Fostering advances in interdisciplinary climate science

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Fostering advances in interdisciplinary climate science

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Climate science is a vast, multidisciplinary research field with foundations spanning physics, chemistry, biology, geology, mathematics, and more. Cutting-edge climate research often straddles one or more basic disciplines, each of which has its own methods, terminology, and research culture. Indeed, many big opportunities and compelling scientific questions are intrinsically interdisciplinary, but disciplinary differences can sometimes impede integrated interdisciplinary research efforts and even pose barriers to scientific progress. A challenge for many interdisciplinary researchers is to develop avenues for communication with multiple partners and audiences, each of whom may have different perspectives on how research is to be conducted, different language for discussing science, and even distinct outlets for publication and sources for funding.

Science has always benefited from a diversity of perspectives. The progress of science reflects its adaptability and willingness to consider new ideas, constructs, and approaches. New methods and subdisciplines are often introduced or emerge within a broader field, as that field shifts to tackle new problems or paradigms (e.g., refs. 1, 2). Even within a given discipline, a range of approaches often exists for conducting research. For instance, theoreticians, dynamics modelers, statistical modelers, and experimentalists can each bring an important and distinct vantage to the study of a given problem. Bringing together this diversity of perspectives benefits scientific advance and proceeds with limited impediments within established subdisciplines (e.g., synoptic meteorology); however, newer subdisciplines, particularly those arising from the integration of diverse fields, may struggle for recognition in their nascency.

In climate science this problem appears to many to be increasingly acute. The field is growing more interdisciplinary as interest in climate impacts, adaptation, and mitigation increases. Indeed, the disciplinary breadth of the community of scientists engaged in active study of climate-related research has expanded. Scientists from fields as diverse as macroeconomics, civil engineering, agriculture, infectious disease, and mental health, to name a few, increasingly collaborate with climate scientists and work to improve understanding of feedbacks and linkages between the climate system and the broader world. This diversity speaks to the increased scientific concern over climate change and variability, an increased understanding of the interconnectedness of climate and physical conditions with the health of the planet and human society, and an intellectual appreciation of the complexity of these interdisciplinary connections.

Although the intellectual appeal of interdisciplinary research may often be apparent, challenges remain to the planning, funding, execution, and dissemination of this work. Universities and government agencies are increasingly stressing the importance of interdisciplinary research; however, these same institutions still struggle to develop mechanisms that recognize and support innovative interdisciplinary research ideas. Certainly, it would benefit the scientific community and the broader public if good interdisciplinary ideas that foster new research directions, and even new research fields, were identified and supported as soon as possible. Earlier recognition accelerates development of new science and facilitates the training of students in those emerging fields.

On March 31–April 2, 2011 an Arthur M. Sackler colloquium was held in Washington, DC to discuss challenges inherent to interdisciplinary climate research. The colloquium was used as an opportunity both to celebrate interdisciplinary scientific advances and to discuss how novel interdisciplinary ideas might be better recognized and nurtured in the future. The participants at the colloquium represented a diversity of perspectives. In addition to scientific presentations, a portion of the colloquium was devoted to panel discussions. Panelists included officials from federal funding agencies, private foundation representatives, journal editors, and scientists. This introduction is not intended as a comprehensive review of the challenges inherent to pursuing interdisciplinary research—indeed, the National Academies of Science published a report on the broader topic within the last decade (3); rather, here we highlight a few of the recurrent ideas discussed at the colloquium.

Top–Down- vs. Bottom–Up-Driven Approaches

Colloquium panel sessions sparked a discussion of whether interdisciplinary research is primarily a bottom–up self-organized phenomenon that emerges from local clusters of scientific activity or whether top–down calls, or even demands (e.g., the Manhattan Project), for interdisciplinary ventures are the principal catalyst. The general consensus at the colloquium was that for better or worse a system of bottom–up development predominates. Such a system no doubt has advantages; e.g., one might argue it affords the scientists themselves greater say in the progression of a field; but it also puts a greater burden on those scientists not...

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only to develop the novel science, but also to find mechanisms that will facilitate and fund the research. That is, scientists must not only work as researchers; they may also need to (i) pursue diverse funding streams for the work, often by making connections with program managers, foundation directors, etc., to facilitate support and pursuit of novel interdisciplinary ideas (seed funding at universities and other research institutions can be vital at initial stages); (ii) develop larger initiatives at the federal level, which may require convincing program managers and even federal elected officials that such pursuits are an appropriate and needed allocation of resources; and (iii) find appropriate venues for dissemination of interdisciplinary science to multiple peer groups (recognizing that not every new interdisciplinary work will start off with a bang in PNAS or Nature).

Scientists are not explicitly trained as promoters and networkers. Researchers often must learn on the job how to present and advocate their work, not merely within the scientific community but also to the larger community of foundations, policy makers, government organizations, and the public. The opportunities to provide this promotion of novel interdisciplinary science, particularly for early career scientists, are often self-made (e.g., a program manager will not typically call someone up and ask to hear of his or her research, its worth, and need for funding). Thus, the onus is on the individual to provide the hustle and initiative to make these connections.

One might argue, at least for the current US environment, that these additional burdens are de rigueur for most scientific endeavors and that, certainly, if an idea is compelling, many researchers are willing to take on the challenges. Many interdisciplinary ideas have been pursued in this vein to great success (e.g., refs. 4, 5). However, fostering recognition of a great novel interdisciplinary idea can be difficult and slow. For example, recognition of the public health burden imposed by indoor air pollution in the developing world, particularly due to biomass and coal combustion in household cooking (6, 7), was hard fought and slow to develop. Indeed, identification of the scope and severity of the problem and funding of investigations into this issue evolved only after more than a decade of championing the cause by a few individuals. Now this topic is a funding priority for the National Institutes of Health; however, one might wonder how many lives might have been saved and improved had the science and mitigation of the problem been targeted earlier.

Part of the slowness to recognize a problem can stem from difficulties in assessing interdisciplinary scientific ideas within traditional review frameworks. A National Science Foundation study carried out at the turn of the century showed that evaluation of interdisciplinary projects within traditional discipline-specific programs leads to poor grading of the applications, whereas scientists carrying out interdisciplinary research are better equipped to grade and rank these applications. This finding suggests a path forward; however, there is a sense that the community may continually be playing catch-up, as evolving interdisciplinary ideas continue to fall outside the purview of existing interdisciplinary programs.

Although the bottom-up approach can slow scientific development, the top-down approach has its problems, too. It is very difficult for an agency or governing body to anticipate where new connections at the interface of disciplines will arise, i.e., where “new science” will emerge, nor can the direction of science be directed exclusively by fiat. That said, there are telling examples of successful top-down management of interdisciplinary research (3). One example is the US Global Change Research Program (GCRP). GRRP, which emerged partly as a result of diverse bottom-up efforts over many years, follows a congressional mandate “to understand, assess, predict, and respond to human-induced and natural processes of global change” (8). The GCRP is a multi-agency program that seeks to direct climate change research and use the findings to inform policy and deliver services. Programs such as the GCRP can provide guidance and identify priorities, but agencies still need to find resources, and managers and reviewers vetting projects for the program have to maintain an open, trans-disciplinary perspective if the program is to succeed.

An alternate federal funding approach seeks partnerships with industry. These programs, such as carried out by the Defense Advanced Research Projects Agency (DARPA) and the Advanced Research Projects Agency–Energy (ARPA-E), endeavor to identify and fund novel, and often interdisciplinary, research in the defense and energy sectors. The DARPA and ARPA-E programs benefit from partnerships with the military and industry, both of which are positioned to transfer research findings to marketable technologies. Much of climate science research does not possess established connections to industry and technological development; however, a more systematic consideration of potential linkages between climate science research and technology may be warranted. Such study may reveal the benefits of a broad climate program in the vein of ARPA-E.

**Successes and Failures**

Many of the colloquium presentations included examples of successes and failures in interdisciplinary climate research undertaken to date. One informative discussion topic was the development of initiatives spanning the natural and social sciences. Some of these initiatives have struggled because of methodological and cultural differences between these two broad fields, as well as limited funding.

Interdisciplinary ideas often begin as bottom-up initiatives, conceived and spearheaded by groups of scientists. These initiatives expand and develop faster and are less likely to fail, if funding for the science is secured earlier. Some institutions are better aligned to recognize and support new science quickly. Indeed, seed funding through universities, foundations, and centers or institutes developed and cultivated in collaboration with key individuals at the foundations, universities, or government has often accelerated development of ideas at the interfaces of different disciplines. In some instances, seed funding from such institutions has proved vital for initiating pilot interdisciplinary projects (9).

The need for advocates in positions of authority was also discussed: that is, individuals who, when convinced by their own evaluation of the evidence or the advocacy of their constituent scientists that a new funding program or directive is needed, use their influence and leverage to bring greater recognition and support to a nascent field of inquiry. Such mentoring can come from colleagues, program managers, or foundation directors, any of whom may have influence within their institution to nurture, value, and reward novel interdisciplinary science.

Panel discussions did not address the effects of university structure and institute environment on the facilitation of collaborative, interdisciplinary enterprises. Certainly, some institutions are more or less receptive to interdisciplinary research. Those institutions with receptive cultures will foster and seed the work, whereas those institutions that do not may impede interdisciplinary research efforts. In particular, at the point of promotion and tenure, researchers may be penalized for generating interdisciplinary work rather than producing more traditional and recognizably discipline-specific
publications. These issues have been detailed previously (3), but remain problematic at some institutions.

Training and Mentorship
The importance of training and mentorship arose repeatedly in colloquium discussions. It was concluded that no single method for training interdisciplinary scholars works best under all conditions; however, training should include not only strong discipline-specific training in one or more fields, but also opportunities for interaction with communities outside one’s core field(s). In addition, more attention to education regarding the challenges specific to interdisciplinary research, as well as opportunities to meet and interact with other researchers engaging in interdisciplinary research, would strengthen mentoring.

In addition to mentoring, the dissemination of interdisciplinary findings can be much more difficult, as journals focused on interdisciplinary research are few and relatively new. Researchers increasingly can take advantage of new forums and technologies for the communication of science. Blogs, podcasts, popular media, the Internet, and public lectures all provide interesting and often fruitful avenues for disseminating scientific information.

There is some logic to postponing interdisciplinary research efforts—that is, in learning a single discipline well and investing in a more focused and established community during graduate school. Once a researcher’s credibility in that field has been established, then in later career stages the individual has license (and job security) to pursue more interdisciplinary research. Following a track in which the researcher establishes his or her reputation in a known core discipline before undertaking interdisciplinary projects is in many ways a more secure route; however, it may delay young, energetic scientists from making interdisciplinary research contributions and realizing their full potential.

An alternate path is to embrace multiple disciplines at an early career stage (e.g., during graduate study) and engage in collaborative interdisciplinary research throughout one’s career. This path allows researchers to pursue their interdisciplinary research ideas, but also has the potential to spread the discipline-specific core knowledge of a given investigator across several disciplines. A risk of this approach is that the researcher’s graduate degree may be perceived as less rigorous, and this valuation may make job placement in institutions, such as universities with traditional department structures, more difficult.

Fostering Interdisciplinary Climate Research
Panel sessions of the colloquium focused on environmental, foundation support, and government agency support. The sessions included introductory talks by panel participants followed by moderated discussions. Videos of most of the introductory talks can be found on the Sackler Colloquium Web site.

Journals. The role of both interdisciplinary and specialty journals in aiding identification and dissemination of important interdisciplinary scientific advances was discussed. Journals can shape public recognition of new avenues of research and can, especially in editorials, advocate the importance of interdisciplinary work. Indeed, both journal editors and contributors can add to this discussion through perspective pieces, review articles, and editorials. In effect, it constitutes a grass-roots bottom-up advocacy for a new field or form of science.

Foundations. Foundations provide an important source of support for higher-risk interdisciplinary research. Unlike government agencies, foundations are more willing to take on less conventional projects and are willing to accept longer time horizons for reaping potential scientific dividends. The mandate and vision of these organizations can make them a good complement to government funding.

Government Agencies. Although government agencies establish programs and funding priorities, these commitments are informed by communication with the scientific community. New ideas and interdisciplinary initiatives have to find an existing program or convince the scientific community and government agencies of the need for specific research. This dilemma speaks to the bottom–up vs. top–down dichotomy discussed above.

Furthermore, there are times when government agencies seek advice from the scientific community about its investment in different funding programs. Such opportunities are critical moments when the community should provide input to the agency and help direct its funding priorities. In addition, workshops sponsored by government organizations can be critical for recognizing developments within fields, as well as across fields.

Keynote Address
The colloquium keynote address was delivered by US Secretary of Energy Steven Chu. Secretary Chu spoke about the climate and energy challenge and emphasized that research and development (R&D) and technological improvements will enable the world simultaneously to meet the challenges of higher oil prices and the need to constrain carbon emissions. The Secretary cautioned that an investment in R&D and infrastructure is needed and that austerity is no excuse to abandon science and development. Indeed, Secretary Chu quoted Norman Augustine, former Chairman and CEO of Lockheed Martin and former Undersecretary of the Army (ref. 10, p. 27): “One thing that is clear based upon my own career in industry and government is that when faced with major challenges of high technological content in a time of austerity, the last thing one should under-fund is R&D . . . to do so is the equivalent to removing an engine from an overloaded aircraft to reduce its weight.”

Secretary Chu’s address, which is available for view online, discusses how technological development, in areas such as biotechnology, materials science, and batteries, to name a few, will move society toward a more carbon neutral and energy sustainable future. The Secretary also emphasized the need for efficiency standards and argued that regulation can spur development.

Articles
The papers included in this issue of PNAS represent a distillation of a few of the science constructs presented at the colloquium. Climate science itself has changed significantly over time. Spencer Weart (11) provides an exploration of the history of climate science from its early descriptive beginnings as a science of classification to its development as a field of study drawing researchers from many diverse fields. Weart discusses how in its nascency, much of climatology was a service industry providing local and regional information on rainfall rates, flood recurrence, and seasonal temperatures to farmers, planners and engineers. He also points out that much of the seminal work in meteorology was, although rooted in fundamental physics and often carried out by single individuals, intrinsically interdisciplinary. In the United States, World War II wartime and postwar funding of meteorology and geophysics led to many advances in understanding of climate that drew from a diversity of fields—a result of the continued recognition of the importance of understanding climate phenomena.

However, as the field expanded in the 1960s and 1970s, individual researchers grew more specialized and the field became fragmented such that few could move among fields. Weart characterizes how the
problems attendant with fragmentation led to recognition by some that scientists from different subcommunities needed to engage and work with one another. More recently, the advent of advanced computer models and Internet global connectivity has greatly facilitated cross-disciplinary collaboration. Teams of researchers from disparate fields now routinely join forces to tackle interdisciplinary questions. Weart sees many of these developments as positive and supportive of interdisciplinary research.

Mooney et al. (12) examine the history of interaction and collaboration among natural and social scientists engaged in global change research. This integration has often been motivated by a need to improve understanding of economic and social drivers of climate change. As Mooney et al. detail, a number of initiatives were developed over the last 30 y that have attempted to bring scientists from different disciplines together. Early efforts to integrate the social sciences were less successful, as the focus lay predominantly on communication among natural scientists, especially physicists and biologists. Recent projects have been more inclusive; however, some cultural barriers persist that may impede communication among natural and social scientists.

Mooney et al. describe these impediments to the integrated study of both natural and human components of the earth system. The authors document how these obstacles have partly been overcome but also detail remaining work needed to effect a fuller integrated approach to studying earth system science.

Picking up on this idea of joint natural and social science assessment, Ronald Prinn (13) presents climate projections derived from an integrated global system model (IGSM), a framework that includes socio-economic, physical, chemical, and biological processes. These IGSM simulations are run through the end of the 21st century, using different target greenhouse gas stabilization levels, as well as runs performed with no stabilization. The economic costs of greenhouse gas stabilization are compared with benefits gleaned from averted environmental perturbation. The findings indicate that lower greenhouse gas stabilization targets appreciably reduce the likelihood of extreme changes in the climate system and that the costs are not prohibitive. The implications of these stabilization targets for a number of specific components of the broader system, including ocean circulation, changes to the energy supply sector, and air pollution, are also quantified. This interdisciplinary assessment provides a view of current integrated earth system science modeling and climate change projection science.

Two of the articles in this issue of PNAS focus on disease emergence and improving ability to predict these rare events. Daszak et al. (14) use ecological niche modeling (ENM) to map the potential risk of Nipah virus emergence as the planet warms. Nipah virus emergence has previously been tied to interaction among fruit bats and domestic animals. The authors use an ensemble of Intergovernmental Panel on Climate Change model simulations in conjunction with ENM to project how future climate, land use practices, and socioeconomic conditions might alter the distribution of the fruit bat and Nipah virus emergence risk. Strategies for grappling with the public health threat of emerging infectious diseases are discussed.

In the second disease emergence paper, Shaman and Lipsitch (15) hypothesize a possible link between ocean–atmosphere conditions in the Pacific Ocean basin and the likelihood of influenza subtype re-sortment, a process that can produce novel pandemic strains. The authors find that the four historically well-documented human influenza pandemics all emerged following La Niña events. The phase of the El Niño–Southern Oscillation (ENSO) has been shown to affect the fitness, stopover times, and interspecies mingling of migratory birds, which host multiple types of influenza. The authors speculate that during La Niña events bird species that would otherwise remain segregated intermingle. This confluence in space and time enables simultaneous infection of a single host bird by disparate influenza subtypes, which can then reassort and generate a novel pandemic strain. Methods for testing this hypothesis are detailed.

In the final paper of this issue, Hay et al. (16) describe a new method for multimodel estimation of sea level rise, using a modified Kalman smoother applied to global sea level models. The sea level models simulate internal ocean dynamics, global warming, and freshwater addition. The Kalman filter enables statistically rigorous assimilation of tidal observations into the evolving model structure and improved estimation of global sea level conditions. Kalman filter techniques have been used for a range of estimation and prediction problems in fields as diverse as statistics, engineering design, and weather forecast. In this instance, Hay et al. use the Kalman smoother in conjunction with historic tide gauge data to produce maximum-likelihood estimates of sea level rise. The combined model–filter framework provides more robust estimates of melt rates than previously developed.

Conclusions

There is a continued need and increasing urgency to encourage new cross-cutting scientific ideas and provide the opportunity for them to be investigated and flourish, both within climate science and within science as a whole. It is at the margins, the interface of traditional disciplines, that new ideas and fields often emerge. We cannot predict where these interactions will occur or where the new science will arise; however, scientific understanding and society have benefited time and again from interdisciplinary advances. For the moment, the onus remains with the investigator to promote her or his idea and to take the time to communicate its merit and potential significance to colleagues and administrators. However, it is important that we keep our minds open and afford opportunities to new science by investing the time and energy, individually and institutionally, to understand and recognize novel interdisciplinary ideas and to work with our colleagues to foster early recognition and support for this important scientific inquiry.