

ASPEN GLOBAL CHANGE INSTITUTE

25 Years of Interdisciplinary Global Change Science

BY GERALD A. MEEHL AND RICHARD MOSS

The AGCI has convened scientists to define challenges, develop disciplinary and interdisciplinary research strategies, improve communication across natural and social sciences, and plan assessments and other decision support activities.

Global environmental changes, such as climate change, result from the interaction of human and natural systems. Research to understand these changes and options for addressing them requires the physical, environmental, and social sciences, as well as engineering and other applied fields. In this essay, the authors provide their personal perspective on the role of the Aspen Global Change Institute (AGCI) in global change science over the past 25 years—in particular, how it has contributed to the integration of the natural and social sciences needed to research the drivers of change, the Earth system response, natural and human system impacts, and options for risk management. Drawing on inputs from other AGCI participants, we illustrate how, in our view, the history of AGCI is intertwined with the

evolution of global change science as it has become an increasingly interdisciplinary endeavor.

CONTEXT. Much early research on climate change initially focused on the physics of the climate system and its interactions with the mineral chemistry of the Earth. Over time, climate science evolved to incorporate the role of the biosphere in climate regulation, including the important contributions of human activities in affecting cycles of carbon and other nutrients through emissions from fossil fuel burning and changes to land cover (Weart 2008).

The increasing emphasis on ecological systems and human activities ushered in the study of *global* change involving a far wider range of scientific disciplines. National and international research programs evolved to reflect this interest. The World Climate Research Programme (WCRP) was formed in 1979 and emphasized processes in the physical climate system, human influences on those processes, and whether future evolution of the system could be predicted. In 1987, the International Geosphere–Biosphere Programme (IGBP) was organized to address the role of terrestrial and marine ecosystems and their interactions with physical dimensions of the Earth system. And in 1990, the International Human Dimensions Programme (IHDP) was established to coordinate interdisciplinary social science research on the human causes and impacts of changes in the global environment.

Across the globe, developed nations began to launch their own global change research activities. The U.S. Congress acted to establish the U.S. Global

AFFILIATIONS: MEEHL—National Center for Atmospheric Research,* Boulder, Colorado; MOSS—Pacific Northwest National Laboratory/Joint Global Change Research Institute, College Park, Maryland

* The National Center for Atmospheric Research is sponsored by the National Science Foundation

CORRESPONDING AUTHOR: Gerald A. Meehl, National Center for Atmospheric Research, P.O. Box 3000, Boulder, CO 80307
E-mail: meehl@ucar.edu

The abstract for this article can be found in this issue, following the table of contents.

DOI:10.1175/BAMS-D-15-00204.1

In final form 23 February 2016
©2016 American Meteorological Society

Change Research Program (USGCRP) to coordinate the activities of 13 federal agencies, including the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), the U.S. Department of Energy (DOE), and the National Oceanic and Atmospheric Administration (NOAA). Initial U.S. efforts emphasized building an observational foundation for research through remote sensing and continuing to develop numerical modeling of components of the Earth system. To build capacity and interest in global change research in developing countries, WCRP, IGBP, and IHDP launched an initiative called the Global Change System for Analysis, Research, and Training (START).

During this period, global change was becoming a factor in national and international politics. In the early 1980s, reports from the U.S. National Academy of Sciences and the U.S. Environmental Protection Agency sparked controversy in the United States and placed the issue on the agenda of the U.S. Congress and the Reagan administration. In 1985, an international conference in Villach, Austria, expressed an expert consensus that human activities were changing the climate, and a 1988 conference in Toronto, Ontario, Canada, called for specific restrictions on greenhouse gas emissions. Pressures on national governments to act increased, paving the way for the 1992 United Nations Conference on Environment and Development (or “Earth Summit”). To inform policy making, a new body, the Intergovernmental Panel on Climate Change (IPCC), was created in 1988 to provide an internationally authoritative and consistent assessment of scientific understanding of all aspects of the climate issue, including response strategies.

The impetus to create AGCI arose from this context of the increasing salience of global change, requests to better inform policy, and the need to accelerate integration of the physical, environmental, and social sciences. Even though the international global change programs were collaborating to establish interdisciplinary research on challenges such as land use/cover change, most of the science remained stovepiped in more traditional areas.

Of course, there is a human backstory to AGCI that involved the convergence of interests of three individuals with completely different backgrounds: an educator, a popular entertainer, and a scientist. The first, John Katzenberger, who became the director of AGCI, had a background in biology and ecology and taught math and science at the secondary level. The second, entertainer John Denver, was cofounder of the Windstar Foundation, an environmental conservation and education foundation based in

Aspen, Colorado. Windstar had hired Katzenberger to work on its educational program. The third, NASA scientist Rick Chappell, headed Earth Sciences at Marshall Space Flight Center. The three joined forces in 1988 when Chappell visited Windstar, met Katzenberger, and discussed the idea of forming an interdisciplinary institute that could involve more of the research community outside of NASA in using emerging remote sensing and Earth-observing capabilities (Fig. 1). They also identified education for students and the general public as a central element that would build on Windstar’s environmental education efforts.

Denver and other Windstar board members encouraged Katzenberger and Chappell to pursue the idea. Shelby Tilford, the head of the Earth Science program at NASA, provided a grant for a 1989 planning workshop in Aspen to discuss the possible roles of such an interdisciplinary institute. Jack Eddy, already advancing global change science through the Office of Interdisciplinary Earth Studies at the University Corporation for Atmospheric Research (UCAR) in Boulder, Colorado, was pivotal, with Katzenberger and Chappell, in organizing the planning workshop and inviting its attendees. The workshop coalesced agreement that 1) there was a scientific need for an institute serving the interdisciplinary global change science community, 2) that Aspen would be a good place to locate it, and 3) that education and public outreach would be an important part of the mission. The idea that emerged was to involve senior-, mid-, and early-career scientists in workshops that would be open to interdisciplinary discourse, challenge assumptions, and help participants learn from the edges of their own disciplines, as well as from fields quite orthogonal to their main areas of research. Initially AGCI operated under the umbrella of Windstar’s nonprofit status but became a fully independent organization in 1995.

Shortly after the 1989 planning workshop, an advisory board was formed to provide critical guidance to the fledgling institute and included key figures in global change research such as Mark Meier, Richard Somerville, and Steve Schneider. With initial funding secured, the first summer of interdisciplinary workshops commenced in 1990.

THE RIGHT FORMULA FOR STIMULATING FRANK DISCUSSIONS. AGCI experimented with a number of approaches for convening its interdisciplinary discussions before settling on a blueprint to use in planning the workshops. What emerged as the formula was a weeklong workshop of

roughly 20–30 participants that included presentations, discussions, breakout groups, and some unscheduled time for informal discussions or pursuit of individual or collaborative research at the margins of the workshop. This recipe has proved successful in helping participants gain new insight into their own contributions to a science challenge, forming new collaborations (e.g., the authors of this essay, who first met at a 2006 AGCI session), building interdisciplinary research communities, and producing research publications and reports.

This format has stimulated frank and provocative discussions about some of the central scientific questions in global change, issues that are often at the overlapping boundaries of multiple social and natural science disciplines. Some of these discussions revealed tensions between different communities, as well as between participants with shared disciplinary perspectives. The format of the AGCI sessions was conducive to resolving divergent viewpoints and framing new research to address issues that remained unresolved.

For example, the question of how to balance research that addresses physical and biological processes of Earth systems with social science that advances understanding human drivers and responses was a frequent tension. This issue was central to the 2012 session, where participants were tasked with formulating a definition of *adaptation science*, highlighted in USGCRP (2012). Physical scientists promoted the view that a better understanding of physical science was necessary to quantify with greater skill future conditions to which society would have to adapt. Social scientists argued that even though important uncertainties about future climate conditions remained, research needed to be accelerated on topics such as vulnerabilities, societal influences on implementation of adaptation, building resilience, and the relative roles of adaptation and mitigation to support management of climate risks. In the end, the participants arrived at a mutual understanding involving a combination of these views



FIG. 1. Founders of AGCI pictured in 1990, Rick Chappell (left) and John Katzenberger (right), along with early enthusiastic supporter John Denver (center, photo signed by John Denver).

that outlined what the term *adaptation science* meant to the physical and social sciences, as well as to the stakeholder and policy maker communities (Moss et al. 2013).

Another example of tensions that arise at AGCI sessions occurred in 2013 at a session to plan the sixth phase of the Coupled Model Intercomparison Project (CMIP6). A new structure for CMIP was proposed that would consist of a basic “core” set of experiments to be run by all modeling groups, and a set of elective model intercomparison projects (MIPs) that modeling groups could join based on their scientific interests. Though there was agreement that fundamental characterization experiments should be in the core set (e.g., 1% CO₂ increase, long preindustrial control run, historical climate simulation), there was considerable disagreement about whether and what type of future scenario experiments, and/or experiments to quantify radiative forcing, should be included in the core. Some participants argued that scenario experiments were scientifically important for research on impacts and responses, while others said that they diverted attention from higher scientific priorities. At the end of the session, the result was to include a high and a low future scenario, as well as a radiative forcing experiment, in the core set of CMIP6 experiments (Fig. 2a). In subsequent meetings involving a wider sample of the community, the original concept of a core set of model integrations was confirmed, but the future scenarios and radiative forcing experiments

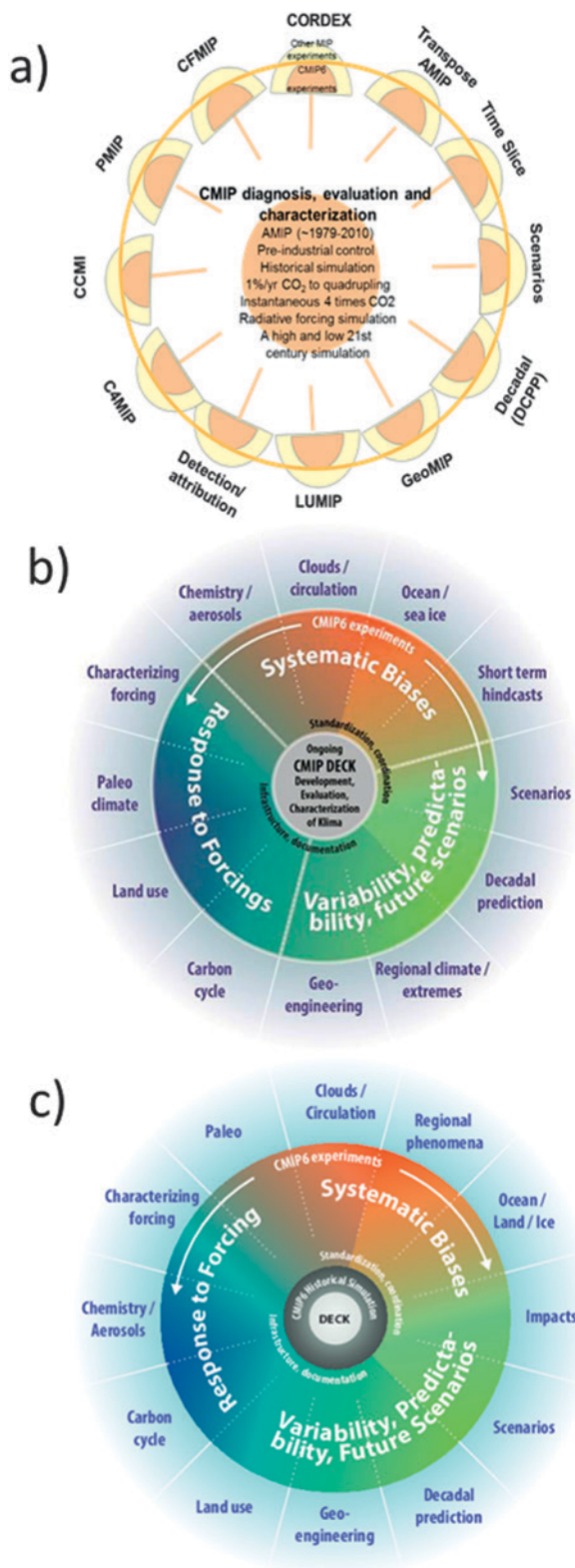


FIG. 2. (a) Schematic of the preliminary CMIP6 experiment design that was formulated at a 2013 AGCI session; (b) modified version that was in the subsequent proposed CMIP6 experiment design (Meehl et al. 2014a); and (c) final version of the CMIP6 experiment design (Eyring et al. 2016).

were removed from the core runs, which were called the Diagnostic, Evaluation, and Characterization of Klima (DECK) experiments in the CMIP6 design proposal in 2014 (Fig. 2b). Additionally, the CMIP6 historical simulation was separated from the DECK but was still part of the characterization experiments. The radiative forcing experiment became part of the Radiative Forcing Model Intercomparison Project (RFMIP). Scenario-based runs were included in one of a number of optional intercomparison projects as part of the process of refining the final CMIP6 design (Fig. 2c; Eyring et al. 2016).

KEY OUTCOMES. We highlight here examples of outcomes that illustrate different dimensions of AGCI’s objectives, highlighting research results, connections to international activities, new interdisciplinary research collaborations, the AGCI web page, and education. Because of space limitations, we can describe only a few of the roughly 80 AGCI science sessions and other activities held over the past 25 years.

Key AGCI science sessions. Science sessions can be grouped into different categories, and here we describe a few workshops that are representative of each category. Some workshops could be described as “scoping” or “community building” and are designed to bring together new combinations of disciplinary expertise to better define research needed to address a problem. Because the issues are just emerging and communication is more challenging, these scoping workshops typically are broad and are intended to provide opportunities for collaboration across different communities. A second set could be described as “deep dives,” which explore new research strategies in detail to advance progress on already defined challenges. A third set has been focused on “assessment and decision support,” with a smaller set on “policy-focused research.” The full range of sessions, as well as lists of participants, supporting documentation, and resulting reports, can be found online (at www.agci.org).

There are many examples of the scoping or community-building AGCI sessions, starting with the first AGCI session in the summer of 1990 involving 38 participants from fields including ecology; atmospheric chemistry and radiation; demography; economics; public policy; climate dynamics, forcing, and modeling; planetary atmospheres; solar–terrestrial physics; and glaciology. This session also included science educators exploring ideas and approaches for integrating global change into science education. This

session reflected the inherently multi- and interdisciplinary character of global change.

Another example in this category was a 1994 session on surprise, cochaired by Steve Schneider, that was particularly interdisciplinary and innovative in moving beyond a discussion of rapid changes in components of the climate system to a focus on incorporating surprises in social systems (e.g., population); natural resource systems, such as agriculture and soils; and development of integrated models for evaluating the consequences of surprise.

A third such session was a 1998 workshop that grew out of the second IPCC assessment (IPCC 1996), which highlighted the importance of future changes in weather and climate extremes for impacts and adaptation research. There was little research being done on this topic in the climate science community; thus, the session brought together climate modelers, observationalists, and impacts researchers to chart a research agenda on weather and climate extremes. Six publications were based on that single AGCI session: Two provided an overview of observations, socioeconomic and ecological impacts, and modeling extremes in projections of future climate change (Meehl et al. 2000a,b); a third reviewed observed variability and trends in extremes (Easterling et al. 2000a); a fourth addressed the role of human factors in increased losses from weather and climate extremes (Changnon et al. 2000); and a fifth dealt with the impacts of extremes on terrestrial biota (Parmesan et al. 2000). The sixth synthesized these technical results into a format for a wider audience (Easterling et al. 2000b). The session improved interactions between the climate science and impacts communities, advanced understanding of past and future extremes and their impacts, and supported subsequent IPCC assessments (Fig. 3). It also influenced the work of many participants. For example, one of us (Meehl) was encouraged to study how climate models simulated heat waves, and how those extremes could change in the future (Meehl and Tebaldi 2004). The session also prompted two AGCI workshops to plan and develop a U.S. Climate Change Science Program (CCSP) Synthesis and Assessment Product (see decision support discussion below).

A final example of an AGCI scoping or community-building session was one held in the summer of 1999 on “Integrating Human and Natural Systems to Understand Climate Change Impacts on Cities.” This meeting grew out of the U.S. National Climate Assessment, was chaired by Tom Wilbanks of Oak Ridge National Laboratory (ORNL) and Bob Wilkinson of University of California, Santa Barbara, and included

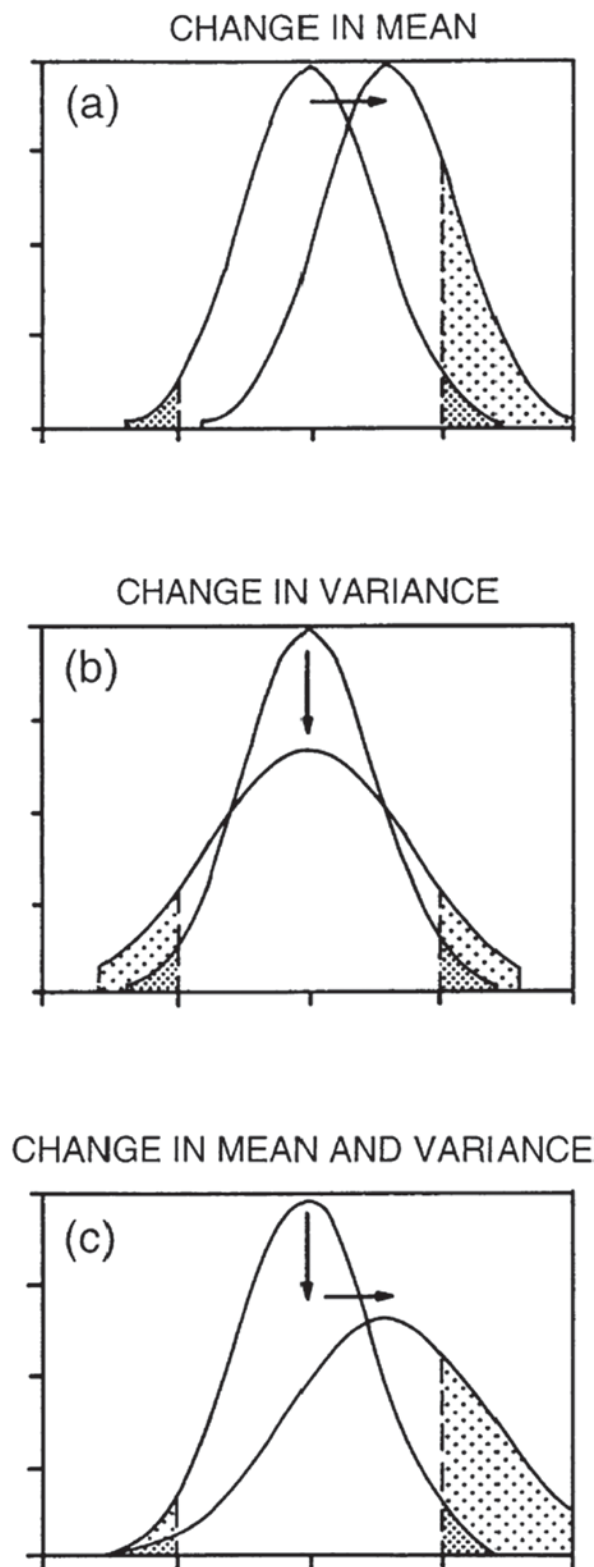


FIG. 3. Schematic for how extreme temperatures could change in the future, formulated to communicate weather and climate extremes to a general audience at the 1998 AGCI session (Meehl et al. 2000b) and subsequently used in the IPCC Third Assessment Report and other publications.

a diverse multidisciplinary mix of 17 scientists and practitioners. The session sparked major publications over the following decade and a half, and influenced urban climate impact research, including the design of several major metropolitan area assessments (e.g., Boston, Massachusetts, and New York City, New York), initiatives by the U.S. Agency for International Development (USAID) in India, the agendas of U.S. National Academy of Science committees, and discussions of research priorities in the USGCRP.

The second category of AGCI workshops—deep dives, which provide opportunities to focus in detail on major topics—includes a number of influential sessions. A prominent example is a workshop that arose from the establishment of a WCRP committee in 1990 to steer the course of climate model development [this group subsequently evolved into the Working Group on Coupled Modelling (WGCM)]. A number of climate scientists believed that climate models would extend beyond atmosphere–ocean–land–sea ice to include other components of the Earth system being studied through IGBP. The resulting 1992 interdisciplinary AGCI session looked ahead to the future of global change science relevant to WCRP and IGBP (Meehl and Schimel 1993). As an example of the type of outcome that could emerge from an AGCI session, the 1992 session proposed next steps to develop future Earth system models (ESMs). Though seemingly obvious now, in 1992 these were formative concepts that promoted the broad objectives of improving data and tools for understanding global change, its consequences, and potential responses:

- *clarifying needs for process research and observations* focused on internal variability, responses to anthropogenic and natural forcings, clouds and cloud feedbacks, decadal variability, and planning observational programs;
- *identifying approaches for improving models* such as improving model physics, enhancing the representation of land surface processes—including atmospheric chemistry and prognostic aerosols, and developing terrestrial ecosystem components;
- *increasing relevance of global change science for understanding impacts and planning responses*, including performing “time slice” experiments with high-resolution atmospheric models; developing a range of models of varying complexity keyed to needs for analysis and impact studies; producing results appropriate for analyses of impacts, adaptation, and mitigation; improving links to research on human forcing and technological options for adaptation and mitigation; and

recognizing that Earth system model information “must be disseminated to national, state and local policymakers based on adaptations of model-based scenarios with appropriate caveats.” (Meehl and Schimel 1993, p. 14)

The discussions at that session set in motion developments in global change research spearheaded by a number of participants. Tom Karl promoted the use of new and improved observational datasets for studying processes and evaluating climate models in his subsequent role as director of NOAA’s National Climatic Data Center (NCDC). Climate modeler Warren Washington led climate model improvements and experiments to understand the role of feedbacks and response to forcings. Ron Stouffer and one of us (Meehl) were involved with organizing CMIP in 1994 as part of a WCRP response to better understand model processes and feedbacks. Dave Schimel was among those synthesizing results from IGBP core projects to include interactive biogeochemistry, aerosols, and dynamic vegetation in Earth system models, and David Victor helped to more fully connect climate impact studies with modeling. The session’s call to integrate research on human forcing and responses was helped by a subsequent AGCI session in 2006, where planning for CMIP included, for the first time, social scientists expert in economic, demographic, and energy systems who were developing integrated assessment models (IAMs). The commitment to outreach and decision support was reflected by the involvement of many participants of the 1992 session as authors and contributors to IPCC and other assessments.

In 1994, another deep dive session focused on an important USGCRP initiative, the Atmospheric Radiation Measurement (ARM) Program, which was a key element of the global change program of the DOE. The session focused on addressing cloud–radiation feedbacks in observations and models. The report of that session was considered such a comprehensive survey of this key topic in climate research that DOE republished the AGCI report verbatim and widely distributed it in 1995 as an ARM report (Somerville and Gautier 1995).

The third category, assessment and decision support sessions, includes numerous workshops that contributed to assessments and the evolution of decision support research and activities. One example was the AGCI workshop held in 1996 that addressed a topic that had become a major issue for the IPCC: how to assess uncertainty and confidence levels in its reports. This issue arises because in assessments,

available (usually incomplete) science is used to answer decision-makers' questions "on demand" instead of waiting until confidence reaches a level traditional in basic research. The session was convened by Stephen Schneider and one of us (Moss), and was organized around reviewing experience in the just-completed IPCC Second Assessment Report (SAR). In the SAR, the three IPCC working groups adopted different approaches to describe uncertainties and confidence levels, with one working group essentially ignoring the issue. This made use of the results and synthesis of conclusions across working groups much more difficult. During the session, SAR lead authors (covering diverse issues including detection and attribution of climate change, impacts on agriculture and water systems, and estimates of the cost of mitigation) shared their experiences and identified a range of challenges involving author team dynamics; heuristics that lead to overconfidence; disagreements over definitions of uncertainty, confidence, and likelihood; and the lack of standardized terminology. The deliberations led to development of the first IPCC guidelines for characterizing and communicating uncertainty, something that has subsequently become a key feature of many assessment reports (see Moss and Schneider 1997, 2001; Moss 2011).

Another example of an assessment and decision support-oriented session was the 1997 workshop on "Planning for a U.S. National Assessment." More than 60 participants from federal agencies, the research community, the private sector, and local government convened to plan a national assessment in the United States, which had been providing support for developing countries to conduct assessments through the U.S. Country Studies Program but had yet to convene an assessment focused on impacts within its own borders. The workshop reviewed results from early workshops on regional consequences of climate variability and change, as well as the IPCC's regional experience (several participants were then conducting IPCC's first regional assessment). Breakout groups discussed topics including issues for major sectors across the country. The result was a detailed set of plans for the assessment, and what was dubbed the "Aspen Spirit," a shared commitment that stakeholder engagement would be a foundation for the process. The result was not just a report, but an ongoing process of dialogue among scientists, government at various levels, and a wide range of users and stakeholders.

The 1998 AGCI session on extremes (described above) prompted not only further research but subsequent AGCI workshops that framed a CCSP Synthesis and Assessment Product. The first, a 2005

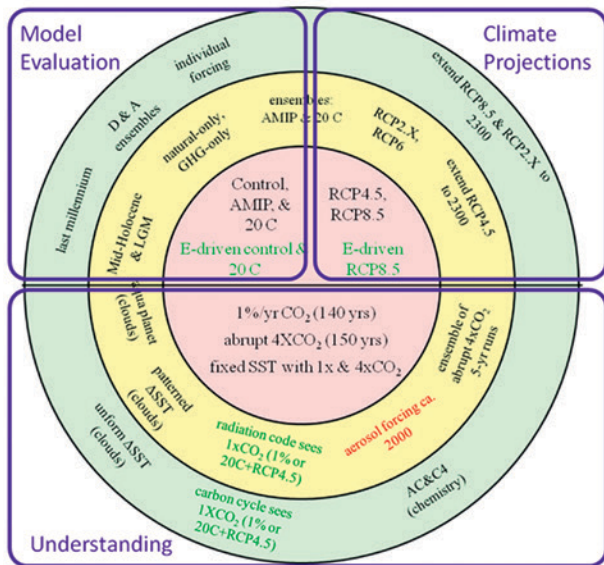
session on U.S. weather and climate extremes, focused on the current state of observations and modeling and surveyed the scientific foundations for a CCSP report on extremes, the first-ever assessment of possible future extremes across the United States. A 2007 AGCI session took the form of a lead author meeting that formulated the final CCSP extremes report (CCSP 2008).

Finally, a few sessions have discussed and explored applications of policy-focused research. An example of this type of session was the one held in the summer of 1995 (cochaired by Abe Chayes, Gene Skolnikoff, and David Victor) that explored the magnitude of the climate mitigation challenge and strategies for policy coordination. Participants included social scientists and lawyers, who drew upon research on the characteristics of effective international environmental agreements. The thinking that crystallized that summer informed other projects on that same topic and led to unconventional (and at the time, controversial) thinking about the potential ineffectiveness of a top-down strategy of international targets and timetables. Initially that thinking had no impact on international negotiations: the Kyoto Protocol, completed just two years later, depended upon targets and timetables. But many of the session participants continued to research and articulate bottom-up strategies, relying on independent national policies and measures. Today, 25 years after diplomatic talks on climate change first began, "intended nationally determined contributions" (to mitigation) are a key bottom-up mechanism in agreements reached at the 2015 Paris negotiations. Many members of the intellectual networks established at this AGCI session continue to work together, now on ways to ensure the bottom-up approach is effective.

Connections to international activities. A unifying theme across these different sessions is the role their outcomes often played in providing inputs to internationally coordinated activities through organizations such as WCRP. A particularly prominent example is the role AGCI has played in CMIP as it has developed and evolved over the years (see the discussion above regarding finding the right workshop "formula" to balance scientific tensions). CMIP started out modestly in the mid-1990s with a few experiments run by a handful of modeling groups. But participation in global coupled modeling diversified (both internationally and disciplinarily) as envisioned in the 1992 AGCI session, leading CMIP organizers to hold an August 2006 AGCI workshop to plan the project's fifth phase of CMIP

(CMIP5). There were 25 participants, including climate modelers, chemistry and aerosol modelers, land surface modelers, biogeochemistry modelers, integrated assessment modelers, and vulnerability–impacts–adaptation (VIA) researchers. A number of firsts were formulated (Hibbard et al. 2007; Meehl and Hibbard 2007) that would influence climate science research for the next decade and beyond, as illustrated by the schematic based on deliberations at the session (Fig. 4):

a) CMIP5 long-term experiments



b) CMIP5 near-term experiments

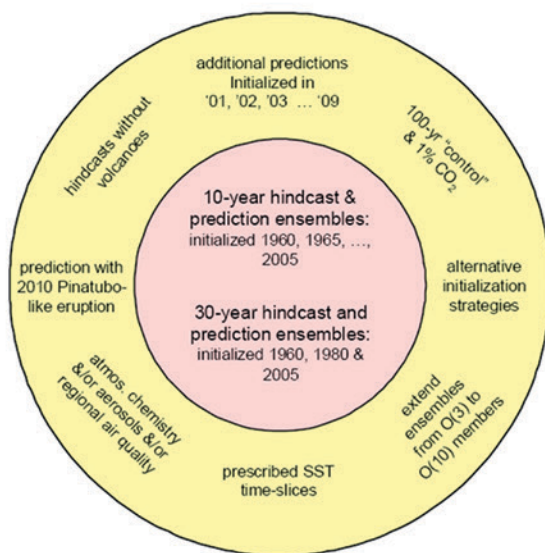


FIG. 4. Schematic diagram that emerged from the 2006 AGCI session for the CMIP5 experiment design

- For the first time the future climate change problem was divided into near-term and long-term time scales, reflecting a shift of the science with the emergence of decadal climate prediction and the needs of the stakeholder community for near-term climate change information.
- Novel experiments from ESMs were included in a CMIP phase, reflecting the incorporation of carbon cycle and biogeochemistry components into standard global coupled climate models.
- The beginnings of a new approach that was subsequently formalized at an Energy Modeling Forum workshop—the “parallel process”—to coordinate scenarios across the ESM, IAM, and VIA communities was proposed; the approach was used for the first time to produce emission scenarios for CMIP5 [the representative concentration pathways (RCPs); Moss et al. 2010].
- Planning of innovative idealized experiments was undertaken to promote *understanding* of the climate system, not just model intercomparison, following “climate process team” efforts in the United States and activities that were part of the Cloud Feedback Model Intercomparison Project (CFMIP), the Aqua-Planet Intercomparison Project, and the Coupled Carbon Cycle Climate Model Intercomparison Project (C4MIP).

Growing directly from the CMIP5 experiment design developed in the 2006 AGCI session, a 2008 AGCI session planned the first-ever internationally coordinated set of decadal climate prediction experiments (Meehl et al. 2009). A follow-up 2011 AGCI session assessed progress in the new field of decadal climate prediction and recommended updates to the CMIP5 experiment design (Meehl et al. 2014b). A 2015 session revisited decadal climate prediction to formulate experiments for CMIP6 aimed at increasing understanding of internally generated decadal climate variability mechanisms that could be simulated to improve the skill of initialized predictions for the next 10 years (Boer et al. 2015).

Also building on the 2006 workshop, a 2013 session involving scientists from the ESM, IAM, and VIA communities (described more completely above, in the discussion of the “right formula”) contributed to planning CMIP6. The outcome helped inform subsequent CMIP Panel decisions for coordinating climate modeling experiments for the next 10 years (Meehl et al. 2014a; Eyring et al. 2016; Fig. 2). Following up on the 2013 CMIP6 planning session, in August 2014, scientists representing several key MIPs gathered to coordinate experiment designs

including future scenarios for CMIP6 (ScenarioMIP), land use (LUMIP); and aerosols and chemistry (AerChemMIP) (O'Neill et al. 2014).

The description of these international collaborations would be incomplete without a brief mention of the close collaboration with another set of international workshops focused on climate change impacts and integrated assessment convened by the Stanford University Energy Modeling Forum (<https://emf.stanford.edu>). These workshops often provided inputs to and built upon AGCI sessions (as noted above), especially related to planning impacts/adaptation and integrated assessment interactions with the ESM community in CMIP.

The AGCI web page. Though the participants in AGCI sessions over 25 years number in the hundreds, the scope of AGCI outreach extends beyond those participants and the research that has resulted from their collaborations through the AGCI web page (www.agci.org), a comprehensive resource for global change science. This web resource includes links to one of the truly unique archives in global change science: video recordings of not only every AGCI workshop but also all of the Walter Orr Roberts public lectures given by AGCI session participants over 25 years (the lecture series celebrates Roberts, a noted humanitarian, scientist, and founder of the National Center for Atmospheric Research). These videos, all produced by the same videographer, Michael Munroe, document key developments in global change science and offer a unique glimpse into how scientists present their ideas and discuss them with one another. Applying this video archive to develop science education resources is the focus of an AGCI project, “From the Horse’s Mouth.” Additionally, there are sections on the web page for classroom resources, AGCI programs, and a “solutions” section devoted to what the public can do to take steps at the individual level to address global change.

Education and outreach. In addition to the Walter Orr Roberts lectures and the education and outreach efforts associated with the website, AGCI also conducted the NASA-supported Ground Truth Studies Project, which created materials to provide hands-on opportunities for students to learn about their local environment and how it relates to global change, and along the way about the geographical information system (GIS) and remote sensing and their use in global change research. AGCI conducted teacher workshops in 35 states, and a teachers’ handbook went into multiple printings to satisfy demand.

Another major education effort, Pre-Service Earth Science Training Opportunity (PESTO), was an intensive residential weeklong program for science teachers from the United States and Canada. The program was taught by leading scientists and environmental educators and exposed participants to resources such as materials and data about the Earth from NASA and other sources.

AGCI has also engaged in other ways with the local Aspen community. In 2006 it conducted a study exploring local vulnerabilities, potential impacts, and adaptations. The project, and the subsequent report, was a cornerstone of Aspen’s Canary Initiative (www.aspenpitkin.com/Living-in-the-Valley/Green-Initiatives/Canary-Initiative/), which established a carbon inventory program and was committed to greenhouse gas (GHG) reductions of 80% by 2050. AGCI was engaged again in 2014 to update the study and consider additional adaptation and resilience strategies.

THE FUTURE. To help plan for AGCI’s future, a 2014 session brought together an interdisciplinary combination of early-career and established scientists to formulate future research topics at the frontiers of global change research where AGCI could make significant contributions (Meehl and Moss 2014). An overarching theme was the increasing need for decision-relevant science, framed to consider uses of the results and drawing on integrated approaches from the social and natural sciences (e.g., NRC 2009; Moss 2015). The session explored how to address some familiar but still challenging topics in new ways. It also identified some new frontiers, including a vision for an integrated Earth system modeling framework ranging from complex and high-resolution models to reduced forms needed to provide improved insight and uncertainty characterization. The session also highlighted challenges related to decadal climate prediction (within credible limits), coordination of observations of natural and human systems, “coproduction” of science involving researchers and practitioners, and the expanded role of women and “citizen science” in global change research and decision support. Another fundamental challenge for the field that AGCI is likely to explore is the limits to which “good science for good climate policy” can solve the problems arising from climate change (Sarewitz 2011; Hulme 2014).

It is the authors’ view that AGCI has provided an important venue for the global change research community to address key challenges. AGCI’s ability to do so in the future will depend upon continued engagement of scientists, stakeholders, and funders.

ACKNOWLEDGMENTS. The authors acknowledge AGCI Director John Katzenberger's leadership over 25 years of memorable and compelling AGCI sessions, and for contributed text and comments by John Katzenberger, James Arnott, Richard Somerville, Tom Wilbanks, and David Victor. We thank Guy Brasseur, two anonymous reviewers, and BAMS Editor Bjorn Stevens for their helpful and constructive comments. Over the years AGCI workshops have been made possible primarily by support from NASA, NOAA, NSF, DOE, WCRP, IGBP-AIMES, and private foundations. Portions of this study were supported by the Regional and Global Climate Modeling Program (RGCM) of the U.S. Department of Energy's Office of Biological and Environmental Research (BER) Cooperative Agreement DE-FC02-97ER62402, and the National Science Foundation.

All the material described in this essay—and much more—is available online (at www.agci.org).

REFERENCES

- Boer, G., G. A. Meehl, and D. Smith, 2015: Toward improving decadal climate predictions. *Eos, Trans. Amer. Geophys. Union*, **96**, doi:10.1029/2015EO041555.
- CCSP, 2008: Weather and climate extremes in a changing climate: Regions of focus; North America, Hawaii, Caribbean, and U.S. Pacific Islands. Synthesis and Assessment Product 3.3, U.S. Climate Change Science Program, NOAA/NCDC, 164 pp. [Available online at <https://downloads.globalchange.gov/sap/sap3-3/sap3-3-final-all.pdf>.]
- Changnon, S. A., R. A. Pielke Jr., D. Changnon, R. T. Sylves, and R. Pulwarty, 2000: Human factors explain the increased losses from weather and climate extremes. *Bull. Amer. Meteor. Soc.*, **81**, 437–442, doi:10.1175/1520-0477(2000)081<0437:HFETIL>2.3.CO;2.
- Easterling, D. R., J. L. Evans, P. Ya. Groisman, T. R. Karl, K. E. Kunkel, and P. Ambenje, 2000a: Observed variability and trends in extreme climate events: A brief review. *Bull. Amer. Meteor. Soc.*, **81**, 417–425, doi:10.1175/1520-0477(2000)081<0417:OVATIE>2.3.CO;2.
- , G. A. Meehl, C. Parmesan, S. Changnon, T. R. Karl, and L. O. Mearns, 2000b: Climate extremes: Observations, modeling and impacts. *Science*, **289**, 2068–2074, doi:10.1126/science.289.5487.2068.
- Eyring, V., S. Bony, G. A. Meehl, C. Senior, B. Stevens, R. J. Stouffer, and K. E. Taylor, 2016: Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization. *Geosci. Model Develop.*, **9**, 1937–1958, doi:10.5194/gmd-9-1937-2016.
- Hibbard, K. A., G. A. Meehl, P. Cox, and P. Friedlingstein, 2007: A strategy for climate change stabilization experiments. *Eos, Trans. Amer. Geophys. Union*, **88**, 217–221, doi:10.1029/2007EO200002.
- Hulme, M., 2014: Climate change and virtue: An apologetic. *Humanities*, **3**, 299–312, doi:10.3390/h3030299.
- IPCC, 1996: *Climate Change 1995: The Science of Climate Change*. Cambridge University Press, 572 pp.
- Meehl, G. A., and D. S. Schimel, 1993: The coupled climate system and global change. *Eos, Trans. Amer. Geophys. Union*, **74**, 2–14, doi:10.1029/93EO00160.
- , and C. Tebaldi, 2004: More intense, more frequent and longer lasting heat waves in the 21st century. *Science*, **305**, 994–997, doi:10.1126/science.1098704.
- , and K. A. Hibbard, 2007: A strategy for climate change stabilization experiments with AOGCMs and ESMs. WCRP Informal Rep. 3/2007, ICPO Publ. 112, IGBP Rep. 57, 37 pp.
- , and R. Moss, 2014: Twenty-five years of interdisciplinary global change science. *Eos, Trans. Amer. Geophys. Union*, **95**, 478, doi:10.1002/2014EO500007.
- , and Coauthors, 2000a: An introduction to trends in extreme weather and climate events: Observations, socioeconomic impacts, terrestrial ecological impacts, and model projections. *Bull. Amer. Meteor. Soc.*, **81**, 413–416, doi:10.1175/1520-0477(2000)081<0413:AITTIE>2.3.CO;2.
- , F. Zwiers, J. Evans, T. Knutson, L. Mearns, and P. Whetton, 2000b: Trends in extreme weather and climate events: Issues related to modeling extremes in projections of future climate change. *Bull. Amer. Meteor. Soc.*, **81**, 427–436, doi:10.1175/1520-0477(2000)081<0427:TIEWAC>2.3.CO;2.
- , and Coauthors, 2009: Decadal prediction: Can it be skillful? *Bull. Amer. Meteor. Soc.*, **90**, 1467–1485, doi:10.1175/2009BAMS2778.1.
- , R. Moss, K. E. Taylor, V. Eyring, R. J. Stouffer, S. Bony, and B. Stevens, 2014a: Climate model intercomparisons: Preparing for the next phase. *Eos, Trans. Amer. Geophys. Union*, **95**, 77, doi:10.1002/2014EO090001.
- , and Coauthors, 2014b: Decadal climate prediction: An update from the trenches. *Bull. Amer. Meteor. Soc.*, **95**, 243–267, doi:10.1175/BAMS-D-12-00241.1.
- Moss, R. H., 2011: Reducing doubt about uncertainty: Guidance for IPCC's third assessment. *Climatic Change*, **108**, 641–658, doi:10.1007/s10584-011-0182-x.
- , 2015: Assessing decision support systems and levels of confidence to narrow the climate information “usability gap.” *Climatic Change*, **135**, 143–155, doi:10.1007/s10584-015-1549-1.

- , and S. H. Schneider, 1997: Characterizing and communicating scientific uncertainty: Building on the IPCC second assessment. *Elements of Change 1996*, S. J. Hassol and J. Katzenberger, Eds., Aspen Global Change Institute, 90–135.
- , and —, 2001: Towards consistent assessment and reporting of uncertainties in the IPCC TAR. Cross Cutting Issues in the IPCC Third Assessment Report, R. Pachauri and T. Taniguchi, Eds., Global Industrial and Social Progress Research Institute, 33–52.
- , and Coauthors, 2010: The next generation of scenarios for climate change research and assessment. *Nature*, **463**, 747–756, doi:10.1038/nature08823.
- , and Coauthors, 2013: Hell and high water: Practice-relevant adaptation science. *Science*, **342**, 696–698, doi:10.1126/science.1239569.
- NRC, 2009: *Informing Decisions in a Changing Climate*. The National Academies Press, 200 pp., doi:10.17226/12626.
- O'Neill, B. C., J.-F. Lamarque, and D. Lawrence, 2014: Developing climate model comparisons. *Eos, Trans. Amer. Geophys. Union*, **95**, 462, doi:10.1002/2014EO490008.
- Parmesan, C., T. L. Root, and M. R. Willig, 2000: Impacts of extreme weather and climate on terrestrial biota. *Bull. Amer. Meteor. Soc.*, **81**, 443–450, doi:10.1175/1520-0477(2000)081<0443:IOEWAC>2.3.CO;2.
- Sarewitz, D., 2011: Does climate change knowledge really matter? *Wiley Interdiscip. Rev.: Climate Change*, **2**, 475–481, doi:10.1002/wcc.126.
- Somerville, R. C. J., and C. Gautier, 1995: Elements of change 1994: Climate-radiation feedbacks: The current state of the science. DOE Publ. DOE\ER-0661T, DOE\ER-0660T, UC-402, Aspen Global Change Institute, 123 pp.
- USGCRP, 2012: The national global change research plan 2012–2021: A strategic plan for the U.S. Global Change Research Program. 132 pp. [Available online at <http://data.globalchange.gov/assets/d0/67/6042585bce196769357e6501a78c/usgcrp-strategic-plan-2012.pdf>.]
- Weart, S. R., 2008: *The Discovery of Global Warming: Revised and Expanded Edition*. New Histories of Science, Technology, and Medicine, Harvard University Press, 240 pp.

NEW FROM AMS BOOKS!

A Scientific Peak: How Boulder Became a World Center for Space and Atmospheric Science

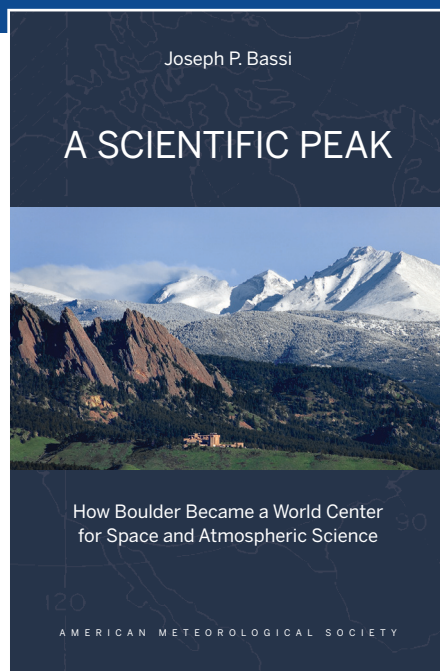
Joseph P. Bassi

Once a Wild West city tucked between the Rocky Mountains and the Great Plains, Boulder is now home to some of the biggest names in science, including NCAR, NOAA, and NIST.

Why did big science come to Boulder? How did Boulder become the research mecca it is today?

A Scientific Peak is a fascinating history that introduces us to a wide variety of characters, such as Walter Orr Roberts, and the serendipitous brew of politics, passion, and sheer luck that, during the post-WWII and Cold War eras, transformed this “scientific Siberia” into one of America’s smartest cities.

© 2015, 264 pages, paperback
print ISBN: 978-1-935704-85-0 eISBN: 978-1-940033-89-1
List price: \$35 AMS Member price: \$25



AMS BOOKS

RESEARCH APPLICATIONS HISTORY

➤ bookstore.ametsoc.org



AMS
American Meteorological Society

GIFTS EVEN A FAIR WEATHER FAN WOULD LOVE

Visit the AMS online
bookstore for gift ideas
for fans of all weather.

[www.ametsoc.org/
amsbookstore](http://www.ametsoc.org/amsbookstore)



Holiday special - 20% discount*

Use code: HOLIDAY16

Offer valid 11/1-12/31

*eligible products

Orders may also be made by check/money order or by submitting Visa, MC, or AMEX information.
Call 617-226-3998, Fax 617-742-8718, or mail your payment to AMS, 45 Beacon Street, Boston, MA 02108.