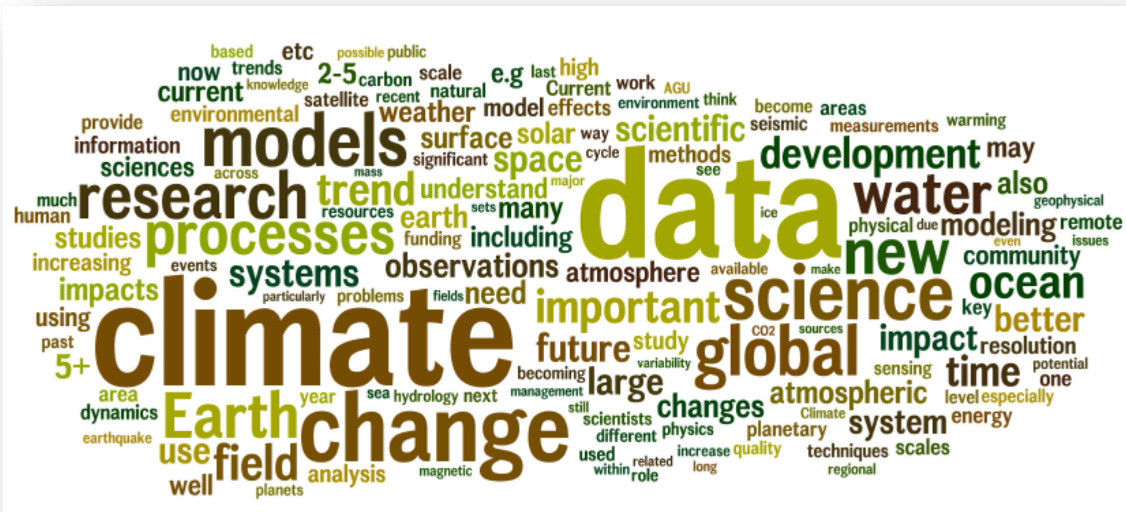
Scientific Trends Survey Results



Report to the Earth and Space Science and Public Communities

December 2014

American Geophysical Union

Preface

The American Geophysical Union (AGU) is an international scientific society whose purpose is to promote discovery in Earth and space sciences for the benefit of humanity.

To help advance the work of AGU and to help stay abreast of the many important changes underway in the scientific areas AGU represents, in spring 2014, the AGU Council initiated a survey to help identify recent and currently emerging trends of Earth and space sciences. This work was overseen by the appointed AGU Scientific Trends Task Force operating as a subset of the Council. The resulting AGU Scientific Trends Survey was issued to more than 55,000 individual entities representing AGU members and non-members. The AGU Council envisioned the results of the survey to be used to guide the internal workings of AGU and also to be beneficial to the broader scientific community.

This report represents a summary of the survey results and is intended to be shared for public consumption. The authors of this report have recommended AGU continue to issue a similar survey every 3-4 years and also to share those results with the entire Earth and space science community.

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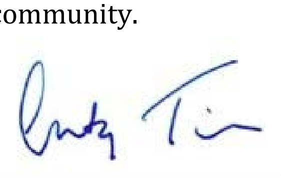
Introduction—Message from the Chair

The AGU 2014 Scientific Trends Task Force (task force) is a working committee composed of 22 members serving on AGU section and focus group executive committees, selected to provide representation across the Union's scientific disciplines. Its mission is to identify and summarize key scientific trends and issues in the Earth and space sciences either currently underway or anticipated in the future. The primary purpose of the task force is to summarize these trends such that they can be used to guide the work of the AGU Council on formulating policy, generating ideas, and advising on science-related issues, as well as to provide a report for the public.

The task force collected scientific trends information through an electronic survey distributed to approximately 55,000 AGU member and non-member contacts. Fielding occurred over 21 days, 2–23 June 2014, and yielded 1166 responses (approximately a 2.5 percent response rate). Respondents were asked to identify the AGU sections and focus groups that best reflected their primary research interests (or select the category "other"). Scientific trends information was collected through an open-ended question that allowed survey participants to "write in" essay-format responses. The unstructured data was later analyzed through a "coding" process that classified responses into broad themes and categories, as well as by the respondents' self-identified section and focus group affiliation. The trends that emerged are exemplified in the word cloud generated from all 1166 responses appearing on the cover page and discussed throughout the body of this report. Additional data and information sources were also considered by the task force in analyzing the trends survey results and formulating this summary report. The additional data and sources are included in the appendices, and readers are encouraged to consider them, along with the survey data, for a complete overview of emerging scientific trends.

A series of 12 major cross-cutting trends across the Earth and space sciences was identified through this effort, and they are presented in this report. Predominant themes include a focus on new developments in research instrumentation, advances in data analysis and modeling, climate change threats and other hazards to the environment.[1] Based on the anticipated value of this work, the task force recommends that AGU issues or updates the Scientific Trends profile every three to four years as a service to the organization, its membership, and the broader Earth and space science community.



Christy Till, Task Force Chair
Assistant Professor, Arizona State University

[1] Additional key trends specific to the preidentified scientific interest areas (i.e., AGU section and focus groups) were analyzed by the survey, but are not presented in this abbreviated public report. The task force found that additional validation and refinement is needed for the discipline-specific trends.

AGU 2014 Scientific Trends Task Force

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Christy Till, Arizona State University, Tempe, Arizona

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Executive Summary

The AGU 2014 Scientific Trends Task Force (hereafter referred to as task force) has identified key scientific issues and trends based on a survey of AGU member and non-member contacts, as well as additional data and information sources. The resulting summary of scientific trends is presented to aid future work of the AGU Council. We find that AGU is a large, complex, and diverse science organization, yet common trends emerge across the Union's various disciplinary groups.

The task force identified 12 common cross-cutting trends in the Union, which are presented here in no particular order and are detailed in the task force report on pages 9-11.

1. Utilizing and managing big data sets
2. Advances in modeling
3. Characterizing, reducing, and communicating uncertainty
4. Quantifying variability
5. Increase in inter-/multi-/cross-/transdisciplinary science
6. Climate change
7. Growing demand for science for society
8. Increasing globalization of science
9. New and innovative tools and methodologies
10. New funding sources and mechanisms
11. Increased interest in planetary and space sciences
12. Increased interest in life in extreme environments

The task force also identified common challenges and opportunities faced by each discipline based on the survey data and additional sources (Appendix B). These challenges and opportunities also exhibit commonality across the Union, similar to the cross-cutting trends. For example, five or more sections or focus groups highlighted challenges associated with:

- declining funding;
- preserving Earth resources and risk reduction;
- the increased politicization of science;
- communicating science to nonscientists; and
- the growth of inter-/multi-/transdisciplinary science.

These challenges and opportunities are closely related to several of the cross-cutting trends, specifically new funding sources and mechanisms, growing demand for science for society, climate change; and increase in inter-/multi-/cross-/transdisciplinary science.

The task force views these cross-cutting trends and challenges as opportunities for AGU to (a) more deeply explore opportunities to enhance connections among sections and focus groups and (b) support its members in addressing these major challenges. These cross-cutting trends are also viewed as opportunities for exploration by the broader Earth and space science community.

Survey Methods and Response Coding Procedures

Scientific Trends Survey. The AGU Scientific Trends Task Force developed and fielded an electronic survey in June 2014. Responses were collected through a secure data collection platform over 21 days, 2–23 June 2014. The survey included both quantitative (precoded, closed response options) and qualitative measures (open, essay-format responses). The electronic survey was delivered to approximately 55,000 AGU member and nonmember contacts. Because of the chosen survey methods, we do not consider the collected trends data to be the result of a statistically significant sampling protocol but rather a broad scan for input that yielded valuable qualitative responses. No sampling margin of error was calculated since sampling techniques were not used. The survey yielded 1166 individual responses, or approximately a 2.5 percent response rate.

Survey Response Coding Procedures. Scientific trends information was collected through an open-ended question that allowed survey participants to "write in" essay-format responses regarding emerging trends in science. The unstructured data were later analyzed through a "coding" process that classified responses into broad themes and categories (i.e., pairing similar responses together into groups). McKinley Advisors (McKinley), a for-profit consulting firm, was contracted to conduct an initial analysis of the unstructured AGU data. A detailed description of this coding can be found in Appendix A.[2]

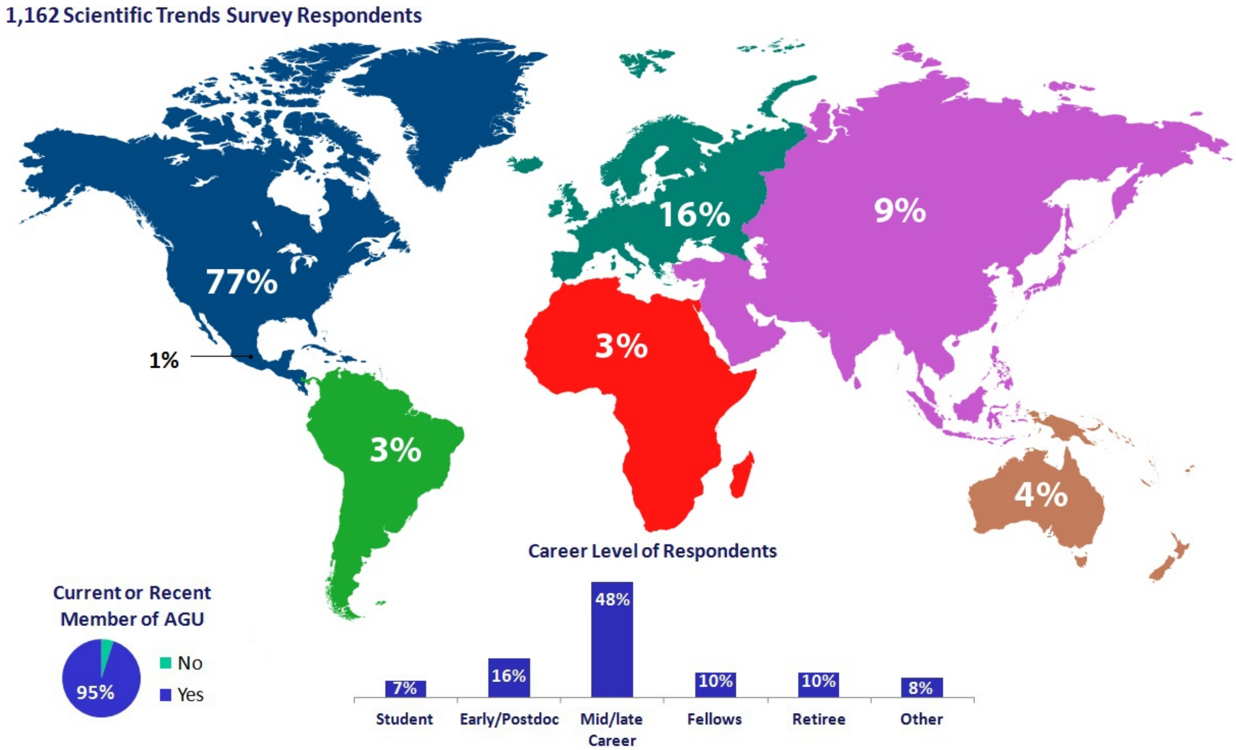
Survey Respondent Profile

Respondents to the survey had the demographic profile as shown in Figure 1 below, including career stage, geographic location, and AGU membership status.

Figure 2 illustrates the percentage of respondents who self-identify as having a science interest in each AGU section and focus group. All AGU sections and focus groups are represented by survey participants. However, several areas are particularly prominent among respondents. For instance, nearly one-quarter of respondents indicate holding an interest in Atmospheric Sciences (26%), Global Environmental Change (25%), and Hydrology (23%).

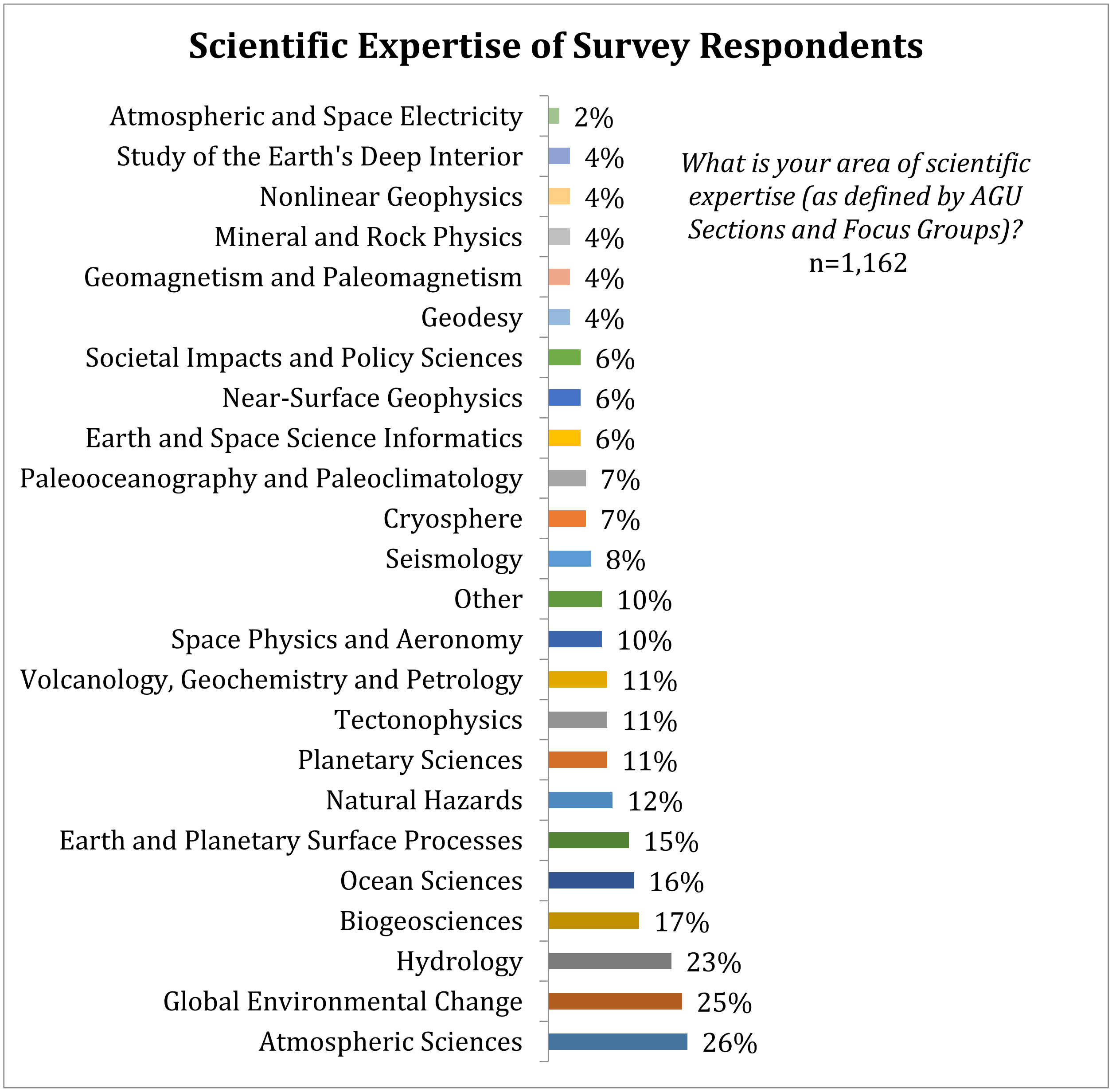
[2] Although survey respondents were asked to identify trends across three time horizons of current, two to five years, and more than five years, survey response analysis by the task force members did not find these time horizons to represent clear distinctions. The survey results in this report are therefore not summarized in a time-horizon regiment.

FIGURE 1: Demographic profile[3] for AGU Earth and space scientific trends survey respondents[4]



[3] A comparison of survey respondents' demographics with AGU membership demographics is provided in Appendix A, Figures A1 and A2.
[4] Survey respondents were able to select multiple geographic regions that they affiliate with, so the survey respondent data total >100%.

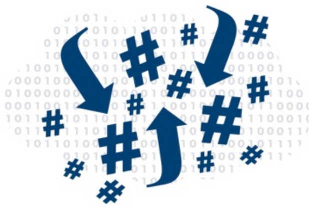
FIGURE 2: Profile of scientific disciplines of AGU Earth and space scientific trends survey respondents[5]



[5] In this table, the category "Other" refers to scientific disciplines not represented by one of the 23 areas of scientific expertise presented in the survey for respondents to identify with. A comparison of scientific disciplines for survey respondents versus scientific disciplines of AGU membership is provided in Appendix A, Figure A3.

Major Cross-Cutting Trends

Through our work, the task force identified the following trends emerging across all of our scientific disciplines. These trends are also apparent in the word cloud generated from all of the survey responses illustrated on the title page.



Utilizing and managing big data sets

- Provenance
- Quality control
- Storage
- Processing
- Organizing
- Data fusion
- Data mining
- Observational data and model outputs
- Archiving

Advances in modeling

- Data assimilation
- Model coupling
- Increasing size of models and model outputs
- New platforms
- Increasing complexity
- High resolution
- Probabilistic modeling
- Multiscale
- Model input output standardization
- Model management and archiving
- Joint inversion of data

$$\sigma_x = \sqrt{\frac{\sum_{j=1}^{N}(x_j - \bar{\bar{x}})^2}{N}}$$

Characterizing, reducing, and communicating uncertainty

- Uncertainty in observations and modeling
- For policy, decision-making
- Predictions/probabilities

Quantifying variability

- Natural variability
- Anthropogenic signals
- Internal variability in modeling
- For policy, decision-making

Increase in inter-/multi-/cross-/trans-disciplinary science

Growth in

- inter-disciplinary,
- multi-disciplinary, and
- trans-disciplinary sciences

needed to solve scientific questions of increasing complexity and societal urgency.[6]

Climate change

- Impacts in the cryosphere
- Extreme weather events
- Ocean acidification
- Drought and water impacts
- Geohealth impacts

Growing demand for science for society

- Human–natural systems interactions
- Geohealth
- Water security
- Resources
- Environmental impact
- Energy
- Drought
- Hazards and disasters, extreme events
- Space weather
- Induced seismicity

Increasing globalization of science

Increases in

- international collaborations
- science funding growth outside the United States
- non-U.S. authorship in scientific journals
- international membership in AGU and other scientific societies

[6] In this report, the AGU Scientific Trends Task Force has adopted the working definition of interdisciplinary research as used by the National Science Foundation and as spelled out in a National Academies report: National Research Council (2004), *Facilitating Interdisciplinary Research,* Committee on Facilitating Interdisciplinary Research, Committee on Science, Engineering, and Public Policy, The National Academies Press, Washington, D.C., p. 2. Interdisciplinary is defined as *a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice.*

New and innovative tools and methodologies

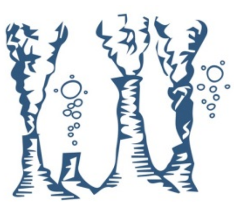
- Remote sensing
- Sensor miniaturization/cubesats
- Sensor networks
- AUVS and ROVS[7]
- Crowdsourcing/citizen science
- In situ analyses
- Advances in isotopic analyses
- Private economy platforms
- Omics (gen/protein…)
- Synchrotron sources
- Hyperspectral

New funding sources and mechanisms

- Crowdfunding[8]
- Big foundation funding
- Increased industry support
- Science entrepreneurship

Increased interest in planetary and space sciences

- Exoplanets and stars
- Planetary origins/early Earth/origin of life
- Comparative planetology



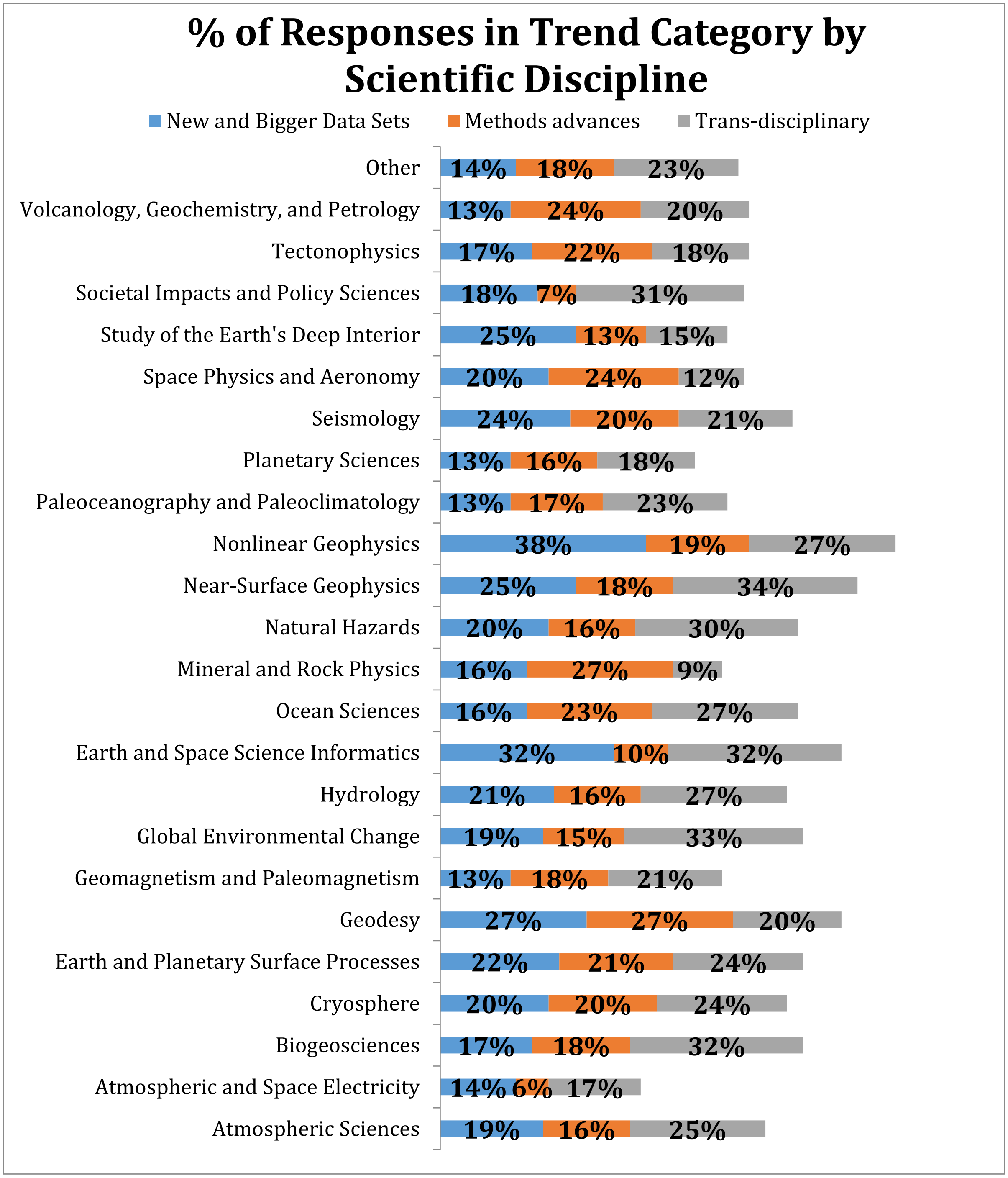
Increased interest in life in extreme environments

- Planetary sciences
- Oceans sciences
- Paleosciences
- Deep Earth interior
- Cryosphere
- Biogeosciences

[7] Automated underwater vehicles and remotely operated vehicles.
[8] The Merriam-Webster Dictionary defines Crowdfunding as "the practice of soliciting financial contributions from a large number of people especially from the online community."

In order to illustrate the ubiquity of the cross-cutting trends across all scientific disciplines, we chose three trends—new and bigger data sets, methods advances, and transdisciplinary trends—and illustrate the frequency with which they were mentioned by scientific discipline in Figure 3 below. Note that trend categories are not mutually exclusive and chart percentages may add up to more than 100%.

FIGURE 3: Illustration of dominant scientific trends themes represented in each scientific discipline



Appendices

Appendix A: Survey Coding Methodology and Demographics

A three-stage process was used in the coding of the survey data.

- Stage one. A random sampling of responses was collected from the full data set. Two McKinley analysts then reviewed the data independently and developed preliminary categories, or codes, into which the survey responses could be classified. The two code books were then compared for similarities and differences in order to develop an optimal coding plan.

- Stage two. The full set of responses was coded into a series of thematic groupings or classes. For example, trends that related to techniques or processes used to evaluate or classify large data sets were coded into an "Advances in Data Analysis" category. The results of the analysis were presented at a meeting of the AGU Scientific Trends Task Force in preparation for the last phase of data analysis.

- Stage three. The task force reviewed the full set of data, using the code labels to filter data and aid in analysis. Task force members representing each AGU section and focus group received and analyzed survey responses provided by survey participants who identify with that particular area of scientific interest. The task force identified high-level trends in each scientific area and populated a predeveloped diagram for this report.

FIGURE A1. Comparison of Survey Respondents' Geographic Affiliations with 2014 AGU Membership Demographics[9]

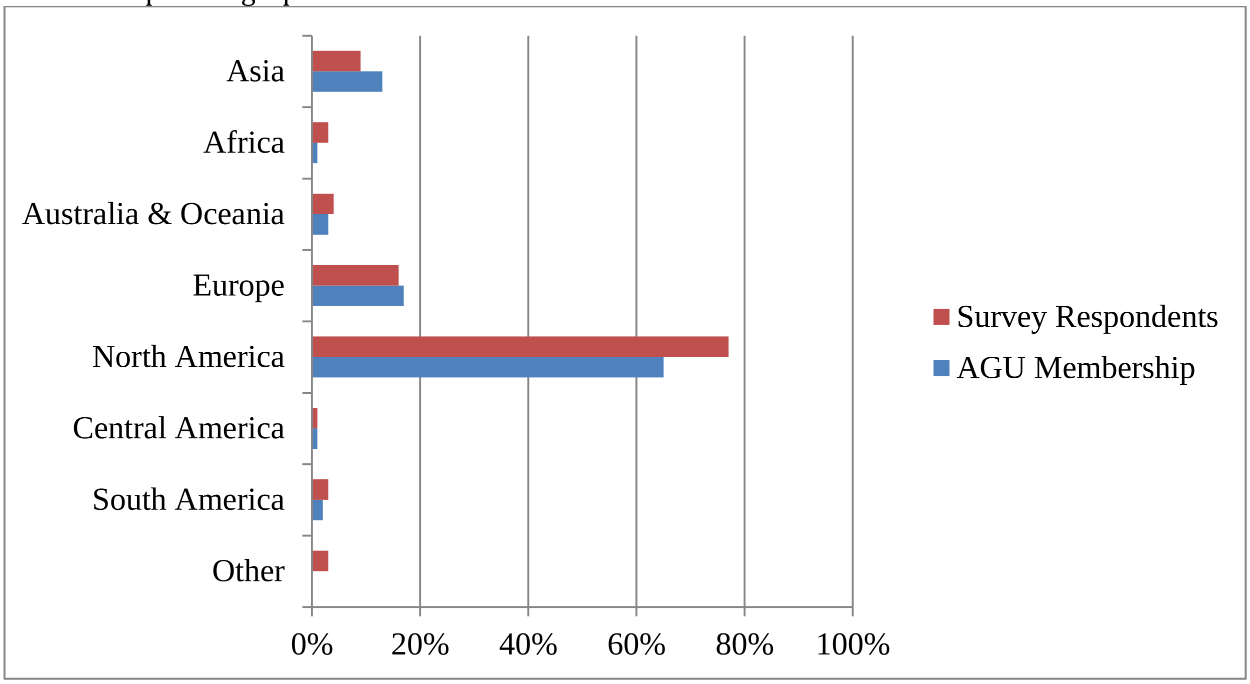
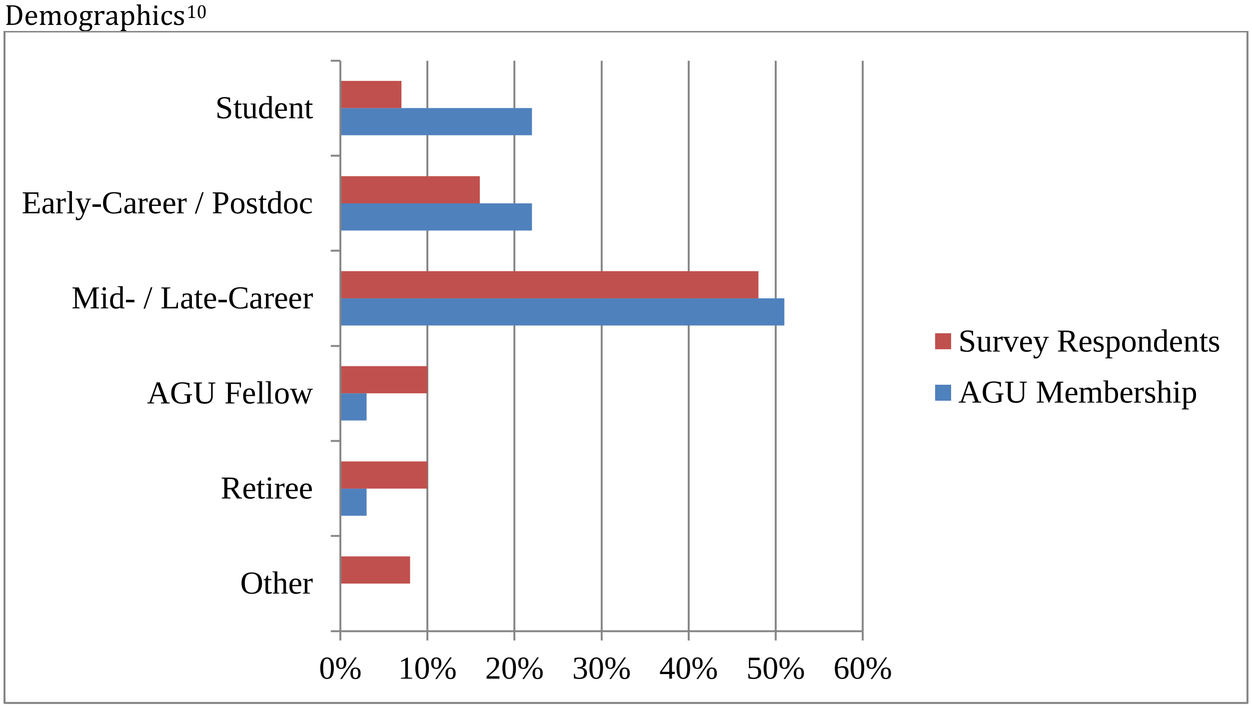
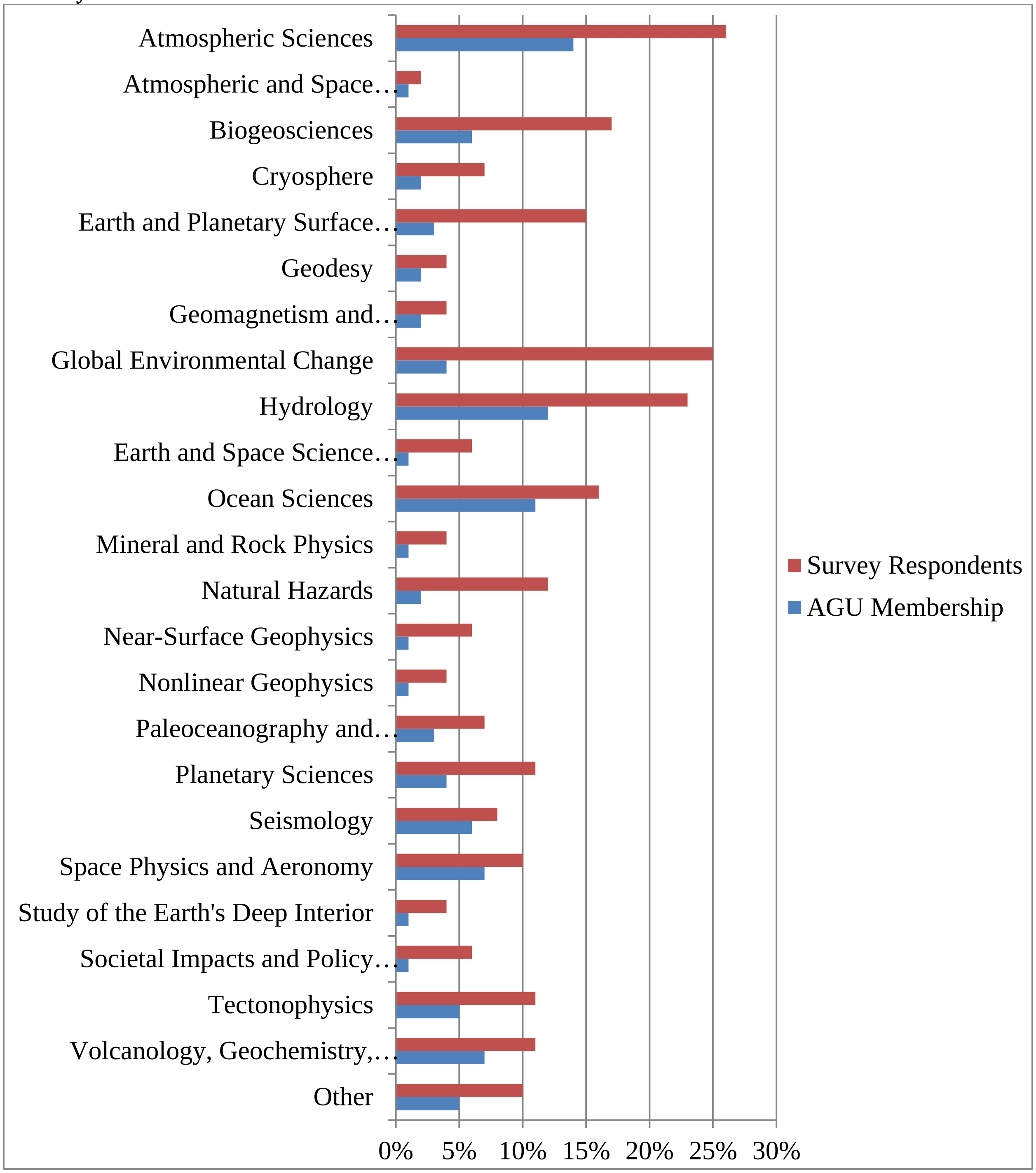


FIGURE A2. Comparison of Survey Respondents' Career Level with 2014 AGU Membership Demographics[10]



[9] AGU membership data are based on a 100% total, whereas survey respondents were able to select multiple geographic regions that they affiliate with, so the survey respondent data total >100%.
[10] Survey respondents were asked to select the category that best described their current career level.

FIGURE A3. Comparison of Survey Respondents' Scientific Expertise with 2014 AGU Membership Primary Affiliations[11]



[11] AGU membership data are based on a 100% total, whereas survey respondents were able to select multiple sections and focus groups that they affiliate with, so the survey respondent data total >100%.

Appendix B: Challenges and Opportunities Related to Scientific Trends

During the course of this work, the task force also identified common challenges and opportunities faced by each discipline based on the survey data and additional sources. These challenges and opportunities also exhibit commonality across discipline groups, similar to the cross-cutting trends. Five or more section or focus groups highlighted challenges associated with:

- declining funding
- preserving Earth resources and risk reduction;
- the increased politicization of science
- communicating science to nonscientists; and
- the growth of inter-/multi-/transdisciplinary science.

These challenges and opportunities are closely related to several of the cross-cutting trends, specifically new funding sources and mechanisms, growing demand for science for society, climate change, hazard mitigation, and increase in inter-/multi-/transdisciplinarity and represent additional areas for organizational awareness.

Appendix C: Trends Input from Nonsurvey Sources (Additional Reference Information)

TABLE C1: Trend: Big Data and Need for Data Scientists	**Growing importance of big data and need for data scientists**	
Research Front Descriptor	Source	Reference
From big data to extreme data: challenges in design and operation of large-scale systems, need for data scientists	IEEE Computer Society: Top Technology Trends for 2014	http://www.computer.org/portal/web/membership/Top-10-Tech-Trends-in-2014
Scientific cloud computing—changing how science is done, allowing new kinds of experiments, and data intensive computing	IEEE Computer Society: Top Technology Trends for 2014	
Cheaper, more agile, collaborative, and adaptive methods for analytics and data sharing	Forbes: Top Technology Trends for 2014 and Beyond	http://www.forbes.com/pictures/ehjh45lihf/1-digital-convergence-erodes-boundaries/

TABLE C2: Trend: Citizen Science	**Rapid growth citizen science—happening now**	
Research Front Descriptor	Source	Reference
More research projects are engaging individuals not trained as scientists in collecting, categorizing, or transcribing data, supported by mobile devices and apps. Support for hypothesis-driven scientific work	Science Magazine: March 2014	http://www.sciencemag.org/content/343/6178/1436
Integration of Internet into everyday life. Growing availability of computers and assessable interfaces	Forbes: Top Technology Trends for 2014 and Beyond	http://www.forbes.com/pictures/ehjh45lihf/1-digital-convergence-erodes-boundaries/
Need for data quality control—reliable data. What should be the data policy? Organized efforts to build capacity in the citizen science field	Citizen Science Central	www.citizenscience.org
Means to engage the traditionally scientific underserved	The West Oakland Environmental Indicators Project 2013	www.woeip.org/air-quality/
Integration of Federal Agency Research Programs for Citizen Science. Federally sponsored citizen science	New Visions for Citizen Science, November 2013 The Wilson Center	http://www.wilsoncenter.org/publication/new-visions-citizen-science

TABLE C3: Trend: Top Global Conservation Issues That Could Impact Biological Diversity	**Potential emerging interdisciplinary science indicators**	
Research Front Descriptor	Source	Reference
Annual scan for assessment of medium and long-term threats. Issues move from new to emerging to widely known to acted upon. (Horizon scanning is the search for issues that are new and emerging, not those that are widely known and certainly not those that already are being acted upon.)	NIH: A Horizon scan of global conservation issues for 2014	http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3884124/ Trends in Ecology and Evolution, January 2014, Vol. 29, No. 1
Listed in Top 15 Issues: • Extensive land loss in Southeast Asia from subsidence of peatlands • Rapid geographic expansion of macroalgal cultivation for biofuels • Redistribution of global temperature increases among ecosystems • High-frequency monitoring of land-cover change • Exploitation of Antarctica • Expansion of ecosystem red listing		

Table C4: Trends Indicator: Journal Citations	**Emerging science trends indicators, based on journal citations**	
Research Front Descriptor	Source	Reference
View of emerging science from research citations: geosciences, astronomy, and astrophysics	Web of Knowledge: Research Front Indicators	http://sciencewatch.com/articles/research-fronts-2013-100-top-ranked-specialities-sciences-and-social-sciences

• Impact of climate change on food crops
• Ocean acidification and marine ecosystems
• Models and impact of land-use change
• Climate warming, altered thermal niches, and species impact
• Carbon black emission and Arctic air pollution
• Event-driven research
    o Studies of the 2008 Wenchuan earthquake
    o Ground motion prediction equations and studies of the L'Aquila earthquake in central Italy
• ExoPlanetary Research: Kepler Mission and the search for extrasolar planets
• Data from Hi-node (Solar B) solar optical telescope and Solar Dynamics Observatory (SDO)
• Galileon Cosmology		

TABLE C5: Trends Indicator: NSF Solicitations and Funded Projects	**Extractable research descriptors from the National Science Foundation**	
Research Front Descriptor	Source	Reference
Funded projects from the Geo Directorate at NSF	Advanced Search Results on NSF-Sponsored Research. NSF Website	http://www.nsf.gov/awardsearch/simpleSearchResult?queryText=geosciences
• Atmospheric and Geospace Sciences • Earth Sciences • Polar Sciences • Ocean Sciences	NSF GeoScience Funding Opportunities	http://www.nsf.gov/funding/pgm_list.jsp?org=GEO

TABLE C6: Trends Indicator: Scans by Other Organizations	**Extractable input to AGU from scientific roadmaps**	
Research Front Descriptor	Source	Reference
Antarctic Horizon Scan	Scientific Committee on the Antarctic	http://www.scar.org/horizonscanning/
Arctic Research Roadmap for the Future	Third International Conference on Arctic Research Planning: International Arctic Science Committee (IASC)	http://icarp.iasc.info/
International Polar Initiative	IASC	http://internationalpolarinitiative.org/More%20Information.html
Report: *A Foundation for Research and Innovation: Grand Challenges in Geodesy*	Report from October 2009 Workshop *Long Range Science Goals for Geodesy* (supported by the National Science Foundation, the U.S. Geological Survey, and the National Aeronautics and Space Administration under NSF Award No. EAR-0959127.)	https://www.unavco.org/community/publications_and_reports/geodesy_science_plan/GrandChallengesInGeodesy-Final-Singles-LR.pdf

TABLE C7: Trends Indicator: NRC Committees and Reports on Emerging Science	Important validated input sources from the National Research Council	
Research Front Descriptor	Source	Reference
Decadal Survey on Ocean Sciences 2015—Active Committee, report in progress	NRC Ocean Sciences Board	http://nas-sites.org/dsos2015/
The Arctic in the Anthropocene, Emerging Research Questions, report, April 2014	NRC Polar Research Board	http://www.nap.edu/catalog.php?record_id=18726
Committee on Geoengineering Climate—Active Committee, report in progress	Board on Atmospheric Sciences and Climate	http://dels.nas.edu/Committee/Committee-Geoengineering-Climate-Technical-Evaluatin/DELS-BASC-12-04
2012 NAS report on "Induced Seismicity Potential in Energy Technologies" A great resource on a specific emerging topic	NRC Board on Earth Sciences and Resources	http://dels.nas.edu/Report/Induced-Seismicity-Potential-Energy-Technologies/13355?bname=besr
2012 NAS report on "New Research Opportunities in Earth Sciences"	NRC Board on Earth Sciences and Resources	http://www.nap.edu/catalog.php?record_id=13236
2013 NAS report on "Frontiers in Massive Data Analysis" Great resource for describing big data and data-intensive computing	NRC Board on Board on Mathematical Sciences and Their Applications	http://www.nap.edu/catalog.php?record_id=18374
2012 NAS Report on "A National Strategy for Advancing Climate Modeling"	NRC Board on Atmospheric Studies and Climate	http://www.nap.edu/catalog.php?record_id=13430
2013 NAS Decadal Survey on Solar and Space Physics (Heliophysics)	NRC Space Studies Board	http://www.nap.edu/catalog.php?record_id=13060

TABLE C8: Trends Indicator: International Conferences on Emerging Trends	**Non-Earth and space science international conferences on emerging trends with associated proceedings publication**	
Research Front Descriptor	Source	Reference
• International Conference on Emerging Trends in Scientific Research, Malaysia, November 2014	Pak Publishing Group	http://www.pakrdw.com/?ic=details&id=5
• International Conference on Emerging Trends in Biotechnology, New Delhi, November 2014	School of Environmental Science, Jawaharlal Nehru University	http://icetb.jnu.ac.in/
• International Conference on Emerging Trends in Engineering and Technology, London, May 2014	International Institute of Engineers	http://www.iieng.org/2014/06/01/45
• International Conference on Emerging Trends in Chemical Sciences, Vellore, India, December 2013	VIT University, India	http://www.vit.ac.in/events2013/IETC/index.asp

TABLE C9: Trends Indicator: Direct Suggestions from Individual Scientists	**Input received outside of AGU Scientific Survey input**	
Research Front Descriptor	Source	Reference
Hot Topics from G-Cubed • Understanding the first 4 billion Years • Mantle and Core Dynamics and Structure • Continental Dynamics and Structure • Crustal Dynamics and Metamorphic Processes • Plate Boundaries and Faults • Exospheric Solid Earth Interactions • Methods and Data	Note from Editor of G-Cubed (Geochemistry, Geophysical, Geosystems)	PDF available showing subtopics for each bullet
Research on new methods to assess exactly what form and how much phosphorus and potassium are held in the soil and are really "excess" and develop methods to extract it, how to extract P and K from surface and ground water, etc. Important minerals for environment, health and security	Senior Scientist at USDA-OCE-Climate Change Program Office	July 1 Email message to Task Force Chair from Senior Scientist at USDA-OCE-Climate Change Program Office

TABLE C10: Trends Indicator: Topical Areas Submitted for AGU Chapman Conferences	**Indicators of trends from AGU scientists based on meeting suggestions**	
Research Front Descriptor	Source	Reference
Topics suggested for AGU Chapman Conference 2014-2016	AGU Meetings Department	http://chapman.agu.org/
• Hydrodynamics and Biogeochemistry of the Stream-Bed Interface • Climate Water and Health • Tropical Ecohydrology • Currents in Geospace and Beyond • Meandering of Rivers and Deep Sea Channels • Transdisciplinary Research Frontiers in Earth and Space Sciences • Groundwater in Fractured Rock • Advances in Measurements of Ice Sheet Mass Balance • Evolution of the Asian Monsoon and Its Impact on Landscape, Environment, and Society: Using the Past as the Key to the Future • The Width of the Tropics: Climate Variations and Their Impacts	• Earth's Magnetospheric Dynamics • The MADE Challenge for Groundwater Transport in Highly Heterogeneous Aquifers: Insights from 30 Years of Modeling and Characterization at the Field Scale and Promising Future Directions • Magnetosphere-Ionosphere Coupling in the Solar System • Low-Frequency Waves in Space Plasmas • Catchment Spatial Organization and Complex Behavior	

TABLE C11: Trends Tools and Techniques	Potential methodologies for identifying and analyzing emerging trends	
Research Front Descriptor	Source	Reference
Methods of Identifying Research Priorities and Emerging Issues in Science and Policy	Methods in Ecology and Evolution, 2011	http://onlinelibrary.wiley.com/doi/10.1111/j.2041-210X.2010.00083.x/abstract
Mixed Indicator Model for Identifying Emerging Research Areas	Scientometrics Journal, Springer	http://link.springer.com/journal/11192 http://link.springer.com/article/10.1007%2Fs11192-011-0433-7#page-1
Horizon Scan Methodology	Scientific Committee on the Antarctic	www.scar.org/horizonscanning/methodology.html
Detailed index terms for potential data sorts, index terms used by AGU Publications	AGU Pubs	http://publications.agu.org/author-resource-center/author-guide/index-terms/
Word Cloud Generator	Wordle (free)	http://www.wordle.net/