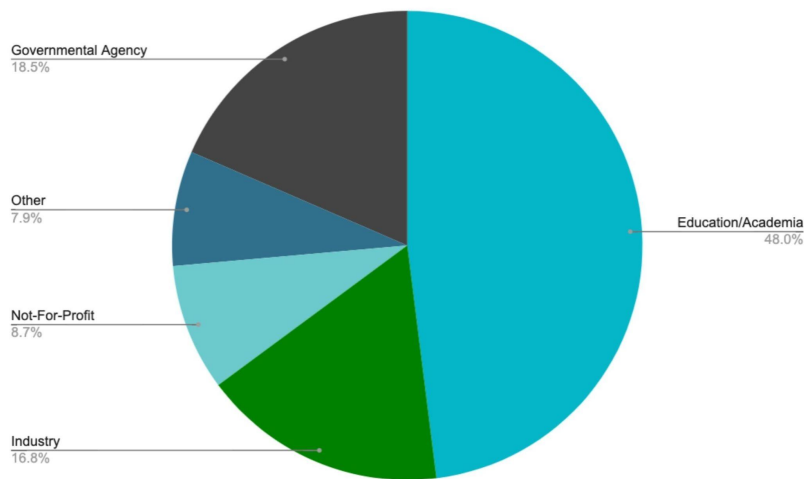
The GeoConvergence Workshop was hosted over three days from May 18-20, 2021. Days One and Three were open to all registered attendees and hosted via Zoom Webinar and also streamed to YouTube live where it was shared to Facebook and Twitter. Day Two required a secondary registration for participants who indicated interest in taking part as active discussants during thematic break out sessions.

Overall, 613 individuals representing more than 500 unique organizations registered to attend the three-day conference (see figure 1 below). The majority, 48%, represented the education/academia sector. Participants from governmental agencies comprised 18.5%, industry 16.8%, nonprofits 8.7% and others including foundations 7.9% (see figure 2 below).

Figure 1: Selected organization of participants



Figure 2: Percent of participants by stakeholder group



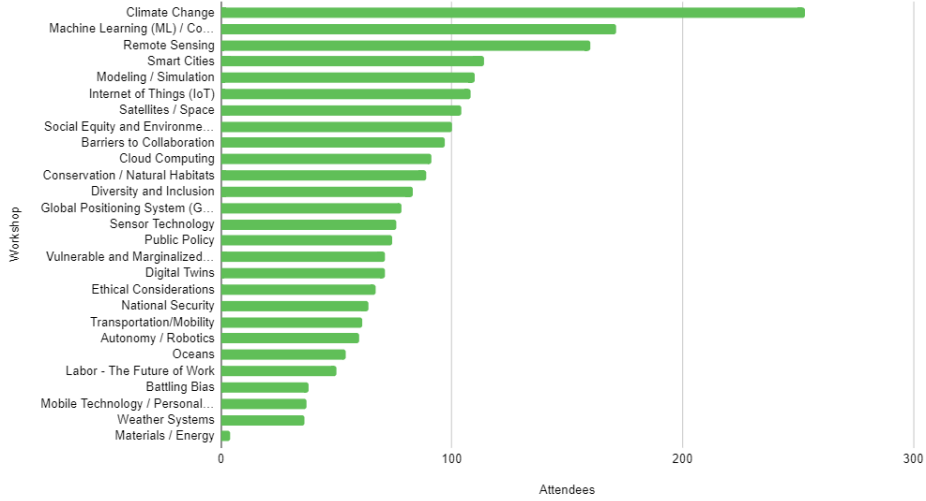
During plenary sessions on Day One, 377 unique participants joined the Zoom Workshop (661 total users). The event was held on May 18 between 10:00 am ET - 3:30 pm ET. The average duration of viewing was 87 minutes. The Day One program has been streamed 288 times on Youtube.

Day Three's plenary summary session was held on May 20 from 11:00 am ET -12:30 pm ET. 147 participants joined during the Zoom webinar, and the session has been streamed 68 times on Youtube since the event.

During initial registration, participants were asked to select from 27 themes related to geographical and geospatial science and analysis to inform the design of breakout session on Day Two. Figure 3 (below) showcases the number of participants who indicated interest in each theme. Participants were encouraged to provide additional areas of interest not listed on the form. The four themes with the lowest amount of interest (Battling Bias, Mobile Technology / Personal Computing, Weather Systems & Materials / Energy) were eliminated and two from the form were added to the breakout session program on Day Two (Public Health & Disaster Mitigation. See more about the breakout session design in Appendix C: Convergence Workshops.

Figure 3: Attendee interest by discussion group

Attendees vs. Workshop



Appendix C: List of Plenary & Lightning Talks

Below we provide the links to the lightning talks and the [schedule](#) for Day 1 (May 18th, 2021) and Day 3 (May 20th, 2021) plenaries which focused on geospatial, environmental, and technological problems and solutions.

Day One: Sharing Knowledge

10:00 am - *Welcome Remarks*

- Dr. John Konarski, CEO, American Geographical Society

10:05 am - *Introduction*

- Dr. Christopher Tucker, Chairman, American Geographical Society

10:15 am - *Keynote*

- Dr. Stacy A. Dixon, Deputy Director, National Geospatial-Intelligence Agency

10:30 am - *The Sciences and Technologies of the GeoConvergence*

- Moderator: Dr. Nadine Alameh, CEO, Open Geospatial Consortium
- Dr. Sarah Battersby, Principal Research Scientist, Tableau/Salesforce
- Dr. Michael Botts, President, Botts Innovative Research, Inc.
- Mr. Patrick Cozzi, CEO, Cesium
- Mr. Sanjay Kumar, CEO, Geospatial World

11:30 am - *Reshaping the Social and Natural Landscape*

- Dr. Parag Khanna, Founder, FutureMap, LLC
- Moderator: Dr. Lee Schwartz, Geographer, Department of State
- Dr. Bhudy Bhaduri, Director of Geospatial Science and Human Security Division, Oak Ridge National Lab
- Dr. Susan Canney, Director, Mali Elephant Project
- Dr. Gregory Taff, Director of Research and Data Integrity, World Resources Institute

12:30 pm - *Implications of GeoConvergence Disciplines*

- Dr. Michael Crow, President, Arizona State University
- Moderator: Dr. Bob Chen, Director, CIESIN
- Dr. Meredith Gore, Associate Professor, University of Maryland
- Dr. Dee Jordan, Postdoctoral Fellow, Harvard Medical School
- Mr. Shadrock Roberts, Assistant Professor, Clark University

1:30 pm - *GeoConvergence Across Fields of Application*

- Mr. Tony Frazier, Executive Vice President of Global Field Operations, Maxar Technologies, Inc.
- Moderator: Mr. Dean Wise, Principal, Dean Wise LLC
- Dr. Ben Tuttle, Chief Technology Officer, Arturo.ai
- Ms. Janine Yoong, Founder, Bumingham

2:30 pm - *Ethical Implications of GeoConvergence*

- Moderator: Ms. Denise McKenzie, Chair, Association for Geographic Information
- Ms. Stacey Gray, Senior Counsel, Future of Privacy Forum
- Ms. Denise McKenzie, Chair, Association for Geographic Information
- Father Michael Rozier, Assistant Professor, St. Louis University
- Mr. Andrew Zolli, Vice President of Impact Initiatives, Planet

Lightning Talks

- [“Transforming Infrastructure Data Quality”](#) by Mr. Peter Batty, Chief Research Officer, SSP Innovations
- [“Evaluating Machine Learning Algorithms for Mapping Natural Community Habitats: Hi-Res NAIP and UAS”](#) by Mr. Parth Bhatt, PhD Candidate, Michigan Technological University
- [“Dashboard for Ceasefires in a Time of COVID-19”](#) by Dr. Devanjan Bhattacharya, Marie Skłodowska-Curie Actions TRAIN@ED Post Doctoral Fellow, University of Edinburgh
- [“GeoConvergence and the Future of Work”](#) by Dr. James Biles, Associate Professor, City University of New York
- [“Global Agricultural & Disaster Assessment System \(GADAS\)”](#) by Mrs. Lisa Colson, GIS & Imagery Specialist, USDA/Foreign Agricultural Service
- [“Proposal for Employing AI to Gather Archive Data to Produce a Web-based GIS”](#) by Dr. Nathan Darroch, Honorary Research Fellow, University of Aberdeen
- [“Community Cadastres: A Solution to Global Land Insecurity”](#) by Mr. William Evans, Project Director, Humanitarian OpenStreetMap
- [“GeoQuery: Making Geospatial Data Accessible for All”](#) By Dr. Seth Goodman, Data Engineer, AidData
- [“Fighting Malaria with Geography”](#) by Dr. Andy Hardy, Senior Lecturer in Remote Sensing and GIS, Aberystwyth University
- [“Consider SBIR Technologies to Accelerate GeoConvergence”](#) by Mr. Dave Jones, Chief Executive Officer, StormCenter Communications
- [“The Role of Mapping Deprived Areas for GeoConvergence”](#) by Dr. Monika Kuffer, Dr. Dipl.-Geogr. MSc, University of Twente, ITC
- [“Urban Observatory Science” Leveraging Data and Experimentation for Sustainability”](#) by Dr. Harvey Miller, Bob and Mary Reusche Chair in Geographic Information Science, The Ohio State University
- [“Realizing the Next-Generation Scalable Geospatial Processing Architecture”](#) by Dr. Eric Shook, Associate Professor, University of Minnesota
- [“FAIMS 3.0: Electronic Field Notebooks”](#) by Ms. Adela Sobotkova, Associate Professor, Aarhus University
- [“What Constitutes a Fair Map?”](#) by Dr. Rebecca Theobald, Assistant Research Professor, University of Colorado, Colorado Springs

- [“Mitigate Negative GeoConvergence: Map Deprived Areas”](#) by Dr. Dana R. Thomson, Coordinator, IDEAMAPS Network
- [Biodiversity Assessment, Conservation, and Indigenous People: GeoConvergence Philosophy](#)” by Dr. Dipankar Saha, ARS Scientist & Head, Regional Research Station of ICAR-CAZRI

[Day Three](#): *Advancing Solutions: Creating Recommendations to Share with Policymakers Guiding Research*

11:00 am - *Debrief & Summary*

12:00 pm - *Closing Remarks*

Appendix D: Convergence Workshops

The second day of the conference featured 5 workshops with participants from over 475 representative institutions. Each workshop was divided into 5 breakout groups (25 sessions in total) to encourage dynamic, engaging, and intriguing discussions about a range of GeoConvergence themes.

Workshop	Breakout Groups	Participants
11:00 am - <i>Convergence Workshop #1</i>	Room A: Cloud Computing	22
	Room B: Sensor Technology	31
	Room C: Climate Change	47
	Room D: Ethical Considerations	20
	Room E: National Security	11
12:00 pm - <i>Convergence Workshop #2</i>	Room A: Machine Learning/Computer	42
	Room B: Satellites/Space	26
	Room C: Conservation/Natural Habitats	35
	Room D: Diversity and Inclusion	9
	Room E: Transportation/Mobility	18
1:00 pm - <i>Convergence Workshop #3</i>	Room A: Autonomy/Robotics	11
	Room B: Remote Sensing	54
	Room C: Public Health	16
	Room D: Vulnerable and Marginalized Groups	15
	Room E: Barriers to Collaboration	34
2:00 pm - <i>Convergence Workshop #4</i>	Room A: Internet of Things	28
	Room B: Digital Twins	16
	Room C: Oceans	20
	Room D: Social Equity and Environmental Justice	33
	Room E: Public Policy	23
	Room A: Modeling/Simulation	30

3:00 pm - <i>Convergence Workshop #5</i>	Room B: Global Positioning System	13
	Room C: Disaster Mitigation	41
	Room D: Labor - The Future of Work	18
	Room E: Smart Cities	20

Appendix E: Submission Form

Prefix | First Name | Last Name | Email

Title | Organization

Stakeholder Group

- *Education*
- *Government*
- *Industry*
- *Not-for-Profit*
- *Foundation*
- *Other*

Workshops are being organized around the following topics. Please select your top five topics of interest.

- *Autonomy / Robotics*
- *Barriers to Collaboration*
- *Battling Bias*
- *Climate Change*
- *Cloud Computing*
- *Conservation / Natural Habitats*
- *Digital Twins*
- *Diversity and Inclusion*
- *Ethical Considerations*
- *Global Positioning System (GPS)*
- *Internet of Things (IoT)*
- *Labor - The Future of Work*
- *Machine Learning (ML) / Computer Vision (CV)*
- *Materials / Energy*
- *Mobile Technology / Personal Computing*
- *Modeling / Simulation*
- *National Security*
- *Oceans*
- *Public Policy*
- *Remote Sensing*
- *Satellites / Space*
- *Sensor Technology*
- *Smart Cities*
- *Social Equity and Environmental Justice*

- *Transportation/Mobility*
- *Vulnerable and Marginalized Groups*
- *Weather Systems*

If your area of interest is not listed above, please list here:

Describe your work in 1-2 sentences.

Would you like to participate in interactive workshopping sessions on May 19 as a discussant?

A limited number of slots to present 5-minute Lightning Talks highlighting challenges or emerging solutions related to GeoConvergence are available. If you are interested in presenting, please describe, in less than 200 words, your topic of interest.

Appendix F: More About GeoConvergence

What Do We Mean By GeoConvergence?

As the Geospatial Revolution continues to infuse every academic discipline, field of technology, profession, industry, and government mission, there is no organized dialog to remove the barriers hindering the larger “GeoConvergence” that is afoot, which is poised to integrate all of human endeavor within a common 4D framework. Realized fully, GeoConvergence could serve as a force multiplier in our nation’s efforts to tackle the grand challenges we face as a society - climate change, sustainability, urban resilience, mobility and intelligent transportation, national security and more. But first, we must rally to remove the impediments that unnecessarily complicate, and hinder its realization. A broad and diverse set of stakeholders from every discipline, profession, and sector of society must be convened to identify, characterize, and remove the outstanding scientific, engineering, interoperability, and policy challenges that hamper the real-time convergence of AI/ML/CV, Modeling/Simulation, AR/VR/MR, Sensors, Things, and Robotics & Autonomy, GIS & Remote Sensing, within a common, accurate, and precise, 4D geographical framework. Without proactive investment in thoughtful research and consideration of the social, economic, environmental and ethical implications of these technologies, we will likely fail to realize their fullest potential while increasing the likelihood of suffering the unintended consequences of technology run amok. Without such an effort as outlined above, we as a nation will fail to accelerate and reap the full benefits of GeoConvergence, ceding global leadership to other nations. The “GeoConvergence Workshop” that we propose is a first step in that direction.

The Intellectual Merit of Advancing GeoConvergence

GeoConvergence is what happens when an ancient field of inquiry is supercharged by the explosion, collision, and convergence of a wide variety of scientific and engineering fields that all rely on a common, accurate, and precise, 4D geographical framework. Geographic inquiry and practice has been going strong since the Babylonians created the first known maps in the 9th century BCE, but is often rooted in the work of Eratosthenes of Cyrene in the 3rd Century BCE, when he authored his three volume work entitled *Geographika*. Yet, the fields of inquiry and practice currently attempting to harness the power of geospatial technologies and data have their own origins, communities, and languages which often Balkanize collaboration, and hinder the synergies that might be realized. It is not just the S&T fields of AI/ML/CV, Modeling/Simulation, AR/VR/MR, Sensors, Things, and Robotics & Autonomy, GIS & Remote Sensing that have striven to overcome such Balkanization. It is so many other academic disciplines and professional fields whose advancement depends upon overcoming data silos, and organizing their observations and knowledge within a rigorous, common 4D space/time framework. The potential of GeoConvergence to

advance society's grand challenges is great, if only we could identify the barriers hindering its progress, and invest in initiatives that clear the way for the just, ethical, and empowering use of GeoConvergence for the betterment of society. Otherwise, these various "silos of excellence" will waste their intellectual energies working without the benefit of an organized intellectual community dedicated to easing the common barriers, liberating scholars and practitioners to focus on the truly fundamental advancements needed by all.

The Broader Impacts of GeoConvergence

The uneven distribution of geospatial enablement across various fields of technology, disciplines and professions has stunted the broader positive impacts that would otherwise be available to our society and our planet with the synergies of GeoConvergence. Establishing a community, framework and roadmap for advancing and accelerating GeoConvergence would allow us to enjoy the real world impact of GeoConverged technologies within complex geographies such as urban environments, natural (physical & biological) environments, and challenging mission environments. If we are able to coordinate S&T investments in the frontiers of GeoConvergence, we will be able to unleash broader impacts that would transform a wide range of different industries, different public sector missions, and different communities of use as it relates to climate change, sustainability, urban resilience, mobility and intelligent transportation, national security and more.