GEOSPATIAL FRONTIERS IN HEALTH AND SOCIAL ENVIRONMENTS
GRANT NUMBER 5R13CA162823

FINAL REPORT

SUBMITTED TO THE NATIONAL INSTITUTES OF HEALTH
BY THE ASSOCIATION OF AMERICAN GEOGRAPHERS

NOVEMBER 20, 2013

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1. Introduction

The Association of American Geographers (AAG) received funding from NIH for a project entitled **GEOSPATIAL FRONTIERS IN HEALTH AND SOCIAL ENVIRONMENTS** (5R13CA162823). The aim of the project was to examine the possibilities and challenges for health-and-environments research associated with advances in the field of geographic information science (GIScience).[1] The grant helped support a core set of research and outreach activities that included organizing and participating in scientific meetings, building and deepening interdisciplinary communities and connections, developing publications, and conducting a broad range of dissemination activities. In particular, leading researchers in geography, GIScience, biomedical research, public health, and other computational, social, and behavioral sciences actively participated in a series of three interdisciplinary scientific symposia in 2012-2013 and engaged in substantial discussions around health research needs and GIScience developments and innovations. This document serves as the final report for this project.

Following this introduction, Section 2 of this report provides the context for the project – how health sciences research that takes full advantage of the latest advances in geography and GIScience can lead to a more sophisticated and integrated understanding of the interactions between people, health, and the environment and create new opportunities for scientific discoveries. Section 3 then outlines a set of AAG-NIH initiatives related to GIScience and health and the prior research foundations for the **GEOSPATIAL FRONTIERS IN HEALTH AND SOCIAL ENVIRONMENTS** project. Section 4 includes an overview of the broad range of activities accomplished through this project, including summaries of each of the three interdisciplinary symposia. Section 5 presents key outcomes of the project, including a research agenda focused on enhancing the integration and sophistication of GIScience-based approaches in health sciences research, followed by a conclusion in Section 6.

[1] See Goodchild (1992, 2010) for discussions of the development of GIS as a science with its own research agenda.

2. Context

Revolutionary changes are taking place in how we observe, monitor, and understand the earth's social and physical environments. Geographic information systems (GIS) were the focus of a first revolution in the analysis and visualization of geospatial information that occurred during the 1980s and 90s, but now a second revolution is underway which emphasizes the collaborative analysis of data distributed over both space and time. In connection with these advances, the past two decades have seen dramatic increases in the use of geography and geospatial data, methods, and tools in health sciences research (Cromley and McLafferty 2012; Richardson et al. 2013). From tracking disease outbreaks (Brouwer 2012), to modeling the impacts of environmental risks on substance abuse (Mennis and Mason 2011), to understanding how neighborhood environmental characteristics affect obesity and physical activity (Zenk 2011; Torio 2012), geography and GIScience are transforming our ability to investigate, visualize, and understand environmental and contextual effects on health (Kwan 2012a,b; Kwan 2013). Interest in utilizing GIScience increasingly cuts across the social and biomedical sciences, and across the diverse Institutes and Centers of the National Institutes of Health (NIH).

The increasing use of geography and geospatial data, methods, and tools in health sciences research is closely tied to interrelated and converging trends. First is the rapid increase in the availability of geospatial data. Massive quantities of geospatial data are streaming in from a variety of fixed and mobile sources, including sensor networks that record environmental conditions in real time (Hart and Martinez 2006); GPS-enabled devices that record people's everyday movements (Kwan 2004; Wesolowski et al. 2012; Richardson et al. 2013); Internet-based geospatial information volunteered by citizens (Goodchild 2007) or "participatory sensing" (NRC 2012b); biosensors that collect spatially- and temporally-referenced biological data (Stahler et al. 2013); real-time ecological momentary assessment (EMA) tracking of spatiotemporal data on psychological states, behaviors, and social interactions (Epstein et al. 2013); and satellite-based sensors that continually monitor land uses, human settlements, vegetation, and atmospheric conditions (Herbreteau et al. 2007; Bell, Wilson, and Liu 2008). Using this expanding array of geospatial technologies, researchers can record and analyze changes in both built and natural environments and people's movements and social interactions within these environments.

Second is the rapid development of methods for analyzing spatial and spatiotemporal data. Researchers have implemented new data models for representing and managing spatiotemporal information (Goodchild, Yuan, and Cova 2007). Methods have been developed to model people's daily movement patterns and the environments with which they come into contact (Kwan 2009), to trace people's migration histories over their life course, and to study the clustering of diseases in space and time while accounting for mobilities and flows (Jacquez, Meliker, and Kaufman 2007).

Third is the development of cyberinfrastructure[2] (Atkins 2003, 2005), the geospatial Web, and cyberGIS. Comprising distributed and networked computing resources, these systems enable researchers to work collaboratively on large data sets from dispersed locations, to integrate and analyze data of varying provenance and quality (Zhang and Goodchild 2002), and to incorporate dynamic spatiotemporal data about people and environments. Frameworks for these Web-based systems have been developed (Wang 2010; Wright and Wang 2011; Wang et al. 2012), and many researchers view such systems as the GIS of the future, as sharing data and working collaboratively are critically important in multidisciplinary research. Fourth are the increasing opportunities for data integration by using space and time as frames for integrating data from multiple, disparate sources, including social and environmental data (Richardson 2013).

At the same time, there is growing interest in how the environment, broadly defined, shapes people's health both directly and indirectly through its impacts on health-related behaviors, social interactions, and genetic and socio-demographic risks (NRC 2012b). Attention to environmental determinants (ranging from organic and inorganic pollutants to viruses and single- and multi-celled organisms) cuts across many domains of the health sciences. In infectious diseases research, although the impacts of environment on disease risks and transmission have long been recognized, a large and rapidly expanding group of researchers is investigating how environmental transformations such as climate and land-use change affect disease spread (Mayer 2000) and how people's social interactions and networks intersect with environmental risks in affecting vulnerability to infection (Ali et al. 2009). With respect to obesity and physical activity, evidence is mounting that environmental characteristics such as urban sprawl, street connectivity, access to recreational spaces, and local food environments play an important role (Moore et al. 2009; Zenk et al. 2009). In cancer research, the impacts of environmental exposures, together with geographical access to care, on disparities in late-stage diagnosis, and variations in these impacts across places and geographic scales, are also attracting attention (McLafferty and Wang 2009; Mobley et al. 2010). Contemporary research on substance abuse shows that neighborhood environments present a mix of risky spaces and opportunities for positive social interactions that differentially shape people's risks of substance abuse (Galea et al. 2004; Mason et al. 2004; Thomas et al. 2008; Mennis and Mason 2012). Although genetic influences on health have been widely studied, there is growing interest in how environmental factors might modify genetic influences – or alternatively, how genetics might modify environmental influences – with potentially complex implications for human health. Addressing these research questions requires us to characterize both place environments and people's interactions with and within such environments, and these tasks are increasingly accomplished via GIS (Cromley and McLafferty 2012).

[2] "…refers to infrastructure based upon distributed computer, information and communication technology. If *infrastructure* is required for an industrial economy, then we could say that *cyberinfrastructure* is required for a knowledge economy" (Atkins et al 2003:5).

"Cyberinfrastructure and its use is both an object of research as well as an enabler of research...[it] both enables and requires a new wave of collaboration. (Atkins 2005:2).

Yet despite their tentative adoption, most health-science applications do not take full advantage of the latest advances in spatial and spatiotemporal data analysis and modeling, or the new types of geospatial data and computing resources and tools that are becoming readily available (see for example, Auchincloss 2012; Matthews 2012; Torio 2012). Much ongoing research relies on GIS as a means of managing and analyzing georeferenced data on health outcomes and environmental characteristics. However, the vast majority of research studies adopt a static perspective that views people's locations as fixed within an unchanging environment (Kwan et al. 2008; Kwan 2009).Yet we know that people are mobile, moving from place to place in their daily lives and changing their residential locations over longer time scales (Kwan 2000, 2004, 2013; Matthews 2012). Research shows that low-income households undertake their daily activities in locations that extend well beyond the boundaries of their residential census tract (Matthews, Detwiler, and Burton 2006). There are also important differences in such spatial behavior based on age, gender, race/ethnicity, and access to transportation. These everyday mobilities affect people's encounters with, and experiences of, diverse place environments, which in turn affect health-related behaviors including physical activity (Troped et al. 2010) and injection drug use (Williams and Metzger 2010).

Over longer time scales, migration is an important consideration in health and environments research (see Matthews et al. 2011 for a discussion on spatial demography). Approximately one-fifth of the U.S. population moves each year, with each move altering a person's daily environmental exposures. Moreover, migration can lead to selection bias in statistical models of health and environmental associations. Migration also varies over the life course, potentially confounding assessments of life-course changes in health-related behaviors. Thus, the geographic and temporal dynamism of people's lives is a key and understudied dimension of research on health and social environments.

Natural, built, and social environments are also dynamic, changing in response to social and natural processes. In cities and metropolitan areas, built environments and land uses are in constant flux as competitive forces and urban expansion affect how land is used and by whom. Changes in residential environments, access to employment and services, locations of and exposures to environmental hazards, and access to various forms of social and neighborhood capital—both drivers of and outcomes of environmental change—have potentially significant implications for human health.

These issues are of growing importance across NIH where GIS and spatial modeling are already used in research, for example on the epidemiology of cancers (NCI); heart disease, stroke, asthma, and COPD [chronic obstructive pulmonary disease] (NHLBI); infectious-disease transmission, ecology, and spread (NIAID and Fogarty Center); understanding the relationship between UV radiation, vitamin D levels, and MS prevalence (NINDS); small-area analyses of pain and access to care for pain-related conditions (NINDS); and in social epidemiology research related to drug abuse and treatment (NIDA)[3]. However, the

[3] National Cancer Institute (NCI); National Institute of Allergy and Infectious Diseases (NIAID); National Institute of Neurological Disorders and Stroke (NINDS); National Institute on Drug Abuse (NIDA)

potential for GIScience and spatiotemporal analysis to support and enrich NIH's research portfolio, to serve as an "incubator" for interdisciplinary and transdisciplinary research (Matthews 2012), and to substantially inform research on health interventions and outcomes has yet to be fully realized.

3. Related Initiatives and Prior Research Foundations

The **GEOSPATIAL FRONTIERS IN HEALTH AND SOCIAL ENVIRONMENTS** project builds on several recent joint AAG-NIH initiatives. The AAG has been working closely with NIH for nearly a decade on the integration of geography and GIScience in medical and health research. The AAG and NIDA, for example, have jointly sponsored special symposia at the AAG's Annual Meetings for more than five years on the previously undeveloped research area of geography and drug addiction. One result of this effort was the publication in 2008 of the book *Geography and Drug Addiction*, developed and co-edited by NIH and the AAG.

Three years ago, the AAG began to build on this collaborative foundation with NIH with a far-reaching new initiative for GIScience, health, and geography, called the *AAG Initiative for an NIH-Wide GIS Infrastructure*. The rationale for this AAG Initiative is the unmet need for spatial and spatiotemporal data and analyses, as well as for geographic context, across nearly all of the NIH's 30 individual institutes. This need is pressing for research undertaken at NIH ranging from gene-environment interaction in biomedical contexts to the tracking of disease outbreaks and the assessment of health service delivery. See Appendix A for a description of the AAG Initiative.

After discussions with NIH officials in multiple Institutes, the AAG received support from and worked with NIH to hold a high-level workshop in February 2011 to further develop the conceptual framework and GIScience research needed for implementation of an NIH-wide GIS infrastructure. This workshop, co-sponsored by the AAG, NCI, and NIDA, included senior scientists and administrative leaders from all across NIH, as well as intramural and extramural researchers. Recommendations, priorities, and next steps in this process are the subject of a recent report prepared by the AAG and NIH, entitled *Establishing an NIH-wide Geospatial Infrastructure for Medical Research: Opportunities, Challenges, and Next Steps.* See Appendix B to access a copy of this report.

In connection with these initiatives, the AAG received a competitively-awarded grant from NIH's crosscutting OppNet Program to examine the possibilities and challenges for health-and-environments research associated with innovative developments in the fields of geography and GIScience. The specific aims of the project have been: 1) disseminating information on GIScience developments and on health research needs related to GIS; 2) fostering interdisciplinary collaboration and common terminology; 3) identifying key challenges, including such issues as maintaining confidentiality of location-specific data, analyzing data of varying quality, and integrating spatiotemporal data with behavioral and genetic information; and 4) developing a research agenda to address these issues and enhance the integration and sophistication of GIScience-based approaches.

Working with experts at the intersection of geography, GIScience, and research in the public-health sciences, intensive research and outreach activities were conducted, including the organization of three scientific symposia held in 2012–2013, to foster new collaborations and dialogue among geographers, GIScientists, biomedical researchers, computational scientists, and social and behavioral scientists around health and environment research needs and GIScience developments and innovations. The three symposia were organized around the following three themes: **Spatio-Temporal Analysis for Health Research, Enabling a National Geospatial Cyberinfrastructure for Health Research,** and **Synthesis and Synergy: Towards a Shared Vision.**

4. Core Research and Outreach Activities Conducted

A core set of research and outreach activities were conducted as part of this project that included organizing and participating in scientific meetings, building and deepening interdisciplinary communities and connections, developing publications, and conducting a broad range of dissemination activities to examine the possibilities and challenges for health-and-environments research associated with advances in the field of GIScience research. For example, in preparing for the three scientific symposia on health and social environments that were held in 2012–2013, substantial research was conducted to 1) identify the fundamental topics and core questions addressed in each symposium, and 2) identify and invite leading researchers in geography, GIScience, biomedical research, public health, and other computational, social, and behavioral sciences to contribute expertise and ideas to these important topics.

The research presented and discussed in these symposia also helped guide the topics proposed for the special symposium on “Geography, GIScience and Health: Spatial Frontiers of Health Research and Practice” at the 2013 Annual Meeting of the AAG. With over 170 presenters, this special symposium provided an unprecedented opportunity for geographers and health researchers, including researchers from NIH, to meet and discuss this project and shared interests around health research needs and GIScience developments and innovations. Examples of other related research and outreach activities are included in Section 5 (“Outcomes”).

Summaries of the three symposia proposed, conducted, and organized under this project are described in the three subsections that follow. Selected key ideas addressed during the group discussions at each symposium are included in Appendix C. See Appendix D for materials developed for each symposium (agenda, list of participants, biographical sketches, and selected presentations).

4.1 First Symposium: Spatio-Temporal Analysis for Health Research

The first symposium on **Spatio-Temporal Analysis for Health Research** was held April 27–28, 2012 on the campus of Howard University in Washington, D.C. Researchers representing geography, GIScience, biomedical science, public-health research, and computer science, as well as other social and computational sciences participated, including representatives from seven NIH Institutes and Centers. The symposium included 12 formal presentations accompanied by significant discussion.

The April symposium opened with a sequence of two "foundations" panels. During the first panel, speakers discussed existing geography and GIScience research on health-related topics. Key themes included: space/time dynamics; transmissions of infections; environmental exposures; importance of migration and social networks; data uncertainty and quality; new research opportunities emerging from Big Data and cyberGIS; the importance of GIScience as a policy implementation tool; and the need to be able to display dynamism and paradigm shifts. For example, Sara McLafferty, University of Illinois, Urbana-Champaign, noted the importance of "place contexts" and "activity spaces" in geography and health research, particularly the role of spatial and temporal scales and dynamic changes. Michael Goodchild, University of California, Santa Barbara, described the critical nature of time scales and provided examples of how the temporal dimension is being added to spatial data and integrated into GIS in near real time, with environmental sensors and people acting as "intelligent sensors." Nevertheless, displaying dynamic interactions on maps remains a challenge. He also noted that Big Data, of growing interest in health, GIS, and other scientific domains, is characterized by variable quality and synthesis before analysis. Nate Heard, using examples of global AIDS research, described how well-established work in this area has helped build many of the spatial data networks now used in a variety of health-research areas.

The second panel included representatives from NIH who discussed key trends affecting programs and high-level planning at NIH. Speakers noted that current priorities include, for example: an increased focus on life-course systems; prevention, exposure, and other environmental factors; health disparities; policy interventions; the communication of healthcare data; access to healthcare resources; real-time surveillance and sensors; activity spaces; environment-based interventions; location-stamped social media; and prediction based on simulation. Robert Kaplan, Director of NIH's Office of Behavioral and Social Sciences Research (OBSSR), noted that there will be a new era soon in the healthcare system dealing with life-course systems, prevention, exposure, and other environmental factors. Robert Croyle, National Cancer Institute (NCI), described the large body of work related to geospatial analyses developed at NCI including cancer mapping, spatial statistics, spatial analysis and modeling, transdisciplinary science, data visualization, pattern analysis, measurement tools, and geospatial data development. Bethany Deeds, National Institute on Drug Abuse (NIDA), described NIDA's GIScience research portfolio related to the social environment of

drug use, including activity space, real-time surveillance, structural/neighborhood analyses, growth and spread of abuse, and development of platforms and tools.

On the second day, intramural and extramural scientists had an opportunity to discuss their work in GIScience, health, and spatio-temporal analysis through two research panels. Research topics included geographic contextual influences on health (Mei-Po Kwan, University of California, Berkeley); exposure monitoring with ubiquitous sensing technologies (Michael Jerrett, University of California, Berkeley); spatial data mining and pattern analysis applied to health (Shashi Shekhar, University of Minnesota); hierarchical Bayesian methods in spatio-temporal modeling (Li Zhu, NCI); mutli-dimensional concepts of geographic access and their influence on chronic disease control and prevention (Gerard Rushton, University of Iowa); and the role and complexity of geographic and social contexts in understanding behavior and designing effective interventions (Jeremy Mennis, Temple University).

A federal panel with representatives from NIH, the Centers for Disease Control and Prevention, the National Science Foundation, the White House Office of Science and Technology Policy, and the U.S. Department of State next described their respective GIScience and health research activities and challenges. The concluding session of this symposium was a discussion that focused on key needs and opportunities for spatiotemporal analysis in health and social environments.

4.2 Second Symposium: Enabling a National Geospatial Cyberinfrastructure for Health Research

The second symposium on **Enabling a National Geospatial Cyberinfrastructure for Health Research** was held July 27–28, 2012 in San Diego, CA immediately following the Esri International User Conference (UC). Over 13,000 professionals across many industries attend the UC and momentum from and developments at the UC offered the potential to inform and inspire this second symposium. Similar to the April symposium, researchers representing geography, GIScience, biomedical science, public-health research, and computer science, as well as other social and computational sciences participated, including experts on health, education, and geoprocessing from Esri. A total of 12 formal presentations were made during this symposium (interspersed with significant discussion). Several participants who attended the April 2012 symposium on **Spatio-Temporal Analysis for Health Research** also attended this second symposium. This overlap was by design in preparation for the third “synthesis” symposium in June 2013.

The July symposium opened with a review, given by AAG Executive Director, Douglas Richardson, of the **GEOSPATIAL FRONTIERS IN HEALTH AND SOCIAL ENVIRONMENTS** project and its continuity with previous efforts, followed by a sequence of two panels introducing cyberinfrastructure, GIScience,

and cyberGIS. During the first panel, speakers provided an overview of recent advances in cyberinfrastructure and the distinctive advantages of a “spatial cyberinfrastructure” or “cyberGIS”. For example, Shaowen Wang began with the origins of cyberinfrastructure presented in a 2003 Blue Ribbon Advisory Panel report commissioned by the National Science Foundation (NSF) (Atkins et al. 2003), and then described the NSF-funded cyberGIS project led by the University of Illinois, Urbana-Champaign, noting that cyberGIS has the potential to transform GIScience research that is increasingly dynamic and complex with distributed research teams. Michael Goodchild described the unique characteristics of a spatial cyberinfrastructure and suggested that there are several lessons from the development of GIS and GIScience over several decades that could benefit cyberinfrastructure for health research, in areas such as data sharing, metadata standards, spatial data infrastructures, and working with Big Data.

The second panel included presentations about health applications that illustrated the promise and challenges associated with cyberinfrastructure. David Balshaw, National Institute of Health and Environmental Sciences (NIEHS), provided an overview of environmental health priorities at NIEHS, emphasizing exposure science and the Gene, Environment, and Health Initiative. He shared several examples of distributed and mobile sensors used to collect personal exposure data over space and time. Robert Shankman, U.S. Department of Health and Human Services (HHS), presented the MedMap application that is used to provide geospatial information to decision-makers for disaster preparedness, response, and health situations. The distributed application includes over 1,000 data layers and real-time streaming of data from across the U.S.

On the second day, participants in a series of three panels presented on topics ranging from industry perspectives on GIScience and health, to how public-health researchers and geographers are using GIScience to advance their work, and to social networks and high-performance computing opportunities for GIS. The first panel included representatives from Esri. David DiBiase focused on infrastructure as it relates to workforce needs and professional development, indicating that most public-health professionals currently learn GIS on the job. However, there is growing awareness in public-health schools and programs of the value of integrating GIS in public-health research. Christina Bivona-Tellez mentioned that the HL7 standard that is applied to electronic health information could be very important to GIScience and health research. Lauren Rosenshein-Bennett demonstrated new technologies for sharing and distributing geoprocessing routines, as well as data, as packages to facilitate collaborative research.

The second panel included case studies of how public-health researchers are using GIS, including some of the challenges they typically face. Kimberly Brouwer and Tommi Gaines, both public-health researchers at the University of California, San Diego, presented research projects focused on the spatial epidemiology of drug use and HIV transmission along the U.S./Mexico border and described the importance of GIS to their research, together with several challenges related to working in this

international context. Brouwer mentioned how important it was to her research to receive a career award from NIH on GIS and epidemiology. She has used this experience to mentor others in her program. Mei-Po Kwan, University of California, Berkeley, concluded this panel with a presentation of her research on the uncertain geographic context problem (Kwan 2012a,b), i.e., the methodological challenges associated with the spatial and temporal uncertainty of geographically-delineated neighborhoods and context and how such areas reflect actual contextual influences.

In the third panel, Ming-Hsiang Tsou, San Diego State University, and Shashi Shekhar, University of Minnesota, provided their perspectives on the relationships between high-performance computing and cyberGIS. Tsou described the role of cloud computing and grid computing in conducting complex simulations with large data sets, and also included examples using crowd-sourced data from social media. Shekhar described the growing importance of spatial Big Data and opportunities for collaboration on complex questions. However, he cautioned that Big Data is exceeding the capacity of traditional systems, including long-standing institutional cultures.

The concluding session of this symposium was a discussion that focused on key needs and opportunities for enabling a national geospatial cyberinfrastructure for health research.

4.3 Third Symposium: Synthesis and Synergy: Towards a Shared Vision

The third and concluding symposium on **Synthesis and Synergy: Towards a Shared Vision** was held June 6-7, 2013 at the Cosmos Club in Washington, D.C. and served as a final review of the project goals, a synthesis of the work that had been carried out to that point, and an opportunity to discuss overall concepts and needs going forward.

The symposium began with series of brief presentations organized to provide an overview and summary of key activities and issues related to health research and GIScience. Douglas Richardson, AAG Executive Director, described ongoing collaborative geography and GIScience activities between NIH and AAG going back several years. He also noted that key goals of this NIH-funded **GEOSPATIAL FRONTIERS IN HEALTH AND SOCIAL ENVIRONMENTS** project are to develop a research agenda to foster better integration of health research with GIScience and identify GIScience capabilities that need to be better developed or improved to more fully benefit health research and enable the potential for new scientific discoveries. Jean McKendry, AAG Senior Researcher, followed with remarks highlighting data privacy and confidentiality issues (particularly with geocoded spatial data) and their importance to health and GIScience research.

Michael Goodchild, University of California, Santa Barbara, outlined key emerging themes in spatiotemporal analysis: real-time analytics (early disease warning through social media); trajectory

data (tracking people, which is critical for studying disease transmission); visualization (making sense of patterns and behaviors); and simulation through high-performance computing. He also noted that a strong vision of cyberinfrastructure-supported science includes teams studying complex questions distributed across disciplines or space; access to vast repositories of data and powerful software tools; well-connected communities; and efficient methods of sharing knowledge. A potential challenge to achieving this vision is the legacy of identifying problems compatible with available tools, and ignoring other questions. Goodchild also noted that the spatial science field has been using metadata for over two decades and that the community has a strong tradition of data sharing.

Mei-Po Kwan, University of Illinois, Urbana-Champaign, stated that multi-level and multi-scale modeling allows for complex and layered analysis of communities and that there are concepts of positive and negative socio-geographic exposures in any human environment. She cautioned that these concepts are complicated and modeling can be difficult due to the uncertain geographic context problem and individual mobility.

Sara McLafferty, University of Illinois, Urbana-Champaign, concluded the panel with remarks about geographers' interest in a wide variety of health issues and how the use of novel and sophisticated geospatial technologies is critical. She described three key known factors that are central to linking GIScience and health: 1) health outcomes vary greatly from place to place and people experience places differently; 2) environmental factors can account for a wide range of health outcomes; and 3) geographically-targeted interventions can improve public health.

Following the opening panel, group discussions were organized around specific topics that focused on linking GIScience, technology, and data with health research and crosscutting health and GIScience research advances and challenges. Due to new, parallel developments at NIH in the BD2K Initiative (Big Data to Knowledge),[4] there was substantial interest and discussion about the following challenge that needs to be overcome: while most geographers, GIScientists, and other scientists have long viewed geospatial data and analysis as integral and representative of Big Data, many health and biomedical researchers tend to view GIScience and geospatial data and analysis as a specialization, or something "different." Yet, many of the challenges and opportunities identified under the BD2K Initiative are core to developments in geography and GIScience.

5. Project Outcomes

The specific aims of this project were: 1) disseminating information on GIScience developments and on health-research needs related to GIS; 2) fostering interdisciplinary collaboration and common terminology; 3) identifying key challenges, including such issues as maintaining confidentiality of location-specific data, analyzing data of varying quality, and integrating spatiotemporal data with behavioral and

[4] http://bd2k.nih.gov/

genetic information; and 4) developing a research agenda to address these issues and enhance the integration and sophistication of GIScience-based approaches. Specific outcomes associated with each of these aims are described below.

5.1 Dissemination of Information on GIScience Developments and Health-Research Needs

From the initial proposal development through the preparation of this report, this project has offered multiple opportunities to discuss, share, and disseminate new ideas with the potential to advance interdisciplinary geography, GIScience, and health research. The development of a shared vision for research, infrastructure, and education has emerged from a broad suite of synergistic activities and from the collaborative commitment and enthusiasm of project participants and other colleagues.

Each symposium included formal presentations from health researchers, geographers, GIScientists, and others about the current status of health research needs related to GIS and ongoing developments in GIScience. Participants were drawn from diverse scientific and technical fields, as well as diverse institutional settings. Each symposium provided a unique opportunity for interdisciplinary exchanges, dissemination, mutual learning on the subject of health and GIS, and new and deepening professional collaborations. Information and materials about related activities were provided in advance of each symposium to demonstrate continuity of related efforts. For example, the report of the 2011 AAG-NIH workshop on "Establishing an NIH-wide Geospatial Infrastructure for Medical Research" (Richardson et al. 2011) was distributed at all three symposia. This 2011 report documents the demand for a common geospatial infrastructure across the NIH and within the NIH-funded research community.

Other events, activities, and publications provided opportunities for further dissemination:

— An influential article entitled **"Spatial Turn in Health Research" was published in *Science***, co-authored by PI Richardson, project senior personnel Goodchild and Kwan, and senior leaders from NIH. The article, which appeared on March 22, 2013, describes how new developments in geographic science and technology can increase understanding of disease prevalence, etiology, transmission, and treatment, and has been influential in generating a great deal of interest in this area. The authors are leading researchers in this area and key participants in the *Geospatial Frontiers in Health and Social Environments.* The full citation is: Douglas B. Richardson, Nora D. Volkow, Mei-Po Kwan, Robert M. Kaplan, Michael F. Goodchild, and Robert T. Croyle. 2013. Spatial turn in health research. *Science* 6126: 1390-1392. PMCID: PMC3757548. See Appendix E to access a reprint of this article.

— Senior Personnel Kwan published two important articles on **the uncertain geographic context problem (UGCoP)**: (1) Mei-Po Kwan. 2012. The uncertain geographic context problem. *Annals of the Association of American Geographers* 102(5): 958-968. (2) Mei-Po Kwan. 2012. How GIS can help address the uncertain geographic context problem in social science research. *Annals of GIS* 18(4): 245-255.

— Senior Personnel Kwan published an article about **integrating time in research on segregation, health, and accessibility**: Mei-Po Kwan. 2013. Beyond space (as we knew it): Toward temporally integrated geographies of segregation, health, and accessibility. *Annals of the Association of American Geographers* 103(5): 1078-1086.

— A 2-year research project, entitled **"Addressing Challenges for Geospatial Data-Intensive Research Communities: Research on Unique Confidentiality Risks & Geospatial Data Sharing within a Virtual Data Enclave,"** was funded by NSF and began in 2012. Symposia discussions about the challenge and importance in health research of protecting the privacy of individuals' information associated with geospatial data helped refine and deepen the rationale for this related research effort.

— PI Richardson gave a **keynote presentation at the Seventh International Conference on Geographic Information Science** (GIScience 2012) in Columbus, OH, September 20, 2012. These biennial GIScience conferences have a tradition of focusing on basic research findings across all sectors of the field and are widely considered to be the leading meeting in GIScience.

  Richardson's presentation, entitled: **"Creating Spatial Infrastructure: Geographic Context, Data, and Analysis in Health Research,"** addressed the landscape of research challenges and opportunities generated by three inter-related AAG health initiatives: 1) the AAG Initiative for an NIH-wide Geospatial Infrastructure for Health Research; 2) Geospatial Frontiers of Health and Social Environments (funded by NIH); and 3) Addressing Challenges For Geospatial Data-Intensive Research Communities: Research on Unique Confidentiality Risks & Geospatial Data Sharing within a Virtual Data Enclave (funded by NSF). These collaborative AAG initiatives have generated linked and interactive research needs and agendas in the rapidly expanding domain of spatial technology, data, and methods in health research. They have also created an increased awareness by health and biomedical researchers as well as by geographers of the core role that geography and GIScience can play in addressing global health needs, both in research and in practice.

— **A special symposium on "Geography, GIScience, and Health: Spatial Frontiers of Health Research and Practice"** was organized for the **2013 Annual Meeting of the AAG** in Los Angeles. This Symposium took place over three days, April 10–12, with nearly 175 researchers in

geography, GIScience, biomedical science, and public health presenting in over 40 separate sessions, and included presentations and participation by researchers closely involved in this Geospatial Frontiers project. This symposium provided a key opportunity for geographers, GIScientists, and health researchers to share their research and make new connections. See Appendix F for the Call for Papers that was issued and Appendix G for a list of sessions that were organized.

— A collection of refereed articles on **"Geographies of Health,"** edited by Senior Personnel Kwan, was published as a special issue of AAG's flagship journal, ***Annals of the Association of American Geographers*****,** in September 2012 (Volume 102, Number 5). The issue **included 34 peer-reviewed articles** organized under the categories of health inequalities; environmental health; spatial analysis and modeling of disease; health-care provision, access, and utilization; health and well-being; and global/transnational health and health issues in the global south. Copies of this issue were widely disseminated to researchers in geography, GIScience, biomedical science, and public health. An edited volume entitled **"Geographies of Health, Disease, and Well-being"** was also published based on this special issue.

— Senior Personnel Kwan gave a **keynote presentation at the 13th International Conference on Computers in Urban Planning and Urban Management (CUPUM 2013)** at Utrecht University, Utrecht, the Netherlands, July 2-5. Kwan's presentation was entitled "Advances in GIS for Neighborhood and Health Research."

— PI Richardson gave the opening **keynote presentation at the XVth International Symposium in Medical/Health Geography (IMGS 2013)** at Michigan State University, East Lansing, MI, July 7, 2013. Richardson's presentation was entitled **"Spatializing Health: Trends in Geography and Health Research."**

— Senior Personnel Kwan gave a **keynote presentation at the XVth International Symposium in Medical/Health Geography (IMGS 2013)** at Michigan State University, East Lansing, MI, July 7, 2013. Kwan's presentation was entitled **"GIS Applications to Address the Uncertain Geographic Context Problem in Health Research."**

— PI Richardson gave a presentation entitled **"NSF and NIH Research on Geographic Data Confidentiality and Privacy"** at the 2013 annual spring conference of Harvard University's Center for Geographic Analysis. The theme of this conference was **Creating the Policy and Legal Framework for a Location–Enabled Society.**

— PI Richardson authored an article entitled **"*Real-Time* Space-Time Integration in GIScience and Geography,"** published in the ***Annals of the Association of American Geographers****,* 103(5) 2013, pp. 1062–1071, PMCID; in process.

— Jean McKendry, AAG Senior Researcher, participated in an NSF-funded workshop on the **Ethical and Legal Implications of Geospatial Privacy** at the University of New Mexico in May 2013 and prepared a white paper for discussion entitled "Privacy and Disclosure Risks with Geographically Referenced Data and Maps" that had a particular emphasis on privacy and health.

— PI Richardson and John Wertman, also of the AAG, shared details of the project and symposia at various meetings and events of the Consortium of Social Science Associations (COSSA) and the Coalition for Advancement of Health Through Behavioral and Social Science Research (CAHT-BSSR).

— The AAG submitted responses to two RFI's (Request for Information) issued by NIH in 2013 on topics relevant to health, geography, and GIScience:

  The first RFI was **"Training Needs in Response to Big Data to Knowledge (BD2K) Initiative"** (NOT-HG-13-003), and AAG's response and recommendations focused on how Big Data biomedical research that incorporates multi-scale context (place and time) and geographic analysis, and that is supported by interdisciplinary cross-training and collaboration, will create opportunities for new research hypotheses and discoveries linking environment, behavior, and health outcomes in ways that have never before been possible.

  The second RFI was issued by NIDA and entitled **"NIDA Dissemination and Implementation Priority Areas"** (NOT-DA-13-014C), and AAG's response focused on how the increased use of geographical data and analysis of health and environments can contribute to more tailored and effective drug treatment interventions and practices.

  See Appendix H for the RFIs.

5.2 Fostering Interdisciplinary Collaboration and Common Terminology

Through this symposia series and associated presentations and discussions, new collaborations, common terminology, shared understanding of interdisciplinary research challenges and opportunities, and dissemination of information on GIScience research and health-research needs

was facilitated among geographers, GIScientists, biomedical researchers, public-health researchers, and computational scientists. Collaboration was further enriched by participants from other federal agencies whose portfolios also include aspects of health research (e.g., the Centers for Disease Control and Prevention (CDC), the National Science Foundation (NSF), the Office of Science and Technology Policy (OSTP), the U.S. Department of Health and Human Services (HHS), the U.S. Department of State, and the U.S. Department of the Interior (DOI)) and the private sector. Importantly, researchers from under-represented populations have been engaged in these symposia and related activities, particularly through several of the senior personnel associated with this project and through the relationship with Howard University, and have offered important perspectives on the geography of health and social environments. In addition, the symposia included officials and researchers from across NIH who often cover different Institutes and topics in their research.

5.3 Identification of Key Challenges

GIScience, together with spatiotemporal data, models, tools, methods, maps, and visualization, continues to permeate diverse scientific domains, with health science research a particularly rich area for interdisciplinary advances (see for example, Richardson et al. 2013, and the growing availability of publications, such as *Health and Place* and the *International Journal of Health Geographics*). Yet, challenges remain in realizing the full potential of integrating the latest advances in GIScience and spatiotemporal analysis into health and environments research. The interdisciplinary approach of the **GEOSPATIAL FRONTIERS IN HEALTH AND SOCIAL ENVIRONMENTS** project (together with related activities) has provided a crucial opportunity to explore these issues and identify the core challenges to expanding the boundaries of health research and practice. These core challenges are presented below and organized under research, infrastructure, and training and education.

5.3.1 Identification of Key Research Challenges

- integrating and preserving the explanatory richness and complexity of geographic theories and concepts of place and context (e.g. the uncertain geographic context problem) in the design of health-research projects and protocols.
- translating investments in mobile exposure monitoring and data capture (at both the individual and community level) to meaningful research outcomes and public-health interventions.
- integrating environmental data (and metadata) with genetic, biomarker, and behavioral health data.

- integrating spatially and temporally referenced data about individuals and their environments, such as those data derived from diverse sources, including surveys, medical records, satellite imagery, GPS, and bio- and environmental sensors.
- developing analytical methods that can incorporate the rich data sources now available, including challenges associated with very large datasets, hierarchical data (e.g., people and their neighborhoods), network data (e.g., people and their social contacts), combining quantitative and qualitative data, and more.
- characterizing the exposome,[5] measuring personal exposure, and identifying the variables (including context and activity) to be measured (what is included/excluded) and the scale and frequency of measurement across space and time.
- understanding the role of geographic variability and complexity in gene–environment interactions, and the prevalence and etiology of specific diseases.
- determining the geographical components and/or drivers of health disparities.
- understanding the diversity and complexity of social networks in space and time, and their roles in disease transmission, information exchange, behavioral decisions, and other health-related issues.
- developing spatial and social network data models that support the representation and interaction of geographic and social contexts of health behaviors and outcomes.
- determining geographic and temporal scales that are most relevant for varied diseases, behaviors, and health conditions.
- managing or overcoming spatial and temporal variation in data quality and in data collection protocols.
- standardizing data collection protocols for future data collection (particularly Big Data) as appropriate and in balance with individual researchers' and project needs.
- protecting confidentiality of location-specific data while making such data available for research.
- addressing geographic variability in health-policy interventions and health care service delivery.
- optimizing the use and application of electronic medical records and other electronic medical systems in advancing health and environments research.

[5] "…the totality of environmental exposures (including lifestyle factors such as diet, stress, drug use, and infection) from the prenatal period on, using a combination of biomarkers, genomic technologies, and informatics…" (NRC 2012b:29.)

- understanding the role of ecology and ecological processes in infectious disease transmission and human health.
- capturing the transformative potential of crowd-sourced or volunteered geographic information while maintaining valid and robust research protocols.
- anticipating breakthroughs in health research tied to rapidly-evolving geographic technologies.

5.3.2 Identification of Key Infrastructure Challenges

- moving toward distributed data infrastructures with improved data interoperability and more consistent data standards and metadata.
- making computing resources and capacity readily available to deal with complex and dynamic health-related spatio-temporal research problems and datasets.
- solving issues of access to existing, large geospatial datasets, including those maintained at NIH, other federal agencies, state agencies, private sector organizations, and other data archives.
- improving speed to application for health researchers whose research can benefit from spatial thinking and geospatial methods, data and tools, but who encounter impediments created by user interfaces, complicated licensing, technical resources with a high ratio of jargon to information, and other technical issues.
- improving tools for analysis and modeling in space and time, and addressing varying data quality in such analyses.
- sharing access to geospatial data and customized tools, packages, and scripts that may be proprietary or subject to intellectual property considerations.
- documenting research data to be multi-purpose, i.e. not single project use, to deal with the issues of sharing inadequately documented data as well as redundancy of efforts and investments in data collection efforts.
- geocoding existing large datasets (after the fact) and creating incentives to geocode new datasets in real time, even where the gecoded data might not directly or immediately benefit a project's purpose.
- capturing, harmonizing, indexing, and utilizing burgeoning amounts of geo-referenced social-media data, e.g., as an early warning system related to disease outbreaks and transmission.
- providing targeted and sustained funding opportunities to support interdisciplinary research communities and infrastructure for geospatial health and environments research.

5.3.3 Identification of Key Training and Education Challenges

- establishing and maintaining productive dialogue and reciprocal feedback opportunities between health researchers and geographers/GIScientists to continue to exchange ideas about advances and needs in their respective domains.
- fostering acceptance of changing norms of science in an era of Big Data and exploratory data mining and analysis and demonstrating that large-scale spatial-data infrastructures offer new opportunities for spatial-pattern detection that can contribute to hypothesis generation and testing.
- creating opportunities to compile and share examples that demonstrate the relevance and efficacy of spatial thinking in health research.
- making expertise readily available to assist researchers interested in identifying core spatial questions or concepts that could potentially enrich their research.
- updating or reinventing current training regimes and portfolios to proactively incorporate changing geospatial technologies and opportunities emerging from cyberinfrastructure and distributed computing resources.
- identifying ways in which training in spatiotemporal methods can be inserted into existing curricula and to make such training available in both pre-service and in-service contexts.
- balancing the allure of Big Data possibilities with the lessons learned from experiences with smaller datasets.

5.4 Development of a Research Agenda

Advances in geography and GIScience and in health research are becoming increasingly intertwined. With developments in Big Data, computational power, and data intensive social science, the potential for scientific discoveries through “spatializing health” is extraordinary. Through the symposia and related activities funded by this grant, five broad themes emerged to help guide health-and-environments research and address the challenges described above. These areas are: 1) developing an integrated geospatial data infrastructure for health research; 2) utilizing advances in GIScience for health research; 3) integrating GIScience methods, data, and tools in health research; 4) building capacity for GIScience and health through training and education; and 5) addressing institutional and coordination issues.

For each of these five areas, recommendations and priority research areas are presented in more detail below. References to related initiatives, such as the report of the 2011 AAG-NIH Workshop on Geospatial Infrastructure for Medical Research (Richardson et al. 2011), and other relevant

information sources shared or obtained during the project are also included as supplemental explanation and background.

5.4.1 Developing an Integrated Geospatial Data Infrastructure for Health Research

As the data and computational dimensions and demands of research continue to intensify, GIScience is increasingly adopted and integrated into health research, and cyberinfrastructure becomes more essential to scientific collaboration and discovery, the development of an integrated geospatial data infrastructure for health research is required. “Large-scale spatial data infrastructures are themselves powerful resources for generating and testing hypotheses, detecting spatial patterns, and responding to health threats” (Richardson et al. 2013: 1291).

RECOMMENDATIONS

- Establish an NIH-wide geospatial data infrastructure for health research. Such an infrastructure “should be broadly conceived to encompass technology, architecture, integrated and interoperable spatiotemporal databases, metadata and standards, analytical methods and tools, visualization, data access and privacy protocols, and training and capacity building in geographic theory and analysis” (Richardson et al. 2011:2).
- Leverage and learn from related and parallel infrastructure research and development occurring elsewhere, such as NSF’s investments and ongoing research in cyberinfrastructure and cyberGIS.[6] “An NIH-wide geospatial infrastructure needs to be forward-looking and adaptable to rapid changes in GIScience research and technology (such as real-time data collection and analysis, social media, crowd-sourcing, electronic health records, individual sensors), cyber-infrastructure, cloud computing, and related technologies” (Richardson et al. 2011:3).

PRIORITY RESEARCH ISSUES

- How can distributed data and analytical infrastructures and capacity for cyberGIS be developed and made available that, by design, readily provide for improved interoperability and integration, consistent data standards, data integrity, provenance, security, privacy, the effective use of metadata, and computing resources appropriate to health research needs (also see NSF 2013)?
- What technical and institutional mechanisms and investments are needed to improve access by individual researchers and collaborative research teams to large datasets

[6] http://www.nsf.gov/news/special_reports/cyber/
http://cybergis.cigi.uiuc.edu/cyberGISwiki/doku.php/home

(public and private) and cyberinfrastructure to advance health research (also see Atkins et al. 2003:ES4 for a discussion of the dangers of not acting, e.g., "…increased technological ('not invented here') balkanizations rather than interoperability among disciplines; wasteful redundant system-building activities…")?

- How can legacy geospatial data and newer data be integrated given the challenges of multiple data formats, quality, validation, uncertainty, and availability (or not) of metadata?
- What infrastructure and methods will support the "continuous and timely collection, fusion, and curation" (CCC 2013) of streaming spatiotemporal data from ubiquitous mobile and fixed sensors?
- What are the challenges of spatiotemporal data collection which could impact data analysis and sharing for health research, and how can they be addressed? For example, "sampling survey design needs to consider representativeness in terms of the contextual characteristics of places as well as individual characteristics" (Richardson et al. 2011:3).
- How can user interfaces be improved, tools developed, and best practices shared that focus on removing or reducing impediments to health research, where that research should benefit by applying geographic methods and GIScience tools and data?
- What new data search and filtering tools can assist researchers in finding relevant research literature – by place, time, theme – from the growing number of health-science and GIScience publications (also see MacEachren et al. 2010)?
- How should the community tasked with implementing electronic medical records (EMRs) be engaged in developing a distributed geospatial data infrastructure?
- What is the range of potential uses, advantages, and protections needed for geo-coded EMRs and how might demonstration projects related to research using EMRs be integrated into a geospatial infrastructure for health research?

5.4.2 Creating and Utilizing Advances in GIScience for Health Research

GIScience, with its origins dating back more than 40 years, offers a strong foundation of research and a spatial-thinking approach that is important to apply to health research questions and challenges. The symposia and other activities supported by this grant highlighted several unique and highly relevant areas in which utilizing advances in GIScience is and will be particularly important to future scientific discovery in health research. These areas include

spatial/spatiotemporal Big Data; spatial analysis; scale; modeling and simulation; data mining; volunteered GIS, crowdsourcing, and social media; and visualization. Reciprocally, health research needs will also likely influence or contribute to advances in GIScience as well.

RECOMMENDATIONS

- Draw upon a proven legacy and continuing advances by GIScientists in dealing with the challenges of collecting, integrating, analyzing, and sharing computationally-intensive spatial/spatiotemporal Big Data to help address emerging health research needs. For example, metadata standards for geospatial data were introduced in 1992 and a National Spatial Data Infrastructure (NSDI) was launched in 1993.The NSDI is currently being revised under the auspices of the Federal Geographic Data Committee.
- Identify/inventory the full range of spatial analysis methods (see Wang 2010 for examples related to statistics, heuristics and optimization, and simulation) available for health and environment researchers, and develop best practice guides and examples or applications to illustrate their use in health sciences research.
- Work with the health research community to identify needs for *new* spatial analysis and statistical procedures in spatiotemporal analysis.

PRIORITY RESEARCH ISSUES

- What geospatial infrastructures, data, methods, and tools are currently available to assist health researchers in identifying, accessing, and utilizing spatial/spatiotemporal Big Data (e.g., to "release, process, aggregate, integrate, visualize, and analyze")?[7] How can spatiotemporal environmental and exposure data be integrated with genetic, biomarker, and behavioral data?
- How can GIScientists' experience and expertise with spatial data help address the data ingest challenges from ubiquitous sensors – data integration and analysis, and also data communication and storage (NRC 2012a) – for spatial/spatiotemporal Big Data, including real-time, space-time data integration in health research (see also Richardson 2013)?
- How can social network analysis be integrated with spatial analysis methods to better understand health-research issues such as mobility, migration, behavioral influences, disease transmission, communication, and more (also see Matthews 2012)?
- Which geographic and temporal scales are most relevant for different diseases and health conditions and situations?

[7] See NIH RFA-HG 13-009 (http://grants.nih.gov/grants/guide/rfa-files/RFA-HG-13-009.html)

- How can the increased availability of precise spatiotemporal data about individuals (e.g., from GPS data streams) be utilized in geographic modeling and simulations to provide insights about complex health processes (Richardson et al. 2013)?
- What is the role of spatial and spatiotemporal data mining and computational science in contributing to new questions and discoveries in health research, where hypotheses are developed to account for observed data (see Farmer and Pozdnoukhov 2012)?[8]
- What analytic methods are available in spatial and spatiotemporal data mining to understand patterns, identify outliers, and deal with spatial/spatiotemporal Big Data?
- What contributions can volunteered geographic information and crowdsourcing technologies and methods make to the development of real-time surveillance and location-stamped data on environmental influences on health?
- How can the accuracy and quality control issues of volunteered geographic information, crowdsourcing, and social media data be balanced with the need for valid and robust research protocols? How can these approaches complement traditional health research study designs?
- In what situations can volunteered geographic information, crowdsourcing, and social media signal important health trends faster and more broadly than traditional surveillance methods, e.g., early warning systems for disease outbreaks (also see Savel and Foldy 2012) and/or early detection of other spatiotemporal health events?
- How can volunteered geographic information, crowdsourcing, and social media approaches serve public-health needs in areas that are under-served ("low resource settings") (see Cinnamon and Schuurman 2013)?
- What is the role of geographic visualization in promoting interdisciplinary communication and collaboration?
- What is the range of geographic visualization techniques available that complement and extend traditional 2-dimensional and/or static maps?
- How can GIScience visualization tools and methods be applied to spatial Big Data to identify, observe, anticipate, or predict patterns and relationships (e.g., contagion, infectious transmission, disease vectors), generate hypotheses, and help develop theoretical and conceptual frameworks for further research and discovery (also see Torio 2012; Wang et al. 2012)?

[8] Also see Dyson 2012 for a discussion of Kuhnian versus Galisonian science.

5.4.3 Integrating GIScience Methods, Data, and Tools in Health Research

The importance of the geographic concepts of space, context, neighborhood, and environment and their critical role in many areas of health research emerged as a key focal point of the activities supported by this grant. Therefore, a spatial perspective that integrates GIScience methods, data, and tools in health research will be a core component of the next wave of discovery across many health domains. Some areas are particularly ripe for benefits in a near-to-intermediate time frame. For example, public health, epidemiology, substance use, and cancer control and surveillance are areas in which GIScience has already been utilized, though not fully (see Achincloss et al. 2012).

In this section, we focus on recommendations in the selected areas of health research discussed in detail at the symposia, such as social environments; health disparities; exposure and physical activity monitoring; substance use and misuse; privacy; disease ecologies; and crosscutting initiatives.

RECOMMENDATIONS

- Inventory spatial research activities across NIH Institutes and Centers, including a review of NIH grants to identify all that use geospatial tools or whose study goals include geographic aspects of health, and highlight breakthroughs that have occurred in health research because of GIS (Richardson et al. 2011) and areas of health research that best illustrate the most highly integrated use of GIScience and spatiotemporal analysis.
- Develop a comprehensive strategy to incorporate geographic context across the breadth of biomedical and public-health research at NIH (Richardson et al. 2011).
- Expand health-research portfolios beyond the study of individual people and/or diseases to include multiple scales (i.e., groups, populations, neighborhoods, cities, etc.)
- Identify broad cross-cutting initiatives in health and how they could benefit from GIScience, e.g., by organizing a series of relevant workshops.

PRIORITY RESEARCH ISSUES

- How can GIScience further an understanding of the role of social environments; geographic variability, heterogeneity, and complexity in gene-environment interactions; and the prevalence, etiology, and interactions of specific diseases, such as cancer, obesity, or substance abuse?

- How can GIScience both reveal and help manage the uncertain geographic context problem (Kwan 2012a,b), the complexity of multiple contexts, and multiple delineations of neighborhood (Spielman and Logan 2012) in health and social environments?
- How are social and spatial networks interlinked, and how does this relationship affect particular health outcomes in social environments?
- Through its capacity to integrate data and increasingly overcome the limitations of scale, how can GIScience contribute to the development of micro-targeted, customized interventions related to treatment, outcomes, and access in health and social environments?
- Can data from individual space-time trajectories and activity spaces in social environments, along with spatiotemporal environmental data streams, be scaled up to draw meaningful inferences about population-level health-related exposures?
- How can GIScience be used to identify, illustrate, and analyze the geographical components or drivers of health disparities, including disparities in access to health services?
- What is the role of spatiotemporal analysis in revealing the historical components of spatial inequalities and health disparities (also see Matthews 2012)?
- How can GIScience be used to help guide characterization of the exposome, collect and analyze data about exposure and physical activity, and account for multiple environmental variables, including time, the spatial and temporal frequency of sampling, mobility over the lifecourse, and the influence of social networks (physical and virtual)? What role does GIScience have in the potential “to consider exposures from source to dose, on multiple levels of integration within the ecosphere (including space, time, and biologic scales) to multiple stressors, and scaled from molecular systems, to individuals, populations, and ecosystems” (NRC 2012b:34)? How can the development of sensor networks be informed by these complex issues?
- How should metadata standards for environmental data related to exposure and physical activity be developed to integrate effectively with existing geospatial metadata standards?
- How can lessons from the earlier adoption and diffusion of GIS and its widespread presence throughout local communities and governments leverage investment in monitoring exposure and physical activity, including data capture and analysis, to achieve meaningful research outcomes and public-health interventions?

- How does geographic context influence substance use and misuse, including substance use initiation, treatment adherence, and relapse? How does geographic context interact with other individual and contextual characteristics to produce substance use behavior?
- What GIScience methods and tools are available to protect privacy and confidentiality that minimize constraints on research and minimize the potential for disclosure of sensitive information that is possible through geocoding locations and activity paths? What new methods and tools are needed?
- How can geospatial datasets be linked and fused to advance health research while maintaining privacy and confidentiality protections?
- How can qualitative GIScience methods and tools be applied to ethnographic and related data in health research and to investigating how health behaviors are related to individuals' perceptions and interactions with the environment?
- How can GIScience improve understanding of the role of ecology and spatiotemporal processes in infectious-disease transmission and human health, or disease ecologies? What is the role of GIScience in advancing research on the relationship between ecosystem health and human health?
- How can GIScience help integrate studies of climate change and associated progress in downscaling predictive models with better understanding of disease ecologies?
- How can GIScience research enhance crosscutting initiatives that include health-research priorities, such as the BRAIN Initiative which borrows many geographic concepts related to space, proximity, variability, scale, and visualization; NIH's Big Data to Knowledge (BD2K) Common Fund Program; and the Computing Community Consortium's Spatial Computing 2020 initiative?

5.4.4 Building Capacity for GIScience and Health through Training and Education

At all of the symposia organized under this grant, training and education in GIScience and health emerged as an important issue. "Although there are technical challenges…, arguably the larger challenge is promoting a clearer understanding on fundamental spatial concepts and critical thinking about how we use, analyze, and interpret spatial data" (Matthews 2012:518). This issue includes "cross-pollination" needs, i.e., teaching health researchers GIScience and spatial thinking, opportunities for geographers and GIScientists to learn about health research areas, and

building interdisciplinary collaborative teams around researchers with different approaches to science.

RECOMMENDATIONS

- Establish and support a cross-cutting community of practice drawn from extramural and intramural researchers in geography and GIScience and health and biomedical research from across NIH Institutes and Centers (Richardson et al 2011). This community could: mentor early-career researchers; assist established health researchers in the use of GIScience data, methods, and tools; assist established geographers and other social and behavioral scientists in understanding health-research needs; compile examples that demonstrate the contributions of spatial analysis in health research; and share resources to help researchers formulate and analyze questions that are spatial, relevant to their studies, and valued for their potential insights.
- Identify institutional and educational models of the successful integration of GIScience into health research and practice (Richardson et al. 2013).
- Develop and promote educational and training opportunities that stimulate interdisciplinary collaboration in health and GIScience at all educational stages. Examples could include encouraging curriculum changes that reward faculty exchanges across departments (e.g., health and geography) or the development of interdisciplinary courses that serve multiple departments; service-learning projects focused on community health-research needs; encouraging geographers and GIScientists to seek NIH fellowships; integrating GIScience into ongoing educational and training opportunities already available through NIH; emphasizing a GIScience focus in NIH study sections to encourage researchers to promote a spatial perspective in health research; and developing reciprocal sessions and support at the conferences of relevant professional societies.
- Compile and share best practices on spatiotemporal data collection and analysis (e.g., web-based repositories or archives) with health researchers who are interested in geographic theory, methods, and tools but who may be unsure how best to proceed.
- Commission a geospatial workforce plan that is focused on emerging needs and demands in health and GIScience research and which draws from other relevant workforce efforts in GIScience and in health respectively.

5.4.5 Addressing Institutional and Coordination Issues

Interest in interdisciplinary research in geography, GIScience, and health involves many different organizations and institutions across government, the private sector, and the academic and nonprofit sectors. Advancing interdisciplinary health and GIScience research has institutional and coordination components.

RECOMMENDATIONS

- Develop a strategic plan at NIH that specifically focuses on the current and potential role of GIScience and spatiotemporal analysis in health-research initiatives across Institutes and Centers, within current and planned cross-cutting initiatives (such as the BD2K initiative), and builds interdisciplinary research communities. Such a planning effort could lead to a "Geography Division for NIH, an Office of the Geographer, a Geographic Information Officer, or a Center for Spatial Analysis at NIH" (Richardson et al. 2011:5) and increase the visibility of GIScience within the NIH organizational structure.
- As part of the strategic planning effort, or independently, identify ways that state and local governments can contribute their needs and ideas, resources, data, and other assets into a coordinated system of GIScience and health research that addresses geographically driven disparities and unique issues that change over time and space (life course) ranging from access to health care, delivery of services, treatment, and interventions.
- Identify the academic, economic, institutional, cultural, and other incentives and disincentives to data sharing and interdisciplinary research collaborations (also see Wright and Wang 2011).

6. Conclusion

Developments in GIScience hold great promise for research on health and social environments. Achieving this potential requires an interdisciplinary approach with interactions among GIScience researchers on the one hand, and biomedical researchers and social and behavioral scientists on the other. The **GEOSPATIAL FRONTIERS IN HEALTH AND SOCIAL ENVIRONMENTS** project – with its outcomes, recommendations, and proposed research agenda – represents a key step in advancing the integration of geography and GIScience-based approaches in health-and-environments research across NIH.

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8. List of Appendices

A. The AAG Initiative for an NIH-wide GIS infrastructure
B. Establishing an NIH-wide Geospatial Infrastructure for Medical Research: Opportunities, Challenges, and Next Steps -- Report of the AAG-NIH Workshop on Geospatial Infrastructure for Medical Research, 2011
C. Key group discussion ideas from each **GEOSPATIAL FRONTIERS IN HEALTH AND SOCIAL ENVIRONMENTS** Symposium
D. Detailed information about each **GEOSPATIAL FRONTIERS IN HEALTH AND SOCIAL ENVIRONMENTS** Symposium (agenda, list of participants, biographical sketches, presentations)
E. "Spatial Turn in Health Research," Douglas B. Richardson, Nora D. Volkow, Mei-Po Kwan, Robert M. Kaplan, Michael F. Goodchild, Robert T. Croyle, *Science* PMCID: PMC3757548
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Appendix A. The AAG Initiative for an NIH-wide GIS infrastructure

The AAG Initiative for an NIH-Wide GIS Infrastructure is described in an article by Executive Director Douglas Richardson, and published in an issue of the *AAG Newsletter* (Volume 47, Number 3, March 2011). The content of this article is available at http://www.aag.org/cs/health_geographies.

Appendix B. *Establishing an NIH-wide Geospatial Infrastructure for Medical Research: Opportunities, Challenges, and Next Steps* -- Report of the AAG-NIH Workshop on Geospatial Infrastructure for Medical Research, 2011

To evaluate the potential development of an NIH-wide geography and geographic information infrastructure ("geospatial infrastructure") to support basic biomedical research and public-health applications, the Association of American Geographers (AAG), the National Cancer Institute (NCI), and the National Institute on Drug Abuse (NIDA) co-sponsored a highly-successful workshop in February 2011. Participants included senior scientists from across the National Institutes of Health (NIH), leading researchers in GIScience, NIH-funded researchers who use geographic theory and methods in their research, and industry experts on geographic technologies. The workshop was held on February 22-23, 2011 at NIH facilities in Rockville, Maryland. The report, available on line at http://www.aag.org/galleries/project-programs-files/NIH_GIS_Report.pdf, presents the key ideas along with a series of proposed next steps that emerged from workshop presentations and discussions.

Appendix C. Key Group Discussion Ideas from Each GEOSPATIAL FRONTIERS IN HEALTH AND SOCIAL ENVIRONMENTS Symposium

First Symposium on Spatio-Temporal Analysis for Health Research

Key research areas discussed at the first symposium:

- the complexity of how people experience places, contexts, and activity spaces at different spatial and temporal scales, including the geographical dimensions of health disparities, outcomes, and interventions. This research needs to extend beyond the level of the individual to include groups, local populations, cities, etc. Also, research focused on the built environment and infrastructure (as "places") and their impact on human behavior and health is particularly lacking.
- the spatial and temporal characteristics of social networks and infectious disease transmission.
- how social media influence the interplay of health research with geography and GIScience research as well as how spatiotemporal data and information are organized and shared. New or augmented methods for real-time surveillance and location-stamped social media of environmental influences on health are needed.
- locational privacy and the need to protect personal health data in GIScience research involving human subjects.
- how investments in mobile exposure monitoring and data capture can be used for meaningful public-health interventions.
- the geographical components of healthcare service delivery, access to health care resources, and the opportunities provided by electronic medical health records.

Key infrastructure areas discussed at the first symposium:

- the capacity to capture, display and communicate the dynamism and interaction of people *and* places through time.
- individual monitoring devices and methods for groups or communities to use to capture data and learn about environmental conditions.
- improved data access, including large datasets at NIH Institutes and Centers and access by public-health researchers to private-sector and government data from health care providers and others.

- the challenges of locational privacy issues in health research, and the potential for the National Human Genome Research Institute's (NHGRI) Ethical, Legal and Social Implications (ELSI) Research Program to serve as a model to help manage these challenges.

Key training and education areas discussed at the first symposium:

- the need to determine the extent to which biomedical and public-health researchers know what GIScience is, their awareness that there are rigorous theories and methodologies associated with GIS analysis and research, and how translational approaches might be used to facilitate cross-disciplinary communication and training among health researchers, geographers, and GIScientists.
- the importance of interdisciplinary training in K-12 and through to the post-doc stage.
- the advantages of promoting training and education on GIScience and health by exploring how relevant topics could be integrated into ongoing training and educational programs and opportunities to marketing this to various Institutes and Centers (e.g., NIH Director's Pioneer Awards for crosscutting, grand ideas).
- the need for new training opportunities to stimulate interdisciplinary collaboration between geography and health.

Second Symposium on Enabling a National Geospatial Infrastructure for Health Research

Key research areas discussed at the second symposium:

- breakthroughs that have occurred in health research because of GIS, what can be learned to help anticipate/guide new breakthroughs, and what health research questions can cyberGIS answer.
- potential benefits of comparing computational parallels and needs of cyberGIS and the human genome.
- the uncertain geographic context problem (Kwan 2012a,b) and the complexity of multiple contexts in health and social environments, including intervention contexts.
- characteristics of Big Data and when and how it can be used for science problems, particularly health science, that are becoming increasingly more complex.
- developing new statistical procedures for space-time analysis.
- chaining together complex models, e.g., disease hotspots and transportation.

- correlations between exposure and disease over the lifecourse and the corresponding role, organization, and operation of sensor networks.
- the advantages and limitations of using social media and crowdsourced data in health research.

Key infrastructure areas discussed at the second symposium:

- a framework that relates or integrates geospatial metadata with environmental metadata (e.g., from exposure studies).
- elegant solutions to user interface problems (including cumbersome or unwieldy application commands or toolsets), data sharing and archiving challenges, and interoperability across platforms, applications, and data formats.
- methods and tools to protect confidentiality and minimize disclosure risks.
- more standardization of geocoding.

Key training and education areas discussed at the second symposium:

- the need to identify and share mechanisms or resources to help researchers formulate questions that are spatial, relevant to their studies, and valued for their potential insights. Obstacles to applying GIS to health research (full potential) have a social and cultural dimension, not just a technical one and to change cultures within health organizations, there is a need to convince decision makers about relevance and efficacy of spatial thinking.
- the need for interdisciplinary opportunities to explore contemporary shifts in the traditional norms of science across the domains of health and GIScience, such as exploratory data analysis and data-driven research compared with theory-driven research and hypothesis testing and the respective, and potentially complementary, roles of inductive and deductive scientific approaches.
- the need to develop resources and tools for to help Institutional Research Boards (IRBs) reasonably evaluate research protocols that include the use, sharing, or display of confidential geospatial data.

Third Symposium on Synthesis and Synergy: Towards a Shared Vision

Key research areas discussed at the third symposium:

- how to deal with huge, complex spatial problems that may be too big for modern computing systems (e.g., divide and conquer?).
- ways to measure "personal exposure" and collect data – personal exposure is a complex concept due to the great amount of individual mobility in society and the fact that individuals can experience the same place differently.
- how understanding the complexities of social and environmental contexts can contribute to the development of micro-targeted interventions.
- how to determine which geographic and temporal scales are most relevant for varied diseases and health conditions.
- the role of electronic medical records, and associated data about location, lifecourse, and treatment, in geography, GIScience, and health research.
- linking datasets to provide more data for health research while maintaining confidentiality protections.
- coupled natural –human systems, disease ecology and infectious diseases in health research, e.g., NSF's program on Ecology and Evolution of Infectious Diseases.
- the geographic aspects of healthcare policies and interventions, especially related to access and outcomes.
- how to better integrate social network analytical methods with spatial analysis and spatial statistics.
- how interdisciplinary health and GIScience research can be applied or linked to other related initiatives, such as the BRAIN Initiative (Brain Research through Advancing Innovative Neurotechnologies),[9] which borrows many geographic concepts, as well as NIH's BD2K Initiative, the Computing Community Consortium's(CCC) Spatial Computing 2020 initiative, and others.

Key infrastructure areas discussed at the third symposium:

- importance of building awareness across NIH that geospatial theories, methods, data, and infrastructure are integral component of Big Data initiatives, including the NIH's BD2K

[9] http://www.nih.gov/science/brain/

Initiative, with many GIScientists experienced with Big Data, data integration, and their associated challenges.

- recognition that health data is often generated by state and local governments that follow different standards and that health research would benefit from the development and use of standards that provide for more data interoperability.
- importance of geocoding key health research datasets to add analytical and explanatory power.

Key training and education areas discussed at the third symposium:

- mechanisms to encourage spatial scientists to seek NIH fellowships and related opportunities that will cultivate increased interaction between GIScientists and health research communities, including demographers and medical sociologists.
- development of cross-cutting research teams that have appropriate training in the variety of fields involved in a particular research question. Perhaps a core group of geospatial specialists could be available as service providers across NIH.
- development of a geospatial workforce plan and to assist in promoting education, training, and preparation for health researchers and providers, including online/distance education as a key delivery mechanism that could be expanded to an international context.
- encouraging more universities to offer courses on GIScience and health research and/or medical geography and encouraging faculty to “cross-pollinate” by teaching in other departments, e.g., geographers teaching medical and public-health schools and health researchers teaching in geography departments.
- considering how adjustments in training regimens can be made to account for Big Data and other emerging factors and keep scientific disciplines effective.
- importance of visualization as an area in which GIScience can promote inter-disciplinary communication and collaboration.
- addressing how methods of hypothesis generation and theory building vary for the GIScience community compared with health research community and the complementary roles of data-mining and controlled survey methods and studies.

Appendix D. Detailed Information about Each Symposium

The materials developed for each symposium are available online at the following website: http://www.aag.org/health_geofrontiers.

- Agendas
- Participant Lists
- Biographical Sketches
- Selected Presentations

Note regarding gender and minority participation: NIH final report instructions include a request for information on the inclusion of gender and minority study subjects. This grant was an R13 mechanism to support scientific meetings, and did not involve study subjects. At the same time, this project substantially engaged women and minorities in leadership and participation – through the project's senior personnel and through the active involvement of minority researchers in all three symposia, particularly through ongoing relationships with Howard University.

Appendix E. Spatial Turn in Health Research

An article on spatializing health research, published in *Science,* was prepared with support from the **GEOSPATIAL FRONTIERS IN HEALTH AND SOCIAL ENVIRONMENTS** project. A copy of this article is available through the following link: http://www.aag.org/spatial_turn_article.

Douglas B. Richardson, Nora D. Volkow, Mei-Po Kwan, Robert M. Kaplan, Michael F. Goodchild, and Robert T. Croyle. 2013. Spatial turn in health research. *Science* 6126: 1390-1392. PMCID: PMC3757548.

Appendix F. Call For Papers
Geography, GIScience, and Health: Spatial Frontiers of Health Research and Practice, Special Symposium Organized for 2013 Annual Meeting of the Association of American Geographers

AAG2013
LOS ANGELES

SPECIAL SYMPOSIUM | CALL FOR PAPERS

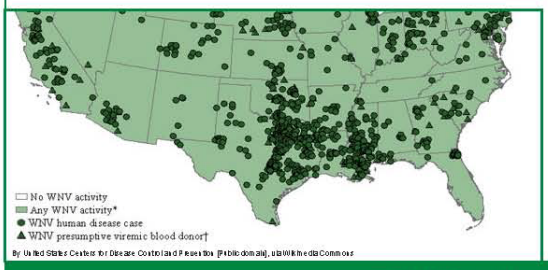
Geography, GIScience, and Health: Spatial Frontiers of Health Research and Practice

Building on several recent AAG initiatives together with the National Institutes of Health in this research area, this Symposium within the AAG Annual Meeting will explore new research frontiers in health and social environments, and also address progress generated by the AAG Initiative for an NIH-wide Geospatial Infrastructure for Health Research. These AAG initiatives have generated an increased awareness by health researchers as well as geographers of the core role that geography and GIScience can play in addressing global health needs, both in research and in practice. Sessions will include leading medical and health researchers, and we encourage geographers active in these areas of research to present their work.

We welcome participation from geographers, GIScientists, health researchers, and other scientists working at the frontiers of geography, GIScience, and health at the AAG Annual Meeting in Los Angeles, April 9-13, 2013. Papers on all aspects of health research and its intersections with geography or GIScience are welcome.

Topics may include but are not limited to:

- genomes and geography
- exposure monitoring utilizing real-time GPS/GIS methods
- spatial patterns of drug abuse and treatment
- gene-environment interactions
- crowd sourcing of geospatial data for health
- mHealth and global health service delivery initiatives
- health disparities and inequalities
- disease ecologies
- interactions among environment, pathogens, humans, and institutions
- neighborhood effects on health behaviors and outcomes
- geographies of public health policies
- spatial analysis and modeling of disease
- mobilities and health
- health care provision, access, and utilization
- health and well-being
- methodological issues in health research (e.g., MAUP, UGCoP)
- global health research and public health initiatives



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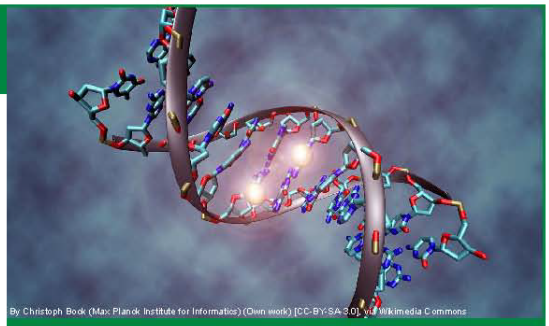

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CALL FOR PAPERS

AAG ANNUAL MEETING
Los Angeles, California
April 9–13, 2013
www.aag.org/annualmeeting

To participate in the Geography, GIScience, and Health sessions, please submit your abstract at www.aag.org/annualmeeting. When you receive confirmation of a successful abstract submission, please then forward this confirmation to: geohealth@aag.org. The abstract deadline is October 24, 2012.

For more information, please visit www.aag.org/annualmeeting, or contact members of the Symposium organizing committee at geohealth@aag.org.

The Symposium organizing committee members are:

Mei-Po Kwan (University of California, Berkeley), Co-Chair
Sara McLafferty (University of Illinois, Urbana-Champaign), Co-Chair
David Balshaw (National Institutes of Health - NIEHS)
Amy Blatt (Quest Diagnostics)
Kimberly Brouwer (University of California, San Diego)
Bethany Deeds (National Institutes of Health - NIDA)
Martin Dijst (Utrecht University)
Michael Emch (University of North Carolina, Chapel Hill)
Debarchana Ghosh (University of Connecticut)
Mike Goodchild (University of California, Santa Barbara)
Sue Grady (Michigan State University)
Tim Hawthorne (Georgia State University)
Poh Chin Lai (University of Hong Kong)
Jonathan Mayer (University of Washington)
Jean McKendry (Association of American Geographers)
Doug Richardson (Association of American Geographers)
Mark Rosenberg (Queen's University)
Gerard Rushton (University of Iowa)
Tim Schwanen (Oxford University)
Zaria Tatalovich (National Institutes of Health - NCI)

AAG
ASSOCIATION of AMERICAN GEOGRAPHERS

We look forward to seeing you in Los Angeles!

Appendix G. List of Sessions
Geography, GIScience, and Health: Spatial Frontiers of Health Research and Practice, Special Symposium Organized for 2013 Annual Meeting of the Association of American Geographers

A description of each session is available online by clicking on the title of each session below:

- Access to Health Services: Comparisons Across Places
- Addressing Challenges For Geospatial Data-Intensive Research Communities: Research on Unique Confidentiality Risks & Geospatial Data Sharing Issues
- Aging, Health and Access to Services
- Author Meets Critics: Sampson's 'Great American City: Chicago and the Enduring Neighborhood Effect'
- Built Environment Impacts on Urban Health and Behavior
- Characterizing Risk Environments for Spatial Substance Use Research
- Ecologies of Well-Being I
- Ecologies of Well-Being II
- Ecologies of Well-Being III
- Ecologies of Well-Being IV
- Encryption for confidentiality protection in geospatial studies with human subjects
- Geo-Health Research at NIH: Issues in modelling population based cancer statistics
- Geographies of HIV/AIDS: Prevalence, Treatment, and Risk
- Geographies of Obesity I: Causes, Rates, and Interventions
- Geographies of Obesity II: Diet and Food Environments
- Geographies of Public Health Policy
- Geography and Health: International Perspectives
- Geography and Mobile Phone Data: is there a privacy caveat?
- GIScience Analyses Applied to Health Research
- GPS/GIS and Space-Time Analysis for Health Research
- Health and Social Environments: Dimensions of Crime and Poverty
- Health and Social Environments: Mental Health and Substance Use
- Housing Geographies: Design & Social Factors in Low-Income Housing
- Landscape Genetics, Ecology, and Epidemiology
- New Approaches to Neighborhoods and Health I: Food access
- New Approaches to Neighborhoods and Health II: Social determinants of health
- New Approaches to Neighborhoods and Health III: Mobility, Boundaries, and Scale
- Opening Plenary on Geography, GIScience, and Health: Spatial Frontiers of Health Research and Practice
- Producing Disease: Exposure, Environmental Quality, and Health Outcomes
- Spatial Analysis of Cancer
- Spatio-temporal Analysis of Vector-borne Disease I
- Spatio-temporal Analysis of Vector-borne Disease II
- Spatio-Temporal Patterns of Infectious Diseases and Outbreaks
- Synthesis, Trends, and Directions for Geography, GIScience, and Health: Spatial Frontiers of Health Research and Practice
- Uneven Geographies of Health Disparities
- Urbanization, Agricultural Intensification, and Habitat Alteration in Vietnam: Modeling Transitional Development and Emerging Infectious Diseases: Part I
- Urbanization, Agricultural Intensification, and Habitat Alteration in Vietnam: Modeling Transitional Development and Emerging Infectious Diseases: Part II
- Walkable Communities: Physical Activity, Mobility, and Health

Appendix H. AAG Responses to NIH Requests-for-Information Relevant to Geography, GIScience, and Health

In 2013, the AAG submitted responses to two NIH Requests-for-Information (RFIs) relevant to geography, GIScience, and Health: “Training Needs in Response to Big Data to Knowledge (BD2K) Initiative” (NOT-HG-13-003) and “NIDA Dissemination and Implementation Priority Areas” (NOT-DA-13-014).” Copies of these responses are included on the following pages.

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The Association of American Geographers welcomes the opportunity to respond to the RFI issued by NIH entitled **"Training Needs in Response to Big Data to Knowledge (BD2K) Initiative" (NOT-HG-13-003)**. The era of Big Data that has "arrived for biomedical research" has also arrived for geography and geographic information science (GIScience). For example, massive quantities of geospatial data are streaming in from a variety of fixed and mobile sources, including sensor networks that record environmental conditions in real-time (Hart and Martinez 2005); GPS-enabled devices that record people's everyday movements (Kwan 2004); and Internet-based geospatial information volunteered by citizens (Goodchild 2007). Biomedical and geographical research domains are increasingly intersecting to produce large spatiotemporal datasets that now capture detailed health data about specific individuals and places over time. The AAG proposes that the "characteristics and contents of plans for cross-training of biomedical, clinical, computational, and quantitative scientists and informaticians at all career levels" [from RFI] could be enhanced by incorporating geographic theory, methods, data, and analysis to effectively and holistically meet the emerging challenges and opportunities for Big Data in biomedical research.

Background

Research combining a variety of intensive geographically-referenced data streams is spreading across many scientific domains, including biomedical research and public health. In addition to geospatial data streams from GPS-enabled devices, advances in web-services, cyberinfrastructure, and new geoprocessing tools for analyzing, exploring, and visualizing large, multi-scale spatiotemporal datasets are driving this research (Richardson 2013, Richardson et al. 2013). These trends suggest a growing and exciting potential for the use and integration of new and existing spatiotemporal data sets, new multi-disciplinary and data-intensive scientific collaborations, and important new avenues for biomedical research.

The need for data-intensive spatiotemporal analysis arises in numerous areas of NIH research, and NIH Institutes and Centers increasingly recognize the importance of geographic context and data. For example, GIS and spatial modeling are being used in research on the epidemiology of cancers (NCI); social epidemiology research related to drug abuse and treatment (NIDA), studies of gene-environment-health interactions (NIEHS); heart disease, stroke, asthma, and COPD (NHLBI); infectious-disease transmission, ecology, and spread (NIAID and Fogarty Center); understanding the relationship between UV radiation, vitamin D levels, and MS prevalence (NINDS); small-area analyses of pain and access to care for pain-related conditions (NINDS); and on themes related to global health and health disparities. Large spatiotemporal datasets associated with health and biomedical research are a key example of Big Data.

Recommendation

The AAG has been collaborating with NIH for nearly a decade on the integration of geography and GIScience in medical and health research (please see http://www.aag.org/health). Through these collaborative activities, several recommendations have come forth that are important to educational and training needs and relevant to converting Big Data to Knowledge, the subject of this RFI. A key recommendation is:

Incorporate spatial context in health data and research and develop education and training initiatives that advance geographic analysis, spatial thinking, and GIScience.

This recommendation is elaborated in more detail under the following two bullets:

- Health outcomes are likely influenced by social and physical environmental contexts that operate at different geographic and temporal scales. Clear methodological frameworks and methods for capturing and quantifying the effects of these multiple contexts need to be established. Parallel education initiatives addressing geographic methods and spatial thinking are needed to enable application of geographical analysis in health research. Education efforts need to focus on more than simply the capabilities of GIS software programs but, rather, on the full range of concepts and methods of geography and spatial thinking, and could utilize appropriate training opportunities already in place at NIH, such as the R25 Research Education grant mechanism and/or K Career Development Awards. Efforts should be made to document and widely disseminate information about best practices, methods, and tools.
- Opportunities to incorporate geography and GIScience into NIH meetings across a wide range of institutes can be identified and leveraged. Health research sessions at geography and GIScience meetings could be expanded. Geographers and GIScientists could be further encouraged to serve on NIH review panels.

Conclusion

"Big data" biomedical research that incorporates multi-scale context (place and time) and geographic analysis, and that is supported by interdisciplinary cross-training and collaboration will create opportunities for new research hypotheses and discoveries linking environment, behavior, and health outcomes in ways that have never before been possible.

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Additional Resources

"Establishing an NIH-wide Geospatial Infrastructure for Medical Research: Opportunities, Challenges, and Next Steps: Report of the AAG-NIH Workshop on Geospatial Infrastructure for Medical Research, 2011 (available at: http://www.aag.org/galleries/project-programs-files/NIH_GIS_Report.pdf).

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Symposium on Geography, GIScience, and Health: Spatial Frontiers of Health Research and Practice (nearly 40 sessions organized within the 2013 Annual Meeting of the AAG, April 9-13, Los Angeles, CA; please visit http:// http://www.aag.org/AM2013/GIS-Frontiers).

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The Association of American Geographers (AAG) welcomes the opportunity to respond to the RFI issued by NIDA entitled **"NIDA Dissemination and Implementation Priority Areas" (NOT-DA-13-014)**. As detailed in a recent *Science* article, "recent developments and the widespread diffusion of geospatial data acquisition technologies are enabling creation of highly accurate spatial (and temporal) data relevant to health research" (Richardson et al. 2013: 1390).

These advancements are relevant to a broad range of drug abuse and treatment research topics and are beginning to enable new and innovative approaches to specific place-based healthcare interventions and practices that will benefit individuals with substance-use disorders. In fact, NIDA has been supporting some social epidemiology research related to drug abuse and treatment but could further benefit from additional investments.

New approaches and cutting-edge research in geography and geographic analysis using highly-accurate spatiotemporal data, as exemplified in the section below, is directly relevant to several of the questions posed in the RFI. Spatiotemporal research addresses issues related to individual and population-level interventions and allows for analysis of the heterogeneous challenges that impose barriers to specific treatment approaches in mixed environments.

Relevant Examples

Recent published research provides examples of how the use of geospatial data and analysis supports evidenced-based healthcare interventions. Richardson et al. note, "Researchers have integrated patient demographics, daily activities, and HIV viral concentrations to map and model changing spatial patterns of HIV infections and their relationships to health care treatment programs (Smith et al. 2012), or to social risk factors (Das et al. 2010)." Other examples include:

- Gene-environment interactions – Research in this field provides new understanding of how the interaction of genetics, epigenetics, environmental factors, and social environments impact drug abuse, prevalence, and treatment.
- Crowdsourcing – The collection of data from multiple individuals through mobile devices with geographic functionality holds potential for better understanding of drug use patterns and the effectiveness of treatment programs (Mooney et al. 2012).

- Social-risk influences – By using geographic technologies (e.g., GPS-enabled devices) to better understand individuals' life paths, researchers can more-accurately assess exposures to social-risk factors (Kwan 2012).

To augment this last example, a recent study of HIV infection among injection drug users in Tijuana, Mexico found that "Spatial clustering of HIV cases by injection site, but less so by other activity locations, suggests the importance of collecting the most pertinent location data possible when exploring disease distribution. Our study also indicates the importance of collecting longitudinal data and exploring spatial data by sex. The dynamic nature of this epidemic suggests the need for intensified prevention efforts involving community outreach, mobile treatment, and harm reduction programs" (Brouwer et al. 2012: 1197).

This study is one of a multitude of evidenced-based intervention concepts that have emerged from advances in spatially-focused biomedical research. By capitalizing on these research approaches, drug treatments and associated policies can be better designed as appropriate for localized and, if need be, wider settings. Researchers, practitioners, administrators, and policymakers alike will benefit from geospatial inquiry into drug interventions.

The AAG has partnered in recent years with NIDA to foster basic and translational research on topics of common interest and to lay the groundwork for increased usage of spatially-driven inquiry in the development and usage of treatments for drug abuse. We encourage NIDA to build upon existing work, such as in the examples identified above. Practitioners increasingly need or could benefit from geospatial data to provide better treatment and administration of treatment programs. It is our overarching view that "Research agendas that systematically incorporate spatial data and analysis into global health research hold extraordinary potential for creating new discovery pathways in science" (Richardson et al. 2013: 1391).

Additionally, "There is also an urgent need for the creation of distributed, interoperable spatial data infrastructures to integrate health research data across and within disparate health research programs. In addition to fostering standards and scientific access, such large-scale spatial data infrastructures are themselves powerful new resources for generating and testing hypotheses, detecting spatial patterns, and responding to health threats" (Richardson et al. 2013: 1391).

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