Appendix to AGU Report to NSF on Accelerating Research and Impacts in GeoHealth

Participants

This effort was lead and organized by a Steering Committee that included:

Ben Zaitchik
Susan Anenberg
Gabe Filippelli
Gordon Grant
Brooks Hanson
Raj Pandya
Mark Shimamoto
Laura Lyon

In addition, the AGU GeoHealth Advisory Board and staff participated in a second workshop and provided input throughout:

Paloma Beamer
Rita Colwell
Arthur C. Evans
Robert Finkelman
Andrea Hess
Claire Horwell
Howard Kurtzman
Christine McEntee
Aubrey Miller
Franziska Landes
Geoff Plumlee
Wassila Thiaw
Jalonne White-Newsome
Matt Giampoala
Lauren Parr

Other participants who participated in the first workshop and/or provided input to this report include:

Azar Abadi
Angela Beehler
Hannah Carey
Alissa Cox
Morgan Gorris
Patricia Lasley
Fiona Lo
Tatiana Loboda
Katelyn O'Dell
Yuhan Rao
Ramesh Singh
Marie Studer
Michael Wimberly

Approximately 80 participants responded to and provided input to the survey; these were anonymous.

Survey

A copy of the survey questions is included below:

1. By continuing, you agree to allow AGU to collect and use your responses to the questions below as described for this work. Partially completed responses will be saved and used as appropriate.

- I agree
- I disagree

2. Suggest one or more high priority, impactful, interdisciplinary/convergent challenges in GeoHealth where important progress, outcomes, or a high value deliverable can be made in the next 2 to 3 years with appropriate funding/support. For more than one idea, please use the 2nd or 3rd area below.

GeoHealth is defined as "...advancing our understanding of the complex interactions between the environment (including earth, water, soils and air) and the health, well-being, and continued progress of human populations." See https://connect.agu.org/geohealth/home for further information.

[Open response]

3. Another suggestion (optional)

[Open response]

4. Another suggestion (optional)

[Open response]

5. What do you see as the largest challenges or barriers to making progress in these areas (Select up to three)

- Lack of funding
- Lack of career paths
- Lack of interdisciplinary training background or awareness of participants
- Finding colleagues in other disciplines or with needed expertise to collaborate
- Lack of institutional or departmental support
- Lack of access to environmental data
- Lack of access to human health data
- Lack of a collaborative network, community of practice, or colleagues
- Other [Open response]

6. Please feel free to amplify or expand on your answer to the question above.

[Open response]

7. What are the most important information, training, or other resources needed to embed a culture of innovation, entrepreneurialism, and translational research in GeoHealth (please select no more than three)

- Open, interoperable data, methods, and software
- Dedicated funding programs in GeoHealth
- Meetings featuring GeoHealth that connect the community
- Training programs for emerging GeoHealth scholars
- Collaboration with professionals outside of Geohealth (business professionals, entrepreneurs, development, etc.)
- Increased diversity of skills and mindsets within GeoHealth workforce
- Resources to develop community collaborations or partnerships
- Other [Open response]

8. What do you see as the one largest challenge to developing this culture.

- Incentives for sharing data
- Clear career paths
- Funding potential for GeoHealth research
- Institutional programs in GeoHealth that break barriers between medical, health, and physical science research
- Other [Open response]

9. What should NSF consider doing to foster these efforts that would be effective within the next 2 years (so without reorganization)

[Open response]

10. What should science societies do to help foster these efforts?

[Open response]

11. Please add any other thoughts or recommendations

[Open response]

12. What is your career stage?

- Undergraduate student
- Graduate student
- Early career (within five years of terminal degree or postdoctoral fellowship)
- Mid-career (5-20 years of terminal degree)
- Later career (>20 years after degree)
- Retired
- Prefer not to answer

13. Which societies are you currently a member?

- AGU
- AAAS
- APHA
- SETAC
- FASEB affiliated society
- ESA
- AMS
- EGU
- GSA
- ISES
- ISEE
- Other [Open response]

14. Please indicate your main areas of research or what best describes your departmental affiliation or expertise (please select best one or up to three)

- Climate or atmospheric science
- Other Earth science
- Environmental science or engineering
- Health science
- Environmental health science
- Biology or biological sciences
- Microbiology
- Epidemiology
- Toxicology
- GeoHealth
- Public Health
- Other [Open response]

15. Please indicate your recent, main funding source(s) for GeoHealth-related work in the past 5 years (can select more than one)

- Government employee
- NSF (provide program below)
- NIH (provide program below)
- NASA
- NOAA
- HUD
- EPA
- USDA
- DOD, including NRL
- USAID
- DOE
- CDC
- NIOSH
- USGS
- US state or local government

- Seed or other funding from your university or institution
- NGO (e.g., Foundation support, such as HHMI, Gates, Wellcome...provide name below)
- Non-US government funder (EU, UKRI...)
- I have done work without funding support
- Other [Open response]

16. If you selected NSF, NIH, or and NGO above, please provide the grant program (e.g., EAR for NSF or HHMI for an NGO).

[Open response]

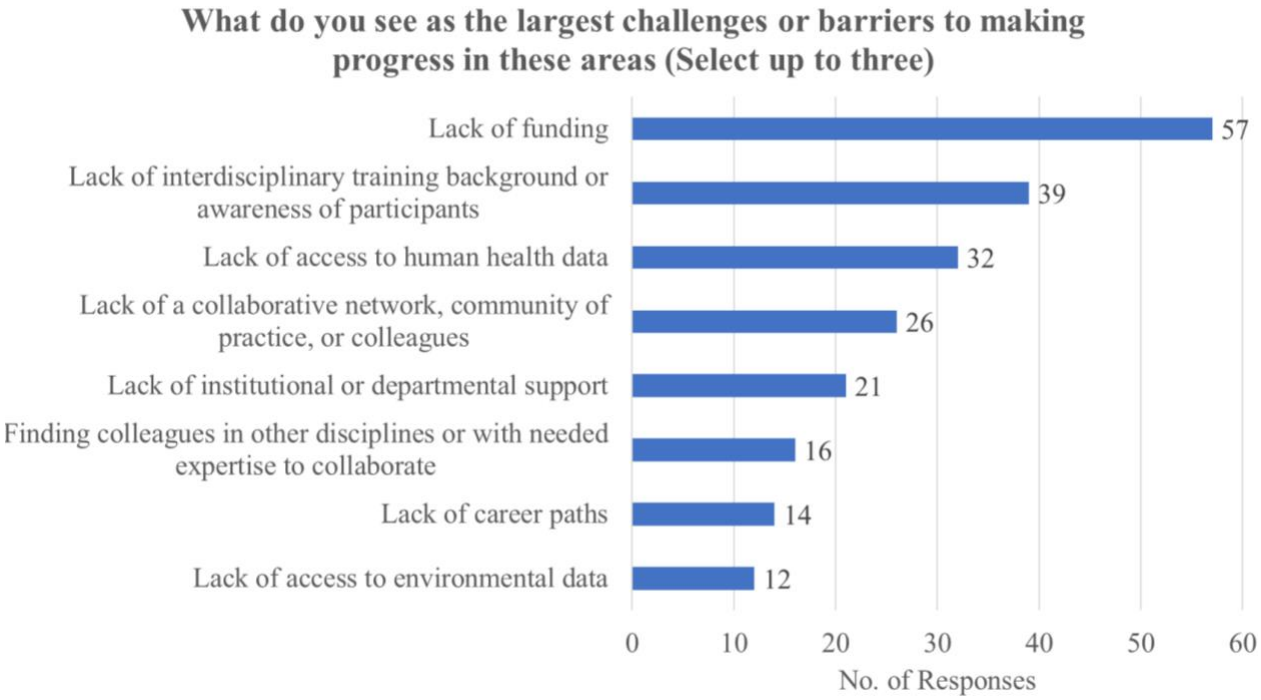
17. In what journals are you most often publishing your GeoHealth-related papers? Please list top three or so (not all).

[Open response]

Survey Results – Key Results

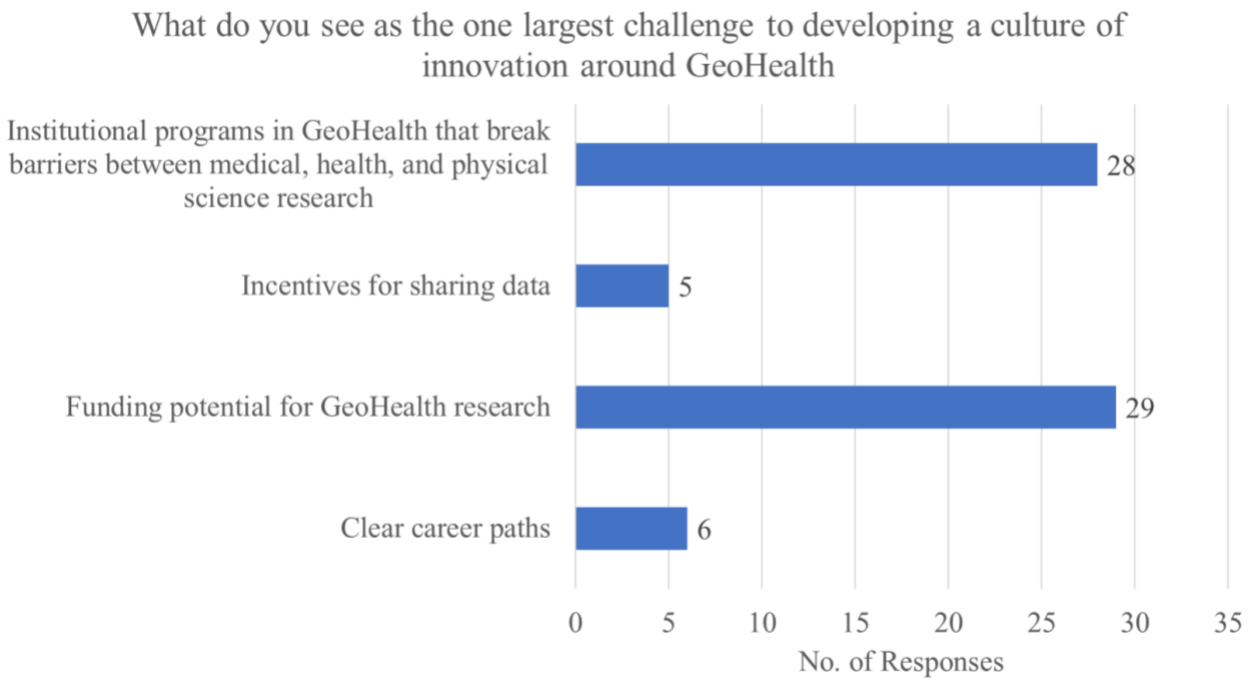
Several key survey results are illustrated in the graphs below:

Q5:

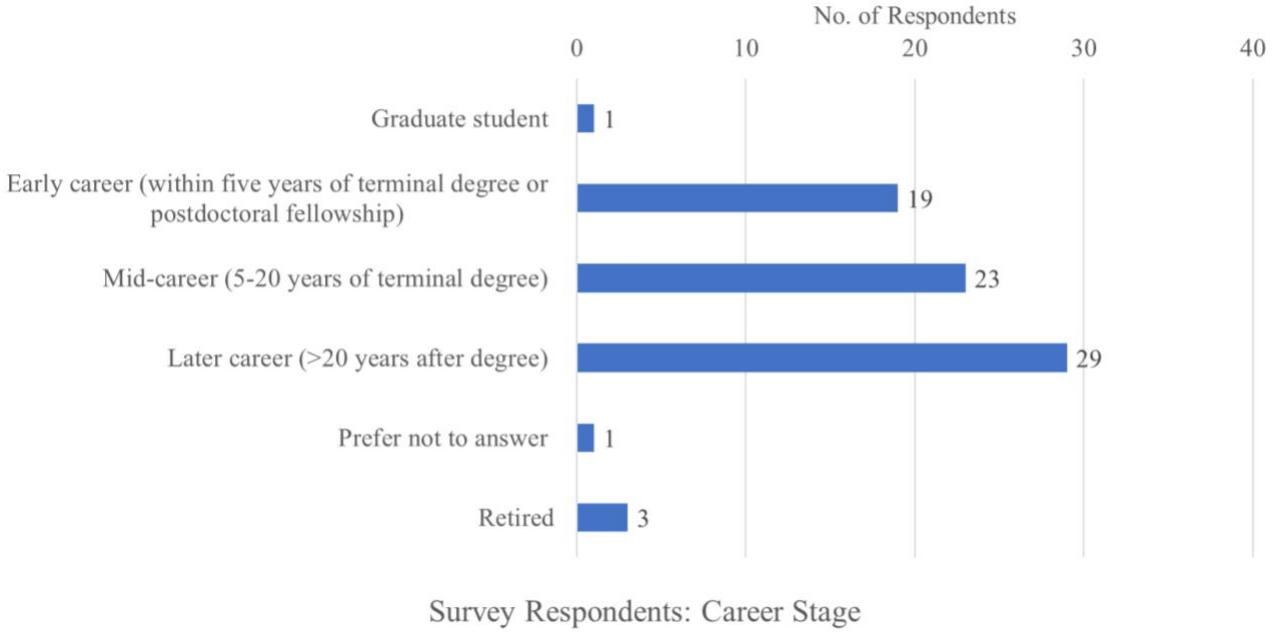


Q7:

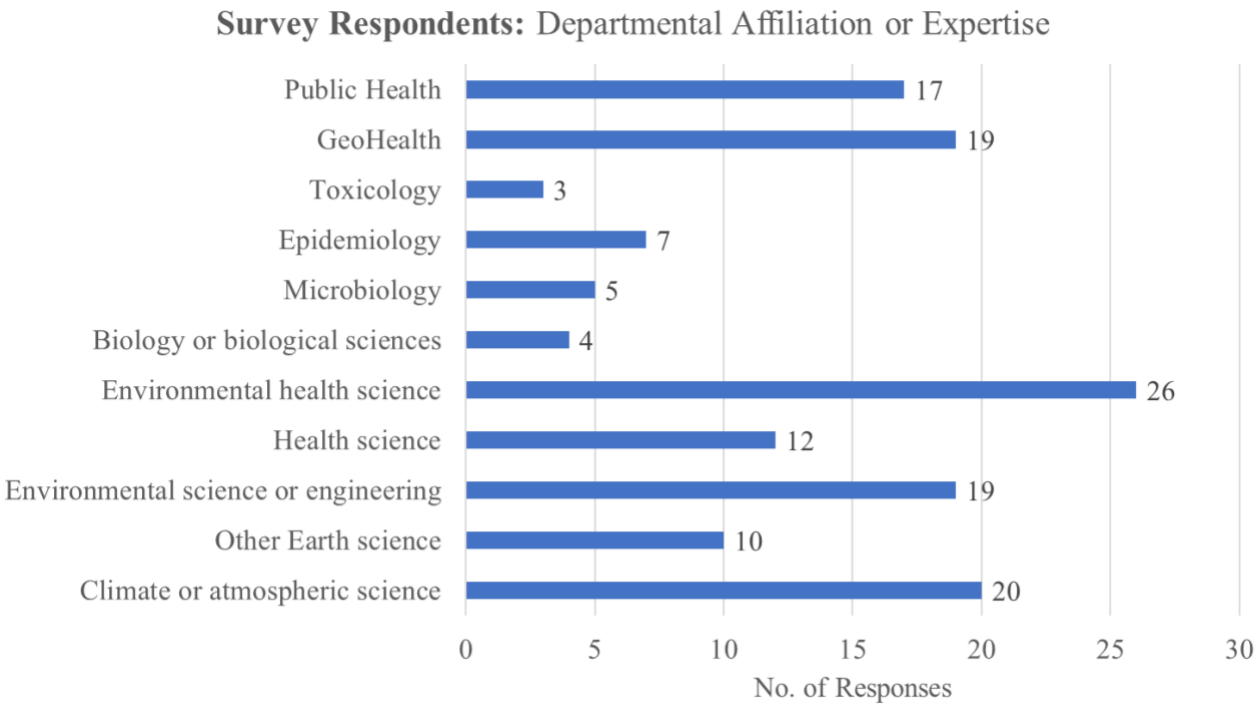
Q8:



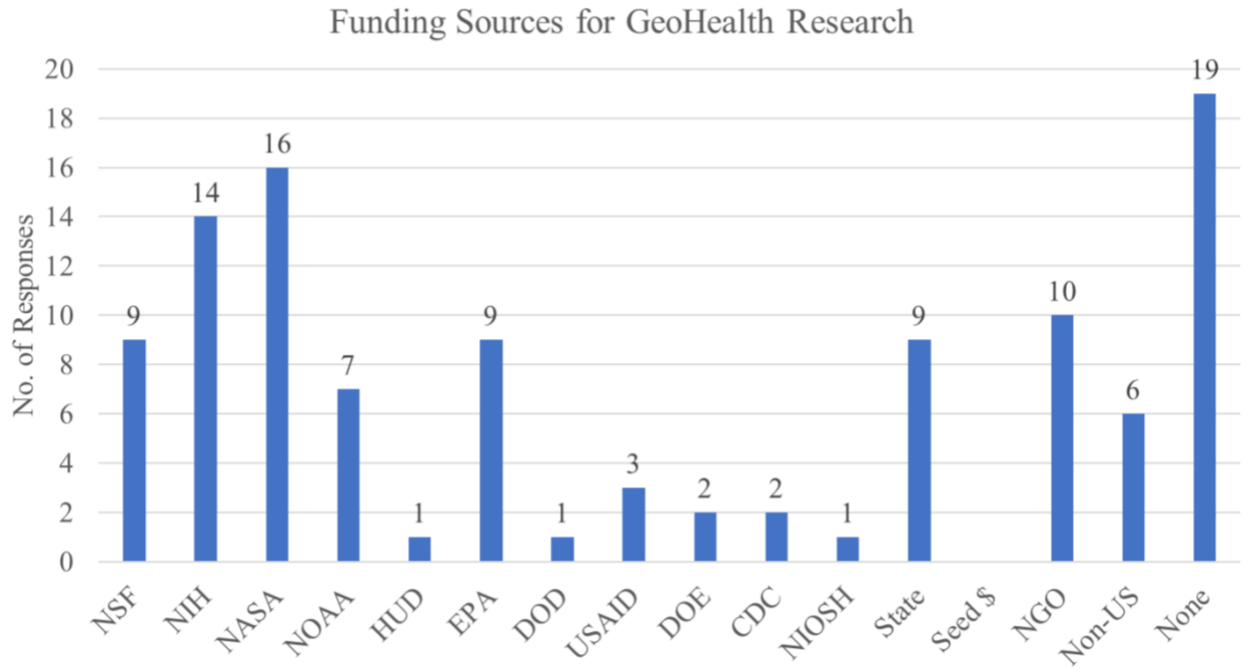
Q12: What is your career stage?



Q14: Please indicate your main areas of research or what best describes your departmental affiliation or expertise (please select best one or up to three)



Q15: Please indicate your recent, main funding source(s) for GeoHealth-related work in the past 5 years (can select more than one)



Survey Results: Open-ended Questions

The full responses to several of the open-ended questions are below.

Interdisciplinary/convergent challenges in GeoHealth

Q2, Q3, Q4: Suggest one or more high priority, impactful, interdisciplinary/convergent challenges in GeoHealth where important progress, outcomes, or a high value deliverable can be made in the next 2 to 3 years

- Modeling future health impacts of climate change in the US and/or globally through various pathways - e.g. wildfire smoke, dust, vector and water-borne disease, heat, aeroallergens, etc. In 2-3 years we wouldn't have certain and precise values, but could get decent estimates that could be used to inform policy-relevant metrics like the Social Cost of Carbon.
- Risk assessments of extreme climate change induced events on human and animal health (e.g., extreme heat, weather-related events such as flooding, water and soil contamination, etc) using complementary convergent science teams of geoscientists and biomedical researchers
- Understanding the distribution and mix of soil metals not impacted by the road side or the dripline
- Issues of environmental justice and how GeoHealth can inform policy makers in this space
- How does the geochemical character of cities affect human health?
- Health and economic impact assessment of climate change mitigation and adaptation policies, which leverages the strength and leadership of AGU's climate modeling field
- There is a recent trend both in state and federal agencies to better understand cumulative impacts - how multiple environmental hazards impact communities. It is sometimes difficult to quantify outside of environmental measurements what this exposure looks like - more engagement with EJ communities for qualitative or 'lived-experiences' that align with environmental measures would help to advance understanding and build systems to reduce exposures in these communities.
- Climate change
- The impact of mining on livelihoods and health
- Air pollution epidemiology
- global characterization of ground-level air quality together with its anthropogenic and natural sources
- Research that goes beyond simply identifying problems (e.g., climate change impacts on X, health disparities, etc.) and includes actionable pathways to mitigate these issues
- Mapping and forecasting emergence and spread of zoonotic diseases.
- impact of gas stoves on climate, indoor air quality, and health
- Identification and testing of "essential GeoHealth variables" for monitoring and predicting environmental health risks in space and time.
- Health and safety effects of dust storms, including infectious diseases (Valley fever), highway safety, etc.
- Air toxics released from fires at the wildland-urban interface
- Supporting community-led, interdisciplinary environmental health research and investigation
- Elements toxic to human health occur naturally in ground and surface water. Levels in water can vary considerably both temporally and spatially. While these variations can result in misclassification of human exposures in epidemiology studies, our ability to understand and predict concentration variability is poor. Better approaches to addressing this aspect of exposure are needed.
- It would be great to see the NSF provide funding for a focus on sustainable interventions that allow for addressing a reduction in infectious disease burden at the intersection of environment and health.

- soil health as it relates to the food chain and industrial farming the US
- Our understanding of the factors that cause harmful algal blooms (HABs). Many HABs result from exponential increases in cell numbers due to nutrient inputs from land. However, with certain species such as Pseudo-nitzschia, these factors leading to cell increases are not well understood. Furthermore, while cell numbers may be high, toxin production does not always correlate with cell number and toxin is not constitutively produced. Thus, there must be a trigger or triggers for toxin production. A focus on HAB species (both marine and freshwater) would incorporate biological and physical oceanography, analytical chemistry, molecular biology and even ecosystem modeling and bioinformaticians in order to predict, prevent, and mitigate these events.
- Biophysical understanding of environment and health connections only become meaningful to progress of human populations IF they are they are utilized in policy formulation and implementation. NSF should support both theory, practice, and obstacles to this critical aspect of GeoHealth.
- Explore how marketing can effectively educate consumers towards sustainable consumption behavior through the use of positive psychology.
- Decentralized wastewater infrastructure management to protect public & environmental health
- Assessing health impacts (i.e., air quality) of climate action plans proposed (or planned to be proposed) by local and federal governments
- Sustainable protein/food production from marine ecosystems to meet growing population demands
- Drinking water
- Diversifying the environmental health and GeoHealth workforce
- Understanding the relationships between increasing temperature and acidification of the ocean with coral disease and the effects upon species diversity and human health.
- experimental collaborations between geochemistry/mineralogy and toxicologists, i.e. carry out exosure experiments in the laboratory by using Earth materials
- waterfront coastal health
- Fund ways to support alternative energy
- Air quality, especially extreme weather events such as dust storm and wild fires
- Identify the factors that contribute to successful adaptation of diverse communities to the risks for and occurrences of wildfires, floods, and other disasters driven by climate change.
- I think the GeoHealth and Planetary Health communities should engage more intentionally and directly. This is less of a research area, but more of a community-building activity that I think will help accelerate the transdisciplinary work needed to achieve GeoHealth / Planetary Health (PH) / the Great Transition.
- Sustained funding support for the highly diverse teams of investigators whose research seeks to identify origin and control of zoonotic outbreaks, from molecules to ecosystems. These efforts are truly interdisciplinary, require convergent science approaches, with multiple aspects of earth science (e.g., soil, water, air) and include some or or kingdoms of life - from microbial, to plant, animal and human populations and their interactions at the community level. These highly challenging problems expand the standard definition of ""GeoHealth"" to include the critical aspect of the health of other members of an ecosystem.
- One of the biggest challenges for GeoHealth research is the interlinked data of environment, health, and other related disciplinary data (e.g., socioeconomic, policy). The lack of access to the interlinked and user-friendly data hinders the capacity of researchers to tackle these extremely interdisciplinary topics. Therefore, coordinated support from the federal and state government (including NSF, DHHS, NOAA, NASA, USGS, USDA, etc) to establish a federated data infrastructure that provides access/services to interlinked data that can be used to study GeoHealth can make really long term impact. Of course, the data infrastructure should follow the guiding principle of FAIR, TRUST, and CARE (for indegenous data) and relevant data sharing policies regarding privacy protection.

Additionally, the coordinated infrastructure will expose the current gap in data that can support GeoHealth research and policy and direct future investment.

- Funding for transdisciplinary work: this is a long-term project, but in the short term NSF programs like CIVIC or perhaps SBIR could be leveraged for GeoHealth-oriented calls.
- climate impacts on health
- How can we quantitatively show the direct links between climate change, disasters and disease burden, especially in marginalized communities?
- Expanding previous studies on the measurement and health impacts of high PM2.5 in minority areas across many more cities in the U.S.
- Translating Geohealth research into actionable information for the layperson
- Techniques for the radical reduction in the use of tobacco products world-wide and the conversion of tobacco growing fields and supply chains to food-stuffs like corn, and grains, etc... and/or using the land to plant trees to replace those lost in Brazilian rainforests.
- Develop a training and career pipeline for GH practitioners to further develop the discipline
- Translating environmental remediation and intervention technologies to wide-scale implementation to help benefit all of society and therefore improve human and ecosystem health.
- funding opportunities
- Supporting research to operations: AGU-endorsed Evidence-Based Best Management Practices for practical responses to GeoHealth issues for individuals and organizations.
- GeoHealth should look to already well-established OneHealth communities and identified OneHealth priorities and problem sets. OneHealth predominantly focuses on the human and non-human animal side of health and would greatly benefit from more robust environmental focused engagement.
- addressing climate change
- Predicting Covid-19 from atmospheric parameters.
- Assess and evaluate the interactions among chemical stressors and non-chemical stressors (such as food deserts, lack of greenspace, lack of healthcare access) to understand mechanisms of action within human receptors.
- Address cumulative impacts
- A low hanging fruit would be to change dietary practices - most particularly greatly reducing beef consumption from factory farms in the U.S. This would have health benefits, occupational health (slaughterhouse workers) benefits, methane emission reductions, antibiotic use reductions, and would reduce animal suffering.
- Climate change and human health
- What are the relations between point source coal fired power plants and distributed poor heath/learning outcomes in downstream communities?
- Data integration
- Developing data repositories around environmental health topics such as climate change and natural disasters that include geospatial, health, vulnerability data
- Challenge: Providing health care to those in need in the immediate aftermath of a natural disaster, in a region where the health system is overwhelmed, damaged, or non-functioning.
- Use of high resolution datasets and advanced analytics / machine learning techniques to understand the impacts of extreme conditions (droughts, floods, post-disaster scenarios) on geohealth challenges (water and sanitation breakdowns, health infrastructure damage, air quality degradation, urban heat island effects, waterborne and vector-borne disease outbreaks)
- The interdisciplinary nature of wildfires
- Addressing vector-borne disease threats at a time when pesticides are under Endangered Species Act review, climate change is expanding the ranges of vectors, and public health department are stretched thin recovering from the COVID-19 pandemic. Deliverable would be increasing capacity

of states to monitor and respond to disease threats, measurable by a follow up NACCHO survey (follow-up to the 2017 and 2020 surveys).

- Better connect challenges related to climate, water availability and soil health to food security and food sovereignty.
- The soil/water/air vectors are vital yet understudied components of quantitative microbial risk assessment (QMRA). Nsf should specifically calm for research at this environment-health intersection.
- Mapping satellite derived to climate/environmental hazards to actual demographic patterns on the ground that are relevant to policymakers/stakeholders. The former is widely studied, but the demographic side of things is poorly understood because we lack high resolution, validated, geo-located data on demographic patterns for much of the most populated places on the planet. This is especially true in terms of understanding health risks linked to migration, but also for low-income urban residents (some 3 billion people or so).
- One interdisciplinary challenge is understanding the downwind effects of wildfire smoke on human health.
- Data synthesis of open information on environmental pollutants, from information sources such as satellite information, remote and personalized sensing, crowd-source, and existing monitoring.
- Climate change related health diseases and their mitigation
- How can refugee or migrating populations get access to clean water?
- Advancing the integration of environment and health information to predict health outcomes and to translate forecasts into actions.
- engaging communities in helping scientists frame meaningful questions - how do we do this in a meaningful, impactful way.
- Drought impacts on Nutrition and food security
- Drought impacts on nutrition and food security
- Addressing the nexus of climate change and toxics in agriculture (especially Midwestern agriculture) and agricultural practices, and how this intersection impacts human health (both directly and indirectly).
- Solid Earth Geohazards and Human Health
- Using solar and/or mini wind turbines to power street and highway lights would not only reduce late night crime rates but also it would reduce the accident rates (e.g. awareness of deer crossings) by installing more lights than we have on every street. In the long run this would also reduce the cost.
- Curbing compounded toxic pollution effects on maternal and child health, and child development.
- Reaching out to earth science researchers regarding the interdsciplinary links between their work and GeoHealth, because many scientists are not aware. This could be in the form of small seed grants or funding initatives to intiatiate conversations.
- Climate change adverse effects on the agroecosytem and food chain safety
- Taking an intersectional approach to geohealth hazards to avoid making this thing a siloed endeavor from the beginning
- Impacts of climate on mental health
- Quantifying the health burden of exisiting extreme weather events, such as wildfires, heatwaves, hurricanes, flooding, droughts.
- Environmental justice
- Identifying natural sources of environmental pollution (e.g. wildfire, dust storms, flooding) and making spatially and temporally explicit assessments (not just quantitative) to model near- (5- 10 year) and mid-range (25-30 year) scenarios of impact on health outcomes and burden on the healthcare system
- how shifts in energy use will impact equity in air pollution exposure and health impacts

- Development of new, dynamic and mechanistic approaches for projecting the effects of climate change on infectious disease risk. These approaches should account for the influences of climate variation (i.e., floods, droughts, and heat waves) rather than just mean temperature trends.
- Investigating causes and solutions for environmental health disparities, particular racial disparities
- Identify how consumer brands can address their role in consumer skepticism with purposeful marketing to help them focus on the promotion of mutual gain and collective sustainable development.
- Predicting how climate change will affect disease patterns in marine ecosystems
- Infectious diseases resulting from climate change
- Communicating goals and impact of GeoHealth to a wider audience in a shared plain language
- Examination of the effects of increasing global temperature upon plant and animal (including human) pathogens
- water table quality
- water quality, especially concerning harmful algal blooms
- Advocate for transdisciplinary research funding, academic departments (and rewards / recognition for such scholarship), and policy development that can reduce barriers to getting critical research done and translated into action for society. One of the biggest challenges facing our communities is that many societal structures that should be supporting and advancing well-being societies remain siloed. There aren't research funding mechanisms, academic department advancements, or policy institutions (e.g., Ministries of Health or Ministries of the Environment are the norm, rather than Ministries of GeoHealth / PH --- or advisors who can connect the two) that are integrative or transdisciplinary. We need a new approach to deal with our urgent and complex challenges.
- Data coordination networks/grants: funding to link health and environment data in a manner that preserves space-time resolution while protecting privacy
- pollen and allergies
- GeoHealth as a discipline (and/or subject of study) in university public health programs
- Creating high volume processing to recycle plastic containers at a reasonable cost and prevent the need for plastic waste dumping in land and oceans. This is in contrast to reducing the use of plastic containers, which are difficult to replace with glass, etc.. alternatives that need to be cleaned with harsh chemicals between use.
- Develop models for integration of environmental and human health data at a scale appropriate to advance critical questions of population health
- Finding colleagues in other disciplines or with needed expertise to collaborate
- Identify, characterize, and quantify decision support needs for GeoHealth issues that align with AGU's role.
- methane and carbon reduction
- Spatial analysis and Lead-Risk assessment
- Assess and evaluate the interactions and impact of ecological resources (lack of or contaminated) on human responses/impacts when exposed to pollution.
- environmental justice
- Asking people to "donate" the water from their lawns to agricultural uses - to grow food (e.g. urban gardens, urban greenhouses, etc)
- Health equity
- Are brownfield redevelopment practices uniform? What are relations between the demographics of the communities impacted and the nature of the end use?
- Should consider a multi-agency approach to share data and resources since NSF doesn't have all.
- More training opportunities and workshops across different sectors, professions, and skill levels to promote interdisciplinary work
- Challenge: Organizations responding to natural disasters utilize interventions that may be based more on experience rather than scientific evidence.

- The community health impacts of far-reaching smoke plumes
- Environmental justice focused on soil/rock activities (mining, oil, gas) - community based research focus
- Incorporation of data science (statistical science, machine learning) to optimize the collection and curation of health data, including the development of cyber-infrastructure to facilitate real-time data engagement.
- Impact of waste management on human and ecological health
- connections between climate change science and health-related climate services
- Climate impacts on disease patterns
- Funding to convene working groups of geoscientists, biologists, and biomedical researchers to define strategies and begin the design of priorities for implementing interventions, resilience and prevention of health risks of ecosystem disruption
- In collaboration with stakeholders develop modeling systems (to be adopted by stakeholders) to enable evaluation of outcomes in relation to specific management decisions (e.g. afforestation projects or prescribed burning) or policies over near- and mid-range temporal scales.
- Animal habitat
- Quality information to help mitigate misinformation regarding the environment to discourage apathy and dismissiveness by certain political parties.
- Enhanced use of the Belmont Forum, which is already supporting and planning additional support for climate and health projects. Perhaps these could be augmented with an additional RFP, supplementary funding (e.g., for transdisciplinary or additional country collaboration), or extra funds for something like an Early Career Investigator addendum to the planned RFP.
- Identify specific workforce needs and Union structural aspects of incorporating indigenous practices and ways of knowing in GeoHealth research.
- Dramatically reducing the cost of public transportation (FREE!), and increasing the services offered, to incentivize people to use it.
- Health geography
- Are U.S. based ecotourism efforts usurping indigenous stewardship practices?
- Data integration should be a part of the NSF cyber infrastructure

Largest Challenges and Barriers to Making Progress in GeoHealth

Q6: Please feel free to amplify or expand on your answer to the question above (What do you see as the largest challenges or barriers to making progress in these areas).

- Many of the other options are the downstream effects of lack of funding. If the funding is there, there will be career paths, more awareness, more colleagues with needed expertise to collaborate, institutional support etc. Lack of access to health data is another critical challenge - typically hard to access, doesn't have the needed spatiotemporal resolution or spatial coverage, and creates a barrier to conducting geohealth research.
- Given the pressures to maintain scientific focus to secure project funding in one's area of expertise for funding and career advancement, it is critical to promote opportunities for convergent research.
- One "other" is the failure to be self aware of our racist scientific and societal systems and treat some solvable things as "just the way they are"
- Access to human health data is the largest problem, followed by funding
- As a truly interdisciplinary field, GeoHealth research is inherently difficult to get funding either from NSF due to its health component or from NIH due to its lack of large, detailed, study population and inherent nature of the geographical analysis.
- Spatial data at the resolution of neighborhoods are difficult to obtain, particularly when it comes to health outcomes. It is also expensive to collect and monitor environmental conditions (soil, air, water) consistently to make determinations on how exposures have impacted the health of communities. Increased use of 'wearable' monitors and technologies is helping, but they need to be standardized to some degree in how to use and collect data to advance legislation/policies/interventions to protect human health.
- Particularly the field of sand mining is highly understudied, though we know it links to a broad variety of disciplines.
- The effects of air quality on human health are immense, but there are few funding agencies that support its global characterization, especially for the Global South
- All components listed above are important but the progress made is largely defined by the funding landscape. Building cross disciplinary (e.g. public health / geophyscial scientists) teams is time consuming and complicated. Some areas (e.g. air quality) has a head start - it's been ongoing for a while. Other areas, will have to start close to from scratch. But unless we start that effort development of cross-disciplinary teams in other aspects of public health, we will not be able to upscale the effort. I would also strongly suggest supporting new teams rather than exclusively well-established ones. There is a lot of benefit from new ways of thinking brought in by novices who don't know the "that's not how it is done" mantra. Aim for a very broad participation. And possibly even arrange scientific match making workshops.
- There is a massive pre-project lift for interdisciplinary work to ensure teams are speaking the same "language" and understand each others technical terms and project goals. Communication is key on interdisciplinary teams, but it takes a lot of work, especially when working with collaborators new to interdisciplinary work.
- I believe supporting community-led partnerships will be important to engaging diverse populations in the process of using science to answer pressing questions. Current funding and hiring/promotion practices rarely value the long-term, fluid, and often challenging relationships researchers sustain with their community partners.
- When NSF attempts interdisciplinary work one can assume the biases of each discipline will conflict resulting in lowest common denominator dollars pushed out the door. How will this be different?

- Universities have become top-heavy for many reasons. Individual investigators, mainly tenure-track faculty often do not benefit as much from collaborative research as from their own initiatives, so while rewarding for all, collaborative research projects across disciplines becomes a lower priority for most faculty. Building trust between university departments so department faculty believe that Deans and administrators will not take away resources or otherwise slow the pace of research when collaborations are established is vital.
- If sufficient funding is available to fund many groups of investigators all other problems (e.g. finding collaborators, institutional support, etc.) resolve themselves because funding is something that all investigators need.
- Academics talk about doing very complex, interdisciplinary work, but it is very difficult to actually do it because we aren't rewarded for these pursuits.
- I think GeoHealth (and interdisciplinary fields like it) suffer from a lack of diversity. By "diversity" in this context, I mean, race, gender, and professional background (i.e. prior training that lead to GeoHealth). I believe there are several ways that improving diversity in the field is a benefit to industry as well as the potential employees. I also believe there are several ways to go about addressing this problem.
- The research network to displace tobacco use world-wide and its associated growing fields will require at least 20 researchers from a number of social and science disciplines and the populations to test any techniques is complex and expensive.
- Basically, I think that we are lacking in all key aspects that define known disciplines. Having said that, we do have a vibrant section and a strong journal that can serve as cornerstones of this development
- The fact that GeoHealth exists separate from OneHealth (an already internationally recognized and supported approach to complex, intertwined health systems) suggests that professional silos exist and need to be broken down.
- The fastest way to address climate change is in policy change - and that takes leadership willing to take bold steps forward.
- The scientific practice of reductionism hurts the ability to do the above types of investigations. And when this kind of work gets done, it's done by researchers who don't understand or know how to bring the results to the policy realm. So on the rare occasions when this work is done, it stays in the library.
- Sustained engagement with communities can uncover data gaps and could lead to new approaches to solve problems. The lived experiences of communities must be respected and incorporated, in the earliest development of any intervention or research planning.
- NSF's COPE program strikes me as a novel approach for more holistic research with real broad impact. I might be off the mark but I suggest widespread further testing of this sort of funding model.
- Data integration challenge. See my article, Liu, Z., D. Tong, J. Wei, and D. Meyer. 2021. "Integrating Data to Find Links Between Environment and Health." Eos, 102: [10.1029/2021eo158802]
- It's very difficult to get access to human health data generally and even more so if near real-time data are desired
- There are very few networks or funding mechanisms that directly interdisciplinary collaboration around geosciences, climate and health disciplines. I work in the intersections of water security and global health, and it has been extremely challenging to find appropriate funding mechanisms across NSF, NASA, and NIH.

- Especially when it comes to funding, wildfire research is siloed into forestry, air quality, and public health... there are very few opportunities for interdisciplinary projects to be funded.
- There is a Vector-Borne Disease Network and many agencies that recognize the problem. Their is a lack of funding to political subdivisions and a lack of funding to the federal agencies that would need to collaborate. There is an authorization for funding, but vector-borne disease is not high on the list of priorities for large public health organizations because there are so many other issues to consider relating to climate change and environmental justice.
- Those trained in the physical sciences doing interdisciplinary work tend to have a weak understanding of demography and often use demographic datasets (e.g. Worldpop) without understanding their limitations. This is especially true among the climate impact modeling community. Because of this, funders (NASA, NSF) often have reviewers of proposals that lack training in best practices in merging human and environmental data. So for example, a remote sensing trained reviewer will lampoon the social science side of a proposal without proper expertise. This is improving as more truly interdisciplinary-trained early career scientist review proposals and draft new funding calls, but it's a slow change.
- In 2021, the impact of wildfire smoke on human populations in the (western) US became readily apparent. However, free and easy access to health data remains a challenge. Then, as the frequency and duration of the events increased, it became apparent that the current collaboration/funding system was too slow to provide adequate response. A similar shortcoming was revealed as the COVID-19 pandemic began to ramp up in the US.
- Funding climate is tough for bold data and infrastructure development. Environmental data come in various forms and are not easy to synthesize. Human health data are very difficult to obtain.
- Translating health security outlooks into actions requires interdisciplinary and multidisciplinary collaboration with participation of research community as well as practitioners, policy makers, and program managers. Given recent scientific advances, it is timely to bring together relevant stakeholders to advance health early warning systems.
- For many in Geosciences, societal implications as is often captured by GeoHealth topics, are not valued or considered scientific enough. This attitude leads to there being limited support for expanding research beyond typical metrics to explore important GeoHealth topics such as local community impacts or environmental injustice issues.

What should NSF consider doing to foster these efforts?

9: What should NSF consider doing to foster these efforts that would be effective within the next 2 years (so without reorganization)?

- Create a collaborative funding program with NIH or an NSF funding opportunity specific for GeoHealth, ensure that the review panel has adequate interdisciplinary representation.
- Promote workshops to connect researchers with expertise in OneHealth and GeoHealth with facilitators whose research is multidisciplinary; funding begets interest in such convergent research but would be helpful to specify cross disciplinary team structures
- DCL that create programs that incentivize co-funding of proposals are really effective. It would be trickier here when working with groups like NIH, but worth it.
- Multidisciplinary, interdisciplinary funding calls aimed towards GeoHealth
- Special funding opportunities dedicated to GeoHealth
- Rethink how grants are allocated. Higher Ed institutions received 50% or more in indirect costs, this eats away at institutions, researchers, and community partners ability to work - set a lower cap on indirect costs. Another way would be to structure the grants so they pay over longer periods of time to maintain relationships - the extractionary nature of some academic research based on grant cycles does lasting harm.
- develop a new program with sustained funding
- Expand opportunities through existing or new funding mechanisms that encourages research that is less basic/fundamental in nature and more applied.
- I would suggest a 2-step funding programs. Step 1 to fund many exploratory stage projects (smaller grants) for no more than 2 years. Step 2 select the most promising projects to move further for additional 3 years (larger grants & longer timeframe). Broaden initial participation to as many teams as feasible to manage - flood the field with new ideas and approaches.
- Training programs for researchers at any stage who want to engage in geohealth research but don't know how to establish interdisciplinary projects and teams.
- More funding (beyond just the EEID program) directed toward GeoHealth topics
- A dedicated funding opportunity to support health studies of dust storms.
- Break down institutional barriers with NIEHS and NIH
- Create flexible funding streams to support collaborative partnerships that can adapt as needed over the course of a project. Include direct payments to community partners.
- Might be useful to begin with some focused workshops that are multidisciplinary AND multisector.
- Provide funding specifically to address interventions at the intersection of environment and health.
- An increase in "Center" grants
- Create a transparent mechanism that allocates budget to a unit of NSF that is not subservient to traditional disciplines.
- Be more open-minded when it comes to the convergence of STEM with social sciences.
- Convene brainstorming/listening sessions; bring interested people together to explore approaches to solutions
- Expanding funding opportunities for interdisciplinary topic of research (i.e., climate chante and public health)
- Collaborative funding opportunities to engage more scientists with skills sets that are currently more aligned with medical research (e.g., -omics). The oceans are our new patients.
- Funding personnel to work under PIs to facilitate collaboration and grant management
- Increased funding for these efforts

- come up with a program between NSF and NIH/NIEHS
- promote honest education about pragmatic solutions to achieve more bipartisan supped for these initiatives
- to provide related funding opportunities
- Provide funding and guidance to encourage greater interactions among physical science, health, and social science researchers.
- Provide transdiciplinary funding streams that clearly supports GeoHealth / Planetary Health research. This will allow critical research to move forward, which may inspire academic institutions to value and reward such work.
- Establish clear funding lines for GeoHealth research; support for networks that link GeoHealth researchers and trainees to potential interdisciplinary collaborators (e.g., similar to Research Collaboration Network (RCN), support GeoHealth training programs
- Use cyberinfrastructure programs or leveraging the Harnessing Data Science effort to support the development of data infrastructure to provide data sharing and services for interlinked data.
- Targeted RFPs by existing programs: CIVIC, DISES, EEID, etc.
- When I talked with an NSF program manager about supporting geohealth funding, they're very wary about stepping on the toes of NIH. And NIH seems more concerned with spending money on clinical trials, so geohealth seems to fall between the cracks of NSF and NIH.
- Have NSF break out of its silos- Right now, it is difficult to pigeonhole GeoHealth into a given program (as far as I am aware...).
- Encourage sharing of data across communities.
- Actively and aggressively implement programs aimed that growing the pool of GeoHealth professionals
- Create a global conference focused on tobacco use or plastic recycling with invited scholars and practitioners on a number of social and physical sciences to develop a plan.
- Develop several cross-agency (i.e.,. NSF/EPA/NIEHS/HUD/NASA) funding calls focused on developing a viable pipeline for GeoHealth scholars
- Create incentive for collaborative proposals that are community-focused and also effectively develop the next generation of scholars. Making a greater abundance of small award proposals for graduate students and young PI's with limited barrier of entry could help foster this.
- Collaboration with local health departments to facilitate data sharing
- Delineate long-term boundaries between NIEHS, NASA, and NSF on GeoHealth. Implement a cross-directorate program like CNH, with GeoHealth as an applied subset.
- Drive more practical GeoHealth/OneHealth cooperation and alignment.
- COLLABORATE WITH COLLEAGUES OUTSIDE GEOHEALTH incentives for sharing data.
- Look for dedicated, broad-thinking individuals no matter their current affiliation or science expertise that have the vision, passion and willingness to be part of a team (not prima donnas looking for accolades) and recruit them, even if part time.
- Incentive and compensate communities to be partners and research and intervention development.
- Recruit "champions" from various organizations and fields of study to begin generating interest and to educate
- Provide funding opportunities
- Promote community-centered workshops.
- Why not? NSF supports basic scientific research. Right?
- Develop curricula or educational programs and increase outreach to schools/academic institutions, public health practitioners at the local and state level

- support more collaborative, interdisciplinary research training
- Targeted proposal opportunities in Geohealth - and other appropriate opportunities distributed through EEID, DISES, PIRE, Hydrological Sciences, etc programs
- purposefully fund interdisciplinary research teams!
- Encourage members to join other organizations. Encourage professional associations to add a trial membership option that is inexpensive for the first year.
- provide funding calls that target this need
- Dear colleague letter to target specific interdisciplinary efforts within existing funding mechanisms
- Make publishing code mandatory with all NSF funding.
- I think pilot programs to test out innovative funding strategies or NSF-led directed partnerships might be ways forward.
- Some workshop or IDEA lab?
- Provide large fund (5 million minimum) to support doctoral and postdoc studies in GeoHealth
- Support training and internships
- Work with health agencies such as HHS, NIH and CDC and environmental agencies such as NOAA, NASA, USGS, EPA, and development agencies such as USAID to create a dialogue that leads to interagency agreements that enable actionable environmental forecasts in health.
- support non-academics entering the review process for NSF grants, lower barriers for grants to support non-traditional grantees
- Water-climate-health research
- Creating significant public awareness and convincing the youth about a clear career path.
- Promote interdisciplinary research and training
- Seed Grants within existing structures, e.g., Oceans or Petrology / Geochemistry with a required GeoHealth component to research and outreach (in which both research output and broader impacts will be properly evaluated)

What Should Societies Do?

Q10: What should science societies do to help foster these efforts?

- Bring together the leaders of GeoHealth with leaders of relevant sections of other societies to share ideas and create collaborations, potentially organize a joint science meeting to highlight GeoHealth research, publish position statements or short commentaries describing the importance of GeoHealth research and what could be done to grow the field
- Create educational and research opportunities towards a larger awareness of the value of GeoHealth research from complementary disciplines and investigators from biological, biochemical, biomedical, agriculture and earth sciences. The societies of AGU and FASEB have begun the process of engagement annually since 2019, convening cross-disciplinary areas to discuss effects of climate change and health.
- Support hybridization. For example, in AGU the creation of sections is viewed by many as part of a power thing (for example, consider the history of earth surface processes breaking from hydrology.) Making this a zero sum game just sucks.
- Continue to support webinars, conferences, workshops, etc.
- Active engagement with responses to funding organizations' calls for suggestions (like this one) and help disseminate research findings to policymakers through organization statements or policy briefs.
- If an institution can not maintain the relationship, it may be that the professional society can step in to play the role of support or convener for these groups. I think the AGU Thriving Earth Exchange is a good project-to-project model, but can this somehow be extended or maintained for longer?
- promote awareness of the impacts of air quality on human health
- Continue to host sessions at conferences and symposia on geohealth
- Since geohealth issues belong to no one particular country, science societies in the U.S. like AGU could encourage more deliberate partnerships with geoscience/health societies in other countries, especially in the global south, through joint conferences, travel grants, mentoring programs, etc.
- Host workshops and networking events (at aforementioned conferences, virtually, and/or in person at different times of year) to help scientists, especially ECR, make connections and plan research. "
- How about workshops that foster scientific match making? I would suggest numerous smaller events culminating in a couple of large events throughout the year. Smaller vents (1.5-2 hours) would allow for a manageable time commitment to meet several teams who are working in the same domain and give them 5-10 min to talk about what they ere doing and have a moderated Q&A to show how they differ. The large events can be associated with annual meetings and do in-person topical meet & greet events.
- Work toward understanding the current career prospects for GeoHealth scientists and increases future opportunities.
- Continue to develop forums for GeoHealth research
- Like the AGU TEX model, find ways to fund/support/build capacity for community partnerships/community-led research among your members. Seek out partnerships with non-scientific societies to deliberate on potential
- Joint meetings would be valuable.
- Ensure that the concepts are promoted in their societies so that this type of research is normalized.
- They should promote interdisciplinary research by forming "joint society" national meetings and opportunities for showcasing interdisciplinary Ocean and Health related research.
- Be more collegial and share data.
- Publicize them, offer sponsored meeting options/subportions of their annual conference(s)

- Healthy relationships among scientific communities, stakeholders, and the general public via frequent and effective communications.
- Media efforts to highlight challenges and opportunities in these areas.
- Appoint journal editors who want to publish such research
- Have sessions at national and international meetings that address these areas of research.
- Seed funding
- need more grassroots efforts with practical approaches to achieve broader buy-in nationally and globally
- Form network to bring together scientific communities and the public
- Scientific societies can work together and with NSF to support stronger interdisciplinary interactions, through meetings, workshops, and publications.
- Reach out to like-minded societies to build community across their societies. Potentially, find common goals and share those across all society members to demonstrate a large, coordinated commitment to working on particular topics from different vantage points.
- Partner with funding agencies to expand awareness of GeoHealth as a crucial factor to sustained human, animal/plant/microbe, and geophysical resources. Individual societies to encourage their members to develop prospectus on how their discipline is currently making, or planning for future, input to GeoHealth, to help establish a "community of experts" - type network that benefits all.
- Convening conversations between agencies and researchers from different disciplines to prioritize the development of data infrastructure and high priority data sharing and collection targets.
- Engage the broader health and geoscience research communities in these conversations, in order to expand the community interested to work on these topics.
- Recognize and encourage interdisciplinary research.
- Highlight the need for expert generalists that make links between highly-specialized experts.
- Bring visibility to the areas of greatest need through podcasts, newsletters, special workshops, etc.
- Actively and aggressively implement training programs aimed at preparing students who have been accepted to college, but may not have the necessary math and science skills to succeed in the field
- Focus on a single problem - such as tobacco use and displaced farm land - similar to the effort behind COVID 19 vaccines and treatments.
- Provide advertising/recruiting/leadership identification for the initiatives above.
- Promote proposals and community-based events where researchers incorporate communities in their GeoHealth research and are encouraged to train the future generation of scholars to be more interdisciplinary in their research approach.
- Identify and begin to address bottlenecks in the research to operations pipelines
- Stop coming up with new siloed paradigms to address shared problems and continue to re-center focus on long-term interspecies survival as the primary purpose of science.
- Provide more funding for Geohealth
- Do a talent search among their memberships to find such individuals described in #9.
- Respect the knowledge and experience of communities and see the humanity within the data. Stop normalizing "acceptable risk" and set goals to minimize and hopefully eliminate risk in the future.
- Public awareness through advertising, guest lecturing at churches/schools/universities, showing how marginalized populations could benefit, find ways to show powerful benefit from small changes
- Advocate for funding resources
- Foster cross-fertilization. As I understand it, the emergency management community has a similar lack of diversity as the geoscience community has. Connecting emergency managers with epidemiologists with geoscientists with social scientists seems worth some effort.

- Data integration not only helps GeoHealth, but also other research areas.
- Continued engagement at conferences and hosting webinars that bring the geospatial and health communities together
- Encourage more collaboration across disciplines and with partners outside academia
- Workshops and symposiums with targeted research questions - not just not networking or promotion service
- create conference sessions specific to interdisciplinary work
- Increase science clubs and projects in the schools. Create internships, mentoring programs.
- Prioritize these challenges via special issues, workshops, events, and funding opportunities
- Rethink fellow and other reward structures. Make nomination process tiered such that only CVS and a one pager is needed for rewards additional materials requested from shortlist with feedback to nominees. Explicitly reward interdisciplinary and community engaged work
- Lead open data science best practices workshops.
- In my opinion, science societies are responding well given their membership and mandates. I've been impressed with the response of AGU and the GEO Health Community.
- To collaborate between health, geo and data science disciplines.
- Promote GeoHealth discipline; mentor future professionals and dedicate sessions at annual meetings to Geohealth.
- Bring spatial literacy to conferences by inviting keynote speakers who can speak to the importance of "where".
- Promote this initiative through annual meetings, conferences, and workshops. Advocating for multidisciplinary scientific research that advances early planning and early actions.
- support non-traditional research alongside traditional; encourage engagement with social scientists, science policy professionals, and others who can help create effective, necessary bridges that cross disciplines and connect research and practice.
- Build partnerships with industry that has a consumer arm (e.g. general mills, Kellogg and their sourcing; where do they get their ingredients? What farms do they work with? What are the practices on those farms? How are those farms either hurting or helping their communities?)
- Communicate and create taskforces whose members come from different societies.
- Collaborate with stakeholders on interdisciplinary training of the workforce
- Develop specific sessions, early career networking events, and small seed grants for workshops and local community events to emphasize the importance of integrating GeoHealth topics across the Geosciences.

Any Other Recommendations

Q11: Please add any other thoughts or recommendations

- One might think if NIH as a potential supporter in this area, but NIH lacks the geoscience emphasis that is sorely needed, especially at the global scale
- To accelerate the growth of the field, we need target strategies that facilitate very broad engagement. The organic growth will be insufficient to address this field. We should also bring economists into the fold - they can make matters so much more interesting and appealing.
- PI workloads have become impossible as university budgets have shrunk!
- Generally the US government must increase research funding support for all areas of science.
- Not at this time
- Don't do a call for participants....recruit. The best ones often will not volunteer because they are busy.
- Those who are disproportionately impacted should be equal partners and have decision-making power.
- Education, awareness, inclusiveness, interdisciplinary
- We need to invest in leadership in communities that have historically been excluded.
- Agencies (and reviewers) are not ready to fund large interdisciplinary teams and activities. Cyberinfrastructures don't address multi-agency data integration challenges.
- Thank you for the opportunity to comment.
- This is a great survey
- Urge NIH leaders to promote physicians' collaboration in Geohealth research with earth scientists
- This is a long overdue initiative that if done right will lead to tangible societal benefits.
- There is a huge cultural difference between NIH and NSF. It is very difficult for individual researchers or small groups of researchers to span the chasm and obtain funding. Anything NSF could do to bridge that gap would be helpful.

Q17: In what journals are you most often publishing your GeoHealth-related papers? Please list top three or so (not all).

- GeoHealth, Lancet Planetary Health, Environmental Health Perspectives
- Environmental Research Communications
- GeoHealth
- Environmental Research; Environment International; The Lancet Planetary Health
- Sadly, any place with low or no cost associated with publishing.
- Env. International, Env. Research Letters
- Nature Sustainability
- GeoHealth, Journal of Exposure Science and Environmental Epidemiology, Environmental Monitoring and Assessment
- ES&T, Nature and Science family of journals
- GeoHealth, ERL
- Environmental Science and Technology; AGU's GeoHealth
- American Journal of Tropical Medicine and Hygiene, Malaria Journal, Int J. Health Geographics
- GRL, BAMS
- PLoS; ERL; EcoHealth
- Environmental Science and Technology, Limnology and Oceanography, Frontiers in Marine Science
- Body Image
- Appl Environ Microbiol
- Journal of Physical Chemistry B, Bioorganic and Medicinal Chemistry
- AJPH, Enviro Justice, Health & Place
- Applied and Environmental Microbiology, BMC Microbiology
- GeoHealth, Journal of Environmental Research and Public Health, Environmental Science and Pollution Research, Atmospheric Environment, Chemical Research in Toxicology
- GeoHealth
- Science of Total Environment
- Lancet family of journals, GeoHealth
- Science of the Total Environment, Environmental Health
- NHESS
- EGU AMT
- GEOHEALTH
- Science of the Total Environment, GeoHealth, Environment International
- GeoHealth, Science of the Total Environment
- APHA or National Environmental Health Association
- IEAM
- Journal of the American Heart Association, AJPH, JEH
- Oceanography
- Eos, Data Science Journal
- GeoHealth
- Geohealth, Lancet group, American Journal of Tropical Medicine and Health
- Wetland Ecology and Management
- Global Environmental Change
- Gateways, Risk Analysis
- PNAS, ERL

- Environmental Science and Technology
- JESEE.
- IJERPH
- AMS
- Environment International, Nature Communications, Exposure and Health
- International Journal of Disaster Reduction Research, International Journal of Environment and Public Health
- Haven't yet published GeoHealth papers but interested in doing so.