Global-Local-Global Analysis of Systems Sustainability

GLASSNET

An International Network of Networks

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SUSTAINABLE DEVELOPMENT GOALS

The United Nations Sustainable Development Goals (SDGs) describe a global resolve to transform our world across 17 related economic, social, and environment thematic areas. The compelling challenge, however, is the inevitable set of conflicts and tradeoffs among competing SDG demands for poverty reductions, food and energy security, clean water, biodiversity, and climate change mitigation. While local circumstances require fine-scale analyses, market forces and government policies drive global changes that compel macro-level analyses. Equitable and sustainable resource use requires harnessing new data streams and modeling approaches across natural and social science disciplines. The critical need for such analyses in land- and water-related SDGs inspired the international network of networks *Global to Local Analysis of System Sustainability (GLASSNET).*

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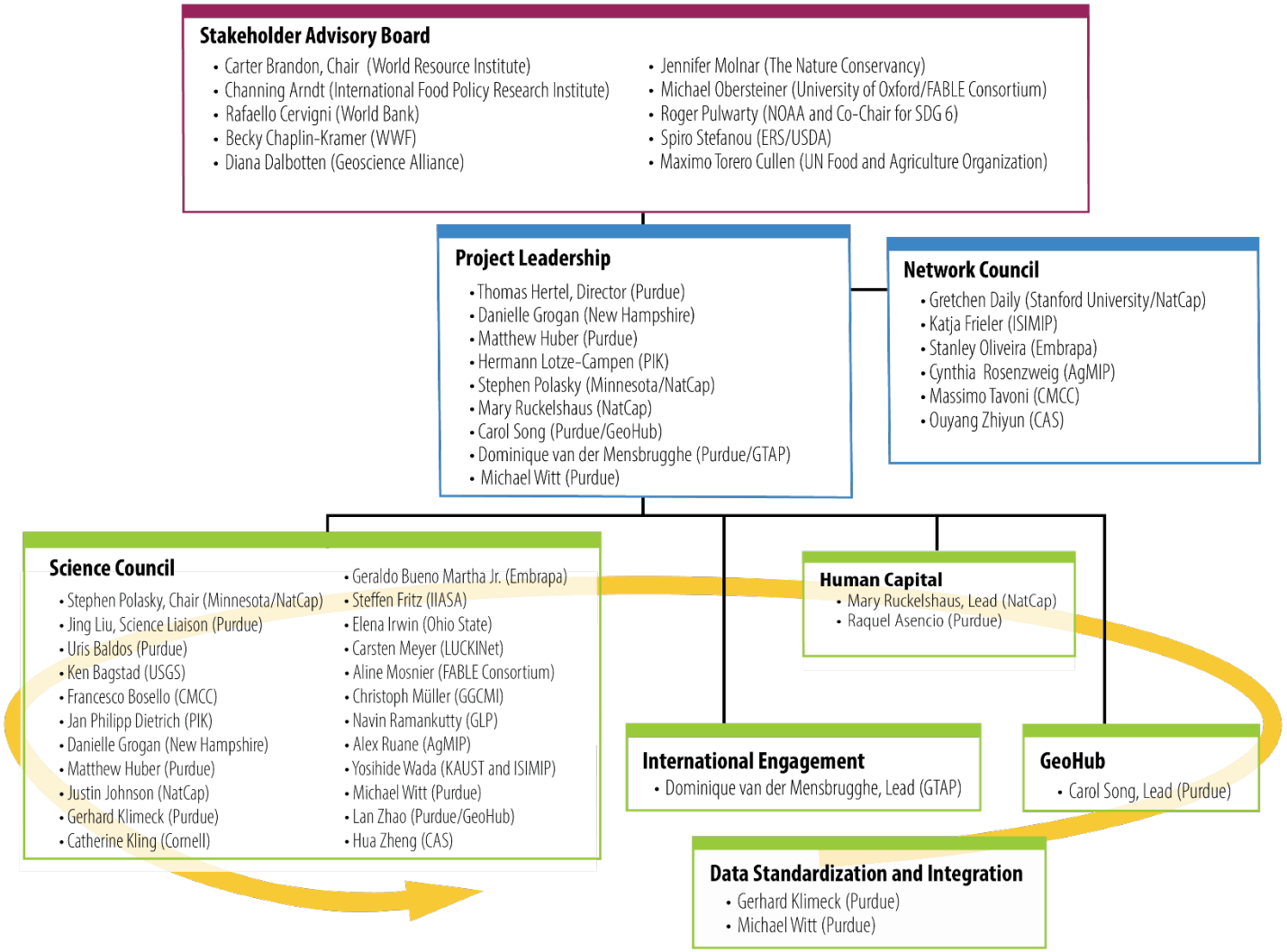
GLASSNET Mission

The global grand challenge posed by the United Nations Sustainable Development Goals (SDGs) remains hindered by an incapacity to chart alternative sustainable pathways and analyze tradeoffs and synergies across local- and global-level policies. This urgent need to link global communities of practice on more than a researcher-to-researcher basis calls for a collaborative infrastructure that is not proprietary or excessively complex, and necessitates a strategy to leverage complementary expertise, integrate cross-disciplinary multiscale data and analyses, and systematically address communication, cultural, and procedural barriers.

The GLASSNET network is a deep integration across scientific teams and research communities undertaking global analyses in an international network of networks supported by the powerful GeoHub global bridging cyberinfrastructure. Three prominent U.S.-based networks (Global Trade Analysis Project (*GTAP*), Natural Capital Project (*NatCap*), and the Consortium of Universities for the Advancement of Hydrologic Science Inc (*CUAHSI*) are partnering with eight vibrant networks: Global Gridded Crop Model Intercomparison (*GGCMI*), *GlobEcon*, the Inter-Sectoral Impact Model Intercomparison Project (*ISIMIP*), Global Land Programme (*GLP*), Land Use Change Knowledge Integration Network (*LUCKINet*), Artificial Intelligence for Environment and Sustainability (*ARIES*), the Agricultural Model Intercomparison and Improvement Project (*AgMIP*), and The Food, Agriculture, Biodiversity, Land-Use, and Energy (*FABLE*) Consortium to:

GLASSNET is building a shared vision, harmonizing data, deploying modeling tools, developing innovative training for diverse participants, testing workflows to analyze tradeoffs and synergies across SDGs, implementing sustainability plans, and disseminating network of networks convergence best practices.

GLASSNET Organizational Structure



Global-Local-Global Analysis of Systems Sustainability

GLASSNET

An International Network of Networks

Goals and Accomplishments

Integrate networks into network of networks to accelerate innovation

Major Activities

On October 1-3, 2023, we held the 2nd biennial meeting of GLASSNET at the University of Minnesota. It was the first major opportunity to face interactions amongst international collaborators and network representatives within GLASSNET.

The first day began with an overview of the evolving GLASSNET network, led by Witt, and included a survey of participants covering shared identity, goal commitment, member development and value added from the network. The editors of the GLASSNET special issue of ERL reported on the main findings from that issue and discussed future challenges. We then broke into small groups to develop ideas around the 'GLASSNET Challenge', namely identifying a unifying research theme that could leverage our integrated network of networks and increase the strength and frequency of interactions across these networks. Discussions focused on tradeoffs and synergies associated with attaining the Sustainable Development Goals as well as respecting planetary boundaries. This led into a discussion of potential research proposals which could be developed by GLASSNET members. On the second day, a session with the GLASSNET Stakeholder Advisory Board resurfaced the issues around the gap between science and policy making when it comes to achieving the UN Sustainable Development Goals. We resolved to have a series of workshops in 2024 focusing on the tradeoffs and synergies associated with achieving these SDGs in a just and equitable manner. We then heard from the ECRs who had been funded by GLASSNET in 2023. We also had a comprehensive report on developments on the GeoHub. Two exciting developments involve the release of integrative tools that bridge different networks in GLASSNET. The LandInG tool, developed by collaborators in Germany, allows scientists working on land-based sustainability challenges to access fine-scale, reconciled, time series data on land and resource use globally. The AgMIP tool delivers to member networks the latest results from the AgMIP, ISIMIP and GGCMI member networks on climate impacts on agriculture using the latest climate science as well as the most recent crop modeling work. This tool makes these results available to any GLASSNET member in a format and aggregation suitable for use in their own research. The meeting concluded with focused discussions of a number of specific requests for proposals that had been identified. Next steps will involve submissions of collaborative, interdisciplinary research proposals to these different programs, which include NSF

ECR-led network exchange and engagement

- Haqiqi (Purdue) who traveled to PIK (Germany) participated in workshops and meetings to integrate research on global nitrogen use and planetary boundaries by integrating knowledge from the GTAP and GGCMI networks.

- Grogan and Zuideman (UNH) participated in the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) annual meeting at Czech University of Life Sciences (ČZU) Suchdol, Czechia. The purposes of the trip are to gain familiarity with the ecosystem of ISIMIP groups and to assess the potential for participation by the University of New Hampshire Water Balance Model (WBM) user community in the EU-based ISIMIP network. Drs. Grogan and Zuidema also visited PIK to give seminars and to discuss incorporating human decision-making regarding development of groundwater resources. They have invited members of the ISIMIP groundwater group to a groundwater research workshop to be held in the US in Spring, 2024.

- Beier (PIK and Humboldt University-Berlin) visited Purdue. The meetings during her visit deepened her understanding of the SIMPLE-G models and facilitated identifying collaboration priorities and opportunities between GTAP and PIK-based networks.

- Frank (Purdue) presented her work at the World Climate Research Programme Open Science Conference in Kigali, Rwanda and engaged with the Women scientist network in Africa.

- Singh (Humboldt University, currently working in India) visited Cornell University to present her PhD dissertation in the Global Development, and Food Systems & Global Change centers at Cornell University. The first essay focuses on water governance policy measures and the other on dietary transitions in India to achieve national and global environmental goals. Her meetings with the two lab groups helped her improve the research methods to address significant challenges in agri-food systems particularly in South Asia. Vartika has initiated a connection between GLASSNET and the Environment for Development network, based in Sweden.

GLASSNET PI Hertel served on the FABLE Advisory Board in 2023, providing guidance to that new network based on 30 years of experience with the GTAP network.

Part of the challenge in integrating networks is having an overview of the emerging network of networks such that one can identify key gaps as well as new strengths. In order to facilitate such an overview, GLASSNET scientist, Michael Witt, developed a prototype tool for mapping the GLASSNET network of networks – both in terms of individual collaboration, as well as topical focus. With encouragement from NSF-AccelNet leadership, Professor Witt collaborated with the MultiNet AccelNet team at Indiana University to offer a series of three workshops, held in February, March and May 2023, for AccelNet members from a dozen different networks of networks. These workshops covered both technical aspects of network graphing, as well as strategic applications by AccelNet leadership teams.

Significant Results

For the biennial meeting we undertook a GLASSNET member survey that was developed and administered by Raquel Asencio, an expert in network assessment whose key takeaway messages were:

- GLASSNET is doing an excellent job at building an extended research community from various disciplines.

- There is a shared identity among Global-Local-Global researchers and people feel that involvement in GLASSNET has provided great value-add in expanding their network & connecting with other disciplines.

- People are learning from cross-disciplinary collaboration and in-person meetings, but have not seen great learning benefits in short course modules, data access, or early career workshops.

- There is strong commitment to GLASSNET's long-term goal, though reaching it may be difficult.

These findings were based on net favorability scores in response to a series of questions. These scores were obtained by subtracting from the percentage of favorable responses, the percentage of unfavorable. Thus, a score of 100% would indicate all responses were favorable, whereas a score of 0% would indicate equal favorable and unfavorable responses.

We also undertook a survey of biennial meeting participants with regard to major challenges faced and opportunities for GLASSNET to address these challenges.

Major challenges faced:

- Data integration, availability and interoperability
- Time constraints
- Compatibility of different models, data, tools, etc. - a lot of work to bring teams together that have different workflows, ecosystems, and language
- Differences in incentives across disciplines, institutions, sectors, stages of career.

What can GLASSNET do to help address these challenges?

- Cross-network and cross-domain training including summer courses for existing models (e.g., InVEST, SIMPLE-G), and course sequence in which people can rotate through learning the models that each of the networks has.

- Building infrastructure to support greater data integration, interoperability and accessibility

- Develop a platform for internal and external communication (e.g., a marketplace to promote your work, also to support the collaborations that are already happening)

- Capacity building in early career researchers

- Organize and support writing groups to get papers written

Provide transformative analysis for public and private investments for sustainability

Major Activities

In an effort to provide transformative global-local-global analysis of sustainability investments, we hosted a GLASSNET conference at Purdue University in the first week of April, 2022. Fifty participants were organized into six panels, each covering a key sustainability challenge. This conference resulted in a 2023 special issue of the interdisciplinary journal: *Environmental Research Letters* focusing on Global-to-Local-to-Global Analysis of Sustainability Challenges related to the world's land and water resources. This included 13 papers written from the perspective of agronomy, climate science, computer science, decision sciences, ecology, economics, geography and hydrology. GLASSNET PIs Hertel and Polasky edited the special issue, along with GLASSNET Science Council members Elena Irwin and Navin Ramankutty.

Following the success of our 2022 GLASSNET Use Case competition, we solicited new proposals for 2023. The requirement for the 2023 Use Cases was that they must involve at least two different networks in a substantive collaboration. Three proposals were accepted.

- Transportation Infrastructure Expansion in Brazil: A Win-Win Strategy for Agriculture Competitiveness and the Environment?
- Assessing the Interaction between Global Economy and Biodiversity and Ecosystem Services
- Spillover Effects Play a Key Role in Maintaining Planetary Boundaries

The workshops were held in March and September, 2023. They were held virtually and lasted for two hours. During the first hour, the scientists presented their research, while in the second hour a select group of discussants (three or four), provided feedback from a variety of GLASSNET perspectives (each from a different network). Discussants and session Chairs were selected to bring broader perspectives to the Use Case.

Significant Results

In July of 2023, a GLASSNET-led team published an important paper in the Proceedings of the National Academy of Sciences (PNAS). This is the first major piece of research to emerge from the cross-network collaboration between GTAP and NatCap. This paper, *Investing in nature can improve equity and economic returns*, led by ECR and Leadership Team member, Justin Johnson, integrates the macro-economic and trade framework (GTAP-AEZ) developed by the GTAP network with the fine-scale, ecosystem assessment framework (InVEST) developed by the NatCap network. The authors demonstrate that continuing with a Business-as-Usual set of policies to 2030 would result in land use-driven degradation of nature-based ecosystem services costing the global economy $75 billion. These losses would be felt disproportionately by the lowest income economies. However, if agricultural subsidies were repurposed to support productivity-enhancing research and development, these losses could be turned into gains of nearly $200 billion by 2030. Adding national payments for environmental services programs could further boost these gains, which would disproportionately benefit the poorest countries. By linking local interventions to protect ecosystem services, to the global economy, this work has documented the economic benefits of conservation policies (e.g., through degraded pollination services, reduced fish-catch, or degraded timber production). This work has had tremendous resonance with both the environment community as well as with central banks and ministries of finance.

The special issue of *Environmental Research Letters* led by the GLASSNET team included thematic syntheses of five overarching dimensions of the Global-to-Local-to-Global (GLG) challenge to ensure the long-term sustainability of land and water resources. These thematic dimensions include: climate change, ecosystems and biodiversity, governance, water resources and cyberinfrastructure. Based on this special issue, we have concluded that, without fine-scale, local analysis, interventions focusing on land and water sustainability will likely be misguided. But formulating such policies without the broader, national/global context is also problematic – both from the point of view of the global drivers of local sustainability stresses, as well as to capture unanticipated spillovers. In addition, because local and global systems are connected to - and mediated by - meso-scale processes, accounting for key meso-scale phenomena, such as labor market functioning, is critical for characterizing GLG interactions. We also conclude that there is great scope for increasing the complexity of GLG analysis in future work. However, this carries significant risks. Increased complexity can outstrip data and modeling capabilities, slow down research, make results more difficult to understand and interpret, and complicate effective communication with decision-makers and other users of the analyses.

We believe that research guidance regarding appropriate complexity is a high priority in the emerging field of Global-Local-Global analysis of sustainability. In addition, in inviting the papers for the special issue of ERL, a special effort was made to recruit ECR lead authors.

Use Case Workshops

- Transportation Infrastructure Expansion in Brazil: A Win-Win Strategy for Agriculture Competitiveness and the Environment? (March 20, 2023)
    - Chair: Jing Liu (Purdue and GTAP)
    - Speakers: Zhan Wang and Tom Hertel (Purdue and GTAP), Geraldo Martha (Embrapa) and Cicero Lima (Sao Paulo School of Economics, and FGV-EESP)
    - Discussants: Nelson Villoria (Kansas State University) and Angelo Gurgel (MIT)
    - Description: This workshop engaged experts on Brazilian agriculture and geography around the topic of transportation investments. The Brazilian government has a plan to expand the railways into the interior of Brazil in order to boost agricultural production there. This raises serious concerns about environmental degradation. The study presented in this workshop utilized a gridded economic framework developed in collaboration between Purdue University and the GLASSNET Testbed, Embrapa in order to study the impact of this railway expansion. Preliminary findings quantified both the environmental costs, as well as the hidden benefits which include reduced transportation emissions as well as a lessening of pressure on the environment in the South/Southeast of Brazil.

- Assessing the Interaction between Global Economy and Biodiversity and Ecosystem Services (September 7, 2023)
    - Chair: Aline Mosnier (FABLE and Science Council – SC)
    - Speakers: Justin Johnson (University of Minnesota) and Erwin Corong (Purdue and GTAP)
    - Discussants: Nfamara Dampha (NatCap), Stephanie Onder (World Bank) and Iman Haqiqi (GTAP)
    - Description: This workshop featured two of the core developers of the GTAP-AEZ-InVEST framework which was used in the high profile PNAS publication discussed elsewhere in this report. The workshop highlighted how economists working on global trade and the macroeconomy can collaborate with ecologists working at the level of individual grid cells to quantify the economic benefits of local conservation policies.

- Spillover Effects Play a Key Role in Maintaining Planetary Boundaries (September 14, 2023)
    - Chair: Catherine Kling (Cornell University)
    - Speakers: Christoph Muller (PIK and GGCMI), Dieter Gerten (PIK), Jannes Breier (PIK and GGCMI), Iman Haqiqi (Purdue and GTAP), Chris Kucharik (University of Wisconsin-Madison), Monika Zurek (University of Oxford)
    - Description: This workshop featured a collaboration between the GTAP network of economists and the GGCMI network of crop modelers and biogeochemical cycle scientists. Recent evidence suggests that the planetary boundary most endangered by human activity is that related to the nitrogen cycle. Excessive use of nitrogen fertilizer in agriculture has polluted surface and groundwater and resulted in extensive coastal dead zones. This workshop focused on the impacts of taxing nitrogen use in agriculture in order to reduce fertilizer applications to safe levels. Preliminary findings suggest that, contrary to popular perceptions, such a policy would not endanger global food security, as production would shift to other locations, and trade in the fertilizer itself would result in a reallocation to regions where it is more beneficial to crop production. However, the reductions in agricultural activity in some areas would result in significant dislocation of economic activity.

Develop human capital for SDG advancement and sustainability

Major Activities

The Early Career Researcher (ECR) subcommittee of the GLASSNET Leadership Group, comprising Danielle Grogan, Jing Liu and Justin Johnson, conceived and implemented a series of ECR workshops focusing on funding and managing international, interdisciplinary and inclusive research projects. Building upon the information and insights provided by the workshops in this series, participants were invited to propose their own ideas on how to promote, support, and reward interdisciplinary research on sustainable land and water resources across scales. From this pool of submissions, two proposals were selected for GLASSNET support (Carly Jordan Frank and Vartika Singh).

- Workshop 1: Proposal Success, September 21, 2022
- Workshop 2: Developing Successful Interdisciplinary Research, November 7, 2022
- Workshop 3: Co-production of an ECR Travel Fellowship Program, April 5, 2023

ECR travels to improve their leadership skills in inclusive, international, and interdisciplinary research included the following:

- Felicitas Beier (PIK, PhD candidate, Humboldt University Berlin) visited Purdue, September 1-15, 2023 and attended the October 1-3 GLASSNET biennial meeting

- Iman Haqiqi (Purdue, Research Economist) visited PIK (Germany), June 19-23, 2023

- Danielle Grogan (UNH, Research Asst. Prof.) and Shan Zuideman (UNH, Research Scientist) participated in the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) annual meeting, June 5-8, 2023 at Czech University of Life Sciences (ČZU) Suchdol, Czechia. They also visited PIK (Germany), June 12-13, 2023

- Carly Frank (Purdue) presented her work at the World Climate Research Programme Open Science Conference, October 23-27, 2023, in Kigali, Rwanda

- Vartika Singh (PhD candidate, Humboldt University, currently working in India) visited Cornell University, November 20 - December 2, 2023

- Justin Johnson (University of Minnesota, Assistant Professor), presented GTAP-InVEST at the Annual Conference of the Chilean Central Bank, the European Commission in Brussels, and the Norwegian Sovereign Wealth Fund

In an effort to broaden the use of the SIMPLE-G modeling framework which is being widely employed by GLASSNET members for international, interdisciplinary, global-local-global analysis of sustainability, we are preparing for another SIMPLE-G Short Course to be offered in April-May of 2024. The first GLASSNET SIMPLE-G course was offered in 2022.

A SIMPLE-G book is also being finalized and will be submitted to Springer for publication in early 2024. This will provide course participants, as well as other members of the GLASSNET network with a comprehensive introduction to transdisciplinary, multi-scale analysis of sustainability challenges.

Significant Results

Use Case Workshops

- The first workshop featured three prominent women scientists who spoke to questions related to obtaining such grants as well as ensuring they are inclusive and interdisciplinary. Special attention was devoted to engaging with Indigenous populations.

- The second ECR workshop, focused on organization and leadership of these grants, invited three leading scientists who all have extensive experience in managing large-scale interdisciplinary research projects.

- The final workshop in this series led to submission of formal proposals by the ECRs. From this pool of submissions, Carly Frank was funded to participate in the World Climate Research Programme Open Science Conference (WCRP OSC), and Vartika Singh was funded to visit Cornell University. These activities not only supported their interdisciplinary, international research, but also allowed them to become the "GLASSNET ambassadors" to enhance the engagement of scholars in African and South Asia.

The SIMPLE-G Short Course consists of four weeks of on-line training, delivered through the NSF-supported MyGeoHub, and then one week of in-person training at Purdue University. We received 51 applications from 21 countries and 6 continents. Among them, 26 have been admitted. Two-thirds are PhD students and ECRs, while one-third are more senior researchers. We believe this is an ideal mix for boosting long term collaborations.

Most of the book chapters of the SIMPLE-G book were built based on the research led by the ECRs. The book covers theory, model specification, data and parameters, computer implementation, model validation and eight SIMPLE-G applications covering topics ranging from climate impacts and mitigation to water quality, as well as groundwater sustainability and land use change. A complete set of files will enable readers to replicate, critique and extend any of these applications. Short video introductions to each topic will help to motivate readers who are unable to attend the course. This book will also be published as an open access resource to maximize access by GLASSNET members in the Global South.

Liu organized a session on Land Use Change in Brazil at the 2023 GTAP Conference to promote the engagement of GLASSNET researchers in Brazil.

GLASSNET ECR ecologist, Abhishek Chaudhary from the Indian Institute for Technology, attended the 2022 GLASSNET conference at Purdue and discussed his work on biodiversity and international trade in collaboration with several US-based ECRs who bring a trade perspective. In 2023 PI Hertel collaborated with Dr. Chaudhary on a perspective paper for the journal Environmental Science and Technology, highlighting the importance of transdisciplinary analysis when it comes to understanding the linkages between technology innovation, land use change and biodiversity loss.

Workshops

Use Case Workshops

The goal of the Use Case Workshop Series is to provide a broader perspective on sustainability challenges, drawing in GLASSNET scholars from different backgrounds, disciplines, and networks to enrich the resulting use case and identify potential linkages with related work within the broader GLASSNET community.

Assessing the Interaction Between Global Economy, Biodiversity, and Ecosystems Services

September 7, 2023

Assessing the interaction between the global economy and biodiversity and ecosystem services (BES) is crucial for sustainable development, especially with increasing global population, economic growth, and changing climate. The global economy depends on BES, and their depletion can lead to significant economic, social, and environmental costs. However, the current economic system and associated policies often overlook the value of BES, leading to unsustainable practices that harm the planet's natural systems. Recent work has linked high-resolution ecosystem service models (InVEST) with versions of the GTAP model that include detailed information on land as an input to production (defined for different Agro-ecological zones, AEZs). This work has led to important publications (Johnson et al., 2020, 2021, 2023), but as of yet, these models have been based on a comparative statics paradigm in which only two points in time are considered (the base year, and some year into the future). Recent work launched by the World Bank under their Changing Wealth of Nations proposal supports new work to combine a recursive-dynamic version of GTAP-AEZ with InVEST and dynamically calculate land-use change. This will allow for more nuanced work that considers questions that require more specificity on when sustainability policies might be passed and when the impacts are felt. In this proposed GLASSNET use case, we propose to strengthen the quantitative rigor of GTAP-InVEST in the new dynamic framework and make it more useful for analyzing global-scale sustainability policies that affect both humans and the environment.

Spillover effects play key role in maintaining planetary boundaries

September 14, 2023

Efforts to stay within interrelated planetary boundaries (PBs) for land and water systems have primarily relied on biophysical modeling, with little consideration for consumer and producer responses and the spillover effects of policies. We argue that these goals cannot be individually addressed due to significant interactions amongst them. For example, policies respecting nitrogen flows may put freshwater and natural lands at risk. This GLASSNET Use Case highlights the importance of preserving multiple planetary boundaries simultaneously and providing synergistic policies and behavioral responses. This workshop will explore a new approach to assessing options for staying within multiple PBs. We combine a global gridded biophysical model with a global gridded economic modeling system. This will allow us to track the spillover effects of policies to maintain one PB on other PBs. Then we present the results of how policies aimed at one PB (nitrogen flows) may compromise others (freshwater use) due to economic spillover effects.

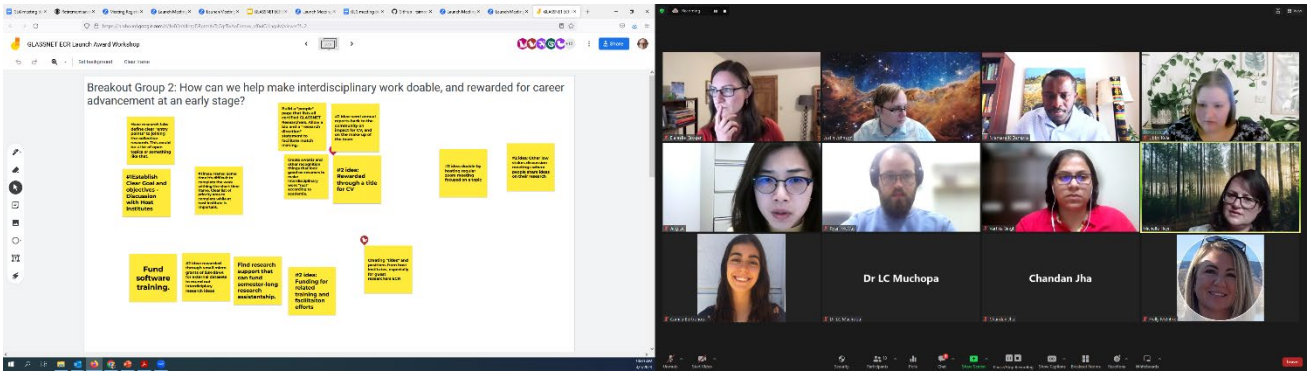
Early Career Researcher Workshops

As a network of researchers, GLASSNET can help connect researchers with diverse expertise across a wide range of disciplines, data holdings, and experience. These connections help researchers more quickly tackle the interdisciplinary challenges that arise in SDG research.

Workshop 3: GLASSNET Early Career Researcher Project Launch Award Workshop

April 5, 2023

As a network of researchers, GLASSNET can help connect researchers with diverse expertise across a wide range of disciplines, data holdings, and experience. These connections help researchers more quickly tackle the interdisciplinary challenges that arise in SDG research. In 2022, we held several Use Case workshops in which experienced researchers presented and received feedback on their ongoing SDG research. Now, GLASSNET will help launch new policy-relevant SDG research by supporting early career researchers (ECR) as they embark on new research endeavors. First, we are asking the GLASSNET community to gather for an online workshop to collectively define the selection criteria for this new ECR Project Launch Award. The award allows for up to USD $6,000 in travel funds, which can be international between US and non-US researchers, or domestic between US researchers.



SIMPLE-G Workshop

The security of food, energy, and water is interwoven with human, economic, and environmental sustainability. This recognition suggests that decision-making for sustainability could benefit from a nexus approach that integrates resources across sectors and scales.

SIMPLE-G Brazil: Transportation Infrastructure Expansion in Brazil

March 20, 2023

Using the recently developed SIMPLE-G-Brazil model, we explore how the 2035 National Logistics Plan (PNL2035) can affect Brazil's agricultural competitiveness and the environment. Results show that the Plan could significantly reduce the cost of transporting central-west produced crops to major exporting ports, but with considerable impacts on local land use change. These changes also generate spatial spillovers to regions outside Cerrado, highlighting the importance of taking into account the market-mediated effects across scales in the analysis.

Meetings and Conferences

GLASSNET researchers actively attended numerous annual meetings in support of the overall project.

NSF-AccelNet Annual Meeting

October 2023

PI Tom Hertel, Co-PI Danielle Grogan (remote) and ECR Carly Frank participated in the AccelNet annual meeting in Washington, DC, Oct 2023. They contributed to the panel on ECR engagement. Dr. Grogan presented the ECR workshops leading to co-production of ECR travel fellowship proposals and Hertel and Frank added to the panel discussion. Hertel initiated contacts with several AccelNet networks of networks working in the land and water domains.

Annual Conference of the Chilean Central Bank

November 2023

Dr. Justin Johnson presented the GTAP-InVEST framework at the Annual Conference of the Chilean Central Bank and also to the European Commission in Brussels. Other engagements have focused on how investors could improve their portfolio analysis to include risks from degraded nature. Specifically, Justin has been working with the Norwegian Sovereign Wealth Fund (NBIM) to extend GTAP-InVEST analysis towards assessing these risks. Finally, with GLASSNET support, progress is currently being made on generating a GTAP-InVEST training course, which aims to scale-up the impact to more decision makers.

Other Achievements and Outcomes

Key Accomplishments

The list below details a number of key accomplishments by GLASS researchers during the past year.

GLASSNET Growth

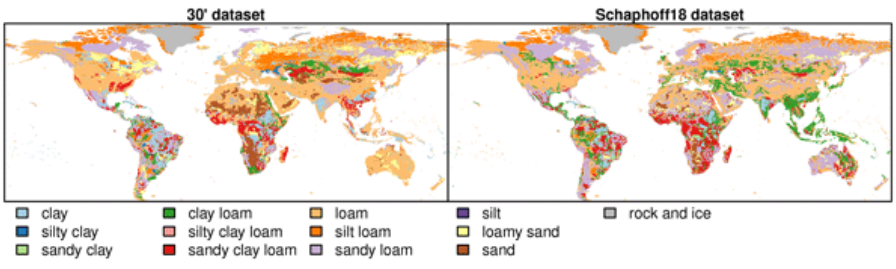
As of the end of 2023, GLASSNET had 174 subscribed members and was comprised of 12 networks spanning three continents and 3 testbeds, which are institutions engaged in joint research, training, and outreach. GLASSNET also added AgMIP-Columbia University to its network of networks, which complements two closely related networks in GLASSNET, GlobEcon and GGCMI, which cover global modeling of the economy and crops, respectively.

Cyberinfrastructure design/implementation facilitates interdisciplinary research/collaboration

One of the biggest challenges to scientific collaboration across GLASSNET networks is the communication of model results across fundamentally different frameworks and disciplines. We have significantly advanced this frontier in the context of sustainable land and water use by developing cyberinfrastructure to enable the communication of results between two of the GLASSNET core modeling groups - the WBM hydrology team and the SIMPLE-G agricultural economics team. We call this system C3F: A Collaborative Container-based Model Coupling Framework. In building C3F we identified challenges and limiting steps to coupled model development and deployment, including different systems and software, data reconciliation, reproducibility obstacles, etc. C3F overcomes these challenges by creating a common and collaborative modeling environment using advanced CI including the ACCESS Anvil High Performance Computing resources and virtual containers. We used MyGeoHub for team communication, and to document our work, including Wiki "how-to" pages on building virtual containers and submitting jobs to ACCESS Anvil to run the coupled model system. This represents a significant advance in interdisciplinary, cross-network collaboration for more robust analysis of land and water sustainability challenges.

Software engineers from Purdue and NatCap-Stanford worked together to make the InVEST suite of ecosystem services models available on the GeoHub. This will greatly facilitate the use of this framework by researchers from other networks and other disciplines. To date this has been done through interactive Jupyter notebook sessions and as a processor in the Purdue team's GeoEDF framework, which opens up access to InVEST to researchers using the GeoHub as well as other HPC systems. Future work will include releasing InVEST as an interactive tool on the GeoHub, creating an interactive demonstration of a case study in Ghana, and developing a clearer, more formal integration between InVEST (NatCap network) and GTAP-AEZ (GTAP network).

All of the networks in GLASSNET require data on global land use, and most of the data were generated independently. Not only is this costly in time and resources, it also means that the resulting analyses are not directly comparable. GLASSNET members at PIK in Germany produced Land Input Generator (LandInG) version 1.0 which is a toolbox for generating input datasets for terrestrial ecosystem models (TEMs) from diverse and partially conflicting data sources. It is designed to make inconsistencies between different sources of data transparent so that users can make their own decisions on how to resolve these issues should they not be content with the default assumptions. The full LandInG toolbox was developed with a focus on the open-source dynamic global vegetation, hydrology, and crop growth model LPJmL (Lund-Potsdam-Jena with managed Land), but many of the created data sets and data processes are also applicable to other TEMs. The LandInG Viewer on GeoHub provides ready access to a subset of these data for the GLASSNET members as well as other scientists working on land and water sustainability. It includes global gridded time series data on crop-specific fertilizer



application rates, crop-specific harvested areas, manure application rates on cropland, soil texture and soil acidity (pH). Deployed on the GeoHub, the LandInG Viewer is developed using the Jupyter Notebook technology to deliver an intuitive and interactive user interface (Figure 10). The backend of LandInG Viewer consists of data retrieval, processing and storage services, which provides fast and secure access to the large set of land use data on-demand.

Another area where GLASSNET member networks overlap in terms of data requirements has to do with climate impacts on agriculture. Estimates of these impacts require input from global climate models and subsequently crop models. This work is coordinated by the Global Gridded Crop Model Intercomparison (GGCMI-AgMIP networks). The resulting outputs are extremely large files that are difficult for other networks to access. Therefore, GLASSNET has launched an updated online tool to allow members and other scientists to access the latest data from the project. Implemented within the Jupyter Notebook environment and available on the MyGeoHub platform, the GGCMI-AgMIP Yield Data Aggregator tool allows users to explore and download yield projections for maize, soybeans, rice, and wheat from twelve crop models and five CMIP6 global circulation models. This tool aggregates relative yield changes under a broad set of climate scenarios from their original 0.5° × 0.5° resolution to the country level or other customized aggregation levels. To enrich the user experience, the AgMIP Data Aggregator supports choropleth map visualization using the Leaflet library and temporal visualization of the yield time series for the user-selected country using the matplot library. The funding for this tool was provided by the Economic Research Service of the U.S. Department of Agriculture.

The SIMPLE-G framework is being widely used by GLASSNET members to study multi-scale sustainability issues. However, it requires specialized software and training. In order to make this framework more widely accessible, GLASSNET has developed the Simple-G Jupyter Notebook, a new version of the online SIMPLE-G-US migrated to the JN environment. Several new features have been added to the SIMPLE-G JN tool on MyGeoHub to increase usability, flexibility, and maintainability in the long run. The redesigned SIMPLE-G JN framework makes it easier to add different SIMPLE-G models as they are containerized. A user can choose a registered containerized model at run time and launch a run on the backend HPC cluster. Users may also upload and use their HAR-formatted input files in their runs. Users can also define the mappings between variable inputs and their physical locations at the computing system in a CMF file. Using this custom input uploading feature, several researchers investigated heat stress's effects on sustainability in the 2023 I-GUIDE summer school. A data download service has also been added to the SIMPLEG-JN. The On-the-fly data exporting feature has been improved - users may click a few coordinates of interest and export the values at the selected coordinates for every geospatial output file, allowing them to quickly analyze data in various locations. Other usability improvements include a progress status display for time-consuming geospatial operations, such as visualization involving loading maps.

Researcher Highlights

GLASSNET Researchers

GLASSNET prepares the next generation of researchers to engage in and lead international sustainability team science by leveraging network best practices for human capital development.

Dr. Felicitas Beier

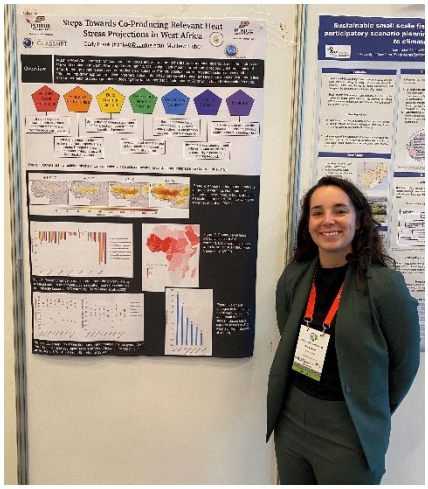
Junior Researcher, Potsdam Institute for Climate Impact Research (PIK)

Felicitas Beier studied International Economics at Eberhard-Karls University in Tübingen, Germany, and Georg-August University in Göttingen, Germany with exchange semesters at Queen's University in Kingston, Ontario (Canada) and Fudan University in Shanghai (China). Since 2018 she works as a junior researcher at Potsdam Institute for Climate Impact Research (PIK) in Potsdam (Germany). She works in the "Landuse and Resilience Group" with the global land use modeling framework MAgPIE and is enrolled as a doctoral student in Agricultural Economics at Humboldt University, Berlin (Germany). Her main focus of research evolves around global irrigation potentials in land-use modeling as well as the interplay of multiple cropping potentials and irrigation.

Carly Frank

Graduate Research Assistant, Purdue University

Carly's research interests are at the intersection of co-production, heat stress in the developing world, and the equality distribution of societal impacts of climate change. While she is early in her research, she plans to quantify heat stress levels in Ghana's cocoa sector through collaboration with faculty and students at the University of Ghana. This includes setting up climate instruments to take on-the-ground measurements of air temperature, radiation, and humidity, assessing the work environment and habits of labors (i.e., how many hours worked, sun/shade, water access, intensity of labor), and recording core temperature and heart rate readings of labors while they work to determine if they are reaching dangerous internal temperatures and if they continue to work or break once these levels are reached. From this information, changes in labor productivity can be quantified and in turn, changes in socio-economic factors such as poverty and food security.



Vartika Singh

PhD candidate, Humboldt University

Vartika is currently pursuing her PhD from Humboldt University in Berlin, Germany, and is a guest researcher at the Potsdam Institute for Climate Impact Research (PIK). Her research interests revolve around the nexus of food-water-energy and land. She utilizes tools such as CGE and PE models to assess the integrated impact of water, energy, and climate policies, which contribute to the development of sustainable transformation pathways for India. These activities constitute the core of her Ph.D. dissertation work and are part of the Nexus-Gains Initiative under the One-CGIAR umbrella.

In addition to pursuing her PhD, she is also a Senior Research Analyst in the Natural Resources and Resilience Unit of the International Food Policy Research Institute, in New Delhi, and also holds the position of Senior Research Officer at the Indian Institute of Management, Ahmedabad, India.

Products

Advance & Accelerate Knowledge

Through GLASSNET's national and international partnerships, we will deliver comprehensive SDG insights to stakeholders.

Journals or Juried Conference Papers

- Haqiqi, Iman and Bowling, Laura and Jame, Sadia and Baldos, Uris and Liu, Jing and Hertel, Thomas. (2023). Global drivers of local water stresses and global responses to local water policies in the United States. *Environmental Research Letters*. 18 (6) .

- Leijten, Floris and Lantz C Baldos, Uris and Johnson, Justin A. and Sim, Sarah and Verburg, Peter H. (2023). Projecting global oil palm expansion under zero-deforestation commitments: Direct and indirect land use change impacts. *iScience*. 26 (6) .

- von Jeetze, Patrick José and Weindl, Isabelle and Johnson, Justin Andrew and Borrelli, Pasquale and Panagos, Panos and Molina Bacca, Edna J. and Karstens, Kristine and Humpenöder, Florian and Dietrich, Jan Philipp and Minoli, Sara and Müller, Christoph and Lotze-Campen, Hermann and Popp, Alexander. (2023). Projected landscape-scale repercussions of global action for climate and biodiversity protection. *Nature Communications*. 14 (1) .

- Kamarajugedda, Shankar Acharya and Johnson, Justin Andrew and McDonald, Robert and Hamel, Perrine. (2023). Carbon storage and sequestration in Southeast Asian urban clusters under future land cover change scenarios (2015–2050). *Frontiers in Environmental Science*. 11 .

- Isbell, Forest and Balvanera, Patricia and Mori, Akira S and He, Jin-Sheng and Bullock, James M and Regmi, Ganga Ram and Seabloom, Eric W and Ferrier, Simon and Sala, Osvaldo E and Guerrero-Ramírez, Nathaly R and Tavella, Julia and Larkin, Daniel J and Schmid, Bernhard and Outhwaite, Charlotte L and Pramual, Pairot and Borer, Elizabeth T and Loreau, Michel and Omotoriogun, Taiwo Crossby and Obura, David O and Anderson, Maggie and Portales-Reyes, Cristina and Kirkman, Kevin and Vergara, Pablo M and Clark, Adam Thomas and Komatsu, Kimberly J and Petchey, Owen L and Weiskopf, Sarah R and Williams, Laura J and Collins, Scott L and Eisenhauer, Nico and Trisos, Christopher H and Renard, Delphine and Wright, Alexandra J and Tripathi, Poonam and Cowles, Jane and Byrnes, Jarrett EK and Reich, Peter B and Purvis, Andy and Sharip, Zati and O'Connor, Mary I and Kazanski, Clare E and Haddad, Nick M and Soto, Eulogio H and Dee, Laura E and Díaz, Sandra and Zirbel, Chad R and Avolio, Meghan L and Wang, Shaopeng and Ma, Zhiyuan and Liang, Jingjing and Farah, Hanan C and Johnson, Justin Andrew and Miller, Brian W and Hautier, Yann and Smith, Melinda D and Knops, Johannes MH and Myers, Bonnie JE and Harmáčková, Zuzana V and Cortés, Jorge and Harfoot, Michael BJ and Gonzalez, Andrew and Newbold, Tim and Oehri, Jacqueline and Mazón, Marina and Dobbs, Cynnamon and Palmer, Meredith

- S. (2023). Expert perspectives on global biodiversity loss and its drivers and impacts on people. *Frontiers in Ecology and the Environment*. 21 (2) .

- Chaplin-Kramer, Rebecca and Neugarten, Rachel A. and Sharp, Richard P. and Collins, Pamela M. and Polasky, Stephen and Hole, David and Schuster, Richard and Strimas-Mackey, Matthew and Mulligan, Mark and Brandon, Carter and Diaz, Sandra and Fluet-Chouinard, Etienne and Gorenflo, L. J. and Johnson, Justin A. and Kennedy, Christina M. and Keys, Patrick

- W. and Longley-Wood, Kate and McIntyre, Peter B. and Noon, Monica and Pascual, Unai and Reidy Liermann, Catherine and Roehrdanz, Patrick R. and Schmidt-Traub, Guido and Shaw, M. Rebecca and Spalding, Mark and Turner, Will R. and van Soesbergen, Arnout and Watson, Reg A. (2023). Mapping the planet's critical natural assets. *Nature Ecology & Evolution*. 7 (1) .

- Ray, Srabashi and Haqiqi, Iman and Hill, Alexandra E and Taylor, J Edward and Hertel, Thomas W. (2023). Labor markets: A critical link between global-local shocks and their impact on agriculture. *Environmental Research Letters*. 18 (3) .

- Johnson, Justin Andrew and Brown, Molly E and Corong, Erwin and Dietrich, Jan Philipp and C Henry, Roslyn and von Jeetze, Patrick José and Leclère, David and Popp, Alexander and Thakrar, Sumil K and Williams, David R. (2023). The meso scale as a frontier in interdisciplinary modeling of sustainability from local to global scales. *Environmental Research Letters*. 18 (2) .

- Hertel, Thomas W. and Irwin, Elena and Polasky, Stephen and Ramankutty, Navin. (2023). Focus on global–local–global analysis of sustainability. *Environmental Research Letters*. 18 (10) .

- Johnson, David R. and Polasky, Stephen and Ricker-Gilbert, Jacob. (2023). Policy collision: a framework to identify where polycentric, multi-objective sustainability solutions are needed. *Environmental Research Letters*. 18 (2) .

- Gesing, Sandra and Stirm, Claire and Klimeck, Gerhard and Zentner, Lynn and Wang, Su and Villegas-Martinez, Braulio M. and Moya-Cessa, Hector M. and Eaton, Carrie Diaz and Donovan, Sam and Song, Carol and Zhao, Lan and Kim, I Luk and Strachan, Alejandro and Zentner, Michael and Kalyanam, Rajesh. (2023). Hubzero: Community Growth for Four Science Gateways Supporting Open Science. *Computing in Science & Engineering*. 25 (1) .

- Troy, Tara J. and Bowling, Laura C. and Jame, Sadia A. and Lee, Charlotte I. and Liu, Jing and Perry, Chris and Richter, Brian. (2023). Envisioning a sustainable agricultural water future across spatial scales. *Environmental Research Letters*. 18 (8) .

- Haqiqi, Iman and Grogan, Danielle S. and Bahalou Horeh, Marziyeh and Liu, Jing and Baldos, Uris L. C. and Lammers, Richard and Hertel, Thomas W. (2023). Local, regional, and global adaptations to a compound pandemic-weather stress event. *Environmental Research Letters*. 18 (3) .

- Liu, Jing and Bowling, Laura and Kucharik, Christopher and Jame, Sadia and Baldos, Uris and Jarvis, Larissa and Ramankutty, Navin and Hertel, Thomas. (2023). Tackling policy leakage and targeting hotspots could be key to addressing the 'Wicked' challenge of nutrient pollution from corn production in the U.S. *Environmental Research Letters*. 18 (10) .

- Johnson, Justin Andrew and Baldos, Uris Lantz and Corong, Erwin and Hertel, Thomas and Polasky, Stephen and Cervigni, Raffaello and Roxburgh, Toby and Ruta, Giovanni and Salemi, Colette and Thakrar, Sumil. (2023). Investing in nature can improve equity and economic returns. *Proceedings of the National Academy of Sciences*. 120 (27) .

- Cisneros-Pineda, Alfredo and Dukes, Jeffrey S and Johnson, Justin and Brouder, Sylvie and Ramankutty, Navin and Corong, Erwin and Chaudhary, Abhishek. (2023). The missing markets link in global-to-local-to-global analyses of biodiversity and ecosystem services. *Environmental Research Letters*. 18 (4) .

- Song, Carol X. and Merwade, Venkatesh and Wang, Shaowen and Witt, Michael and Kumar, Vipin and Irwin, Elena and Zhao, Lan and Walton, Amy. (2023). Cyberinfrastructure for sustainability sciences. *Environmental Research Letters*. 18 (7) .

- Saeed, W. and Haqiqi, I. and Kong, Q. and Huber, M. and Buzan, J. R. and Chonabayashi, S. and Motohashi, K. and Hertel,

- Chaplin-Kramer, Rebecca and Brauman, Kate A. and Cavender-Bares, Jeannine and Díaz, Sandra and Duarte, Gabriela Teixeira and Enquist, Brian J. and Garibaldi, Lucas A. and Geldmann, Jonas and Halpern, Benjamin S. and Hertel, Thomas

Conference and Invited Presentations

- Hertel, Thomas W. (2023). *Agriculture, International Trade and Sustainability*. presentation to the C-FARE preconference workshop, AAEA Annual Meetings, Washington, D.C., July 22, 2023. Washington, D.C. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

- Hertel, Thomas W. (2023). *Building Global Networks to Address Global (and Local) Challenges*. presentation to the College of Agriculture, Purdue University. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

- Hertel, Thomas W. (2023). *Climate Change Impacts on Agricultural Labor and Low-income Households*. presentation to the National Academy of Sciences Food Forum, (virtual) March 29, 2023. virtual. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

- Johnson, J.A. (2023). *Computable General Equilibrium Models and Interactions with Biodiversity*. Potsdam Institute for Climate Impact Research. Liepzig, Germany. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

- Hertel, Thomas W. (2023). *Connecting the Total Factor Productivity Network to Policy and Sustainability*. presentation to the OECD workshop on Agricultural Productivity and Sustainability, (virtual) May 25, 2023. virtual. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

- Zuidema, Shan (2023). *Conservation and carbon pricing effects on the food, energy, water systems and the nitrogen cascade in the Mississippi River Basin*. Seminar at the Potsdam Institute on Climate Impact Research (PIK), June 12, 2023. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

- L. Zhao, C. X. Song, R. Kalyanam, J. Shin, R. Campbell, I. L. Kim, V. Merwade, M. Huber (2023). *CyberInfrastructure Enabling FAIR Science And Workforce Development*. 2023 ISF Resource Expo, March 2023, West Lafayette, IN. West Lafayette, Indiana. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

- Grogan, Danielle (2023). *Development of groundwater methods in a global hydrologic model: towards interdisciplinary groundwater resource modeling for sustainable food production*. Seminar at the Potsdam Institute on Climate Impact Research (PIK), June 12, 2023. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

- Johnson, J.A. (2023). *GLASSNET Early Career Researcher Project Launch*. workshop to co-develop an NSF-funded Early Career Researcher Grant. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

- Hertel, Thomas W. (2023). *Global and Local Policies for Respecting Planetary Boundaries: Tradeoffs and Synergies*. workshop on Integrating Planetary Boundaries in Economic and Social Science Analysis, organized by the Department of Economics, University of Copenhagen. Status = ACCEPTED; Acknowledgement of Federal Support = Yes
- Hertel, Thomas W. (2023). *Global-Local-Global Analysis of Climate Change*. presentation to the Indiana White River Alliance conference on Climate Change and Water, (virtual) June 6, 2023. virtual. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

- Hertel, Thomas W. (2023). *Global-Local-Global Analysis of Land and Water Sustainability*. Plenary address to the annual meetings of the Australasian Agricultural and Resource Economics Society, (virtual), February 8, 2023. virtual. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

- Hertel, Thomas W. (2023). *Global-Local-Global Analysis of Sustainability*. Seminar at IFPRI, Washington, D.C., March 16, 2023. Washington, D.C. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

- Hertel, Thomas W. (2023). *Global-to-Local-to-Global Analysis of Water Security*. presentation to the National Science Foundation Advisory Committee for Environmental Research and Education, (virtual) April 5, 2023. virtual. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

- Huber, Matthew (2023). *Heat, Health and Ability to Work: Wet Bulb Globe Temperature and GTAP*. National Academies of Sciences, Engineering and Medicine (NASEM) workshop on Macroeconomics and Climate-related Risks and Opportunities. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

- Johnson, J.A. (2023). *Implications of Climate Change and Ecosystem Services Degradation for Macroeconomic and Financial Stability*. XXVI Annual Conference of the Central Bank of Chile. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

- Johnson, J.A. (2023). *Integrated Assessment Model with natural capital depletion (ecological IAM)*. European Commission's DG ECFIN-OGWG workshop on Natural Capital. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

- Johnson, J.A. (2023). *Integrating Nature-Climate Scenarios & Analytics for Financial Decision-Making (INCAF)*. Integrating Nature-Climate Scenarios & Analytics for Financial Decision-Making (INCAF). virtual. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

- Stephen Polasky (2023). *Integrating ecosystem modeling into economic models with applications to efficiency analysis, Gross Ecosystem Product, and policy analysis: Implications of Climate Change and Ecosystem Services Degradation for Macroeconomic and Financial Stability*. XXVI Annual Conference of the Central Bank of Chile, Santiago, Chile, November 2023. Santiago, Chile. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

- Hertel, Thomas W. (2023). *International Trade, Food Security and Environmental Sustainability*. presentation to the Mandela- Washington Fellows, Purdue University, July 27, 2023. West Lafayette, Indiana. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

- Hertel, Thomas W. (2023). *International Trade, Food Security and Environmental Sustainability*. presentation to the IAMO Forum 2023, Halle, Germany, June 21, 2023. Halle, Germany. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

- Johnson, J.A. (2023). *Meso-scale analysis of integrated global-local modeling*. GLASSNET Biannual Meeting. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

- Stephen Polasky (2023). *Nature's frontiers: Achieving sustainability, efficiency, and prosperity with natural capital*. Nature's Frontiers Report Launch Event. National Academy of Sciences, Washington, DC, June 2023. Washington, DC. Status = ACCEPTED; Acknowledgement of Federal Support = Yes
- Stephen Polasky (2023). *Nature's frontiers: Achieving sustainability, efficiency, and prosperity with natural capital*. World Bank Seminar, April 2023. Washington, D.C. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

- Johnson, J.A. (2023). *Open-science and progress on sustainable macroeconomic analysis*. FABLE (Food, Agriculture, Biodiversity, Land Use and Energy) Consortium's Annual. Bariloche, Argentina. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

- Hertel, Thomas W. (2023). *SIMPLE-G: A Global Gridded Framework for Analysis of Food Security and Sustainability*. presentation at the Annual Conference on Global Economic Analysis, Bordeaux, France, June 14, 2023. Bordeaux, France. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

- I.L. Kim, L. Zhao, R. Campbell, C.X. Song (2023). *Simplifying and Streamlining Scientific Data Exploration, Visualization, and Dissemination*. RCAC CI Symposium, October 2023, West Lafayette, IN. West Lafayette, Indiana. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

- Huber, Matthew (2023). *Transdisciplinary approaches to Global->Local->Global Sustainability*. Impatti del cambiamento climatico: nuove criticità e soluzioni nella gestione territoriale, Ancona, Italy. Ancona, Italy. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

- Johnson, J.A. (). *Using computable general equilibrium and ecosystem service models to assess financial risk from biodiversity impacts and dependencies*. OECD. 2, rue André Pascal, 75016. Paris, France. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

- Stephen Polasky (2023). *"Nature's frontiers: Achieving sustainability, efficiency, and prosperity with natural capital", Keynote presentation, Mainstreaming Ecosystem Valuation for a Greener Future*. The 1st International Conference on Realization of Ecosystem Goods and Services, Beijing, October 2023. Beijing, China. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

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