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From the oceans to continental heartlands, human activities have altered the physical characteristics of Earth's surface. With Earth's population projected to peak at 8 to 12 billion people by 2050 and the additional stress of climate change, it is more important than ever to understand how and where these changes are happening. Innovation in the geographical sciences has the potential to advance knowledge of place-based environmental change, sustainability, and the impacts of a rapidly changing economy and society. Understanding the Changing Planet outlines eleven strategic directions to focus research and leverage new technologies to harness the potential that the geographical sciences offer.

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Summary

Increasing consumption, a growing and more mobile human population, and climate change are transforming the planet’s surface, creating challenges that scientists and policy makers struggle to understand and address. Yet this era of change is also a time of geographical innovation. In recent years, a rapidly expanding interdisciplinary community of scientists has drawn on new geographical concepts, tools, and techniques to advance understanding of topics such as environmental change, sustainability, globalization, and population dynamics. As a result, geographical ideas and information have become increasingly central to science, as well as to planning, environmental management, and policy making. Dynamic maps and imagery of Earth’s surface are now essential tools for emergency responders, transportation workers, and urban planners, and new user-friendly geographical technologies, such as Global Positioning System (GPS) tools and online maps, are becoming a part of daily life.

Many of the central challenges of the 21st century are tied to changes to the spatial organization and character of the landscapes and environments of Earth’s surface as populations move, natural resources are depleted, and climate shifts. Research in the geographical sciences has the potential to contribute greatly to efforts to monitor, analyze, and prepare for these changes. Technological developments and changing research priorities have inspired the rapid growth of the geographical sciences over the past two decades. Moving beyond geography alone, economists, biologists, epidemiologists, geologists, computer scientists, and others now contribute to the geographical sciences—investigating the links between people and nature, and the flows of mass, energy, people, capital, and information that are shaping Earth’s evolving environment. New technologies such as remote sensing systems have enhanced access to high-resolution, near real-time data, and geographical information systems (GIS), GPS, and geospatial visualization have facilitated the processing, analysis, and representation of geographical data. These technologies are used in contexts from the workplace to everyday life, and they have profound implications for information management, governance, commerce, and travel. At the same time, growing concern about human alteration of the environment and the impacts of globalization, resource depletion, and environmental sustainability have fostered tremendous interest in climate change, land-cover change, watershed restoration, migration, global inequality, and geopolitical conflict. Investigation of all of these phenomena can benefit from geographical research.

Despite the potential of recent advances in the geographical sciences, there is still much to be done to understand the changes that face Earth in the 21st century. Earth’s surface has been in constant flux as physical systems and human societies have evolved, but the pace and extent of human-induced changes have reached unprecedented levels in recent decades. The massive, rapid changes unfolding on Earth’s surface provide a logical starting point for considering strategic research directions in the geographical sciences, with the goal of understanding how Earth’s surface is changing; where, why, and at what rate changes are occurring; and what the implications of those changes might be.
SCOPE AND PURPOSE OF THE REPORT

At the request of the National Science Foundation, the U.S. Geological Survey, the National Geographic Society, and the Association of American Geographers, the National Academies established a committee to determine how the geographical sciences can best contribute to science and society in the next decade through research initiatives aimed at advancing understanding of major issues facing Earth in the early 21st century.

An ad hoc committee will formulate a short list of high-priority research questions in the geographical sciences that are relevant to societal needs. The questions will be written in a clear, compelling way and will be supported by text and figures that summarize research progress to date and outline future challenges.

The committee focused on impacts that are profoundly altering the human and the physical characteristics of Earth’s surface, and considered how the geographical sciences could contribute to understanding and addressing these transformations. In keeping with the charge, the committee developed 11 high-priority research directions that have clear societal significance, are central to the core concepts of the geographical sciences, relate to the agendas of the larger scientific community, have a strong likelihood of being advanced in the next 5-10 years, and can be investigated using methods and sources of data that either currently exist or are expected to be readily available within the next few years.

The committee solicited input from the greater geographical science community to identify research priorities and the approaches, skills, data, and infrastructure necessary to advance research. After arriving at the strategic research questions, the committee outlined the societal significance of each question, discussed the contribution of the geographical sciences to the topic so far, and determined how future work could produce new insight.

STRATEGIC DIRECTIONS

The geographical sciences have the potential to improve understanding of the extent and causes of the changes unfolding on Earth’s surface, to offer insight into the impacts of those changes, to promote the development of effective strategies in response to those changes, and to facilitate the documentation and representation of Earth’s changing character. The order in which the strategic directions are presented reflects the movement from overarching issues of environmental change and sustainability to matters that bear on particular transformations unfolding in the socioeconomic, geopolitical, and technological arenas.
How to Understand and Respond to Environmental Change

1. How are we changing the physical environment of Earth’s surface?
2. How can we best preserve biological diversity and protect endangered ecosystems?
3. How are climate and other environmental changes affecting the vulnerabilities of coupled human–environment systems?

Increasing human populations, urbanization, industrialization, and climate change have modified Earth’s surface and depleted natural resources. Although previous research has documented shifts in climate, soil erosion, habitat loss, and water degradation, the human role in these changes is often inadequately understood, hindering abilities to predict the magnitude and timing of future change. Using paleoenvironmental data such as tree rings and fossilized pollen, geographical scientists are developing reconstructions of long-term environmental history to learn about fluctuations in climate and Earth’s physical systems through time. Geographical scientists are using GIS, remote sensing, and geospatial visualization to analyze alterations to physical processes and patterns over time, and to figure out the relative contributions of the physical and the human to environmental change. A more complete understanding of both natural and human-made changes to Earth’s surface, the distribution of species and genetic diversity, and the varying vulnerabilities of different ecosystems to environmental change will be fundamental to environmental science, hazards management, and ecological restoration, and can guide policy decisions aimed at promoting environmental sustainability.

How to Promote Sustainability

4. How and where will 10 billion people live?
5. How will we sustainably feed everyone in the coming decade and beyond?
6. How does where we live affect our health?

Earth’s population is projected to peak at 8 to 12 billion people by 2050, with most population growth in urban areas. Many cities will struggle to accommodate rapidly increasing populations, and the spread of cities into rural areas will alter biogeochemical cycles, hydrological systems, climate, wildlife habitat, and biodiversity. Research on the changing geographical distribution of populations, the processes shaping different settlement forms, and the sustainability challenges facing an increasingly urbanized population are critical to understanding the challenges facing a more crowded world. Ensuring the availability of food resources to feed Earth’s expanding population will be one of those challenges. Because starvation currently occurs not because of global food scarcity but because of unequal geographical circumstances and inefficient or unfair food distribution systems, meeting the critical challenge of feeding 10 billion people will require a better understanding of geographical influences on agricultural production and distribution systems and on changing food consumption preferences. Access to health care will also be stretched by an expanding, increasingly mobile population, and standards in the treatment and prevention of illness will vary according to location. Using
spatial analysis, GIS, and spatially explicit models of disease spread, the geographical sciences can advance understanding of the impacts of globalization, migration, environmental circumstances, land use, economics, and government policy on health and the spread of infectious diseases. Analysis of disease and healthcare patterns through the course of people’s lives is fundamental to understanding both disease behavior and the varying vulnerabilities of different populations. This information will be essential to developing policies that promote greater human well-being around the globe.

How to Recognize and Cope with the Rapid Spatial Reorganization of Economy and Society

7. How is the movement of people, goods, and ideas changing the world?
8. How is economic globalization affecting inequality?
9. How are geopolitical shifts influencing peace and stability?

From human migration to the movement of freight, global mobility has increased over the past several decades, affecting transportation, communication, the economy, and even patterns of political conflict. There is a pressing need to understand the causes and consequences of increasing mobility, mobility differences from place to place, and the relationship between virtual (as in the Internet and other media) and physical mobility through in-depth assessments of developments in individual places and more spatially extensive studies that use GIS and geospatial information. Globalization is also exacerbating economic disparities in many places, raising concerns about the plight of the needy and social unrest. Geographical research elucidating patterns of inequality and the processes producing those patterns at different spatial scales can shed light on the inequality impacts of the changing socioeconomic environment, as well as the links between poverty and consumption patterns. The geopolitical framework that dominated the post-World War II era has also come apart in the face of economic and social upheaval, raising the need for expanded research on the territorial agendas of influential governments and groups, the changing significance of boundaries, and the role of resource scarcity in cooperation and conflict.

How to Leverage Technological Change for the Betterment of Society and Environment

10. How might we better observe, analyze, and visualize a changing world?
11. What are the societal implications of citizen mapping and mapping citizens?

Since ancient times, observation, mapping, and representation of Earth’s surface have been integral to geographical research, and remain central to the modern geographical sciences today. Web sites that provide geographical information have become a critical part of daily life, empowering citizens as both the sources and subjects of mapping, but the explosion of geographical information has raised significant concerns about individual privacy. Recent advances in geographical tools and technologies to
SUMMARY

observe, analyze, and visualize the changes shaping the human and physical features on Earth’s surface will be critical to answer the research questions in this report and to advance the geographical sciences. However, new approaches are also needed both to take advantage of the ability and willingness of nonspecialists to provide geographical information and to protect their privacy.

MOVING FORWARD

The 11 strategic directions in this report illustrate the great potential of the geographical sciences to address fundamental challenges facing science and society in the early 21st century. Given the extent and magnitude of the geographical transformations currently unfolding, it will be imperative to understand why changes happen in particular places. Although rapid progress has been made in geographical research in recent years, moving forward will require efforts to expand the scope and reach of geographical research. Achieving this goal will necessitate advances in research infrastructure, training, and outreach efforts. For example, most progress in the geographical sciences to date has been the result of independent research initiatives, but large-scale collaborations between researchers with diverse areas of expertise are needed to address many of the challenges facing Earth in the 21st century. Training the next generation of geographical scientists will require an updated curriculum to promote geographical understanding, spatial thinking, and geographical research skills, and to teach students how to make use of recent technological advances. Outreach is needed to inform policy makers, administrators, media figures, and others of the potential offered by the geographical sciences, and to foster links between the geographical science community and the general public. The committee envisions that the research priorities outlined in this report will lead to an increasingly sophisticated, well-organized, and powerful geographical science, which will serve as a foundation for a broad spectrum of scientific research, inform policy decisions, and enable citizens to understand and critique the geographical technologies that play an increasingly important role in everyday life.
UNDERSTANDING THE CHANGING PLANET
STRATEGIC DIRECTIONS FOR THE GEOGRAPHICAL SCIENCES

Committee on Strategic Directions for the Geographical Sciences in the Next Decade
Board on Earth Sciences and Resources
Division on Earth and Life Studies

NATIONAL RESEARCH COUNCIL
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THE NATIONAL ACADEMIES
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The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Wm. A. Wulf is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy’s purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Wm. A. Wulf are chair and vice chair, respectively, of the National Research Council.

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Preface

We are living in an era of receding glaciers, accelerating loss of species habitat, unprecedented population migration, growing inequalities within and between nations, rising concerns over resource depletion, and shifting patterns of interaction and identity. These phenomena are changing Earth’s geography—altering the character and organization of the planet’s surface and the relationships that exist among its peoples and environments. At the same time, we are in the middle of an explosion in the availability and use of geographical information. From the screens of our personal computers to the dashboards of our cars, spatial information abounds. Geographic information systems (GIS)—and the analytical tools for using these systems wisely—now play a fundamental role in the provision of emergency services, transportation and urban planning, environmental hazard management, resource exploitation, military operations, and the conduct of relief operations. In the years ahead, geographical tools and techniques will be of vital importance to the effort to monitor, analyze, and confront the unprecedented changes that are unfolding on Earth’s surface.

The foregoing circumstances explain why Stanford ecologist Hal Mooney has suggested that we are living in “the era of the geographer”\(^1\)—a time when the formal discipline of geography’s long-standing concern with the changing spatial organization and material character of Earth’s surface and with the reciprocal relationship between humans and the environment are becoming increasingly central to science and society. One significant marker of the relevance of geographical analysis is the growing number of scientists from other disciplines who employ geographical concepts and techniques in their work, including archaeologists, economists, astrophysicists, epidemiologists, biologists, geologists, landscape architects, and computer scientists. Their collective work has engendered a transdisciplinary geographical science. Understood in these terms, geographical science is not restricted to the discipline of geography; many geographers are involved, but increasingly so are individuals from other scientific fields and professions. To be a geographical scientist is to be concerned with reciprocal links between people and nature, as well as the spatial analysis and representation of the flows of mass, energy, people, capital, and information that are shaping, or have shaped, the evolving character of Earth’s biophysical and human environment.

This assessment of strategic directions for the geographical sciences reflects the rapid growth of the geographical sciences and the urgency and importance of their applications. What are the most important geographical questions that deserve attention, and what are some of the most promising geographical approaches and analytical tools for tackling those questions? How can we mobilize a community of scientists to develop and use geographical perspectives and tools most effectively to contribute to the effort to understand and respond to a changing planet? These questions are at the heart of this report. Geographical approaches and techniques alone are not sufficient to address the sweeping changes that are remaking the planet, but concepts and tools of the

\(^1\) Personal communication between Hal Mooney and Tom Wilbanks (verified February 12, 2009).

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geographical sciences are essential components of the multidisciplinary task of unraveling the complexities of the changes Earth is confronting.

Geographical inquiry encompasses approaches ranging from the scientific to the humanistic, and this report’s concern with the former end of the spectrum should not be seen as an effort to devalue nonscientific approaches, for the latter have fostered valuable insights into the geographical diversity of the planet and the human–environment dynamic. Rather, the focus on the geographical sciences comes in response to the National Research Council (NRC) of the National Academies’ charge to assess the ways in which the community of geographically oriented scientists can effectively contribute to an understanding of the changes that are remaking the planet. In approaching its work, the committee that produced this report did not adopt a narrow definition of science, however. Instead, the committee evaluated various research endeavors that seek to advance applied and theoretical understanding based on the systematic analysis or assessment of empirical data and information.

This report is substantially different from previous NRC assessments focused on geographical research. Earlier studies focused on the character and perspectives of the discipline of geography (NRC, 1965; Taffe et al., 1970). More recently, Rediscovering Geography (NRC, 1997) sought to highlight what the discipline of geography had to offer at a time of rapidly rising interest in geographical ideas and to consider how geography might respond to that interest. That report was written principally “for the broad audience that is curious about geography's new place in a national spotlight” (NRC, 1997: 15).

This report, in contrast, is written against the backdrop of the emergence of a rapidly growing, interdisciplinary community of scientists that is drawing on a variety of geographical perspectives and techniques. The approaches that these geographical scientists employ include spatial analysis (often making use of GIS and related technologies), remote sensing, geographical visualization, numerical and analytical modeling, and deductive analysis based on spatial data and assessments of linkages among and between places. The central concern of this report is to assess how the array of approaches and techniques of the geographical sciences might be most effectively deployed in the effort to address major social and environmental questions. It is important to emphasize that the goal of the report is not to provide an overview of the geographical sciences or to offer an analysis of successes and challenges. Instead the goal is to elucidate key contributions the geographical sciences can make to the task of confronting some of the most pressing, contemporary large-scale scientific questions of the day.

The audience for the report, then, is twofold. On the one hand, it is written for researchers and scholars in a position to develop and advance the geographical science enterprise over the coming decade. On the other hand, it is aimed at scientifically literate people, including policy makers, who can benefit from an understanding of what the geographical sciences have to offer and who can help sustain and promote geographically grounded efforts to understand life on Earth in the 21st century.

In developing this report, the committee relied on NRC studies, other published reports and literature, and the experience and expertise of its members. The committee also solicited input from the broader community in three ways: first, in the form of presentations at the committee’s open meetings; second, in a public panel session at the annual meeting of the Association of American Geographers (AAG); and third, from a
Web-based questionnaire written by the committee, designed to gather community input on the committee charge. The committee used the community input to shape its discussion of potential research questions, and the research questions that resulted reflect the themes of the input.

The committee held three open meetings. The first was in Washington, D.C., at the National Academy of Sciences, where the committee heard from the sponsoring agencies and organizations, reviewed its task, and charted a course for the study. The second meeting was in Irvine, California, at the Beckman Center, where the committee heard presentations from invited guests and reviewed the community input it had received. Between the first and second meetings, the committee held its public panel session at the AAG meeting, which consisted of seven invited presentations (see Appendix C) and a question-and-answer session with the audience. The public panel session speakers spanned the range of the geographical sciences and were invited for their expertise as well as their broad thoughts on the study charge. The committee held its third meeting in Woods Hole, Massachusetts, at the Jonsson Center, where it reviewed and discussed the draft research questions. The fourth and final meeting was a closed meeting at the University of California, Los Angeles, where the committee reviewed and finalized the draft report.

The committee is grateful for the input it received. As broad as the committee’s expertise was, it could not expect to cover every area of importance to the report. As a result, the committee requested contributions from several researchers to key areas of the report: Yuko Aoyama, Michael Emch, Colin Flint, Geoffrey Jacquez, John Logan, W. Andrew Marcus, Sara McLafferty, and Joseph Oppong. The committee also would like to thank the individuals who made presentations at committee meetings and the AAG panel session: Tom Baerwald, Patrick Bartlein, Daniel Edelson, Mark Ellis, Cindy Fan, Rachel Franklin, Geoffrey Jacquez, Bruce Jones, David Maguire, Susanne Moser, Laura Pulido, Doug Richardson, David Rigby, Paul Robbins, Chris Shearer, Eric Sheppard, Daniel Sui, and Ken Young. The committee also received many responses to its Web-based questionnaire and would like to thank the following individuals for their input, as well as those who contributed anonymously: Tony Abbott, John Agnew, Sharmistha Bagchi-Sen, Oliver Belcher, Denise Chavez, Anne Chin, Kevin Czajkowski, Bernadette de Leon, Martin Doyle, Steven Driever, Stuart Elden, Philippe Foret, William Graf, Carol Harden, John Harrington, Jr., Douglas Herman, John Hatzopoulos, Marlene Jackson, Daryl Jones, Gerry Kearns, Joseph Kerski, Miles Logsdon, David Maguire, Richard Marston, Patricia McDowell, Amy Mills, Jarlath O'Neil-Dunne, David Paschane, Jonathan Phillips, Chris Pringle, Jeffrey Smith, Seth Spielman, Dawn Youngblood, and Paul Zellmer.

Finally, the committee and I are deeply grateful to staff members of the Board on Earth Sciences and Resources of the NRC for facilitating the study from inception to conclusion. We are particularly indebted to our initial study director, Caetlin Ofeish, who was a constant source of help and encouragement during the preparation of the first draft of this report. We are also grateful to Ms. Ofeish’s successor, Mark Lange, who helped to bring this study to completion. Our study directors were ably assisted by Jared Eno and Jason Ortego, who provided invaluable assistance on a range of research and editing matters. We are also grateful for the administrative assistance of Tonya Fong Yee. Finally, we would like to express our gratitude to Tony de Souza, the Director of the
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Alexander Murphy, Chair
February 2010
Acknowledgments

This report was greatly enhanced by input from participants at the workshop and public committee meetings held as part of this study. These presentations and discussions helped set the stage for the committee’s fruitful discussions in the sessions that followed.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council’s Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in the review of this report:

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Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Dr. William A.V. Clark, University of California, Los Angeles, and Dr. Farouk El-Baz, Boston University. Appointed by the National Research Council, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.
CONTENTS

SUMMARY .....................................................................................................................................1
PART I: INTRODUCTION .............................................................................................................7
PART II: STRATEGIC RESEARCH QUESTIONS .....................................................................27
    Chapter 1: How are we changing the physical environment of Earth’s surface?  29
    Chapter 2: How can we best preserve biological diversity and protect endangered ecosystems?  41
    Chapter 3: How are climate and other environmental changes affecting the vulnerabilities of coupled human–environment systems?  55
    Chapter 4: How and where will 10 billion people live on Earth?  65
    Chapter 5: How will we sustainably feed everyone in the coming decade and beyond?  81
    Chapter 6: How does where people live affect their health?  91
    Chapter 7: How is the movement of people, goods, and ideas transforming the world?  103
    Chapter 8: How is economic globalization affecting inequality?  115
    Chapter 9: How are geopolitical shifts influencing peace and stability?  127
    Chapter 10: How might we better observe, analyze, and visualize a changing world?  135
    Chapter 11: What are the societal implications of citizen mapping and mapping citizens?  147
PART III: MOVING FORWARD ...............................................................................................157
REFERENCES .........................................................................................................................215
APPENDIXES
    A Committee and Staff Biographies ......................................................................................215
    B Acronyms and Abbreviations .............................................................................................221
    C AAG Open Session Agenda and Speakers .......................................................................223