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New Report Charts Course for Future of Geosciences

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Over the past century, the geosciences have developed an impressive capability to understand and anticipate events occurring within the Earth system. The past decade has seen an explosion in quantitative geoscience. Progress is continuing to accelerate as advances in observational systems and computational tools are allowing simulations and predictions of geophysical processes with a temporal and spatial resolution unprecedented in human history. With these advances comes the necessity to reflect on the current state of geoscientific research, to reassess the direction in which research should be progressing, and to redefine the goals that can be realistically achieved.

The International Union of Geodesy and Geophysics (IUGG) formed a working group of young scientists charged with developing a vision for the future of the geosciences. The working group combined its expertise and enthusiasm to produce a report, "Geosciences: The Future" (www.iugg.org/geosciences.html), and symposium outlining its view of what is to come. Included in this vision are long-term goals for the major fields of geophysics; that is, plans for 50 years in the future; and short-term priorities, such as plans to address over the next decade. In addition, opportunities for interdisciplinary studies, proposals for the advancement of developing countries, and organizational recommendations for the geosciences are highlighted. The justification for this view of the future is based on the fundamental motivations and societal benefits underpinning geoscientific research.

The overriding aim of the geosciences is to reduce uncertainties as much as possible in predicting geoscientific events and, in so doing, to increase the value of the predictions to society. To this end, many specific short-term projects are discussed, ranging from seismic exploration of Mars, to measuring the water ice content of clouds. The majority of the projects are ultimately concerned with elucidating and understanding key processes, thus contributing to the primary scientific knowledge required to produce high-quality predictions. For example, modeling of volcanic magma-wall-rock interactions and ionospheric sounding are both process-orientated strategies designed to lead to high-quality predictions of eruptions and space weather, respectively.

By Sam Adlen, Emily E. Brodsky, Taikan Oki, Aaron J. Ridley, Laura Sanchez, Claudia Simionato, Kazunori Yoshizawa, and Uri Shamir

Modeling and Observations

Impressive models already exist within each individual Earth science discipline and the models incorporate many major relevant components. Modeling often aims at computing the consequences of understood or proposed physics and is therefore complementary to activities that are focused on uncovering previously unknown physics. To improve our modeling ability, two basic strands of model development are required: improvements in model resolution (both spatial and temporal) and improvements in model parameterizations, including boundary and initial conditions.

The first strand allows finer-scale phenomena to be dealt with more realistically and models to be regionalized; the second allows modeling of elements and processes that cannot be included explicitly. The linkage between individual models as components of a single planetary system becomes critical as the resolution and fidelity of individual models becomes increasingly comprehensive.

Geoscientific studies over the next decade must be shaped by the recognition that contemporary approaches seek to understand,

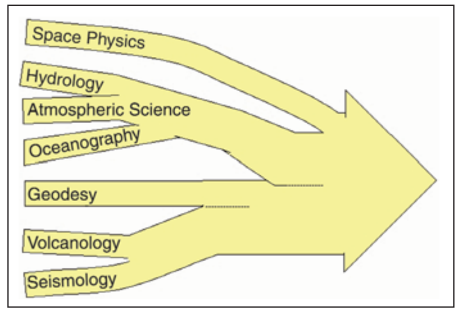

Fig. 1. This schematic shows the possible evolution of the major disciplines currently represented by the International Union of Geodesy and Geophysics. "Geosciences: The Future" recommends organizational changes to accommodate the decreased relevance of disciplinary boundaries.

model, and predict all components of the Earth's environment, including the coupling between systems that until now have been treated independently. Critical scientific questions will focus on the interplay and exchanges of energy, momentum, and chemical constituents between individual components as we seek to consolidate our findings into the ultimate goal of an Earth system model. Recent advances in computational power, and the launch of projects such as the Earth simulator in Japan promise real progress in generating a unified Earth system model. The reconciliation of separate models on vastly disparate spatial and temporal scales is nevertheless non-trivial, and will demand the application of intellect and attention from the whole of the geosciences throughout the next decade and beyond.

Modeling is driven by observations from both the laboratory and the field. The most important development in observational systems will be the deployment of integrated global observing systems. Ultra-high temporal and spatial resolution data is becoming increasingly valuable as our ability to assimilate the data into models progresses. The global coverage possible from satellites is vital in addition to high-resolution in-situ measurements. For instance, satellite measurements of volcanic plumes must be supplemented by continuous measurement of gas chemistry on the ground to capture the full evolution of magmatic systems. All of the desired observation goals and data products could be attained with a well-constructed global observing system. Observations must then be combined and utilized in the most thorough and efficient way. Continual adaptation and advancement of data assimilation techniques will maximize the data that can be extracted from the available observations.

Data-sharing among disciplines should also be further encouraged by freely accessible electronic data archives. Already, disciplines ranging from oceanography to seismology use geodetic data. More effective distribution could foster crossover work ranging from atmospheric uses of space physics observations, to seismological benefits from hydrologic monitoring. Efficient database management will also be central to the validation and progress of models in the future. A concerted effort is needed to develop and maintain spatially and temporally resolved databases. These must be made free and must be easily accessible to all scientists in all countries. Regional models and databases will be vehicles for building the infrastructure for integrated interdisciplinary solutions. E-science also will come into play in projects like using distributed computational load and the construction of community-wide resources. Current techniques in global communication must also be utilized if data and models are to be efficiently combined to produce the end-products that are needed by society.

Comparative planetology and planetary exploration present challenges that incorporate the full spectrum of the geoscientific and engineering disciplines, while also exposing an important and largely untapped data source. Planetary exploration will stretch our intellectual and engineering capabilities, while expanding our physical boundaries and understanding of the universe. Even though planetary exploration presents a considerable challenge, conservatism has never been a friend of science. The geosciences must be pro-active in the sponsorship of planetary exploration. Humanity has the capability to undertake structured planetary exploration, and the value of the results that will be returned may be invaluable. In this era of Earth system science, the capacity to contrast and compare models from other planetary systems is crucial, especially as we seek to understand the likely development of our planet.

Goals

In the very short term, it is probable that the next decade will largely be dominated by a continuation of existing research. Advances in computing power and observational resolution must be continually exploited as we aim to build on the considerable progress already made toward the goal of an Earth system model. The advances that have occurred, however, require that our realistic long-term goals be reassessed. The value of scientific research and the reasons for undertaking it are often best measured by its value to the end-user. In the case of the geosciences, the entire population that experience the variability of the Earth system, and are at the mercy of its extremes, could be considered end-users. Our short-term goals are all largely based on benefit to society through the ability to predict events.

In the long term, we look beyond prediction to the control of events. We must build the capacity to mitigate extreme scenarios, or at least to provide contingency plans should they occur. Countless ethical and political issues are associated with exerting external control over our environment. However, the current planetary environment is no longer strictly natural. Human action is already affecting the Earth in ways ranging from anthropogenically-induced earthquakes, to global climate change. At the very least, we humans must control our own effects armed with some knowledge of the consequences of our actions.

What geoscientists must remember is that our science is for survival and not just advancement, as is the case with many other fields of research. Despite the fact that advances made by geoscientists could be abused, there is an underlying obligation to society to provide the ability to improve humanity's chances of survival. Long-term goals include projects such as weather and climate modification, the precise prediction of volcanic eruptions, CO_2 sequestration in the oceans, and the scientifically-based allocation of groundwater resources. In the very long term, we may gain enough knowledge to not only prevent our actions from doing harm, but actually ameliorate our condition on the planet. We accept that it would be irresponsible in the extreme to begin the forcing of environmental systems while our knowledge is incomplete. However, we see that geosciences are in a position to begin actively pursuing theoretical and laboratory research based on these ideas of control. There is, of course, the real possibility that the geosciences will not be able to control fatal events. To this end, the group encourages projects to locate and/or develop other habitable environments as parallel undertakings. Projects searching for extra-planetary systems and terra-forming initiatives are just two examples highlighted in the report.

Society and Scientific Societies

In addition to the scientific problems to be addressed by the geosciences in the future, there are also several organizational and infrastructure issues that warrant attention. The onset of Earth system modeling has highlighted more clearly than ever the need for interdisciplinary studies. The traditional boundaries within the geosciences are no longer wholly relevant, and a framework must be built that allows for the efficient study of the Earth system as a whole. The working group report anticipates that many of the existing disciplinary boundaries will fade over the next 20 to 30 years (Figure 1). Other disciplines such as the biological sciences must now also be included in this framework as the whole Earth system is addressed. In addition, infrastructure must be developed for communication with engineers and political scientists, as results from the geosciences are converted into beneficial end-results for society; for example, early warning systems, sustainable development, and engineering projects to mitigate extreme events. Basic and applied science must be funded at comparable levels.

Developing countries also form an integral part of research in the geosciences, as they are often most adversely affected by environmental disasters and extremes. Despite this, neither improvements in basic geoscience nor communication of results to policy has been evenly applied worldwide. The inequality is detrimental to developing countries. The geosciences must play a positive role in both the sustainable economic and scientific development of these countries. Specific vehicles for helping developing countries include opening access to data as discussed above.

The final recommendation to the geosciences is in communication and the transfer of knowledge to policy-makers, the public, and young people.

Politicians have many factors to consider in their decisions, and changes in policy cannot be expected until they are justified by quantifiable and easy-to-understand predictions. Channels of communication to policy-makers must be enhanced. The general public is currently subjected to much misinformation. Geoscientific information must be accurately quantified and properly represented. The use of popular media, including television, will be essential in achieving this goal.

The geosciences must also improve communication with young people who are the future of the planet and need to be made aware of the issues facing them. In addition, through education and outreach, the geosciences must seek to interest the best young minds in a future in the geosciences. Many exciting opportunities will present themselves and we must ensure that we motivate the next generation of scientists so that the survival of our planet is in the best possible hands.

We hope that both the general and subject-specific recommendations of the report provide a useful framework for exciting geoscience. Many important and challenging opportunities are facing the geosciences. As the resolution and fidelity of models and observations improve and processes are better understood, the accuracy and resolution of predictions will be enhanced. As a consequence, society will enjoy greater confidence in geoscientific information, and will be able to act more decisively and effectively. The geosciences must also look to the future: We must make brave decisions to both improve our quality of life through predictions, and ultimately control our chances of survival.

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